Combined Convection in Horizontal Circular Sector Ducts of Various Cross-Sectional Orientations

by

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COMBINED CONVECTION IN HORIZONTAL CIRCULAR SECTOR DUCTS OF VARIOUS CROSS-SECTIONAL ORIENTATIONS

BY

CHAISIN CHINPORNCHAROENPONG

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Contents

Abstract

For laminar mixed convection in horizontal circular sector ducts with uniform heat input axially, fully developed Nusselt numbers (*Nu*) [and similarly for the product of friction factor (*f*) and Reynolds number (*Re*)] depend on duct apex angle (2ϕ) and are functions of modified Grashof number (Gr^+) (average heat flux level), Prandtl number (*Pr*) (fluid type) and duct orientation with respect to the gravity vector (as would occur, for example, in horizontal multi-passage tubes). Regarding the latter, the steady pattern of secondary flow (buoyancy induced) varies as the duct changes its cross-sectional orientation, thus influencing heat transfer and pressure drop. A theoretical/numerical study was made of the fully developed results for the H1 thermal boundary condition. *Nu* and *fRe* were computed (via finite difference method; modified SIMPLER algorithm) for various ϕ, each at various orientations and *Pr* over a range of Gr^+ up to approximately 5×10^7. For a fixed Gr^+, *Pr*, and orientation, it was found that Nusselt ratios (relative to pure forced convection) first increased rapidly with 2ϕ but tended to plateau between about $2\phi = 120°$ and $180°$. In these plateau regions, enhancements, for example for $Gr^+ = 10^7$ and $Pr = 4$, reached factors of between about 3.7 and 4.4 depending on orientation. On the other hand, under the same condition, *fRe* ratios fell in the range of about 1.4 to 1.6. For a given circular sector duct in a fixed orientation, it was found (as expected) that for a given *Pr* that *Nu* and *fRe* increased with Gr^+ in an exponential fashion, i.e. buoyancy effects became progressively more influential as the heat flux level was increased. For a fixed duct and orientation, for a given Gr^+, *Nu* increased with *Pr* whereas *fRe* decreased with *Pr*. These dependencies could be removed

by scaling Nu on the product Gr^+Pr and fRe on the parameter Gr^+/Pr^2. Concerning the effect of orientation, for a fixed duct operating at fixed Gr^+ and Pr, orientation was a fairly significant factor, being largest for large ϕ. For example, for $2\phi = 120°$, these differences were about 15% at $Gr^+ = 10^7$ with $Pr = 4$.

A series of experiments using a water loop were conducted on a semicircular duct oriented at 45°, 90°, 135° and 180° in addition to the 0° orientation in the previous study. The flow was fully developed at entry and both the thermal entry region and the fully developed region were explored for uniform heat input axially. The various tests at different orientations spanned from Re of 500–1500 and Gr of $5\text{x}10^6$–$5\text{x}10^7$. The magnitudes of local Nusselt numbers were observed to be steady in the region where x^* was larger than about 0.01 consistently for all α and therefore the fully developed Nusselt numbers were determined in this region. Strong dependence between Nu and Gr^+ were observed. The maximum Nusselt numbers were obtained with $\alpha = 90°$ and 135° whose magnitudes were similar. Similar Nu magnitudes were also observed for $\alpha = 45°$ and 180°. Unlike the theoretical/numerical results, the correlation of Nu vs Gr^+Pr showed little improvement as compared to Nu vs Gr^+. The differences in Nusselt number magnitudes for $\alpha = 90°/135°$ was about 10% compared to $\alpha = 45°/180°$ and about 40% compared to $\alpha = 0°$. The predictions agreed reasonably well with the experiments in terms of Nusselt number magnitudes. The locations of the optimum orientation obtained by the experiments also agreed well with the predictions. In general, the H1 boundary condition was observed to overestimate the Nusselt number in the high Gr^+Pr region.

Acknowledgement

I wish to express my appreciation to my advisor, Dr. A. C. Trupp, for his advice, guidance and encouragement throughout this work. I am also grateful to Dr. H. M. Soliman for his useful comments and suggestions.

I would like to thank Mr. M. Kapitoler for his assistance during the course of rebuilding the test facility. I would also like to thank Mr. K. Majury for his help with electrical equipments on many occasions. Special thanks to Mr. J. Finken for his encouragement and assistance and to Mr. D. Madris for his suggestions.

Finally, I would like to thank my wife and my children for their patience and support throughout the course of this work. This thesis is dedicated, with gratitude, to them.

NOMENCLATURE

A_{fl} = cross-sectional area of the fluid flow passage, m^2

A_{iw} = interior wall area of the heated section, m^2

c_p = specific heat of fluid, kJ/kg·K

D_h = hydraulic diameter, m

f = friction factor (see equation 3.9)

$\mathbf{g}$, g = gravitational acceleration; vector and scalar forms, m/s^2

Gr = modified Grashof number, $\beta g \rho^2 D_h^4 Q_f / \mu^2 k A_{iw}$

Gr^+ = modified Grashof number, $\beta g q' R_o^3 / \nu^2 k$

$H1$ = thermal boundary condition, axially uniform heat flux and peripherally uniform temperature

$H2$ = thermal boundary condition, uniform heat flux both axially and peripherally

h = average heat transfer coefficient, kW/m^2·K

k = thermal conductivity of fluid, kW/m·K

$\dot{m}$ = mass flow rate, Kg/s

Nu = Nusselt number, fully developed, (see equation 3.19)

Nu_x = Nusselt number, local (see equation 4.4)

P = fluid pressure, kPa

P', P_x = cross stream pressure deviation, axial pressure, kPa

Pr = Prandtl number, $\mu c_p / k$

Q_f = heat gain by the fluid, kW

q' = heat transfer rate per unit length, kW/m

R, R_o = radial coordinate, radius of the duct, m

Re = Reynolds number, $D_h\dot{m}/\mu A_{fl}$

S = duct wet perimeter, m

t, t_m = fluid temperature, fluid bulk mean temperature, °C or K

t_w = duct wall temperature, peripherally uniform, °C or K

$t_{x,\theta}$ = duct wall temperature, local, °C or K

U,V,W = fluid velocity in R, θ, X directions, respectively, m/s

x^* = dimensionless axial length, X/D_hRePr

α = oriented angle, measured from duct cross section centre line to the gravitational force, deg

β = thermal expansion coefficient of fluid, K^{-1}

θ = angular coordinate, deg

ϕ = half of the apex angle of circular sector ducts, deg

μ = fluid dynamic viscosity, kg·s/m

ν = kinematic viscosity, m^2/s

ρ = fluid density, kg/m^3

subscript

o = for pure forced convection

m = mean condition at the averaged fluid inlet and outlet temperature

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Chapter 1

Introduction

The studies of heat transfer in uniformly heated horizontal ducts in the area of laminar forced convection have been well established and the solutions for many cross-sectional geometries are commonly known. However, pure forced convection analyses omit buoyancy forces and this can result in failure of the prediction in some situations. Such situations arise when the rate of heating is so high that the effect of buoyancy forces is significant. As a result, for these situations, the knowledge of combined or mixed convection is required instead. The ideas of multipassage tubes that led to the study of combined convection in circular sector ducts, along with the effect of duct cross-sectional orientations and the effect of Prandtl number, are introduced. The objectives and scope of this study are presented at the end of this chapter.

1.1 Introduction and Motivation

Generally speaking, laminar flow heat transfer has abundant applications in industries [1]; for example, heat exchangers designed for viscous liquids in chemical processes and food industries, compact heat exchangers for gas flows, and heat exchangers for biomedical applications. Furthermore, the use of multipassage or internally finned tubes to earn extra interface areas as compared to circular ducts, has perpetuated laminar flow conditions since their use result in smaller hydraulic diameters and consequently smaller Reynolds numbers. Regarding duct axial orientation, the horizontal orientation is the most common for industrial interest [1]. It is for these reasons that laminar flow heat transfer in horizontal ducts have gained large attention in convective heat transfer studies.

1.1.1 Combined Convection

In pure forced convection analysis, the motion of fluid is induced by an external forcing condition such as a pump or fan, thus any flow in the cross-sectional planes is ignored. For the hydrodynamic and thermal fully developed conditions, Nusselt numbers and friction factors are found to be constant. In free or natural convection, as we well know, the fluid can flow due to a temperature gradient. The existence of temperature gradients results in density gradients and hence buoyancy forces arise according to the differences of body forces acting on each part of the fluid in such conditions. Therefore, forced convection flow can not be purely established in practice because temperature gradients always exist. At high heating rates (high Grashof numbers) which is a situation that creates large temperature gradient within the fluid body, many experimental results showed that the magnitudes of Nusselt numbers and friction factors significantly departed from their corresponding forced convection solutions. Research reports consistently attribute the deviations to the effect of buoyancy force or the effect of free convection. Consequently, the analyses are called combined or mixed free and forced convection when the buoyancy forces are added in the formulations. The term combined or mixed convection is also used for the sake of brevity.

There are some close relationships between combined and forced convection. First, the characteristics of combined convection are often compared to pure forced convection, e.g. in terms of a ratio of their Nusselt numbers. This is useful for indicating the buoyancy effect. Secondly, pure forced convection can be regarded as a specific case of combined convection when the heating rate is so low that the free convection flow can be neglected. For experimental studies, forced and mixed convection experiments can share the same test facility if the heating rate can be raised sufficiently to exhibit free convection effect. Finally, it is noted that combined convection is practically meaningful only when the heating rate is high.

1.1.2 Multipassage Tubes and Circular Sector Ducts

The effect of buoyancy force enhances Nusselt numbers and friction factors as compared to their corresponding forced convection solutions. The free convection flow is in the duct cross-section planes and the flow in the duct becomes vortical due to the combination of the cross-stream and axial velocity components and hence the temperature and axial velocity fields are modified. The enhancement of Nusselt number is much larger than the enhancement of friction coefficient especially at large Grashof number.

The enhancement of Nusselt number can be accomplished by many techniques [2]. One of those techniques is the extension of the duct wall and fluid interface area, as in, for example, internally finned tubes and twist tape inserts in tubes. In the case of an internally finned tube with full length fins, the tube becomes a circular-sector duct which is a possible component passage of a multipassage tube. Knowledge of combined convection in circular sector ducts is therefore useful for the study of such multipassage ducts.

1.1.3 Semicircular Ducts

When the number of passages in a circular sector multipassage tube is reduced to two, each passage becomes a semicircular shape. A semicircular passage can also be formed when the pitch of the inserted twist tape is infinitely large. The multipassage tube which allow a larger heat transfer rate can be used as a substitute for the circular duct and thus the application at a higher heating condition is possible.

Circular sector passages can also be assembled in semicircular ducts instead of circular tubes. The outer flat wall of a semicircular duct can fit well with flat surfaces and consequently, a good interface contact can be established, e.g. in fin and tube heat exchangers. This should lead to a new design of heat exchanger components where compact and high heat flux operation are required. These ducts should find many industrial applications such as in nuclear or other power plants.

1.1.4 Effect of Cross-Sectional Orientation

In circular sector multipassage ducts, each of the circular sector passages could orient differently, e.g. the apex may point upward, downward, or any other angle. A circular sector duct comprises two flat walls and a curved wall. As the passage changes its orientation, each flat wall makes an angle with a vertical which is the direction of the gravitational force. As we know, the cross-stream flow is induced by the gravitational force therefore this angle implies the angle of attack, i.e. between the vertical velocity component of the flow and the wall. This indicates that the orientation must modify the pattern of the cross-stream flow because the circular sector passage is not axisymmetric. The modification involves cross-stream velocity, axial velocity and temperature fields and, consequently, Nusselt number and friction factor. How the cross-stream flow impacts on heat transfer and axial flow on each circular sector duct are important for the analyzing the performances of this type of multipassage ducts.

1.1.5 Effect of Prandtl Number

Prandtl number is a fluid property that represents the ratio of momentum to thermal diffusion. In terms of boundary layer development, the velocity boundary layer will develop much faster than the thermal boundary layer if Prandtl number is very high and vice versa. The effect of Prandtl number is clear for cases where there is no cross-stream flow, e.g. axisymetric flow in a tube where Prandtl number has an effect only within the developing region. However, for cases where cross-flows exist, the effect of Prandtl number is more complicated and is still poorly understood. This study attempts to brings about a better understanding of the role of Prandtl number on the heat transfer and flow characteristics in circular sector ducts.

1.1.6 Effect of Apex Angle

For a fixed radius, the sizes of circular cross sections depend directly on apex angles. Since cross-stream flow is confined by the duct cross-sectional shapes, apex angle would significantly affect the cross-stream flow patterns and hence flow and combined convection characteristics. The duct cross-sectional orientation can cause further modification on flow and heat transfer characteristics. Therefore the variations of apex angles and orientations should provide a broad view for combined convection in circular sector ducts.

1.2 Objectives

Theoretical study in the combined convection area is still limited due to the complication of the governing equations. However, recent solution techniques allow the possibility of a numerical study of combined convection. But even though theoretical study facilitates a broader view of studies, experimental studies are equally important. Among circular sector ducts, the semicircular duct is quite unique owning to its single-piece flat wall and hence a variety of potential applications. Therefore more attention is paid to semicircular ducts in this thesis. The purpose of this investigation is to explore the heat transfer and flow performances for laminar combined convection in horizontal ducts with detail as follow.

1. The theoretical study for

    effects of cross-sectional orientations for semicircular ducts,
    effects of cross-sectional orientations for other circular sector ducts,
    effects of Prandtl number for circular sector ducts, and
    effects of apex angle for circular sector ducts.

2. The experimental study for effects of cross-sectional orientation for a semicircular duct.

11.3 Scope of This Work

The theoretical study of combined convection in horizontal circular sector ducts will be confined to laminar fully developed flow with axially uniform heating (H1) conditions. These conditions are common for research in the area of forced convection. The duct orientation angle, α, is varied from 0° to 180°. This covers all cases of orientation with a complete round of rotation since the circular sector shape is symmetric about its centre line. The increment of α is chosen to be 45° for semicircular ducts and 90° for other circular sector ducts. The Prandtl number of 4 will be used for the numerical analyses for the comparison to experimental data. Additional numerical analyses for Prandtl numbers of 10 and 50 are provided for the study of the effect of Prandtl number. The research should achieve the results as summarized in the followings.

1. Numerical solutions for a semicircular duct for $Pr = 4$ with the orientation angles of 0°, 45°, 90°, 135° and 180°.

2. Experiments* for a semicircular duct with the orientation angles of 45°, 90°, 135°, and 180°.

3. Numerical solutions for circular sector ducts, apex angles of 60°, 90° and 120°, for $Pr = 4$ with the orientation angles of 0°, 90°, and 180°.

4. Numerical solutions for the same problems as in 1 and 3 but for $Pr = 10$ and 50.

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* The experimental studies also include the thermally developing region. Heating is uniform axially, but wall temperature is not exactly constant at any cross-section, i.e. the H1 condition is not attained exactly.

Chapter 2

Literature Survey

Although combined convection heat transfer has been studied for decades, the literature in this area is quite sparse as compared to the area of pure forced convection. This is partially due to the difficulty of the analyses that limits the range of theoretical study. Because combined convection problems involve a set of hydrodynamic governing equations, the literature dealing with solution techniques in this area is useful and is included in this survey. Early research work in the area mainly dealt with experiments and analytical solutions, while numerical solutions started to appear more frequently later. The topics in this chapter are accordingly arranged in more or less a chronological order. The first section reviews the reality of free convection flow as observed through flow visualization or other experimental methods. This is followed by a large section on the development of the combined convection study. The last section concerns numerical study of combined convection and its related areas. Basically, the review will focus on horizontal ducts which differ fundamentally from vertical ducts. The review is also generally restricted to only laminar flow and the uniform heating condition (H1). However, works dealing with the uniform temperature (T) boundary condition are sometimes included where especially relevant.

2.1 Demonstration of Free Convection Flow by Experimentations

The evidence of free convection flow arising in forced-convective flow can be demonstrated by experimentation either directly or indirectly. The direct way is by flow visualisation while the indirect way is indicated by Nusselt number or the wall-to-fluid temperature difference compared to the pure forced convection case. Although this section is mainly devoted to experimental demonstrations, a few analytical studies are mentioned to illustrate the indirect approach.

2.1.1 Free Convection Flow Phenomena

In most fluids, free convection is induced by buoyancy forces arising from density gradients which occur due to the existence of temperature gradients. Therefore, in most physical situations, free convection appears as a by-product of forced convection flow and hence it is called secondary flow. When pumped fluid flowing in a horizontal tube is heated, the fluid particle paths are spiral, flowing upward near side walls and falling down near the centre of the tube [3]. The spiral velocity profile was first detected by Woolfenden [4].

Morton [5] presented a mathematical model for laminar combined convection in horizontal tubes which in fact established the idea that the fluid circulation caused by free convection is in the plane normal to the tube axis. The spiral path can be explained as the combination of an axial velocity component and a cross-stream velocity component. The term cross-stream flow is preferred to the term secondary flow due to a broader meaning of the latter term. Bergles and Simonds [6] observed spiral streamlines in flowing water in a nearly transparent tube using a dye injection technique. In addition, when raising the heat flux at a constant flow rate or when decreasing the flow rate at a constant heat flux, the pitch of the spiral was found to decrease. With a similar technique, Newell and Bergles [7] observed a couple of vortexes near the bottom of a small pyrex tube. The spiral streamlines were also seen. Some bibliographies of the free convection flow visualization in water, air and oil are also provided in [7]. Excellent pictures of the cross-stream flow patterns were provided by Mori and Futagami [8]. By introducing NH_4Cl smoke into a uniformly heated transparent tube of 30 mm i.d., a pair of vortices which was symmetric to the vertical plane was observed. The eyes of the vortices moved closer to the tube wall as the heating rate was increased. The above observations consolidate the idea of how fluid flows in a circular pipe in the combined convection situation, i.e. each fluid particle follows a spiral path along the axial direction whereas a pair of symmetric vortices form at each cross-section.

Yousef and Tarasuk [9] used the Mach-Zehnder interferometer to observe the air temperature field in an aluminum tube of 25 mm i.d. with uniform temperature heating. The interferogram of isotherms showed the low temperature contours near the bottom wall. This indicated the descending cool core fluid. The crescent shapes of these contours provided evidence of the rising of hot fluid near the side walls.

2.1.2 The Effect of Free Convection Flow

McComas and Eckert [3] found that the local Nusselt numbers in the down stream side of the heated tube were larger than for pure forced convection and this effect increased with the ratio of Grashof number to Reynolds number. Ede [10] tested seven tubes of 1.27 to 5.08 cm diameters with air and water for Reynolds number of 300 to 100,000. The Nusselt number data for laminar flow were clearly dependent on Grashof number. The magnitudes of Nusselt numbers were enhanced by free convection effects up to six fold. Mori *et. al.* [11] found that the Nusselt numbers at $ReRa$ about 10^5 were twice that for the laminar forced convection case and distorted velocity and temperature profiles were observed. For turbulent flow, the buoyancy effect showed little influence on both velocity and temperature fields. Later, the effect of free convection or buoyancy force was better recognized and well described, e.g. [1]. Based on [1], [3], [6-7], and [9-15], the main characteristics are summarized as follows.

1. The velocity and temperature profiles of the fluid as compared to the forced convection case were distorted by the symmetric vortex flows.

2. By investigating the results of Nusselt number versus the axial distance, the enhancement of Nusselt number was small near the inlet but became higher and further departed from the forced-convection case as the axial distance increased.

3. The velocity and temperature profiles and the Nusselt number were further distorted by raising the heat flux.

4. The measured Nusselt numbers appeared to depend on Grashof number or its equivalent dimensionless groups ($ReRa$).

2.2 Development of Combined Convection Study

The studies of combined and forced convection for circular, rectangular, and circular sector (including semicircular) ducts are reviewed in the following subsections along with internally finned tubes. Bifurcation, which is so far only found in numerical analyses for combined convection, is also included in this section.

2.2.1 Circular Ducts

Morton [5] presented the very first analytic solution for fully developed combined convection by the perturbation method. The solution for Nusselt number contained a power series for $ReRa$ while Pr appeared as the coefficients. Unfortunately, the applicable range of $ReRa$ was limited to only 3000. Del Casal and Gill [17] extended Morton's work by allowing the axial pressure gradient to vary. Similar to Morton's solution, it was applicable only for very low heating rates. Mori and Futagami [8] used a boundary-layer integral method to solve the same problem. They mentioned that their solution was limited to Prandtl number about 1.

Shannon and Depew [12,13] used the relation $Nu = K_1(GrPr)^{1/4}$ where K_1 was a constant as suggested by Mikesell [16]. The experimentation was performed with a rather small tube of 9.53 mm dia. and 6.1 m long. They presumed that $(GrPr)^{1/4}$ might account for the free convection contribution only. The experimental results [13] showed that as $(GrPr)^{1/4}/Nu_{Gz} < 2$ the local Nusselt numbers were independent of $(GrPr)^{1/4}$. It is worth noting that the previously mentioned range corresponds to the region very near the inlet where the magnitude of Graetz number is large. It was believed that the Nusselt number in that region depended on viscosity hence a viscosity ratio with a fraction exponent was added to the correlation in order to account for the variable viscosity effect. It seemed that their works were based on the idea that the temperature and velocity profiles were altered by the variable fluid viscosity while the natural convection flow aided energy transfer to or from the fluid.

However, Siegwarth *et. al.* [14] ignored the variable viscosity in their analysis of combined convection problem for large *GrPr*. Similar to Mori and Futagami [8], in this analysis the flow domain was divided into two distinct zones; one zone within the temperature boundary layer and the other, called core, exterior to that layer. Therefore, two sets of governing equations were separately simplified from the more complex original governing equations. Unlike the external flow problem, the core condition could not be known *a priori*. The main problem with this method was the necessity to find the conditions for the core and to discover how the core and boundary layer interacted. By following assumptions: $(Pr/Re) \rightarrow \infty$, constant viscosity, and small core velocity, it was shown that Nu = $0.471(GrPr)^{1/4}$. In their subsequent work [15], the method of solution was a finite difference method solving for the velocity and temperature profiles to compare with the experimental results.

The common ideas of [12-15] seem to be the use of $(GrPr)^{1/4}$ and the ideas about variable viscosity and backflow are attributed by the influence of Mikesell [16]. On the other hand, Hwang and Cheng [18] obtained the results for various Prandtl numbers and $ReRa$ up to 10^5 by the finite difference method. Their results agreed well with Morton's [5] at low $ReRa$. Cheng and his colleagues solved many combined convection problems. For thermal developing problems, they assumed infinitely large Prandtl number to simplify the problems, e.g. [19-20] for circular ducts. The product $ReRa$ was shown by Patankar *et. al.* [21] to be proportional to modified Grashof number, Gr^+ which was directly defined by the heating rate. This dimensionless variable has been widely accepted and used in the later generation of computational researches. The solutions for combined convection in circular duct was presented by Nandakumar *et. al.* [22] and the results agreed very well with Hwang and Cheng [18].

For the uniform wall temperature condition, the combined convection has a strong effect only within the developing region therefore the main interest is for that region. Similar to [19-20], a large Prandtl number assumption was also used in analyzing the problem with uniform wall temperature, e.g. Hieber and Sreenivasan [23], Yao [24] and Hieber [25]. Eventually, the solution without a large Prandtl number assumption was successfully solved by Hishida *et. al.* [26] and for the H2 condition by Chou and Hwang [27].

2.2.2 Rectangular Ducts

For fully developed combined convection in rectangular ducts with uniform heat flux, Cheng and Hwang [28] presented their finite difference solution for a couple of Prandtl numbers. Again, the Prandtl number was assumed infinitely large in their following works [29-30] for the entrance region. The results were believed to be good only for Prandtl number larger than 10. Later, such Prandtl number restriction was relaxed; for example, for the uniform heat flux condition [31-32], and for non-uniform heat flux condition [33-34].

2.2.3 Circular Sector Ducts

Circular sector passages represent a large family of passages due to the variant of the apex angle therefore the generalized study for circular-sector passages entails exploring the apex angle effects. There is no such generalized study for combined convection known to the author. However, such study for fully developed laminar forced convection was accomplished by Lei and Trupp [35] and [36] for Nusselt numbers and friction coefficients, respectively. The apex angle was varied from 0° to 360° with small increments thus rather detailed results were obtained from the closed form solutions. The Nusselt numbers were obtained by the velocity field established in [36]. The locations of maximum velocities were observed to move from the curved wall toward the apex as apex angle was increased. Sparrow and Haji-Sheihk presented a similar work in [37] but with variable thermal boundary conditions. For uniform heat flux condition, they compared the Nusselt numbers and *fRe* of circular sector ducts to two types of triangular ducts, the results of circular sector ducts were higher and the differences increased as apex angle increased [38]. Trupp and Lau [39] solved Nusselt numbers for circular sector ducts with uniform temperature. The Nusselt numbers of this thermal condition were smaller than the H1 condition but higher than those of isosceles triangular ducts with the same wall condition. For a group of H2 heating conditions, Nusselt numbers of circular sector ducts were studied by Trupp and Lei [40]. The Nusselt numbers of H1 condition were larger than those of H2 conditions for all apex angles.

For the entrance region, Soliman *et. al.* [41] studied laminar flow of four circular sector ducts with the apex angle up to 90° by finite difference method. Semicircular ducts, a special case of the circular sector ducts, were studied by Hong and Bergles [42] for uniform heat flux condition and Zhang *et. al.* [43] for uniform temperature condition. For circular sector ducts, Lei and Trupp [44] analyzed the problem with H1 and H2 thermal boundary conditions.

The combined convection in a semicircular duct with flat wall on the top was studied by Lei [45] and Lei and Trupp [46-47] both numerically and experimentally. For the experimental study, the Nusselt number results appeared to be fully developed at the down stream side and *Nu* and *fRe* were compared to the predictions. The effects of Reynolds number, and Rayleigh number were also presented. Nadakumar *et. al.* [22] also solved the same problem but with the flat wall at bottom. This is a main reference used in [45–46] and the present study for comparisons of the numerical results.

2.2.4 Internally Finned Tubes

Internal finning is a practical heat transfer augmentation technique as internally finned tubes are commercially manufactured. However, the theoretical study is limited due to the complexity of the problem and the alternative of fin shapes. Although some experiments with water in the turbulent region exhibited optimum heat transfer performance for short spiral fins, but for air flow, straight fins with larger height showed the best heat transfer performance [48]. Hu and Chang [48] analyzed laminar forced convection with uniform heat flux in internally finned tubes with straight fins of zero thickness and infinite thermal conductivity. The best Nusselt number, almost 20 times that of the finless tube, appeared when the number of fins was 22 and fin height was 0.8 of the tube radius. Masliyah and Nandakumar [49] were aware of the idealistic assumptions therefore they used a triangular fin with peripherally uniform temperature on both the fins and tube surfaces. A more practical shape of fins was presented by Soliman and Feingold [50,51] in their analyses. The results from [49-51] were similar to those of [48] except that the Nusselt number decreased as the fins were thicker. Soliman *et. al.* [52] further modified the thermal boundary condition toward reality by allowing fin temperature to vary radially. A new parameter involving fin thickness and the ratio of fin and fluid thermal conductivity allowed the investigation of the Nusselt number behaviours. Furthermore, Soliman [53] proposed a technique for solving the energy equation by subdividing the flow domain into two regions and the analytical solutions were presented. For the entrance region problems, Prakash and Liu [54] studied laminar forced convection for simultaneous development of velocity and temperature while Rustum and Soliman [55] studied the thermal developing region with fully developed velocity at entry.

Fully developed combined convection in internally finned tubes was studied by Mirza and Soliman [56]. There were only two fins with zero thicknesses located at the top and bottom of the tube. The effects of fin height and Grashof number were investigated. Combined convection experiments were conducted by Rustum and Soliman [57] with four commercial internally finned tubes and a smooth tube. The effect of free convection appeared strongly at high Rayleigh number. The Nusselt numbers approached those of forced convection when the Rayleigh numbers were low. The numerical analysis by Rustum and Soliman [58] showed that the flow and heat transfer characteristics depended on modified Grashof number, Prandtl number, number of fins and fin height. The finning was found to retard the free convection effect that resulted in less enhancement compared to the smooth tube. Finning in semicircular ducts was studied by Zhang and Ebadian [59] for the entrance region.

2.2.5 Bifurcation

The cross-stream flow pattern of combined convection in horizontal ducts comprise two vortexes which will be called the *two-vortex* or *two-cell* pattern. Such a pattern has been verified experimentally in circular ducts. Numerical solutions also show two-cell pattern, e.g. [22] for rectangular, circular and semicircular ducts.

At an adequate high heating rate, flow patterns of the numerical solutions may become four vortexes, or so-called *four-cell*. The term bifurcation will be used for such transformation of the flow patterns or for the appearance of the four-cell pattern. The earliest detection of bifurcation in combined convection was found in rectangular ducts [30]. It, later, appeared more often, e.g. [21-22], [34], [45-46], for rectangular, circular and semicircular ducts.

The bifurcation can be induced not only by the buoyancy force in combined convection flow but also by the centrifugal force in curved duct flow (without heating). The bifurcation in a curved semicircular duct was found in the numerical solutions and it was confirmed by flow visualisation, see Masliyah [60]. The numerical solutions of curved tubes also showed bifurcation [61].

2.3 Numerical Study of Combined Convection

In solving a combined convection problem, it is necessary to solve the underlying flow field which is characterized by continuity and vector momentum equations in addition to a scalar equation for temperature. The discretization of the convective and diffusive terms in the momentum equations directly controls the accuracy of the predicted flow field and therefore the scalar variable. The discretization techniques are applicable to both the flow and scalar equations. On the other hand, the coupling between continuity and momentum equations is important to the solution procedures which usually depend on how this coupling is handled. Therefore the first two sub-sections are devoted to the convective-diffusion term discretization and the solution techniques.

The finite difference and finite element methods are currently two major approaches for solving the partial differential equations arising from heat transfer problems [62]. Other methods such as boundary element, spectral or pseudo-spectral, and linearization methods have limited applications. This can be observed in a recent review of the development in numerical methods for heat transfer problems by Patankar [63] which particularly addressed the problems of spectral method, e.g. internal discontinuities, and nonuniform transport properties and sources.

In the finite element method, a partial differential equation is transformed by either weighted residual or Rayleigh-Ritz method. Unlike the weighted residual method, the Rayleigh-Ritz method is not suitable because the variational principles can not be developed when advection terms are present [62]. The alternative versions of weighted residual method are classified by the choice of the approximation function and weighted function. If they are chosen to be the same, the method is called Galerkin method. The finite element methods formulated by all these fashions were initially for stress analysis in irregular geometries thus these methods do not directly enforce a conservation principle on confined volumes [64]. In addition, the employment of reduced-order pressure interpolation, in order to avoid a spurious pressure field [65], degrades the accuracy of the pressure field representation [64]. The equal-order elements also suffer the same problem as the non-staggered grid version of the finite difference method. The basic differences and similarities of finite difference and finite element methods are compiled in [62] and they suggested that the choice is up to the users because both methods have their own advantages.

2.3.1 Convection-Diffusion Formulations

Spalding [66] exhibited that the well-known upwind (upstream) difference scheme was more accurate than the central difference scheme when the ratio of convection to diffusion across the grid, frequently called grid Peclet or Reynolds number, was larger than 2 by comparing to the exact solution for the one-dimensional equation with zero source term. Spalding proposed a new scheme called hybrid scheme which had better accuracy than the upwind scheme based on such exact solution. Afterward, Patankar [67] proposed a power-law scheme which employed a less expensive computation while maintained a close accuracy. The power law scheme and hybrid scheme have a similar behaviour because they switch from second-order accuracy to first-order accuracy as grid Reynolds number becomes high [68].

It is interesting to note that the central difference scheme is equivalent to first-order interpolation while upwind scheme is equivalent to zeroth-order interpolation and they have second-order and first-order truncation errors, respectively. As a matter of fact, the schemes were formulated with one-dimentional models and applied to two- or three-dimensional applications therefore such conclusions were extrapolated from the characteristics observed on the one-dimentional problem. The central difference scheme is more accurate when grid Reynolds number is less than 2 but at high Reynolds number it may result in a wiggly solution (oscillation or under and overshoot) and it is unstable, see e.g. [69-71]. Patankar [67] and Roache [72] pointed out that it possibly caused negative coefficients and the discreatized equations might diverge while the upwind scheme was still stable even at high Reynolds number.

Although stability, the major advantage of the upwind scheme, is obtained by sacrificing accuracy, for some specific situations the upwind scheme can introduce additional error. To eliminate such effects, Raithby [70] introduced two new schemes, SUDS (Skew Upstream Differencing Scheme), and SUWDS (Skew Upstream Weighted Differencing Scheme). Both of them were intended to reduce the error arising from flow crossing a grid line with a small angle while the second scheme had an additional feature of low error at high Reynolds number. The skew upstream scheme was later modified by Hassan *et. al.* [71] due to its marginal stability caused by the negative coefficient.

In general, higher order of approximations provide low diffusion results. Runchal [73] proposed an alternative to the central-difference scheme which had unconditional stability. The problems of central-difference and upstream schemes were exhaustively examined by Leonard [74] and he proposed new interpolation schemes called QUICK (Quadratic Upstream Interpolation for Convective Kinematics) and QUICKEST (QUICK with Estimated Streaming Terms) for steady and unsteady flows, respectively. These schemes utilize three nodal data for the interpolation instead of two as in previous schemes. The new schemes have third-order accuracy, better accuracy than the central difference scheme, while the stability is maintained. The upstream interpolations with second-order or higher were studied by Warming *et. al.* [75], Atias *et. al.* [76], Shyy [77] and Vankar [78]. While Shyy was satisfied by his results although it was not yet free from difficulties and inaccuracies, Vankar found that his second-order schemes could not perform well in terms of accuracy and computational stability. Later, Shyy *et. al.* [79] compared the central-difference scheme and three alternative second-order upstream schemes. The upwind-type schemes were more accurate and exhibited no oscillation. The flux-spline scheme, another high-order interpolation, was demonstrated by Karki *et. al.* [80] and it exhibited accurate solutions without excessive grid refining.

The variety of the discretization schemes and their specific-tuned applications made the comparison task very difficult. In May 1981, Smith and Hutton [81] collected results of a test problem from many participants who used various schemes with finite difference and finite element methods. The report concluded that no particular scheme was the best. Huang *et. al.* [82] conducted their own test with a few widely used schemes. They favoured the quadratic upwind over the skew upwind and power-law schemes. Recently, Zurigat and Ghajar [83] conducted a survey on a number of comparative studies and concluded that the second-order upwind, skew upwind and quadratic upwind schemes tended to exhibit better accuracy than the weighted upwind scheme. Another recent comparison, similar to [83], was conducted by Sharif and Burnaina [84]. Their general conclusion was that the schemes which produced less numerical diffusion suffered from more oscillations. Miller and Schmidt [85] also found that while QUICK scheme produced less numerical diffusion, its rates of convergence were poorer than hybrid or upwind schemes. Another series of scheme testings was conducted by Patel *et. al.* (appeared in [65]). They found that QUICK and its variants gave accuracy but failed to converge at high flow rates and coarse grids. The upwind scheme was the best choice by their conclusion. All of these comparison results agree well with what Smith and Hutton [81] stated earlier that; "It seems that advection modelling remains the art of compromise between diffusive and oscillatory".

2.3.2 Solution Techniques

The solution procedure primarily depends on how the governing equations are formulated. For a two-dimensional flow problem, e.g. flow in an infinite width channel or axisymmetric flow in a tube, the governing equations comprise a continuity and two momentum equations. There are four main methods to formulate such problem: primitive variables, vorticity-velocity, vorticity-streamfunction and biharmonic formulation. The first method keeps the original governing equations unchanged and solves for the three dependent variables; pressure and two components of the velocity. The last three methods eliminate the pressure by introducing a streamfunction and a vorticity function. The vorticity-velocity method has three equations; two velocity Poisson equations and a vorticity transport equation, e.g. see [86]. For the vorticity-streamfunction method, e.g. see [87-88], the number of governing equations becomes two; a streamfunction equation and a vorticity transport equation. In the last method, the elimination of vorticity in the vorticity transport equation results in a single governing equation for the streamfunction in biharmonic form and this equation can be solved by Newton's method or likewise, e.g. see [89-90].

The methods involving vorticity or stream functions have an advantage of avoiding the explicit appearance of pressure. There are a few drawbacks arising from the use of vorticity. First, the imposing of vorticity at the solid walls is difficult and lacks physical meaning. Secondly, except for the last method, to determine vorticity demands evaluating derivatives up to second-order in the case of the vorticity-stream function method. Another disadvantage of vorticity-streamfunction is that it is difficult to extend to three dimensions. Otherwise, the primitive variable method is the most popular method. It has the convenience of handling the variables in their original forms rather than those disadvantages of the other methods. But this method suffers two major problems; the spurious pressure field and the coupling between momentum and continuity equations. The spurious pressure can be eliminated by the staggered grid arrangement. This, in turn, is a major problem for the nonstaggered grid system. Owing to such distinct nature, the review procedes separately for staggered and nonstaggered grid arrangements.

2.3.3 Staggered Grid Arrangement

Patankar and Spalding [91] presented a calculation procedure called SIMPLE (Semi-Implicit Method for Pressure Linked Equations) for heat, mass and momentum transfer. A revised version of SIMPLE, called SIMPLER was presented by Patankar [92]. The difference between the two versions is about the treatment of the pressure field due to SIMPLE is likely to diverge because of the overestimation of the pressure correction field. The details of these methods can be found in [93]. The large pressure corrections of SIMPLE resulted in a requirement of underrelaxation which in turn delayed the convergence. There are many variants of SIMPLE which were released for overcoming that problem, for example, PULS, PUMPIN [94-95], and SIMPLEC [96]. The emerging of these modified versions indicates that the handling of pressure updating and pressure correction is very important for the SIMPLE-like methods.

The treatment of pressure-velocity coupling was continued by Issa [97] who proposed the PISO (Pressure-Implicit with Splitting of Operators) method. This method derived the pressure equation from the discretized forms of the momentum and continuity equations. The algorithm, involving the pressure and velocity operations, was split into a series of predictor-corrector steps. The PISO was similar to SIMPLER due to its predictor-corrector nature. In fact, for some it was believed to be the same as SIMPLER [65,99]. In spite of such belief, Jang *et. al.* [98] conducted a test with three problems and concluded that PISO was superior to SIMPLER and SIMPLEC for the problems where the momentum equation was not coupled to a scalar variable. When the temperature was strongly coupled to the momentum equation, SIMPLER and SIMPLEC exhibited better performance while the superiority between SIMPLER and SIMPLEC was difficult to figure out. Latimer and Pollard [99] developed the FIMOSE (Fully Implicit Method for Operator-Split Equations) as a fully implicit alternative of PISO which is semi-implicit.

So far, all of the methods mentioned previously are called segregated method because each dependent variable (e.g. pressure, velocities) are solved sequentially. The calculations involve the solution for predictor equations followed by the solution for the corrector equations of pressure and each velocity separately. In contrast to the segregated solution, the pressure and velocities can be evaluated simultaneously in order to make use of the new values immediately in the next step. This is called block (or coupled) method. The idea is that the dynamically updated pressure and velocity data should speed up the convergence. The earliest proposal seems to be SIVA (SImultaneous Variable Adjustments) by Caretto *et. al.* [100] and later by Vankar [101-103]. All these works were point-block method, e.g. the grid was scanned point by point. Vankar used Gauss-Seidel point relaxation and the process was called symmetrical coupled Gauss-Seidel (SCGS). The convergence rate was reported up to a tenth of that required by SIMPLE in term of computational time, see [103]. It is perhaps worth noting that in [103] the grid numbers were as large as 321x321. Hutchinson *et. al.* [104] commented that such spectacular gains must be viewed in the context that SIMPLE performance degrades drastically as grid is refined.

The line sweeping for block solution was proposed by Raithby's group [105-106] as CELS method (Coupled Equation Line Solver). This method is similar to the previous method except that it is line-by-line sweep instead of point by point. The advantage of point block over line block method should be the simplicity and convenience to fully vectorize on super computers [102]. In addition, the earlier work of Vankar [107] used plane-by-plane technique to cope with the three-dimensional flow in curved ducts.

2.3.4 Nonstaggered Grid Arrangement

In nonstaggered grid systems, the pressure and velocities of each cell locate at the same grid points. This is preferable in contrast to the staggered grid which is chosen for avoiding the checkerboard pressure and velocity. The staggered grids have been widely used in spite of their inconvenience for irregular geometry. One way to solve such problems is to use the general orthogonal coordinate, e.g. [108], which seemed to be too complex. Nonstaggered grid is probably a better choice for curvilinear coordinates.

Rhi and Chow [109] solved a flow problem with nonstaggered grid by using natural coordinates. The calculation procedure was similar to SIMPLE. Later, Majumdar [110] found that the results attained from the so-called momentum interpolation used by Rhi or Peric (as appears in [110]) was affected by the underrelaxation factor therefore he proposed an alternative momentum interpolation for avoiding such effect. Patankar [65] indeed recognized this drawback, not only by himself but also by some others, and mentioned that the finite-element method with equal-order interpolation suffered this problem as well. However, there was no report of such problem in very recent works [111-113] which studied or extended the above methods.

A generic perspective for nonstaggered grid study was given by Shih and Ren [114]. They demonstrated three methods to handle the continuity equation (or, in fact, the hidden pressure). The first method, the continuity equation is discretized as usual. They showed that the oscillatory pressure can simply be avoided if the nodal pressure is properly linked to the boundary. In the second method, the pressure Poisson equation is used instead of the continuity equation. The third method used another form of pressure equation which was derived from the discretized momentum and continuity equations. Incidentally, the solution techniques for nonstaggered grid can probably be classified in accordance with the above three methods. In another words, all methods solve the same momentum equations but with different equations for evaluating the pressure. Therefore, all works mentioned above, except for those clearly stated in [114], fall into the first method. The second method, Poisson pressure equation method can be computer time and storage consuming [114-115]. However, some special techniques were employed in recent studies [116-118]. There is no research yet using the third method.

2.3.5 Multigrid and Other Techniques

There are some techniques that can be added to other computational methods to improve the convergence rates, or accuracy of the solutions, or both. These techniques are increasingly important when the computational time is concerned. The calculation on a fine mesh can be accelerated by the multigrid method. This method employs a number of meshes with different grid spaces. The idea is the fine mesh poorly smooths out the high frequency errors and this delays the convergence. In contrast, the coarse mesh can reduces the high frequency errors efficiently. By switching back and forth between these meshes, the errors are reduced faster and convergence should be reached sooner. A good source for multigrid method is Brandt [119]. For applications in fluid flow and heat transfer problems, multigrid method was successfully applied, e.g. [120], [88], [102], and

[106]. Other techniques that can improve the convergence is to minimize the residual. Chatwani and Turan [121] demonstrated that the underrelaxation factor for the pressure correction in SIMPLE-like methods can be determined from the global residual of the momentum equation. Lee and Dulikravick [121-122] method is quite similar to the above method except that the relaxation factor was determined for each dependent variable.

Chapter 3

Theoretical Formulation

The combined convection in circular sector duct analysis is different from the forced convection analysis because it accounts for the effect of the buoyancy force. This results in two additional momentum equations for describing the flow in the cross-stream plane. Only the assumptions and derivation of the governing equations are presented in this chapter.

3.1 Defining the Problem and Assumptions

Combined convection is affected by cross-sectional orientation with respect to gravitational vector. This effect can be studied by keeping the duct cross-section fixed while the gravitational force is allowed to rotate to a desired angle. The oriented angle, α, is measured from the duct centre line (i.e. the line bisecting the apex angle which is on the Z axis in Fig. 3.1) to the gravitational force in the counter clockwise direction. The duct cross-sectional size is allowed to vary according to the magnitude of the apex angle, 2ϕ. In this way, the definition of the domain under consideration is independent of the oriented angle and the duct size, e.g. $\gamma \leq \theta \leq 2\phi$ where γ is always equal to $\pi/2 - \phi$. The maximum size of ϕ is limited to π/2 which corresponds to a semicircular cross section.

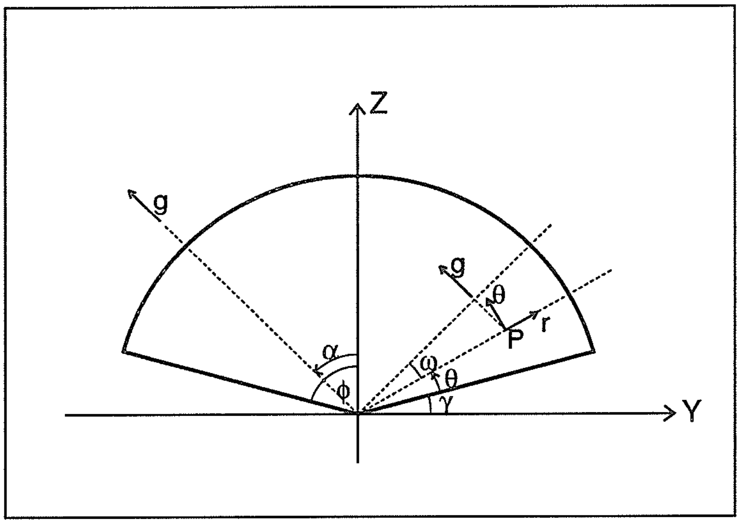

Fig. 3.1 Cross-sectional geometry of a circular sector duct.

The governing equations are formulated according to these assumptions.

1. The fluid is viscous and incompressible.

2. The flow is steady, laminar, and hydrodynamically and thermally fully developed.

3. The fluid viscous dissipation and axial diffusion are negligible.

4. All properties are constant except for the density associated with the buoyancy forces.

5. The duct is subjected to an axially uniform heat input and the wall temperature is peripherally uniform, i.e. the H1 boundary condition.

3.2 Derivation of the Governing Equations

With the above assumptions, the Navier-Stokes equation for a cylindrical coordinate system in vector form is

$$V \cdot \nabla V - \nu \nabla^2 V = -\frac{\nabla P}{\rho} + g. \tag{3.1}$$

Fluid pressure P at any point within the duct can be described as

$$P(R,\theta,X) = P'(R,\theta) + P_x(X) - \rho_w g h, \tag{3.2}$$

where $\rho_w g h$ is the hydrostatic pressure on the duct wall at the same elevation as the point under consideration. Distance h is measured in the same direction as g from a certain reference level, e.g. at centre of the flat wall which can be expressed in general form as

$$h = C + r\sin(\alpha - \theta), \tag{3.3}$$

where C is a constant. Substituting P and h into the right-hand-side of the Navier-Stokes equation above, it becomes

$$-\frac{\nabla P}{\rho} + \boldsymbol{g} = -\frac{\nabla P'}{\rho} - \frac{\nabla P_x}{\rho} + \frac{\rho_w}{\rho} g \nabla \{ r \sin(\alpha - \theta) \} + \boldsymbol{g} . \tag{3.4}$$

Utilizing $\rho_w/\rho = 1 + \beta(t - t_w)$ and rearranging, leads to:

$$-\frac{\nabla P}{\rho} + \boldsymbol{g} = -\frac{\nabla P'}{\rho} - \frac{\nabla P_x}{\rho} - \{1 + \beta(t - t_w)\} g \nabla \{ r \sin(\theta - \alpha) \} + \boldsymbol{g} . \tag{3.5}$$

Executing the operator ∇ and extracting the gravitational acceleration vector $\boldsymbol{g}$ into each coordinate axis, yields:

r component

$$-\frac{\nabla P}{\rho} + \boldsymbol{g} = -\frac{1}{\rho}\frac{\partial P'}{\partial r} - \beta g (t - t_w) \sin(\theta - \alpha) , \tag{3.6}$$

θ *component*

$$-\frac{\nabla P}{\rho} + \boldsymbol{g} = -\frac{1}{\rho r}\frac{\partial P'}{\partial \theta} - \beta g (t - t_w) \cos(\theta - \alpha) , \tag{3.7}$$

axial component

$$-\frac{\nabla P}{\rho} + \boldsymbol{g} = -\frac{1}{\rho}\frac{\partial P_x}{\partial X} . \tag{3.8}$$

Transformation variables are now introduced as follows:

$$r = \frac{R}{R_o}, \quad u^+ = \frac{UR_o}{\nu}, \quad v^+ = \frac{VR_o}{\nu}, \quad w = \frac{W}{W_m}, \quad T^+ = \frac{t - t_w}{q'/k},$$

$$p^+ = \frac{P' R_o^2}{\rho \nu^2}, \quad Re = \frac{\rho W_m D_h}{\mu}, \quad f = \frac{(-dP_x/dX) D_h}{2 \rho W_m{}^2} . \tag{3.9}$$

Modified Grashof number Gr^+ and Prandtl number Pr are defined as

$$Gr^+ = \frac{\beta g q' R_o^3}{\nu^2 k}, \qquad Pr = \frac{\mu c_p}{k}. \tag{3.10}$$

Finally, all governing equations are recast in dimensionless forms as follows:

continuity equation

$$\frac{1}{r}\frac{\partial}{\partial r}(ru^+) + \frac{1}{r}\frac{\partial v^+}{\partial \theta} = 0, \tag{3.11}$$

radial momentum

$$\frac{1}{r}\frac{\partial}{\partial r}(ru^+u^+) + \frac{1}{r}\frac{\partial}{\partial \theta}(v^+u^+) = \frac{1}{r}\frac{\partial}{\partial r}\left(2r\frac{\partial u^+}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{1}{r}\frac{\partial u^+}{\partial \theta}\right) - \frac{\partial p^+}{\partial r}$$

$$+ \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{\partial v^+}{\partial r}\right) - \frac{3}{r^2}\frac{\partial v^+}{\partial \theta} - \frac{2u^+}{r^2} + \frac{v^{+2}}{r} + Gr^+T^+\sin(\theta-\alpha), \tag{3.12}$$

angular momentum

$$\frac{1}{r}\frac{\partial}{\partial r}(ru^+v^+) + \frac{1}{r}\frac{\partial}{\partial \theta}(v^+v^+) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v^+}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{2}{r}\frac{\partial v^+}{\partial \theta}\right) - \frac{1}{r}\frac{\partial p^+}{\partial \theta}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{\partial u^+}{\partial \theta}\right) + \frac{3}{r^2}\frac{\partial u^+}{\partial \theta} - \frac{v^+}{r^2} - \frac{v^+u^+}{r} - Gr^+T^+\cos(\theta-\alpha), \tag{3.13}$$

and *axial momentum*

$$\frac{1}{r}\frac{\partial}{\partial r}(ru^+w) + \frac{1}{r}\frac{\partial}{\partial \theta}(v^+w) =$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial w}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{1}{r}\frac{\partial w}{\partial \theta}\right) + \frac{(1+\phi)^2}{2\phi^2}fRe, \tag{3.14}$$

and *energy equation*

$$\frac{1}{r}\frac{\partial}{\partial r}(ru^{+}T^{+}) + \frac{1}{r}\frac{\partial}{\partial \theta}(v^{+}T^{+}) =$$

$$\frac{1}{Pr}\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T^{+}}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{1}{r}\frac{\partial T^{+}}{\partial \theta}\right)\right) - \frac{1}{\phi Pr}w. \tag{3.15}$$

Hydrodynamic and thermal boundary conditions are

$$u^{+} = v^{+} = w = T^{+} = 0 \qquad \textit{on each wall.} \tag{3.16}$$

When symmetry exists, only half of the domain need to be solved by employing these additional boundary conditions at the symmetry line

$$\frac{\partial u^{+}}{\partial \theta} = \frac{\partial w}{\partial \theta} = \frac{\partial T^{+}}{\partial \theta} = v^{+} = 0 \qquad \textit{where} \ \ \gamma \le \theta \le \phi, \ 0 \le r \le 1. \tag{3.17}$$

Axial pressure gradient, which is solved in term of fRe, must satisfy the conservation of mass equation in dimensionless form as

$$\int_{\gamma}^{2\phi}\int_{0}^{1} w r\,dr\,d\theta = \phi. \tag{3.18}$$

The average Nusselt number is determined by

$$Nu = \frac{\bar{h}D_h}{k} = -\frac{\phi}{(1+\phi)^2}\frac{1}{T_m^{+}}, \tag{3.19}$$

where bulk mean temperature is defined as

$$T_m{}^{+} = \frac{1}{\phi}\int_{\gamma}^{2\phi}\int_{0}^{1} wT^{+} r\,dr\,d\theta\,. \tag{3.20}$$

In case of semicircular duct, $\phi = \pi/2$ and $\gamma = 0$, thus the last three equations become:

$$\int_{0}^{\pi}\int_{0}^{1} wr\,dr\,d\theta = \frac{\pi}{2}, \tag{3.21}$$

$$Nu = \frac{\bar{h}D_h}{k} = -\frac{2\pi}{(2+\pi)^2}\frac{1}{T_m^+}, \tag{3.22}$$

and

$$T_m{}^{+} = \frac{2}{\pi}\int_{0}^{\pi}\int_{0}^{1} wT^{+} r\,dr\,d\theta\,. \tag{3.23}$$

Chapter 4

Experimentations and Experimental Results for a Semicircular Duct

A semicircular duct is the most important member of the circular sector duct family due to its potential application as a stand-alone duct. In addition, its broad shape provides room for the cross-stream flow to be significantly affected by the duct cross-sectional orientation which is illustrated in Chapter 5. Using water as the working fluid, the experiments were conducted for four orientations, i.e. $\alpha = 45°$, 90°, 135° and 180°, and the results are presented in this chapter. The streamwise developments of the duct wall temperatures and local Nusselt numbers are examined corresponding to Grashof and Reynolds numbers. These developments indicated that the fully developed Nusselt numbers were obtained quite early. The lengths of the fully developed regions were larger than a half of the total length of the heated section. The fully developed Nusselt number results are presented with Gr^+ and Gr^+Pr as independent variables. Finally, the friction factors in term of fRe are presented. The comparisons of Nu and fRe to the predicted results are given in Chapter 5.

4.1 Experimental Facility

The major components of the experimental apparatus are shown in Fig. 4.1. This experimental facility was basically the same as the one used in [45] where a complete description is given. However, the essential details are again reported here together with the additional data due to some modifications.

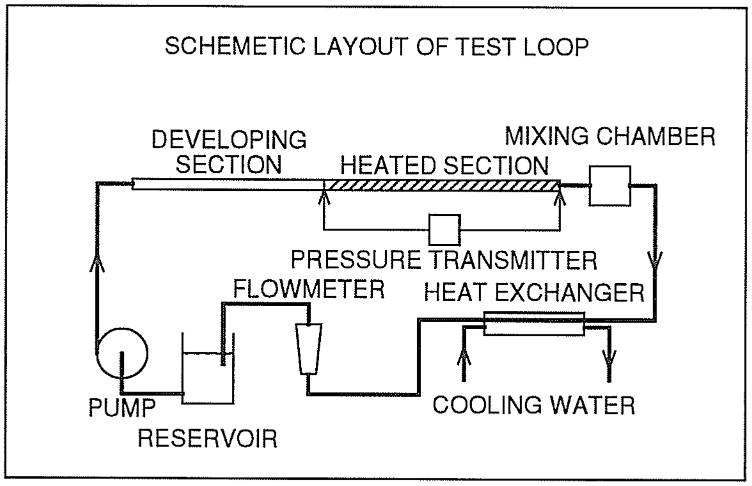

Fig. 4.1 Schematic layout of the test loop.

4.1.1 Test Section

The semicircular test section was constructed from type K copper tubes, inside diameter of 49.8 mm and outside diameter of 54.0 mm. The test-section consisted of two parts, a heated section of 4.7 m length and a preceding section of 3.8 m for flow development. The heat flux was generated by flat electric heater wires, (Copel® ribbon, Hoskins Manufacturing Company). After a few layers of electrical insulating varnish coating, the duct was wrapped with a layer of fibre glass insulating tape to protect the varnish surface from the heater wires. Two heaters were carefully wound in parallel and with a uniform pitch. The resistance of the twin heaters was axially uniform within about 5%. The heating wires covered with high temperature cement to ensure that they remained firmly in place in spite of the different temperature conditions. The total resistance between both ends of the heater was 6.95 ohms. With an adjustable AC power supply, it was possible to deliver a heating power up to more than 5 kW. The duct was finally covered with 5-cm-thick fibre glass thermal insulation over all the heated section. The average heat loss was about 3% (measured by a heat flux meter, HEATPROBE model HA-100, 5% accuracy) of the electrical power input for the most severe operating condition. The test section was aligned horizontally within ±1 mm at the centre of the flat wall. The oriented angle was adjusted to an accuracy of ±1 degree for each orientation.

4.1.2 Other Components

The test facility was installed in a loop whereby the outlet fluid from the test section was recycled by a centrifugal pump. The working fluid, distilled water, from a storage tank of 227 L capacity was partially fed to the test section by the pump while the main part of the fluid was fed back to the tank via a bypass line. This provided not only a stable pressure head over the test section but also fluid circulation in the tank to ensure that the fluid temperature was homogeneous and stable. The hot fluid, leaving the test section, was cooled down to near room temperature by a heat exchanger and passed to a rotameter for flow measurement before returning to the tank. The calibrated accuracy was within 3.3% for all rotameters. The pressure drop was measured across the heated section by a differential pressure transmitter, Rosemount model 1151DP, connected to an analog computer, Macsym 2, which indicated the average values of pressure. The pressure was detected by four pressure taps at each end of the heated section as shown in Fig. 4.2. The pressure transmitter was initially calibrated with water columns. The result was again confirmed with dynamic pressure reading, by running the tests without heating for various flow rates. This test also yielded the critical Reynolds number when the critical flow rate was reached.

For safe operation of the test loop, a pressure switch was installed near the outlet of the test section. The heater circuit was controlled through a magnetic relay by this switch which was normally open unless there was pressure due to fluid flow in the system. Therefore the heating could not be activated without the flowing fluid in the test section.

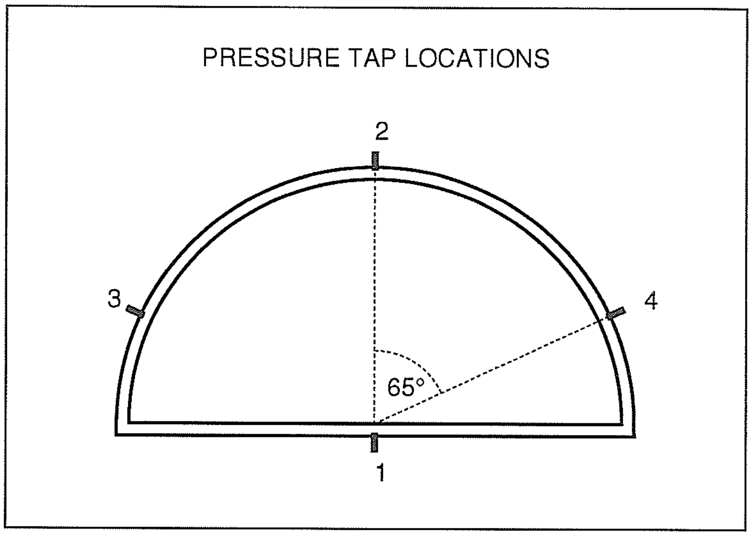

Fig. 4.2 Locations of the four pressure taps.

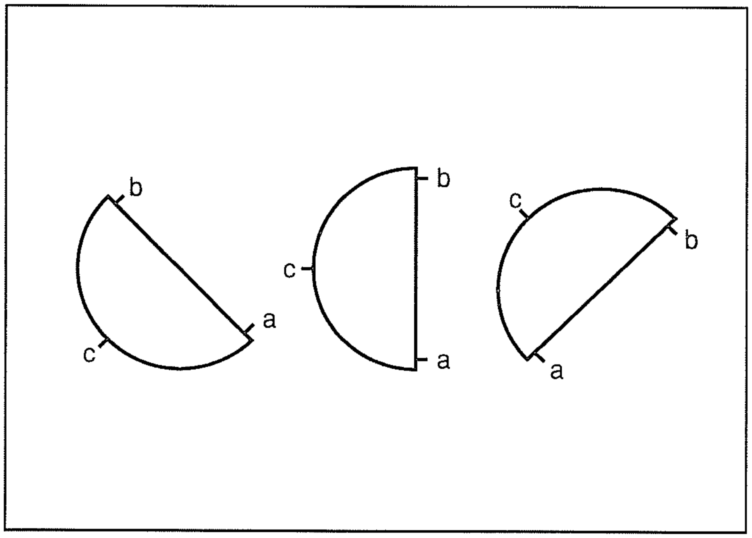

Fig. 4.3 Locations of the thermocouples, for α = 45°, 90°, 135°.

4.1.3 Temperature Measurements

The fluid inlet and outlet temperatures were measured by gauge 24 type T thermocouples. The outlet fluid was passed through a mixing chamber before measuring the temperature. The duct wall temperatures were measured at 19 axial locations* within the heated section. There were 3 peripheral thermocouples at each axial location. Two thermocouples, labelled *a* and *b*, were on the flat wall, 5 mm from the corner. The third thermocouple, labelled *c*, was on the middle of the arc wall. The locations of these thermocouples are shown in Fig. 4.3 for $\alpha = 45°$, 90°, and 135°. For $\alpha = 180°$, the thermocouple *a* and *b* are in the same elevation because the flat wall is horizontal for this case. The thermocouple, Type T, gauge 22, with fibre-glass covers, was directly soldered to the duct wall. These thermocouple were calibrated on-site (therefore any installation effect was eliminated). To create various wall temperature conditions, water at different temperatures was circulated around the loop at near maximum flow rate. The calibration was conducted over 18 runs covering a range of wall temperature from 15° to 76° C (60° to 170° F). All the temperature readings agreed very well, for example, within 0.17° C at 22° C (0.3° F at 72° F), and a maximum of within 0.56° C at 76.7° C (1.0° F at 170° F). The calibration was done by comparing to two selected thermocouples which were already calibrated with a reference junction (Omega®, Temperature Reference Probe, model TRP–T) over a range of 10° to 90° C in a water

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*For actual spacing between stations, see Appendix 1 (for example) which summarized the experimental data for $\alpha = 45°$.

bath inside a vacuum flask. Generally speaking, the two thermocouple were identical, e.g. only variations within 1 least significant digit (0.1° F) were observed. These thermocouple junctions were gently and firmly attached to the duct wall by screws and high thermal conductivity paste (Omegatherm 201) at each end of the heated section. The two reference junctions showed maximum differences only 0.2° F during the on-site calibrations.

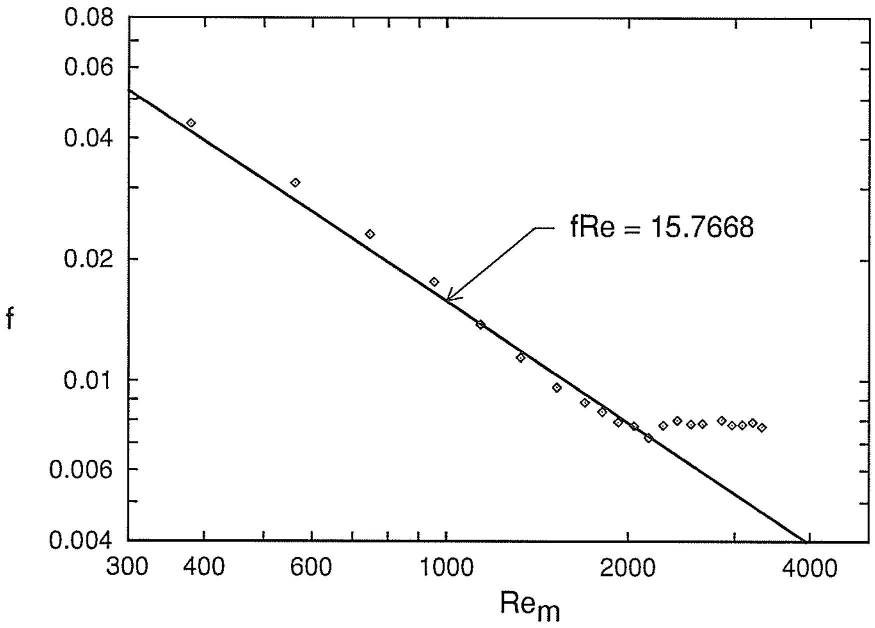


Fig. 4.4 The friction factor versus Re_m.

4.2 Experimental Procedure

The test section was tested for the critical Reynolds number by monitoring the friction factor against Reynolds number. The test were conducted for various flow rates, without heating, and the Reynolds number approximately ranging from 380 to 3300. In Fig. 4.4, the departure of friction factor from the fRe = 15.7668 line[36], which indicated the transition of flow, appeared at a Reynolds number of about 2200. The friction factor agreed well with the line of fRe = 15.7668 for Reynolds number up to the critical value. For Re_m between 380~2000, the averaged and maximum errors for the measured friction factors are 5.4% and 10.5% compared to the prediction from the fRe = 15.7668 relation.

For combined convection, each experiment was run until steady fluid and wall temperatures were established. All the data were recorded when the steady state was established by the fluid and wall temperatures, the heating power and the fluid flow rate. For consecutive experiments, before the next experiment was started, the system was flushed by the fluid at the maximum flow rate to eliminate any possible effects remaining from the previous experiment.

The experiments were generally scheduled for Re_m ranging between 400 and 1600 so as to ensure that the flows were laminar, e.g. the local Re were well below 2100. The heat flux was varied corresponding to the Gr_m nominally ranging from 1×10^6 to 5×10^7 for every orientation. The range of actual operating conditions, evaluated at the average inlet and outlet fluid temperatures, are summarized in Table 4.1. Summaries of the experimental data are given in Appendices 1 to 4 inclusive.

Table 4.1 Range of operating conditions of the experiments.

α	Gr_m	Re_m	Pr_m	$\dot{m}$ (g/s)	no. of runs
45°	$1.0 \times 10^6 – 4.9 \times 10^7$	497–1529	4.2–7.7	12–53	30
90°	$1.1 \times 10^6 – 5.1 \times 10^7$	498–1549	4.6–7.6	14–51	24
135°	$1.1 \times 10^6 – 4.9 \times 10^7$	495–1505	4.2–6.1	11–43	21
180°	$1.2 \times 10^6 – 4.8 \times 10^7$	496–1500	4.2–6.2	12–43	20

4.3 Data Analyses

The main purpose of the experiments was to obtain the fully developed results for the duct at various orientations. In addition, the wall temperature data at the upstream side were used for demonstrating the development of Nusselt number, the effect of buoyancy force, etc. A local Nusselt number can be determined at an axial location, x, and any peripheral location, θ = a, b, c, ..., by

$$Nu_{x,\theta} = \frac{h_{x,\theta} D_h}{k} = \frac{Q_f D_h}{A_{iw}\, k\, (t_{x,\theta} - t_{m,x})} , \qquad (4.1)$$

where $t_{x,\theta}$ is a duct wall temperature, $t_{m,x}$ is a fluid bulk mean temperature, Q_f is the heat gain by the fluid, A_{iw} is the inside wall area exposed to the heat flux and k is the fluid thermal conductivity evaluated at $t_{m,x}$. The axially local Nusselt number could be obtained from the average peripheral temperature, $Nu_{x,t}$ or from the average peripheral heat transfer coefficients, $Nu_{x,h}$, as follows:

$$Nu_{x,t} = \frac{Q_f D_h}{A_{iw} k (\overline{t_{x,\theta}} - t_{x,m})} , \tag{4.2}$$

$$Nu_{x,h} = \frac{Q_f D_h}{A_{iw} k \overline{(t_{x,\theta} - t_{m,x})}} . \tag{4.3}$$

In fact, these two average Nusselt numbers, $Nu_{x,t}$ and $Nu_{x,h}$, showed some differences after the experimental results were analyzed, therefore the average of these Nusselt numbers, Nu_x, is used consistently. Literally, Nu_x is a local average Nusselt number, axially local and peripherally averaged (from both methods), which is simply obtained from

$$Nu_x = \frac{Nu_{x,t} + Nu_{x,h}}{2} . \tag{4.4}$$

The modified Grashof number, Gr, used in experimental data analysis, is defined based on the total heat gain as

$$Gr = \frac{\beta g \rho^2 D_h^4 Q_f}{\mu^2 k A_{iw}} . \tag{4.5}$$

On the other hand, the other modified Grashof number, Gr^+, which emerged in the theoretical analysis, is defined based on the heat flux as

$$Gr^+ = \frac{\beta g q' R_0^3}{\nu^2 k} . \tag{4.6}$$

For a semicircular duct, it can be shown that

$$\frac{Gr}{Gr^+} = \frac{(2\pi)^4}{(\pi+2)^5} = 0.4337 . \tag{4.7}$$

The friction factor is defined as

$$f = \frac{\Delta P D_h \rho A_{fl}^2}{2 L \dot{m}^2} , \tag{4.8}$$

where ΔP is the pressure drop across the heated section of length L, and A_{fl} is the cross sectional area of the fluid flow passage. The Reynolds number is determined from

$$Re = \frac{D_h \dot{m}}{\mu A_{fl}} . \tag{4.9}$$

The uncertainties for the computed results, e.g. *Re*, *Gr*, were estimated from the tolerances of the measurements or the uncertainties of the calibrations, mainly based on the method in [123]. The estimated uncertainty for *Re* was within 4% for $Re_m \approx$

400–1600 and within 8% for f. This resulted in about 9% uncertainty for fRe. The computation for Gr or Nu depends on the total heat gain, Q_f, which had the maximum uncertainty of 4.6%. The maximum uncertainties were estimated to be about 6% for Gr and about 9% for Nu.

4.4 Wall Temperature Distributions

The duct wall temperature distributions for Gr_m about $1\text{x}10^7$ and Re_m about 1000, which is a typical average operating condition of these experiments, are shown in Figs. 4.5(a)–(d) for $\alpha = 45°$, 90°, 135° and 180°. The wall temperatures are plotted along with the fluid bulk temperature so that the magnitude of the wall-to-fluid temperature difference (drop) can be seen. The temperature drop profiles are almost constant beyond $X \approx 30D_h$ (station 6) for all four cases. In the near inlet region where $X < 30D_h$, wall-to-bulk fluid temperature differences are the largest and peaks in these temperature drops can be readily seen. The heights of the peak are approximately 1.6° to 1.7° C in excess of the wall temperature drops in the down stream region. The raised temperature drop indicates that the cross-stream flow is still weak and have little effect on the heat transfer. On the contrary, the decrease of the temperature drop (with axial distance) indicates that the cross-stream flow has developed and become effective in boosting the heat transfer and this results in the wall temperature decreasing as compared to the fluid bulk temperature. After $X = 30D_h$, the temperature drops are uniform. The fully developed temperature drop profile implies that the effect of buoyancy force is steady.

The magnitudes of the two peripheral temperatures at the corners, i.e. t_a and t_b, can be relatively indicated by their elevations. The higher corner always showed a higher temperature. For all α, the corner *b* was rotated to the top and therefore t_b was always higher than t_a as shown in Fig. 4.5(a), (b) and (c). The magnitudes of t_c also behaved similarly; e.g. being the lowest for $\alpha = 45°$ and the highest for $\alpha = 135°$ and $\alpha = 180°$. For $\alpha = 180°$, t_a and t_b were symmetric and this is reflected by them being equal within about 0.2° C. It is also noted that the differences between the maximum and minimum wall temperatures were always quite uniform throughout the fully established temperature region. For the data in Fig. 4.5, the differences averaged over the last 12 stations were 1.33°, 1.19°, 1.08° and 1.17° C for $\alpha = 45°$, 90°, 135° and 180° respectively. Generally, the differences in local wall temperatures (i.e. between wall thermocouples) increased with increasing Gr_m. Difference as large as 3.0° C ($\alpha = 90°$) to 3.7° C ($\alpha = 45°$) were observed at $Gr_m = 5\text{x}10^7$. However, these effects can be illustrated, more generally, in term of Nusselt number as well, and further discussion is made in the next section.

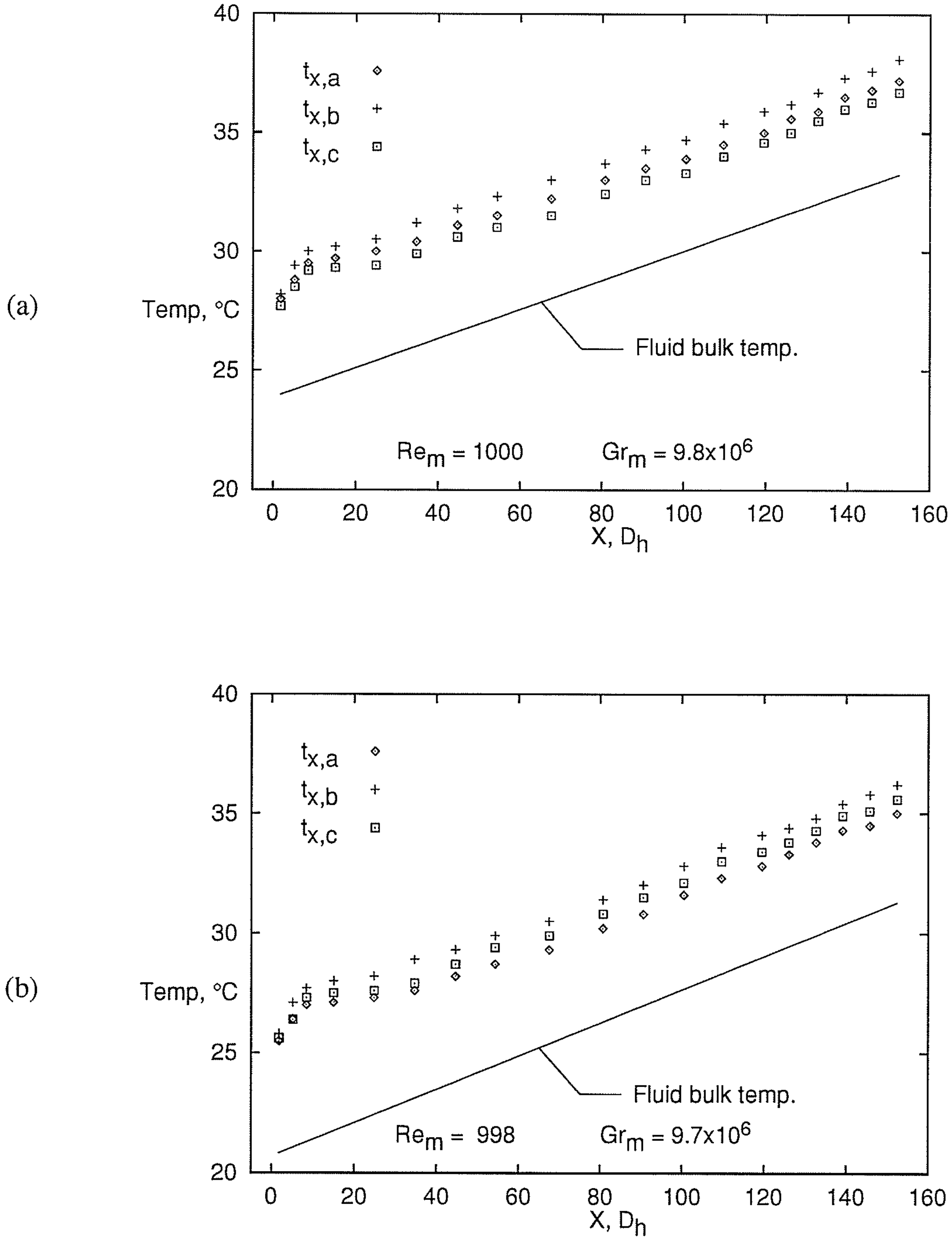
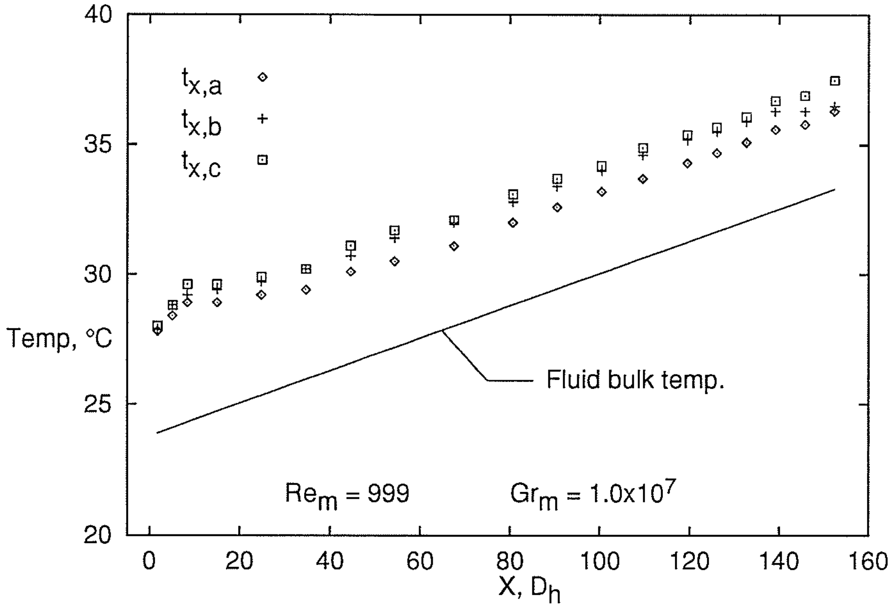


Fig. 4.5 The wall temperature distributions for α = (a) 45°, (b) 90°,

(c)



(d)

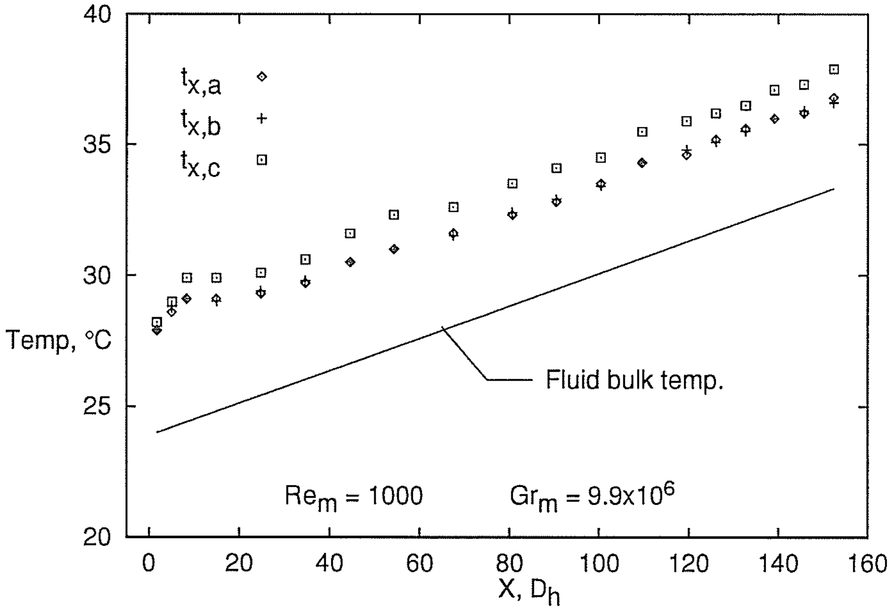


Fig. 4.5(cont) The wall temperature distributions for α = (c) 135°, and (d) 180°.

4.5 Distributions of Local Nusselt Number

The local Nusselt numbers, $Nu_{x,a}$, $Nu_{x,b}$, and $Nu_{x,c}$, were evaluated from $t_{x,a}$, $t_{x,b}$ and $t_{x,c}$ via equation (4.1). These three local Nusselt numbers along with Nu_x are plotted against the axial distance, X in Fig 4.6 using the same data as for Fig. 4.5. The Nusselt number profile is approximately the inverse of the temperature drop profile, e.g. the peaks near the inlet in Fig. 4.5 become sags in Fig. 4.6, and the uniform temperature drops become the uniform Nusselt numbers. After $X \approx 30D_h$, the Nusselt numbers are approximately uniform, however, there is some fluctuation which seem to be normal for combined convection results, e.g. see [3], and [45] for discussion. In fact, the fluctuations are somewhat exaggerated by the Nusselt numbers, as compared to the small variations of the temperature drop profile in Fig. 4.5.

The results from Fig. 4.6 are replotted against x^* in Fig. 4.7, together with the forced convection solutions for H1 and H2 conditions [45]. The Nusselt numbers at the first station agree quite well with the forced convection solutions. This confirms that the buoyancy effect or the cross-stream flow is negligible there. From the first station, the Nusselt number decreases to the minimum near x^* viscosity ≈ 0.001 and increases to a steady level near $x^* \approx 0.01$. The uniform magnitude of Nusselt number after x^* about 0.01 implies that the buoyancy effect is fully developed. The fully developed region includes about eleven stations from the downstream end. In the fully developed region, Nusselt numbers exceed the H1 pure forced convection value (4.0880[35]) by typically a factor of about 5 to 6 as can be seen from Fig. 4.7.

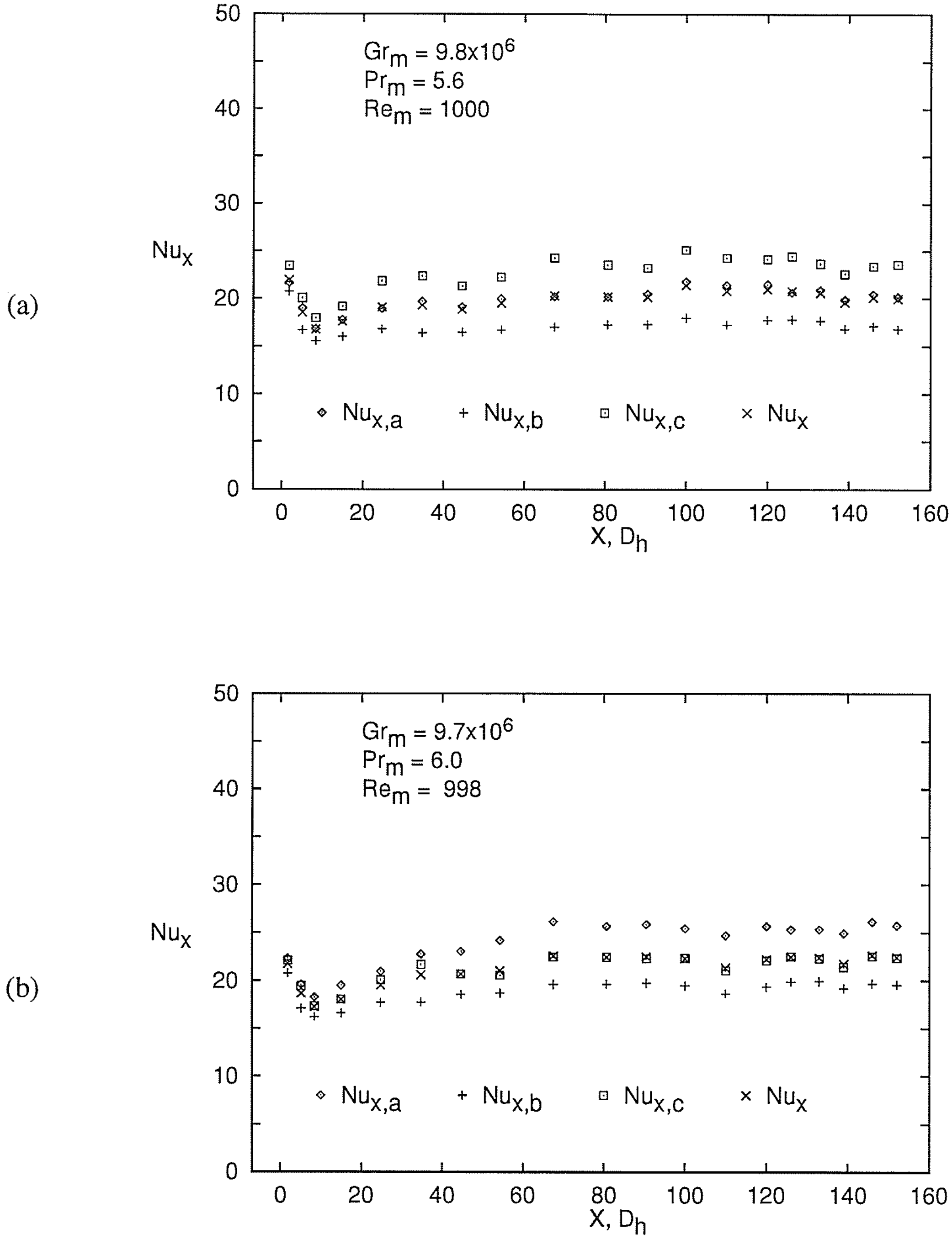


Fig. 4.6 Local Nusselt number distribution of *X* for α = (a) 45°, (b) 90°.

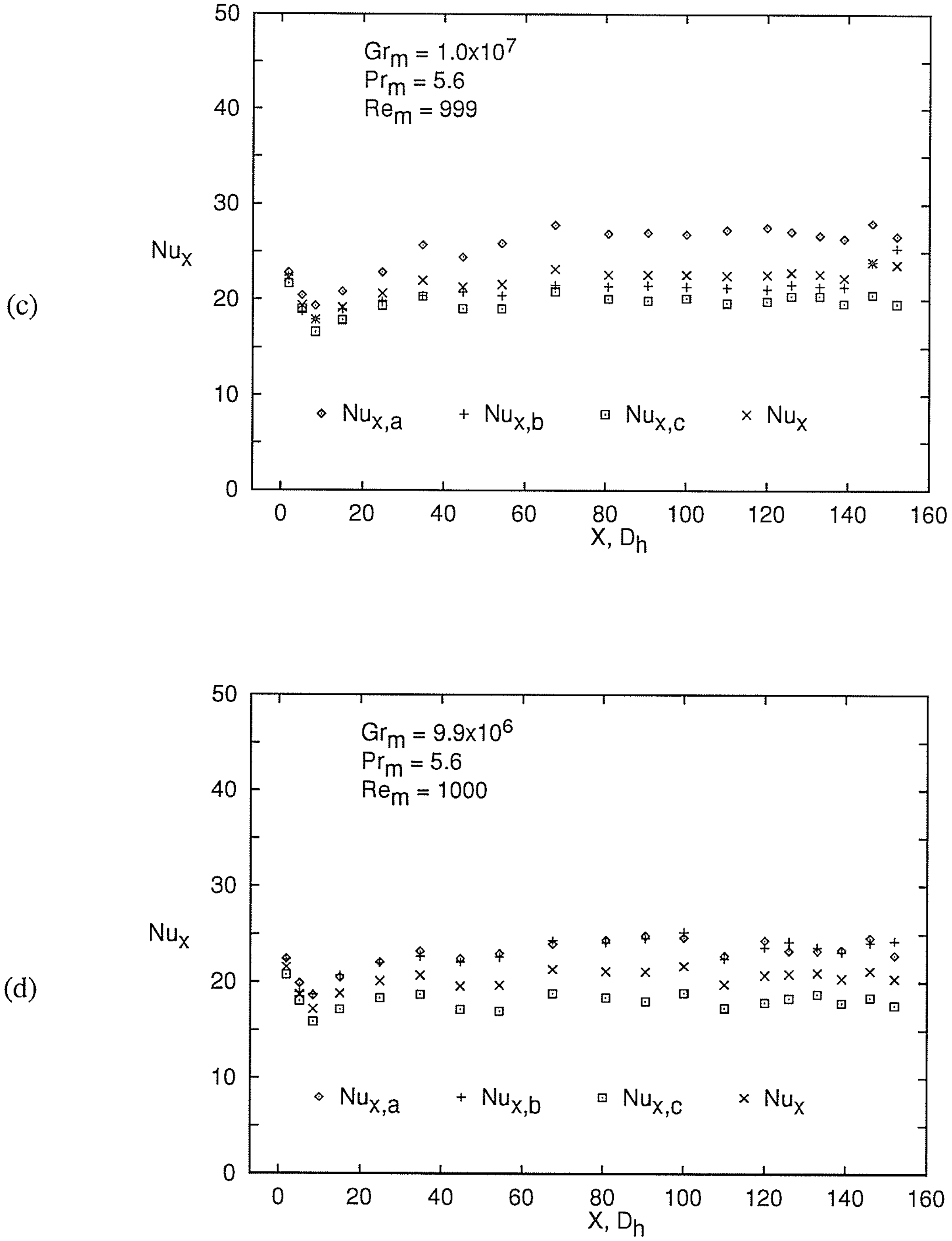


Fig. 4.6(cont) Local Nusselt number distribution of X for α = (c) 135°, and (d) 180°.

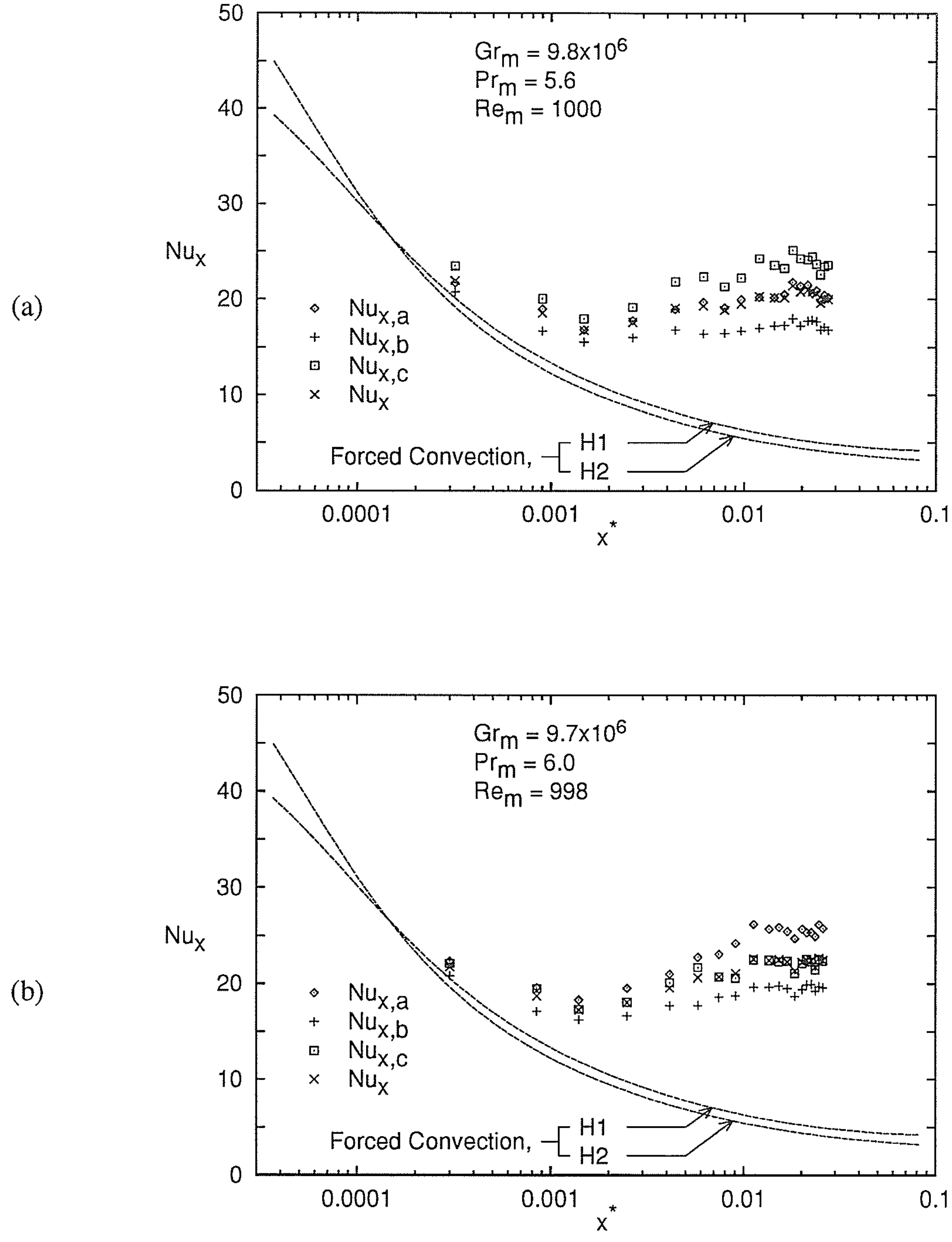
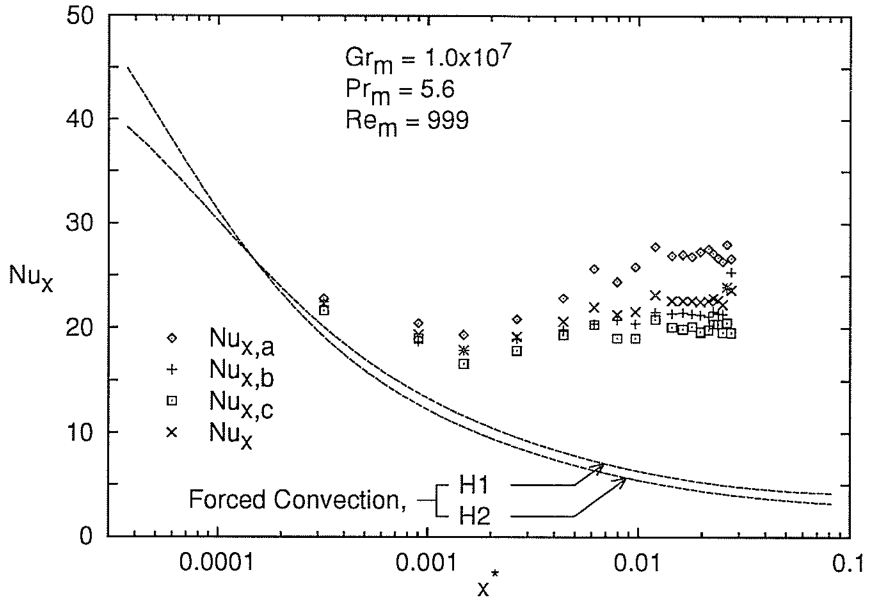


Fig. 4.7 Local Nusselt number distribution of x^* for α = (a) 45°, (b) 90°,

(c)



(d)

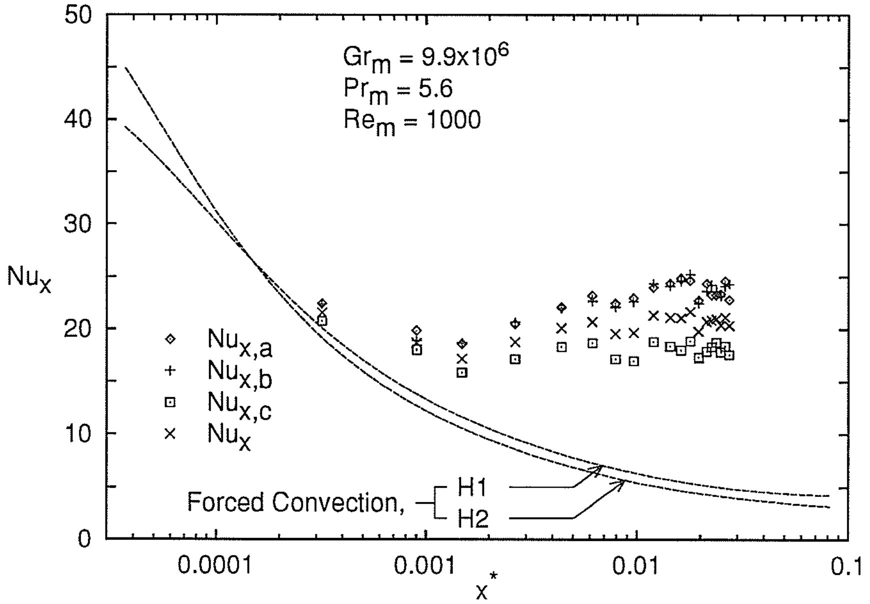


Fig. 4.7(cont) Local Nusselt number distribution of x^* for α = (c) 135°, and (d) 180°.

4.5.1 Effect of Reynolds Number

The effect of Reynolds number on the local Nusselt number was investigated by examining the Nusselt number distributions for a set of experimental results with the same Gr_m and Pr_m but with three different Re_m of about 500, 1000 and 1500. The results for $\alpha = 45°, 90°, 135°$ and 180° for Gr_m of $1\text{x}10^7$ are shown in Figs. 4.8(a)–(d) in term of Nu_x versus x^*.

For all cases of Re and α, Nu_x was maximum at the first station and decreased to the minimum at station 3. (According to Fig. 4.8, the locations of each station is arranged with respect to the abscissa. The experimental data given in the appendices have a few additional stations in the inlet vicinity. To locate the same physical station, station number in Fig. 4.8 must be added by 2, e.g. station 3 in Fig. 4.8 and other similar figures correspond to station no. 5 in the appendices.) From station 3, Nu_x increased to a level at station 6. The magnitudes of Nu_x was approximately uniform (with some fluctuations) from station 6 to the end of the heated section. This range agrees well with the region of the fully established temperature drops observed in the last section. Between stations 6 to 8, Nu_x decreased again and the second minimum occurred at station 7 or 8. From station 9 to the end of the heated section, the ripple magnitude was smaller due to the exclusion of station 6–8. Further decrease of the ripple was generally observed if the range was limited to between station 13 to 18, therefore the fully developed Nusselt number was determined from these six stations (13 to 18). Comparing to the magnitude of the fully developed Nusselt number, the differences averaged over stations 9 to 19 were within 3–4% for all the data in Fig. 4.8. The maximum variations were typically about 5–7%. The averaged differences decreased to 2–3% for the range where the fully developed Nusselt numbers were evaluated.

For each α, the fully developed Nusselt number magnitudes for each *Re* showed very small differences (about 3–5%). Therefore, the effect of *Re* is small for the magnitude of the fully developed Nusselt numbers. This trend was observed before in [45].

The differences in magnitudes of the local and fully developed Nusselt numbers were larger in the entrance regions. For α = 45°, 90° and 135°, the minimum Nu_x at station 3 were about 20–30% less than the fully developed Nusselt number for *Re* of 500 and 1000 and were about 10–15% for *Re* of 1500. For α = 180°, the same trend was observed but with smaller figures of the differences. Hence the *Re* of 1500 showed a slight tendency of an earlier thermal fully developed due to the smaller ripple in the entrance region. Due to such tendency was not consistently observed for all cases, station 9 can be safely regarded as the beginning of the fully developed region. The magnitudes of x^* for station 9 were varied due to the magnitudes of *Re*. For *Re* of 500, 1000, and 1500, x^* values for station 9 are 0.022–0.026, 0.011–0.012 and 0.007–0.008, respectively. These values are 19–23%, 9–10%, and 6–7% of the entrance length for the pure forced convection. These figures can be considered as thermal entrance lengths for design purposes.

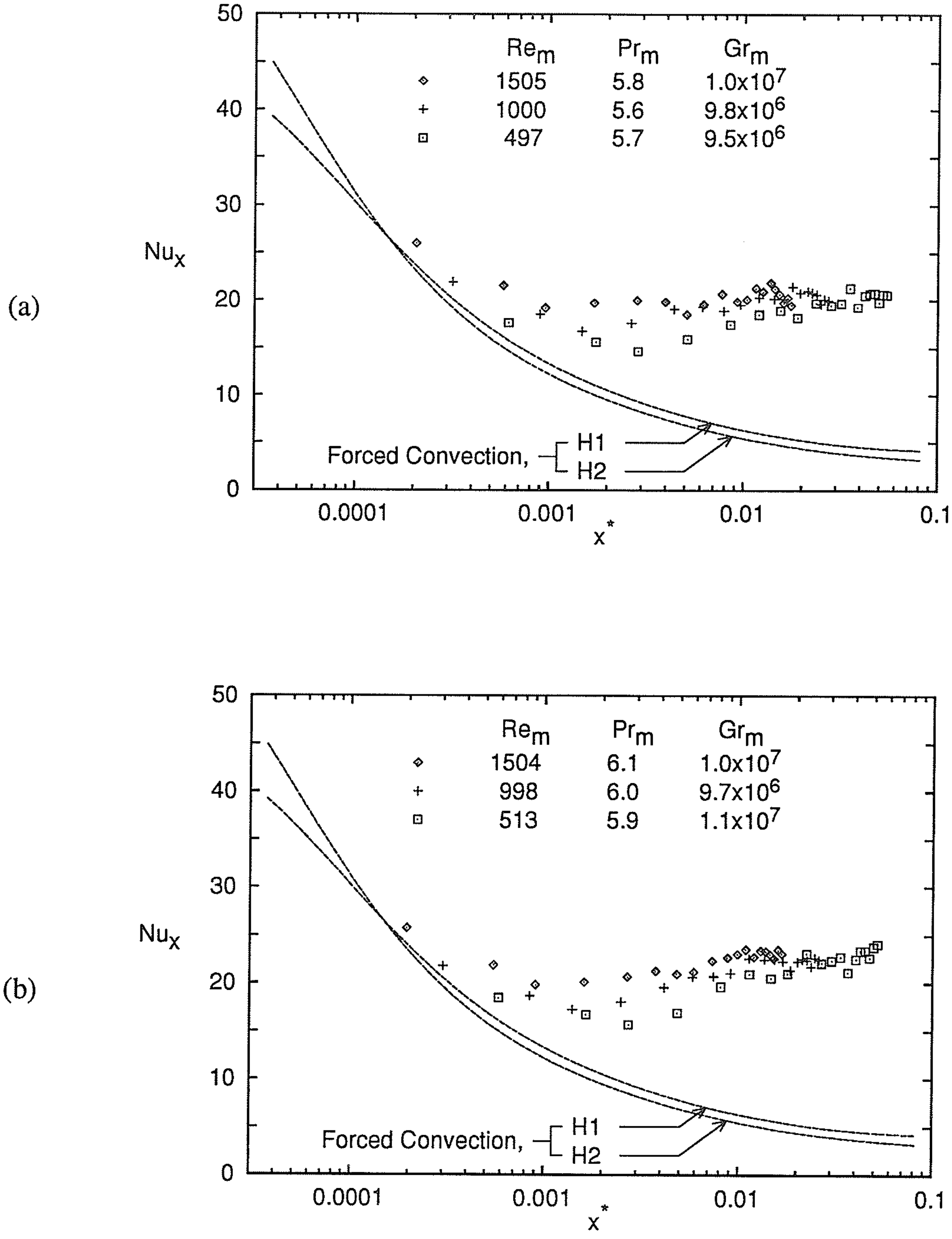
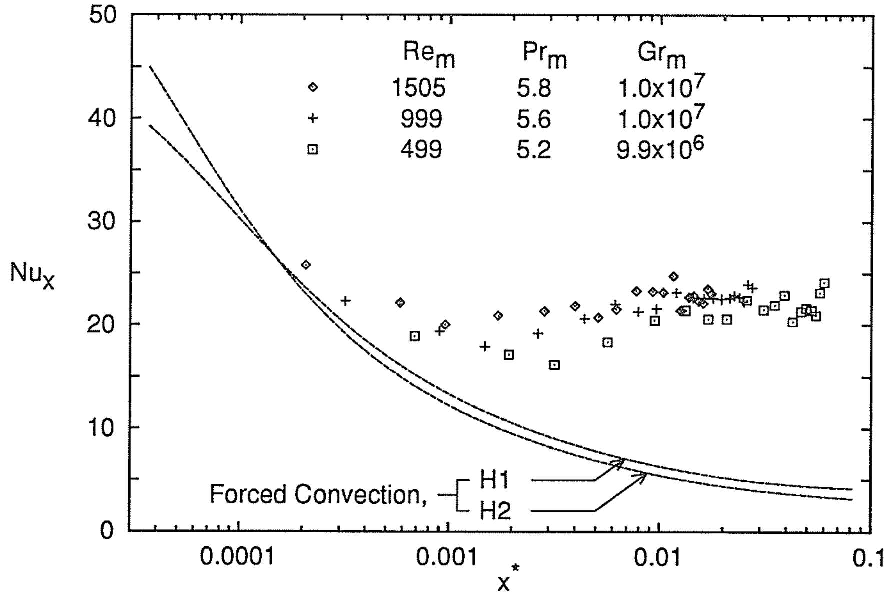


Fig. 4.8 Comparisons of the Nu_x for various Re_m, α = (a) 45°, (b) 90°.

(c)



(d)

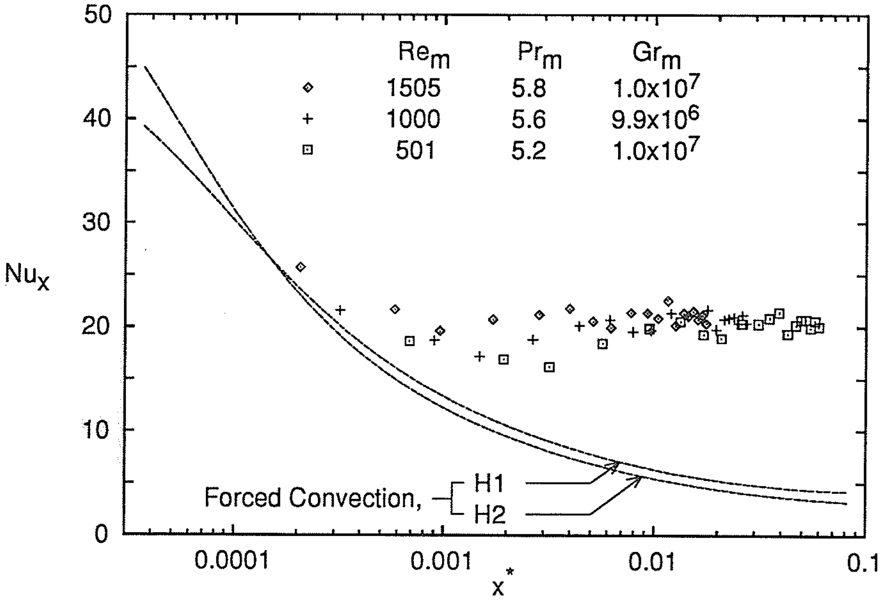


Fig. 4.8(cont) Comparisons of the Nu_x for various Re_m, α = (c) 135°, and (d) 180°.

4.5.2 Effect of Grashof Number

The Grashof number is the major controlling parameter for the Nusselt number. The effect of Grashof number, in term of Gr_m, is demonstrated in Figs. 4.9(a)–(d) for α = 45°, 90°, 135° and 180°, respectively, which contain the data for a fixed Re_m of about 1000 with three Gr_m values of approximately $5\text{x}10^6$, $1\text{x}10^7$ and $5\text{x}10^7$. The Nusselt and Grashof number relationship is well known in that Nusselt number increases with increasing Grashof number. This trend is clearly shown in Fig. 4.9. At the downstream end, the Nusselt numbers for $Gr_m = 5\text{x}10^7$ are much higher than those for $Gr_m = 1\text{x}10^7$ while the differences are comparatively small between Gr_m of $5\text{x}10^6$ and $1\text{x}10^7$. This indicates that the effect on Nu_x of Grashof number is more prominent as its magnitude increases. The plot of the fully developed Nusselt number and Grashof number in the next section will demonstrate this relationship more clearly.

The variations of Nu_x were observed similarly to the last subsection. The averaged variations of Nu_x compared to the fully developed values were typically within 2–3% for station 9 through the last station. The maximum variations are within 2–8% in general. For station 13–18, the averaged variations decreased somewhat, and the similar magnitudes as for the previous case were observed.

The magnitudes of the fully developed Nusselt number for Gr of $5\text{x}10^7$ are about 50–60% larger than those of $Gr \approx 5\text{x}10^6$. This roughly indicates that the fluctuations of Nu_x (which are about 2–3% of the fully developed Nusselt numbers uniformly for each Gr) in the fully developed region increase in magnitudes about 50–60% as Gr

increases from $5x10^6$ to $5x10^7$. This can be observed in Fig. 4.9 as well. The same conclusion was also obtained by Lei [45].

From the inlet, the magnitudes of Nu_x decreased to the minimum at station 3 and then increased to near the fully developed values between stations 5–8. Only small influences of the magnitudes of Gr on the beginning point of the fully developed region were observed for all cases of α. Again, due to the reasonably smooth distributions of Nu_x as mentioned earlier, station 9 was regarded as the beginning point of the fully developed region. The entrance lengths in term of x^* for station 9 are about 0.010, 0.012, and 0.015 for Gr of $5x10^6$, $1x10^7$, and $5x10^7$ respectively. Compared to the entrance lengths for the pure forced convection in semicircular ducts[45], the entrance lengths are about 9%, 10%, and 13% for Gr of $5x10^6$, $1x10^7$, and $5x10^7$ respectively.

The entrance length was experimentally observed to slightly decrease with increasing Gr in the previous experiments for $\alpha = 0°$ by Lei [45], i.e. 7%, 9% and 15% for Gr of about $4x10^7$, $6x10^6$, and $1x10^6$ respectively. Even though the figures given by Lei [45] and the present results are in the reverse order, their magnitudes are similarly about 10%. Cheng and Ou [19] compared their predictions to the experimental results for water (conducted by Petukhov and Polyakov) for circular ducts with uniform heating and concluded that the free convection effect shortens the entrance lengths, similar to Lei's observation above.

The patterns of Petukhov and Polyakov data for Rayleigh number of $8.75x10^4$, $3.75x10^4$, and $7.5x10^5$ are actually very similar to Fig. 4.9 and Fig. 6.8 in [45] in the manner that local Nusselt number decreased to the minimum near the inlet and then increased to a steady level. The Nusselt number distributions predicted by [19] also showed this pattern but only for low Ra (10^4 and 10^5). The appearance of the minimum was discussed in [19] that it is because of the balance of the entrance (inlet fluid stream containing no cross-stream circulation yet) and free convection effects. If there is no minimum point, the patterns become many horizontal lines simply branching from the pure forced convection curve to the right, e.g. see Fig. 13 in [124]. It is true for such patterns that the onset of combined convection (the point on the x^* axis where local Nusselt number is 5% higher than that of pure forced convection) and the entrance length (x^*) becomes smaller as Rayleigh number increases. This is because the curve for a higher Rayleigh number separates from the pure forced convection curve at a higher vertical level and hence at a smaller x^* due to the shape of the pure forced convection curve. On the other hand, when the patterns with large sags (e.g. for the present results, the minimum points differed from the fully developed values up to 30%) are observed, such regions must be excluded from the fully developed regions where the variations should be normally much smaller. And hence the entrance lengths were observed to be approximately the same in terms of X and slightly increased with increasing Gr in terms of x^*.

In fact, the magnitude of x^* ($= X/D_h RePr$) depends on the magnitudes of Re and Pr. For a given value of X, a smaller Re results in a larger x^*. This can be consistently observed either in Fig. 4.8 or [45]. For Fig. 4.8, most of the data for $Re \approx 500$ locate where $x^* > 0.02$ whereas the data for $Re \approx 1500$ locate in the region where $x^* < 0.02$. Although the entrance lengths in terms of X are slightly dependent on Re, the entrance lengths in terms of x^* depend on *Re* quite strongly for the same conditions of *Pr* and *Gr*. The *Pr* has the similar effect as *Re* but with much less influence due to a smaller variations for the data obtained by using water as the working fluid. This appeared in either Fig. 4.9(b) or [45] both of which showed the same trend, e.g. as *Pr* value decreases from about 6 to about 4.6, the majority of the data points in the downstream region shifted significantly to the right. On the other hand, if the magnitudes of *Pr* were the same, all the corresponding data for each *Gr* should line above or below each others more evenly. This, in addition to the slight dependence between the entrance lengths in terms of *X* and *Gr*, implies that the effect of *Gr* on the entrance length in terms of x^* is small for given values of *Pr* and *Re*.

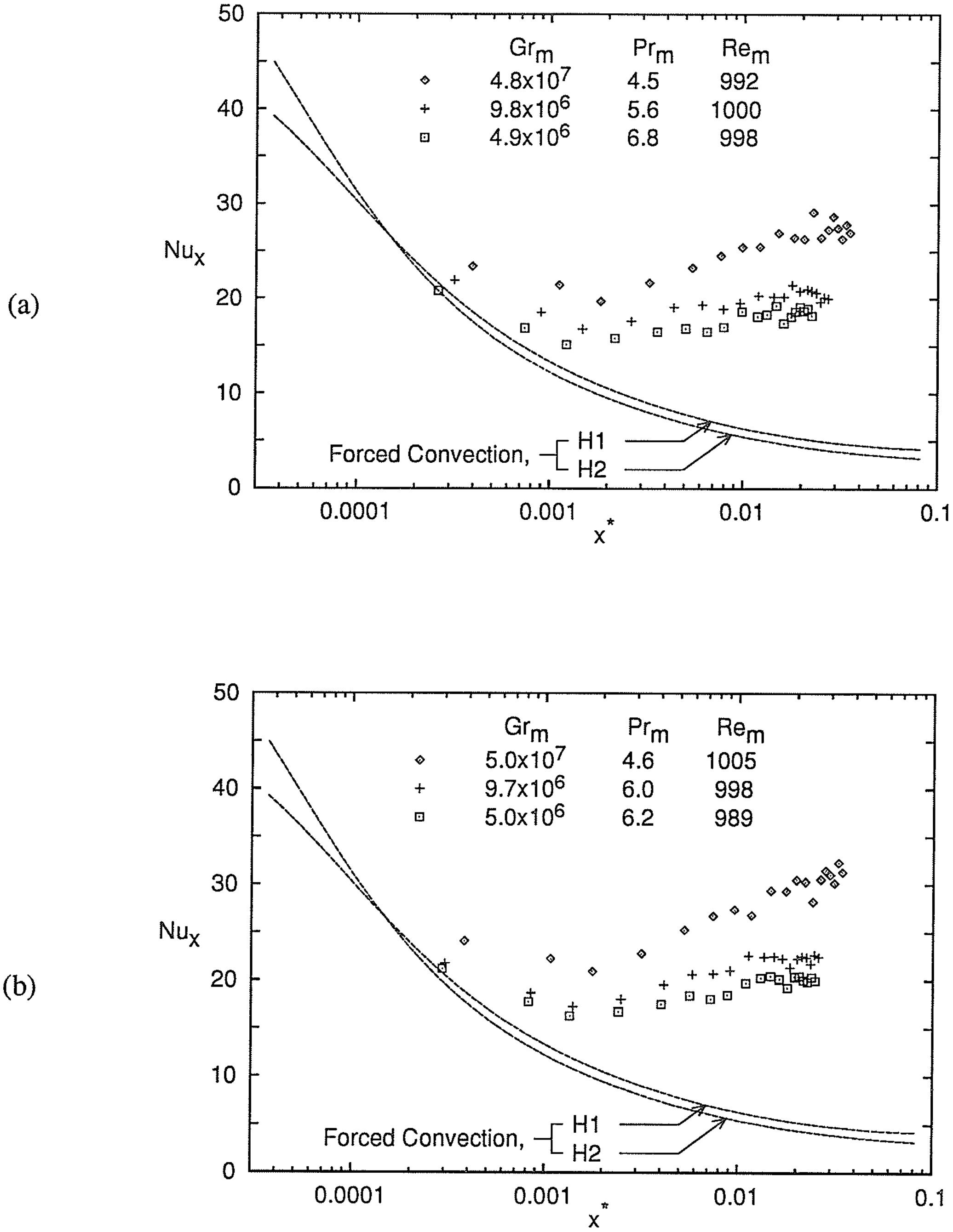


Fig. 4.9 Comparisons of the Nu_x for various Gr_m, α = (a) 45°, (b) 90°,

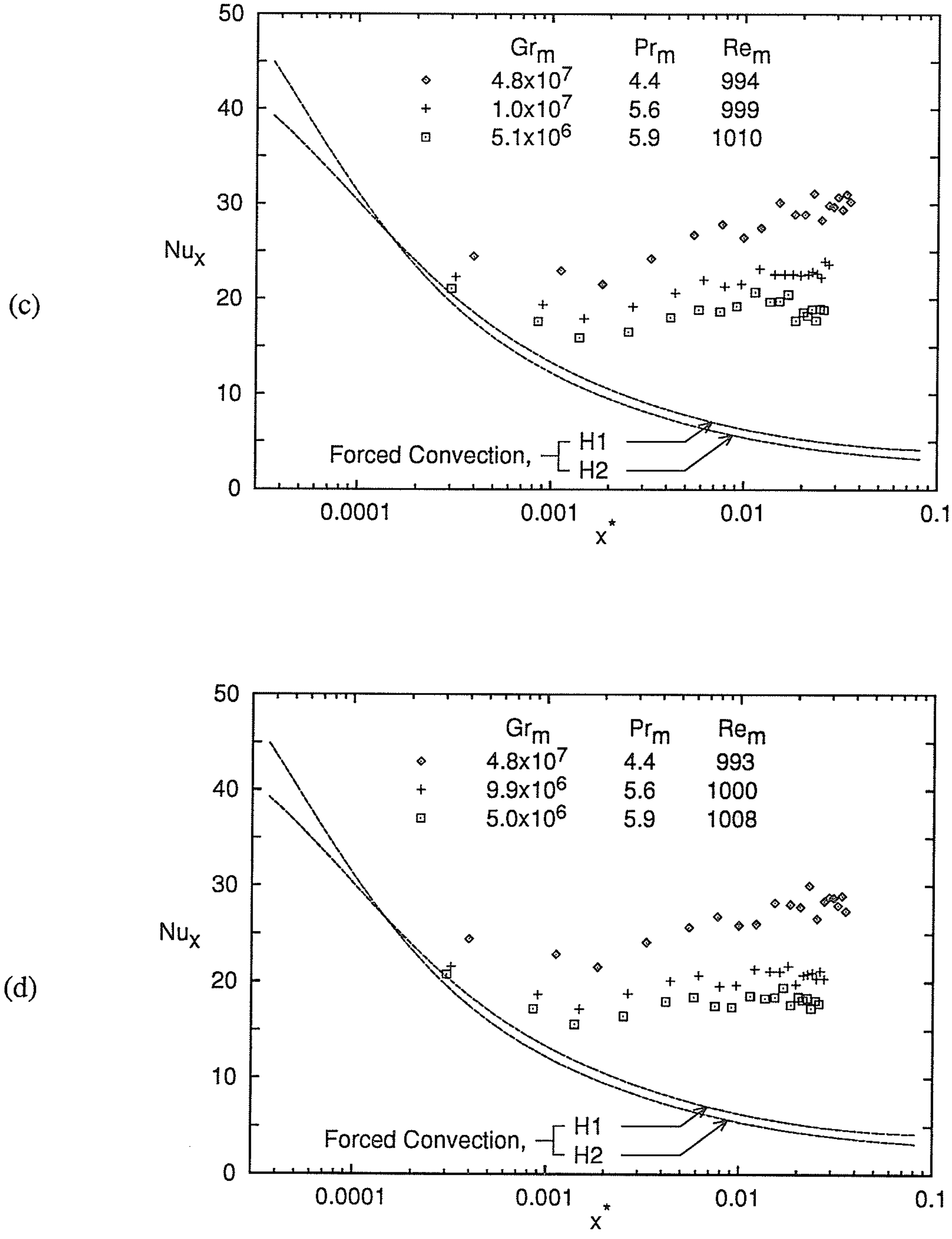


Fig. 4.9(cont) Comparisons of the Nu_x for various Gr_m, α = (c) 135°, and (d) 180°.

4.6 Fully Developed Nusselt Number

In the previous sections, it has been shown that the magnitude of the fully developed Nusselt number depend heavily on Grashof number. In this section, the fully developed Nusselt numbers are evaluated and investigated with the Grashof number as a dependent variable. The effect of Prandtl number, which as shown in the theoretical part of this thesis can be eliminated if the dependent variable Gr^+Pr is used instead of Gr^+, is also included in this section.

4.6.1 With Grashof Number Variable

The examination of Nu_x for all data showed that it was approximately uniform after $x^* \approx 0.01$ which corresponded to more than 10 stations from the downstream end. Fully developed Nusselt number was evaluated by the length mean average of the last six Nu_x, not including the last station (to avoid any end effect even though it was not noticeable). The average thermal conditions for the fully developed region are shown in Table 4.2.

Table 4.2 The average thermal conditions of the fully developed region.

α	Gr^+	Pr	Gr^+Pr	Re
45°	$2.7\text{x}10^6$–$2.1\text{x}10^8$	3.4–7.6	$2.0\text{x}10^7$–$8.1\text{x}10^8$	513–1727
90°	$2.5\text{x}10^6$–$2.1\text{x}10^8$	3.7–7.4	$1.6\text{x}10^7$–$8.4\text{x}10^8$	514–1787
135°	$2.7\text{x}10^6$–$2.0\text{x}10^8$	3.4–6.1	$1.6\text{x}10^7$–$7.0\text{x}10^8$	505–1730
180°	$2.9\text{x}10^6$–$1.9\text{x}10^8$	3.4–6.1	$1.7\text{x}10^7$–$6.9\text{x}10^8$	507–1729

Table 4.3 The coefficients for eqn. (4.10) and standard deviations.

α	a	b	σ	σ_{max}	no. of data points
45°	0.119	0.204	3.3%	6.3%	30
90°	0.107	0.217	3.3%	7.4%	24
135°	0.098	0.220	3.2%	6.6%	21
180°	0.123	0.203	2.7%	5.2%	20

The average fully developed Nusselt number, Nu, will be presented in its relative form as Nu/Nu_o, where Nu_o is a fully developed Nusselt number for the H1 forced convection solution which has a magnitude of 4.0880[35]. The relative Nusselt number are plotted against the modified Grashof number, Gr^+, which is equivalent to $0.4337Gr$, in Fig. 4.10 for $\alpha = 45°$, 90°, 135° and 180°. The data are fitted using the following form

$$\frac{Nu}{Nu_o} = 1 + a(Gr^+)^b \quad . \tag{4.10}$$

The coefficients a and b for $\alpha = 45°$, 90°, 135° and 180° and the standard deviation are summarized in Table 4.3. The data are represented by the equation very well for α of 45°, 135° and 180° while the 90° data show more scatter as is reflected by the slightly larger maximum value of the standard deviation.

The correlations in Table 4.3 are used in generating the curves in Fig. 4.10 whereas the Nusselt number data are shown in terms of points. Fig. 4.10 illustrates that Nusselt number is strongly dependent on Grashof number. The strong relationship of these two parameters has been commonly recognized by both the theoretical analysis (e.g. [5]) and the experiments (e.g. [10]). In addition, the theoretical solutions of the present results demonstrate that the locus of the Nusselt number on the Nusselt–Grashof number plane is always a well defined curve for a given α. The shapes of the curves in Fig. 4.10 show that Nusselt number exponentially increases with increasing Grashof number. This suggests that cross-stream flow strengthens progressively with increasing heating rate which results in continual decreasing of the wall-to-fluid temperature drop.

To demonstrate the effect of the duct orientation, the curves in Fig. 4.10 are replotted in Fig. 4.11. The Nusselt number curves for $\alpha = 90°$ is a little higher than that for 135° but are very close for the entire range of Gr^+. For $\alpha = 45°$ and 180°, the Nusselt number curves are also very close and the curve for $\alpha = 180°$ is a little higher. Considering the two pairs, the differences in Nusselt number magnitudes are the highest at high Gr^+. Between $\alpha = 45°$ and 90°, the difference is about 10% at $Gr^+ \approx 2\text{x}10^8$. The difference is a little smaller between $\alpha = 90°$ and 180°. On the contrary, at the lower end of the Gr^+ range, the differences for all curves are almost negligible. This indicates that the orientation significantly affects the heat transfer performance only if the heating rate is high and the effect decreases with a decrease in heating rate. As we can extrapolate from the results in Fig. 4.11, the four curves must collapse and approach the pure forced convection result if Gr^+ keep decreasing toward zero.

In Fig. 4.11, the Nusselt number ratios are about 7–8 at $Gr^+ = 2 \times 10^8$ for all α. The rate of increases for each curve suggests that a very high Nusselt number is likely if Gr^+ is raised much beyond 2×10^8.

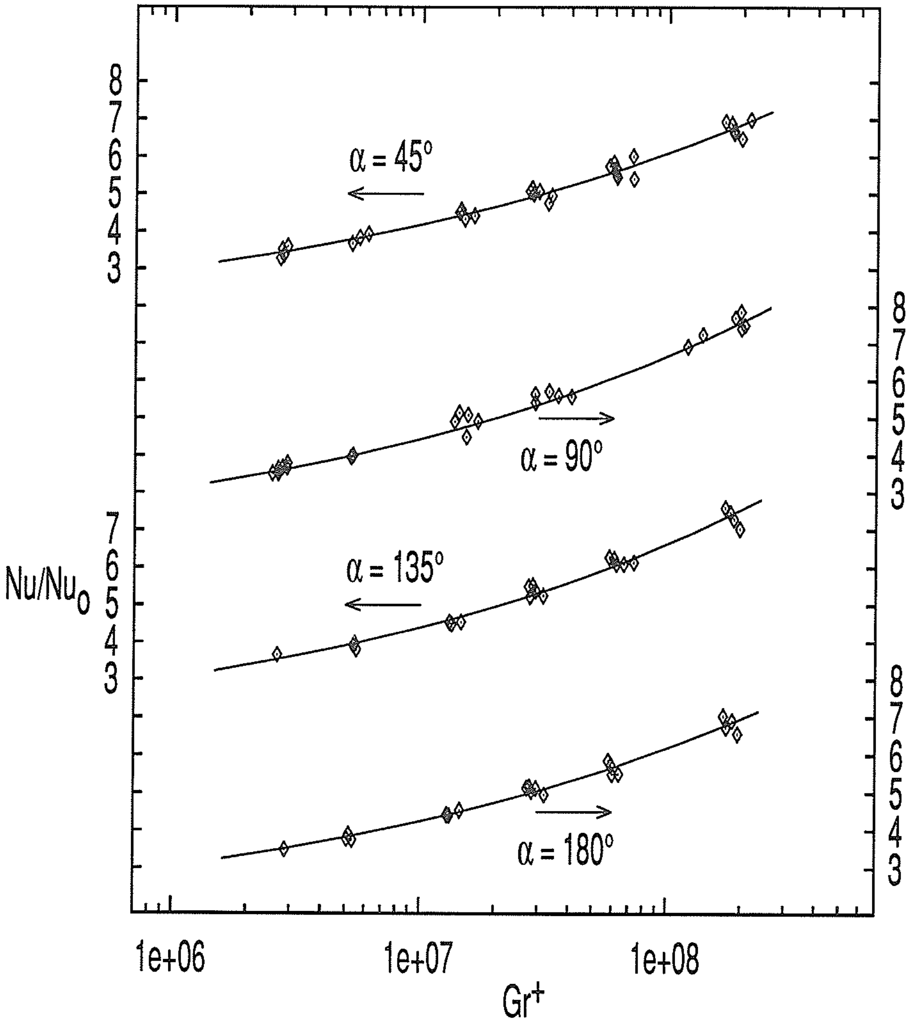


Fig. 4.10 Fully developed Nusselt number versus Gr^+ for α = 45°, 90°, 135° and 180°.

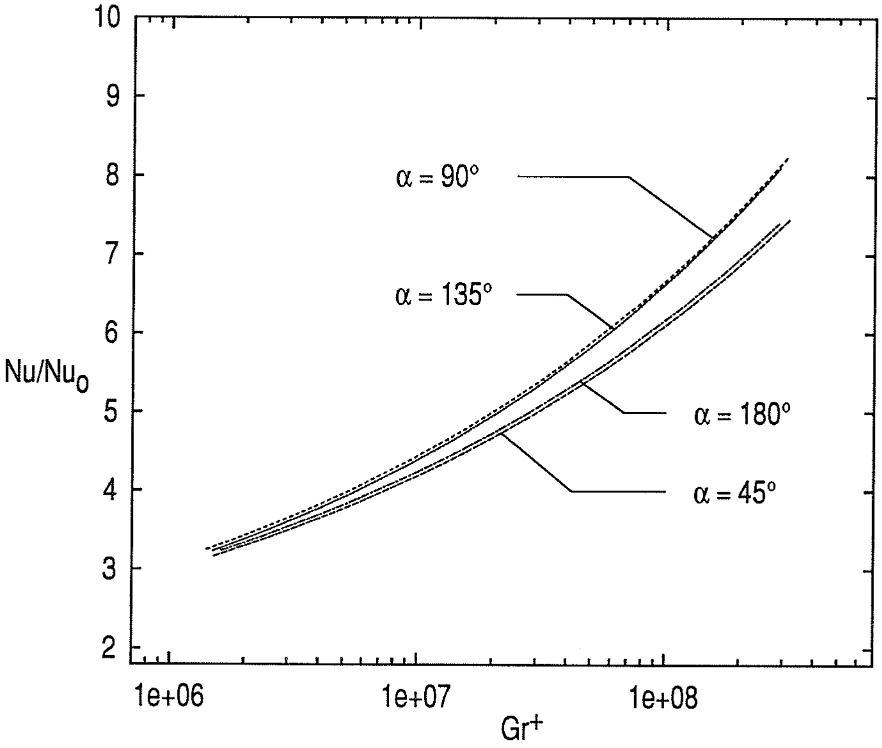


Fig. 4.11 Comparison of Nusselt number for α = 45°, 90°, 135° and 180°.

4.6.2 With $Gr^{+}Pr$ Variable

The same data as previously presented are now modified due to the change of the independent variable from Gr^{+} to $Gr^{+}Pr$ and the results are shown in Fig. 4.12. The Nu/Nu_o data are correlated to $Gr^{+}Pr$ using the form similar to eqn. (4.10) and the results are summarized in Table 4.4.

Table 4.4 The coefficients and standard deviations for $Nu/Nu_o = 1 + a(Gr^{+}Pr)^{b}$ relationship.

α	a	b	σ	σ_{max}
45°	0.0389	0.246	2.7%	4.9%
90°	0.0414	0.247	2.2%	2.8%
135°	0.0378	0.252	2.5%	5.6%
180°	0.0515	0.232	2.0%	3.5%

A slight improvement of the relation of Nu/Nu_o–$Gr^{+}Pr$ over Nu/Nu_o–Gr^{+} can be observed by the reduction of σ in Table 4.4 and also in Fig. 4.12. The points in Fig. 4.12 seem to contract as compared to Fig. 4.10. These improvements are so small that it is not appropriate to draw any conclusion, however, the trends can be seen. This small variation is due to a limited range of Prandtl number data which were from a single fluid type.

The comparison of these curves according to the orientation angles are shown in Fig. 4.13 including the data for $\alpha = 0°$ from the previous experiment [45]. Again the curve for $\alpha = 90°$ and 135° are very close but the 135° curve is now slightly higher at high Gr^+. The gap between the 90° or 135° and the 45° curves are wider in Fig. 4.13 compared to Fig. 4.11. At $Gr^+Pr \approx 10^9$, Nusselt number for $\alpha = 135°$ is about 10% larger than those of $\alpha = 45°$ and 180° and about 40% larger than that of $\alpha = 0°$. At the low end of the Gr^+Pr range, the Nusselt number for $\alpha = 90°$ is somewhat larger than that of $\alpha = 135°$. At $Gr^+Pr \approx 2\text{x}10^7$, the Nusselt number for $\alpha = 90°$ is about 2%, 6%, and 28% larger than those of $\alpha = 180°$, 45° and 0° respectively. At low Gr^+, the curves for $\alpha = 90°$, 135° and 180° agree well while that of 45° is somewhat lower. These results suggest that the effect of α can enhance Nusselt number as large as 10–40% at high heating rate.

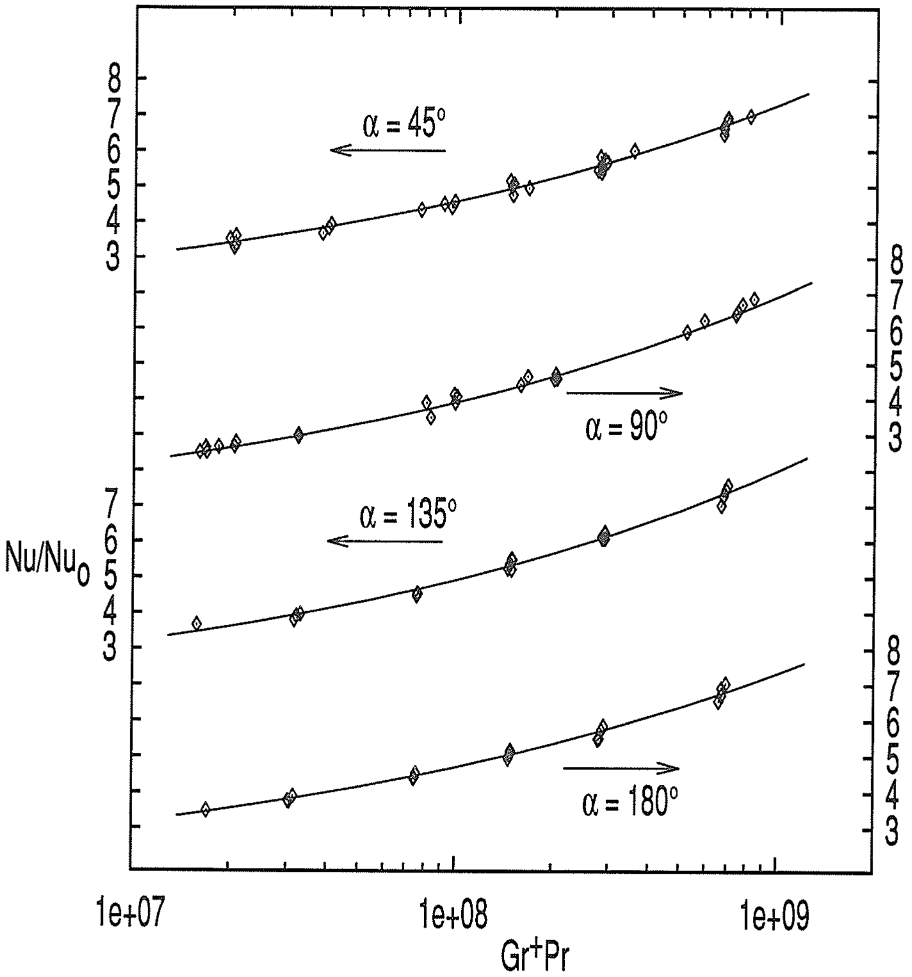


Fig. 4.12 Fully developed Nusselt number versus Gr^+Pr,

for α = 45°, 90°, 135° and 180°.

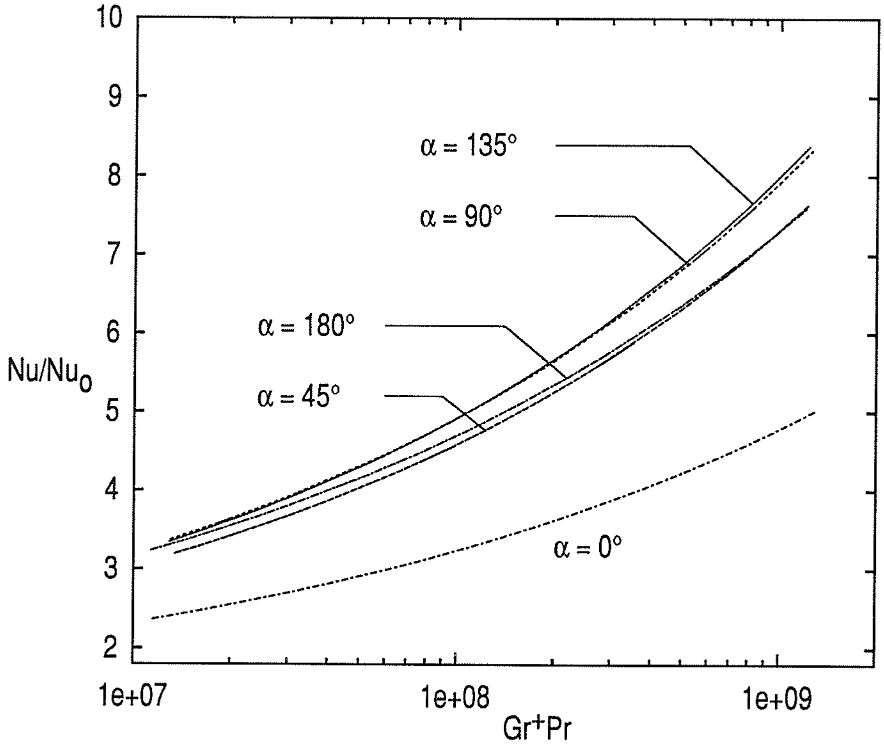


Fig. 4.13 Comparison of *Nu* for α = 0°[45], 45°, 90°, 135° and 180°.

4.7 Friction Factor

Friction factor were determined using eqn. (4.8) which involved measured mass flow rates and pressure drops. Due to the fact that the pressure drops were measured across the whole heated section which included both the thermal developing and fully developed regions, it is first emphasized that they reflect the average pressure drops for both regions. The Reynolds numbers were consequently evaluated at the average of the fluid inlet and outlet temperatures, which should be called Re_m. However, the product of the friction factor and Reynolds number will be referred to simply as fRe. Also it is noted that the symbol fRe is used in the theoretical analyses when dealing with the fully developed condition only.

The fRe is normalized by the forced convection solution $(fRe)_o = 15.7668$[36] and correlated with the variable Gr^+ similar to eqn. (4.10). The coefficients and the standard deviations are listed in Table 4.5. The $fRe/(fRe)_o$ ratios are plotted in Fig. 4.14 against Gr^+ for $\alpha = 0°$[45], 45°, 90°, 135° and 180°. Buoyancy force has a little effect on fRe for Gr^+ less than about $1\text{x}10^7$ which can be seen from the stable magnitudes of $fRe/(fRe)_o$ in that region. The fRe increases gradually as Gr^+ exceeds about $2\text{x}10^7$. The effect of duct orientation is shown in Fig. 4.15. The fRe product is the highest for $\alpha = 90°$, followed by those for $\alpha = 135°$, 45°, 180° and 0°. The fRe magnitude for $\alpha = 45°$ is somewhat higher than that of 180° but the latter becomes higher at the high end of the Gr^+ range. For $\alpha = 0°$ and 45°, the fRe ratios are about 1.3 and 1.5 at $Gr^+ \approx 10^8$.

For all α, the increases between Gr^+ of $2\text{x}10^7$ to 10^8 are quite rapid and the ratios approach the value of 2. However, the increase of *fRe* ratio due to the cross-stream flow is small compared to corresponding increase in Nusselt ratio.

Table 4.5 The coefficients and standard deviations $fRe/(fRe)_o = 1 + a(Gr^+)^b$.

α	a	b	σ	σ_{max}
45°	$1.0483610\text{x}10^{-6}$	0.7094759	4.2%	10.2%
90°	$4.8994200\text{x}10^{-6}$	0.6469435	4.3%	8.4%
135°	$5.5703270\text{x}10^{-6}$	0.6281309	3.5%	6.8%
180°	$6.4307020\text{x}10^{-8}$	0.8597980	3.6%	9.7%

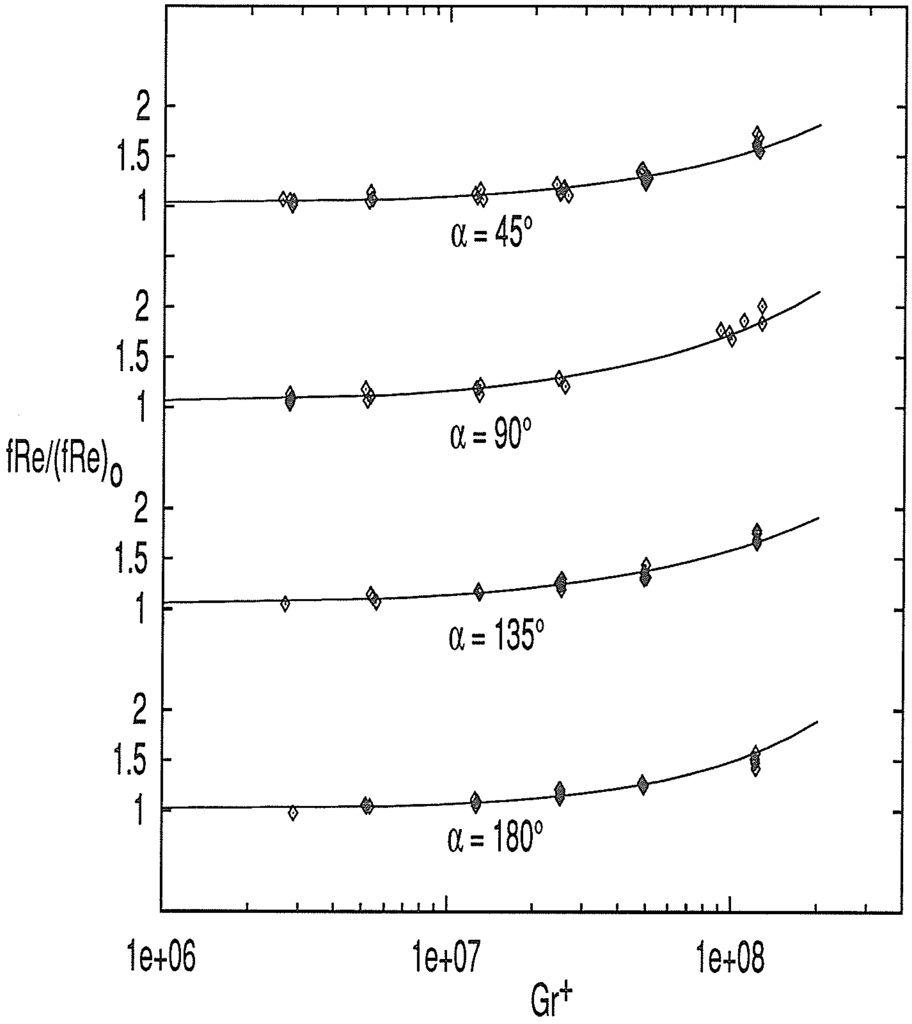


Fig. 4.14 The $fRe/(fRe)_o$ ratios for α = 45°, 90°, 135° and 180°.

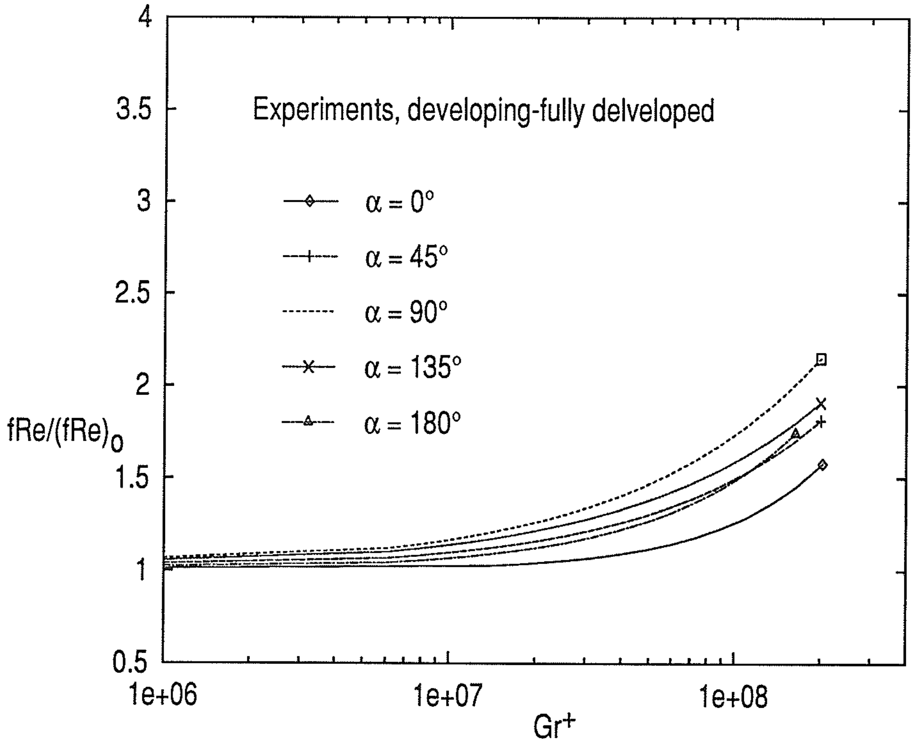


Fig. 4.15 Comparison of *fRe/(fRe)$_o$* for α = 0°[45], 45°, 90°, 135° and 180°.

Chapter 5

Numerical Results for the Semicircular Duct

The numerical results were obtained by solving the governing equations in Chapter 3 by the finite difference method with the aid of a perturbation approach. This chapter is started with the method of solution and accuracy of the solutions. For $Gr^+ = 0$, the macroscopic results from the grid refining exercises are observed by direct comparison to the exact solutions. For cases of $Gr^+ > 0$, the present predicted results were compared to the only* existing published data which correspond to a case of $\alpha = 180°$. The final solutions for $Pr = 4$ were obtained only after good accuracy was established through mesh refining for $\alpha = 0°, 45°, 90°, 135°$ and $180°$. The Nusselt number and friction factor (*fRe*) results are presented and discussed according to the effect of α. The solutions for additional Prandtl numbers of 10 and 50 are also presented

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* The present predictions are based on a modified version of the numerical procedure developed by Lei [45]. Thus comparison to Lei's results for $\alpha = 0°$ is inappropriate.

to illustrate Pr effect. The merging of the results for various Pr leads to an introduction of a new key parameter Gr^+Pr which is a better replacement for Gr^+ due to the existence of a unique relationship between Nu and Gr^+Pr. Again the present results are compared to the published data in term of Gr^+Pr with a good agreement and then the effect of Prandtl number is meaningfully demonstrated. Finally, the numerical results are compared to the experimental results from the previous chapter.

5.1 Solution Algorithm

There are five dimensionless governing partial differential equations comprising continuity, three momentum, and an energy equation. These correspond to five dependent variables: three velocity components, cross-stream pressure deviation, and temperature. In addition, fRe which is proportional to the axial pressure drop is virtually the sixth dependent variable of the system and it must satisfy the total mass conservation equation. The governing equations were discretized by using the control volume integration finite difference method. The coefficients related to the convective-diffusion terms in the discretized equations were formulated by employing the power-law scheme. A modified SIMPLER algorithm (the same version as used in [45]) was employed in solving these equations. The modification was made by solving the pressure and pressure correction fields over the whole domain simultaneously by a band storage linear system solver instead of the iteration technique as suggested in the SIMPLER algorithm.

The rest of the independent variables, which were velocity and temperature fields, were traditionally solved by the line iteration technique. It is interesting to remark that the way of handling the pressure and velocity coupling is very important and this has attracted much attention, e.g. see [100–106]. The simultaneous solution of the pressure field is basically a plane-by-plane technique. The accurate pressure and, as the consequent, velocity solutions obtained by such technique secure the convergence and improve the convergent rate. The convergence were judged by the absolute differences between the current and the previous iterative values of each primitive variables at each node being smaller than 10^{-5}. The mass source terms which indicated the error of local continuity of each control volumes and the *fRe* correction which indicated overall axial mass balance were also required to be smaller than 10^{-5}. The computer program was developed from the one used in [45]. The modification was that the restriction for the semicircular duct was released in order that the circular sector ducts with any apex angle less than 180° was able to be automatically accepted by the program. Another main change was the frequently used subroutines, e.g. in evaluating the coefficients of the variables, which were observed taking a large portion of the run time, were simply modified for speed. Reduction of about 30% of the computing time was observed. The staggered grid arrangement used by the computer program is shown in Fig. 5.1.

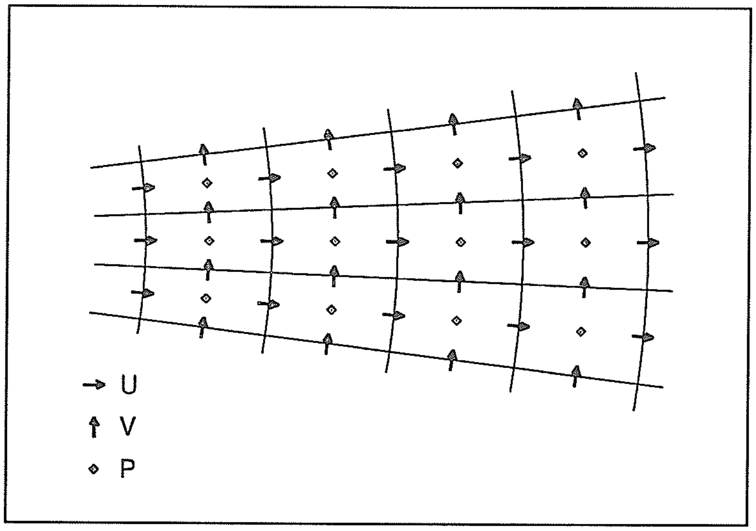


Fig. 5.1 The mesh and location of variables.

5.2 Solution Method

According to the mathematical model of this problem, the parameters that control the flow and heat transfer characteristics are Gr^+, Pr, ϕ and α. The ϕ and α are duct half apex angle and oriented angle, respectively. The Pr nominally represent fluid type although for a given fluid, its Pr value varies according to the fluid temperature. If the fluid properties are assumed constant then a fluid will have a single Pr value and the Gr^+ is proportional to the applied heat flux. The representations of these parameters are useful in the discussion that will appear later. The general idea in solving the problem is by specifying the four parameters to obtain the solutions consisting of velocity and temperature fields and *fRe*. Then the average Nusselt number is evaluated from the axial velocity and temperature distributions. Either a heating or cooling problem can be addressed by simply setting Gr^+ to be positive or negative respectively.

For a certain problem, the values of Pr, ϕ and α are fixed. In practice, the solutions for a given Gr^+ can be obtained directly only if the Gr^+ is small, e.g. 5×10^3. The solution takes more time and is prone to divergence as Gr^+ increases. Increasing Pr also exhibits a similar effect but not as strongly as Gr^+. This seems to be a nature in solving the combined convection problem which in fact is a set of non-linear partial differential equations, and hence the perturbation approach must be employed. The idea of perturbation was suggested by Morton [5] who stated that one way to solve the combined convection problems ($Gr^+ > 0$) is to perturb the forced convection ($Gr^+ = 0$) solutions, i.e. using the forced convection velocity and temperature fields as the first approximation for the combined convection solution. The idea was probably originated for the perturbation method in Morton's analysis. However, this idea has appeared to work very well in many, if not all, finite difference analyses which reached high Gr^+. The techniques obviously stated in [21-22], and [28], whether inspired by [5] or not, appeared to be such perturbation manners, i.e. the solution for a Gr^+ can be obtained by using (perturbing) the converged solutions of another, often slightly lower, Gr^+ as the initial approximation. The perturbation approach is not limited to the perturbing of lower Gr^+, however, that is the usual way to start solving a problem.

5.3 Accuracy of the Solutions

The accuracy of the solutions for $Gr^{+} = 0$ was simply gauged by comparing to the exact solutions. This is in contrast to the case of $Gr^{+} > 0$ where there is no exact solution. The pure forced convection solution is independent of either the oriented angle or Prandtl number due to the absence of the buoyancy forces and hence the cross-stream flow. The problem can be solved over the entire domain of interest (called *full region solution*, for convenience), or within a half of the domain (called *half region solution*), by making use of the symmetry. The use of the half region solution offers some benefit other than saving the computational time for the case that $Gr^{+} > 0$ which is cited in subsection 5.3.2.

Table 5.1 Comparisons of Nu and fRe for $Gr^{+} = 0$, half region solutions, to exact solutions [35] and [36].

Mesh r×θ		20x21	30x24	40x60
Nu error%	4.0880[35]	4.03027 [1.41%]	4.04644 [1.02%]	4.07746 [0.26%]
fRe error%	15.7668[36]	15.64701 [0.76%]	15.66643 [0.64%]	15.71600 [0.32%]

Table 5.2 Comparisons of Nu and fRe for $Gr^{+} = 0$, full region solutions, to exact solutions [35] and [36].

Mesh r×θ		16x40	20x40	24x40	30x48
Nu error%	4.0880[35]	4.06194 [0.64%]	4.07520 [0.31%]	4.08217 [0.14%]	4.08490 [0.08%]
fRe error%	15.7668[36]	15.73902 [0.18%]	15.73931 [0.17%]	15.73942 [0.17%]	15.74803 [0.12%]

5.3.1 For $Gr^+ = 0$

The *Nu* and *fRe* results for $Gr^+ = 0$, solved with various mesh sizes, are compared to the exact results from Ref. [35, 36] in Table 5.1 and 5.2 for the half and full region solutions. The errors for the full region solutions are less than 0.7% for all meshes and about 0.1% for the 30x48 mesh. For the half region solution, the errors are about 0.3% for the 40x60 mesh and larger as the mesh becomes coarser. These meshes arose due to the investigation of the mesh size effect during the computation of the combined convection problem.

5.3.2 For $Gr^+ > 0$

Owning to the lack of exact solutions for the case of $Gr^+ > 0$, the accuracy of numerical results was observed by mesh refining. This process led to the selection of an adequate mesh for the main course of the computation. Initially, the results for $Pr = 4$ were required for comparison to the corresponding experimental study that used water as the working fluid. In addition to the mesh refining, the results were compared to Ref. [22], the only available source of data. Their semicircular duct solutions were for $Pr = 5$ and corresponded to $\alpha = 180°$ in the present study. Therefore the effect of mesh size on the Nusselt number was observed at such conditions to allow a direct comparison to [22], e.g. at the same *Pr* and Gr^+. It is worth noting here that in the study of Prandtl number effect in Section 5.8 the Nusselt number results for $Pr = 4$, 10 and 50 are compared to [22] again.

To compare to [22], the problem with $\alpha = 180°$ was solved for $Pr = 5$ and $Gr^+ = 6.28 \times 10^5$, 9.42×10^5 and 1.26×10^6 which corresponded to the high end of the range in [22]. It was supposed to be the worst cases as the maximum errors between [22] and the present results were expected at such high Gr^+ range. During the computation, it was found that the full region solution suffered the convergent difficulty and could not reach that Gr^+ range thus the half region solution was used instead. Because the results in [22] were in graphical forms and were presented in terms of the ratios relative to the forced-convection solutions, the *fRe* result was skipped due to its narrow variation (about 1.0 to 1.3). The *Nu* results from the 30x24, 30x48 and 40x60 meshes are compared to [22] in Table 5.3 and the agreements are within 3.4%, 1.9% and 2.3%, respectively for the two-cell pattern and within 6.3%, 4.9% and 4.0%, respectively for the four-cell pattern. The discrepancies for the two-cell solutions are quite satisfactory while those of the four-cell solution are larger but still acceptable. The comparison among the present results for the coarser meshes to the 40x60 mesh are given in Table 5.4. The agreements of the 30x24, 40x30, and 30x48 to the 40x60 meshes are within 1.9%, 0.6% and 0.61%, respectively for the two-cell pattern results and are within 2.24%, 0.88% and 1.1% respectively for the four-cell results. Since the maximum discrepancies between the coarsest and finest mesh is within about 2.5%, one can conclude that all results are essentially mesh independent, i.e. even the 30x24 mesh is adequate.

Table 5.3 Comparisons of Nu to [22], Pr = 5.

Mesh rxθ	Gr^+					
	two-cell			four-cell		
	6.28×10^5	9.42×10^5	1.26×10^6	6.28×10^5	9.42×10^5	1.26×10^6
Ref. [22]*	8.79	9.41	10.14	9.57	10.14	10.67
30x24	9.048 2.9%	9.725 3.4%	10.254 1.1%	10.059 5.1%	10.781 6.3%	11.336 6.2%
30x48	8.940 1.7%	9.588 1.9%	10.091 0.5%	9.939 3.9%	10.642 4.9%	11.181 4.8%
40x60	8.995 2.3%	9.541 1.4%	10.147 0.1%	9.869 3.11%	10.544 4.0%	11.059 3.6%

* approximate values (as extracted from graphical results).

Table 5.4 Comparisons of Nu to the 40x60, Pr = 5.

Mesh rxθ	Gr^+					
	two-cell			four-cell		
	6.28×10^5	9.42×10^5	1.26×10^6	6.28×10^5	9.42×10^5	1.26×10^6
30x24	9.048 0.59%	9.725 1.93%	10.254 1.05%	10.059 1.92%	10.781 2.24%	11.336 2.50%
40x30	8.941 0.60%	9.592 0.53%	10.099 0.48%	9.942 0.74%	10.631 0.82%	11.157 0.88%
30x48	8.940 0.61%	9.588 0.49%	10.091 0.55%	9.939 0.70%	10.642 0.92%	11.181 1.10%
40x60	8.995	9.541	10.147	9.869	10.544	11.059

The further investigation of the effect of mesh size indicates that if the 40x30 mesh was chosen for the half region solution then its equivalent mesh for the full region solution, which was the only choice for $\alpha = 45°$, 90° and 135°, should be a 40x60 mesh. Unfortunately, the 40x60 mesh for full region solution showed severe problem of convergence even at moderate Gr^+ in addition to the drastic increase in computing time. As a result, the mesh 30x24 was chosen as a compromise between accuracy and cost of the computation.

While the half region solution was preferred for the symmetric cross-stream flow as it can reach higher Gr^+, the full region solution was necessary for the cases of unsymmetric cross-stream flow. Therefore, a combination of the half and full region solution was required to cover all cases of the orientations. To verify the compatibility of both solutions, the problems with $\alpha = 0°$ and 180° were solved by the half and full region solutions on the 30x24 and 30x48 meshes, respectively. Very good agreements of better than 1% for *Nu* and *fRe* were achieved for all ranges of the Gr^+. The results for are shown in Table 5.5.

Table 5.5 *Nu* and *fRe* for the half and full region solutions, $Pr = 4$.

Gr^+	$\alpha = 0°$				$\alpha = 180°$			
	Half		**Full**		**Half**		**Full**	
	fRe	***Nu***	***fRe***	***Nu***	***fRe***	***Nu***	***fRe***	***Nu***
0	15.666	4.046	15.748	4.085	15.666	4.046	15.748	4.085
$5\text{x}10^3$	15.693	4.261	15.781	4.292	15.709	4.295	15.780	4.306
$1\text{x}10^4$	15.745	4.540	15.835	4.562	15.768	4.589	15.834	4.590
$5\text{x}10^4$	16.080	5.621	16.173	5.635	16.106	5.732	16.160	5.724
$1\text{x}10^5$	16.370	6.270	16.463	6.283	16.373	6.396	16.423	6.386
$2\text{x}10^5$	16.787	7.048	16.881	7.058	16.736	7.160	16.781	7.149
$5\text{x}10^5$	17.588	8.298	17.680	8.306	17.399	8.340	–	–
$1\text{x}10^6$	18.421	9.444	18.510	9.450	18.070	9.402	–	–
$5\text{x}10^6$	21.287	12.983	21.359	12.979	–	–	–	–
$1\text{x}10^7$	22.998	15.016	23.084	15.024	–	–	–	–

5.4 Results for $Pr = 4$

The problem was solved for $Pr = 4.0$ for flow and temperature fields, fRe and Nu for the oriented angles α of 0°, 45°, 90°, 135° and 180° which represents a complete round of duct cross-sectional rotation with 45° increment. All the results were obtained using the perturbation approach by keeping Pr and α constant in each series of solution. It is interesting to note that in the perturbation approach the Gr^+ marching is somewhat similar to the temporal marching in transient problems or the spacial marching in entrance region in duct flow problems except that the marching in the later cases is advanced by the time or length according to their derivatives. The perturbation approach yielded consistent solutions, e.g. the same results for a given Gr^+ were always obtained (if the convergences were possible) by perturbing the converged solutions of the different Gr^+, irregardless as to whether it was higher or lower than the given Gr^+. During the course of computations, it appeared that to obtain the convergences of the velocities and temperatures by the absolute difference of 10^{-5}, the residuals of the local and total mass balances usually dropped to less than 10^{-10}. This indicated the accuracy of the mass conservation, i.e. the continuity equation was well satisfied both locally and globally. Other than the more common two-cell flow patterns, four-cell patterns also emerged as another solution in some orientations. The results for these flow patterns are presented in the following subsections.

5.4.1 Two-cell Pattern Results

The two-cell solutions were the only common solutions among all of the oriented angles and these are summarized in Table 5.6. The effect of oriented angle on *Nu* and *fRe* is demonstrated by plotting *Nu* and *fRe* against Gr^+ for each α in Figs. 5.2(a) and (b) where these magnitudes are normalized by the forced convection solutions; Nu_o = 4.0880 and $(fRe)_o$ = 15.7668. The magnitudes of *Nu* and *fRe* for $\alpha = 90°$ and $\alpha = 135°$ are very much the same, except that *fRe* for $\alpha = 135°$ is a little lower at $Gr^+ < 10^6$ and a little higher at $Gr^+ > 10^6$, and they are obviously the highest of the group. Similarly, the magnitudes of *Nu* and *fRe* for $\alpha = 0°$ and $\alpha = 180°$ are almost the same except that *fRe* for $\alpha = 180°$ is a little lower near $Gr^+ = 10^6$. For $\alpha = 45°$, *Nu* and *fRe* curves are in between the highest and lowest curves, however the *fRe* curve is rather close to the 0° curve. The Nusselt numbers of 90° and 135° are about 20% higher than that for $\alpha = 0°$ at Gr^+ near 10^7 while the differences of their *fRe* are less than 10%. It is worth emphasizing that the cases of $\alpha = 0°$ and 180° which correspond to symmetric cross-stream flows provide the lowest *Nu* and *fRe* of this group.

It is clear in Figs. 5.2 that, for a given α, *Nu* and *fRe* increase monotonically with increasing Gr^+. In addition, the data on both Nu–Gr^+ and fRe–Gr^+ domains form well defined curves. Compared to the pure forced convection data, i.e. Nu_o = 4.0880 and $(fRe)_o$ = 15.7668, at $Gr^+ = 2\text{x}10^7$, the Nu/Nu_o ratios are over 4 for $\alpha = 0°$ and over 5 for $\alpha = 90°$ or 135° while $fRe/(fRe)_o$ ratios are only 1.6 for $\alpha = 0°$ and about 1.7 for $\alpha = 90°$ or 135°. This indicates that the effect of buoyancy force on Nusselt number is much more significant.

Table 5.6 *Nu* and *fRe* for all orientations, $Pr = 4$.

Gr^+	α = 0°		α = 45°		α = 90°		α = 115°		α = 135°		α = 180°	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	15.666	4.046	15.748	4.085	15.748	4.087	15.748	4.085	15.748	4.085	15.666	4.046
$5x10^3$	15.693	4.261	15.779	4.286	15.774	4.261	15.773	4.259	15.775	4.274	15.709	4.295
$1x10^4$	15.745	4.540	15.836	4.577	15.828	4.553	15.822	4.530	15.824	4.541	15.767	4.589
$5x10^4$	16.080	5.621	16.238	5.809	16.284	5.947	16.246	5.888	16.196	5.794	16.106	5.732
$1x10^5$	16.370	6.270	16.590	6.554	16.708	6.791	16.664	6.747	16.570	6.625	16.373	6.396
$5x10^5$	17.588	8.298	17.975	8.855	18.362	9.375	18.363	9.386	18.193	9.225	17.399	8.340
$1x10^6$	18.421	9.444	18.848	10.158	19.394	10.846	19.450	10.893	19.266	10.708	18.070	9.402
$5x10^6$	21.287	12.983	21.735	14.281	22.758	15.411	23.034	15.585	22.835	15.338	–	–
$1x10^7$	22.998	15.016	23.464	16.675	24.709	17.984	25.098	18.215	24.895	17.949	–	–
$2x10^7$	25.036	17.454	25.548	19.525	27.005	20.990	27.506	21.285	27.298	21.008	–	–
$5x10^7$	–	–	–	–	30.603	25.696	31.272	26.102	31.087	25.850	–	–

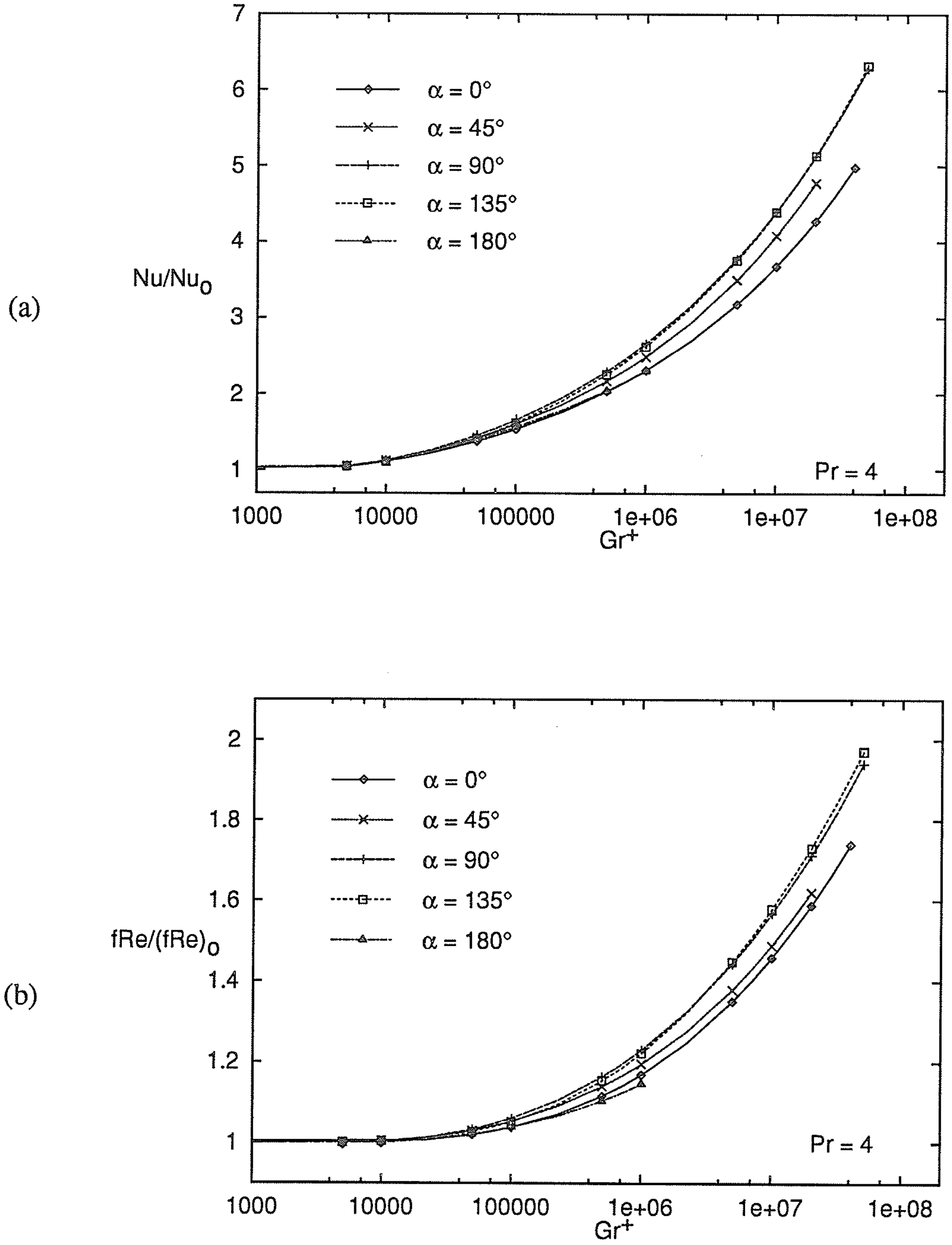


Fig. 5.2 (a) Nu/Nu_o (b) $fRe/(fRe)_o$ for $Pr = 4$.

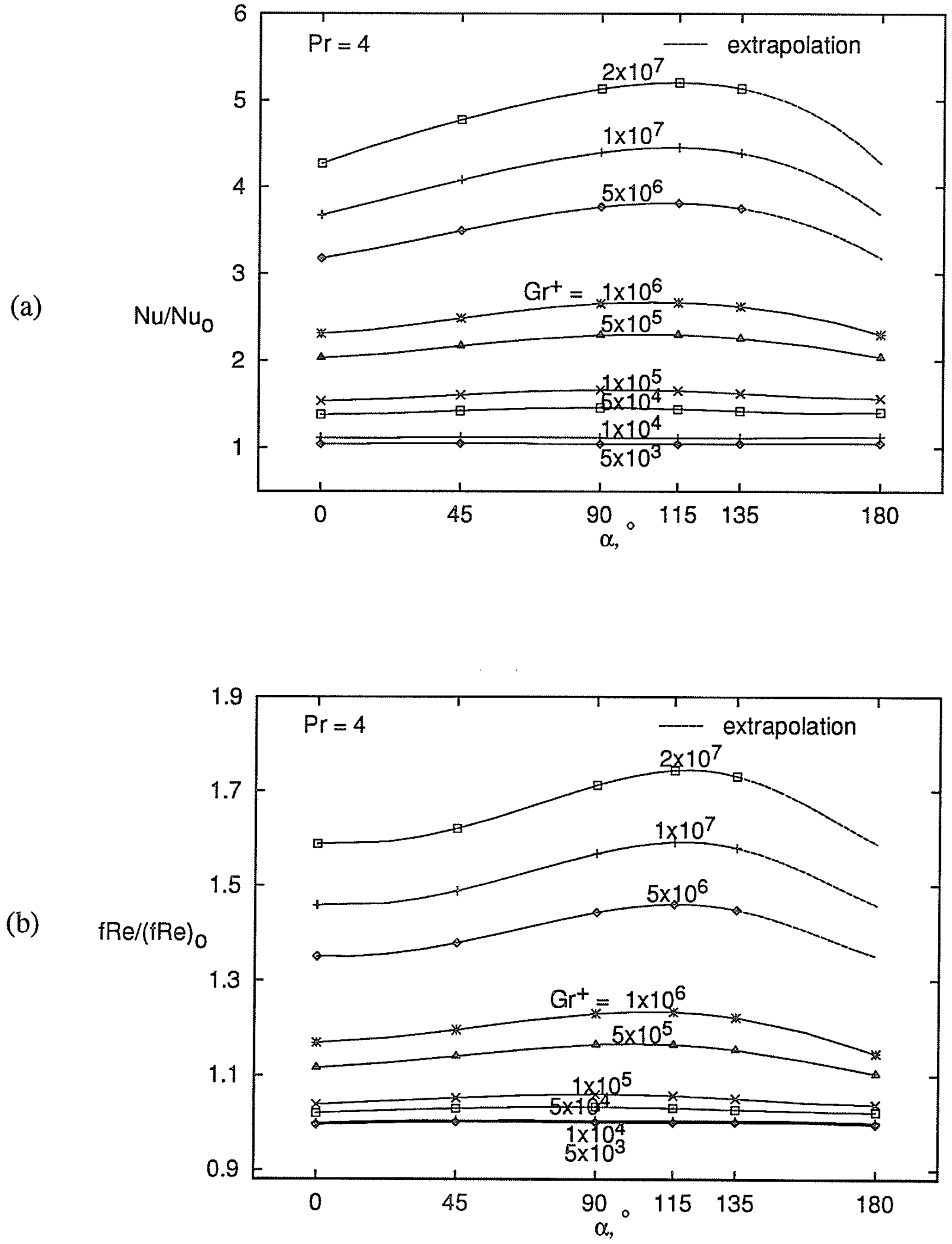


Fig. 5.3 (a) Nu/Nu_o (b) $fRe/(fRe)_o$ against α, $Pr = 4$.

The oriented angle was scanned, to search for maximum Nusselt numbers, using a 20x40 mesh with 5° increments from $\alpha = 75°$ to 120°. It was found that the values of Nusselt numbers were nearly insensitive to α where α was between 90° and 120°. However, the maximum Nu at high Gr^+ was found at $\alpha = 115°$. The Nusselt number and fRe results were generated again with the 30x48 mesh and are added to Table 5.6. In Figs. 5.3, Nu/Nu_o and $fRe/(fRe)_o$ are plotted against α at constant Gr^+. The maximum Nu are at $\alpha \approx 45°$–$90°$ for $Gr^+ = 10^4$, at $\alpha \approx 90°$ for $Gr^+ = 10^5$ and at $\alpha \approx 115°$ for $Gr^+ \geq 10^6$. The similar pattern can be observed in Fig. 5.3(b) for fRe. For $Gr^+ = 5\text{x}10^6$ to $2\text{x}10^7$, the curves in Figs. 5.3(a) and (b) were extrapolated from $\alpha = 135°$ to 180° by presuming the same values at $\alpha = 0°$ and 180°. Even though it is clear that the maximum moves to a higher α as Gr^+ increases, the differences are very small for α between 90° to 135°.

The effect of buoyancy force on Nusselt number can be investigated from the patterns of cross-stream flows. Generally, a larger Nusselt number results from the wall-to-bulk temperature difference dropping due to the cooler part of fluid being pushed to absorb heat energy from the duct wall by the cross-stream current. The resultant cross-stream velocities are computed in term of $\sqrt{(u^+)^2 + (v^+)^2}$ and are plotted in Figs. 5.4(a)–(e) for $\alpha = 0°$, 45°, 90°, 135° and 180°, respectively for a fixed Gr^+ of 10^5. For $\alpha = 45°$, 90°, 135°, the flows are non-symmetric and each cell is different in size. The flow dominated by one major cell provides a rather thorough mixing of hot and cool parts of the fluid therefore the higher Nusselt number is achieved. The quality of this mixing can be noticed by the reduction of the area enclosed by a low temperature contour, e.g. contour line number 9 (without label and next to number 8) in Fig. 5.5. For $\alpha = 90°$ and 135° in Figs. 5.5(c) and (d), it is obvious that the areas are approximately the same and this perhaps explains why their Nusselt numbers are comparatively equal. For $\alpha = 0°$ and 180° in Figs. 5.5(a) and (e), the areas are similar in shape and they are the largest and this corresponds to the lowest Nusselt numbers in this group. Differences in Nusselt number appear to be linked to the shape and orientation of the semicircular cross-section. For $\alpha = 90°$ or 135°, the sharp corner of the cross section is turned to the bottom so that the cooler fluid can not spread widely as in the case of $\alpha = 0°$ or 180°, as a result, the cooler fluid in such a confined space is forced to blend with the, warmer, downward return stream. This results in a smaller size of the cool core fluid.

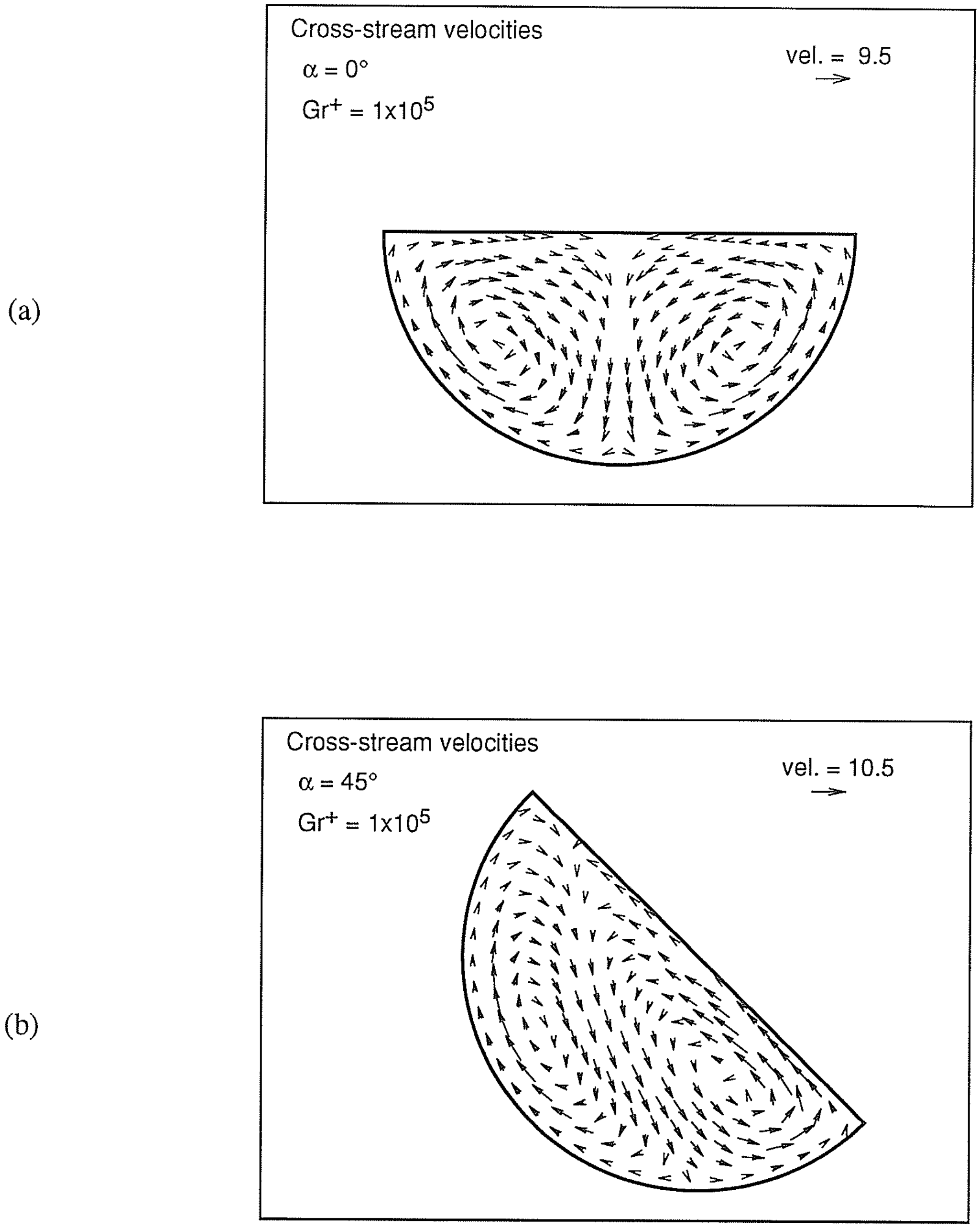


Fig. 5.4 Cross-stream flow pattern, two-cell, α = (a) 0°, (b) 45°.

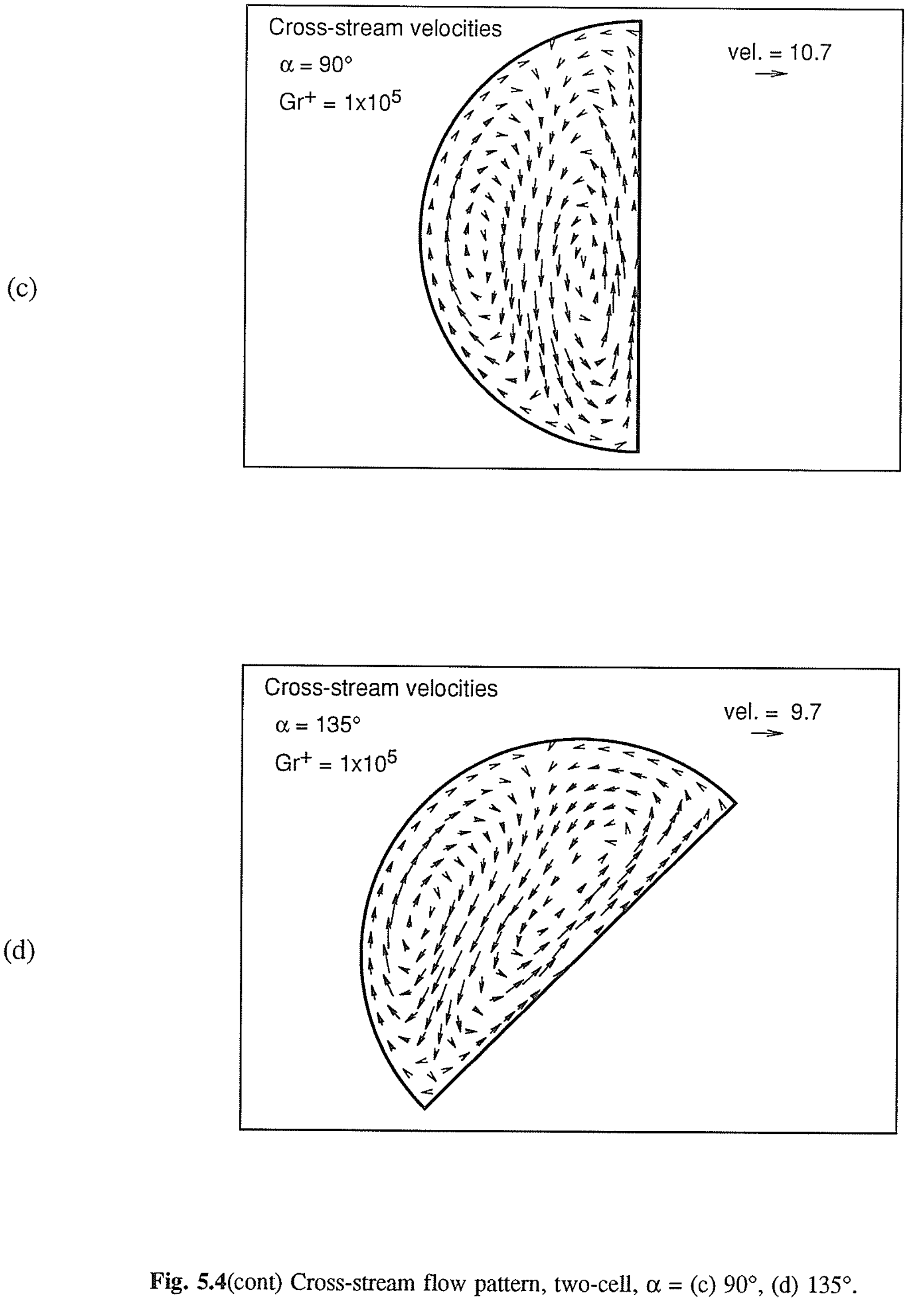


Fig. 5.4(cont) Cross-stream flow pattern, two-cell, α = (c) 90°, (d) 135°.

(e)

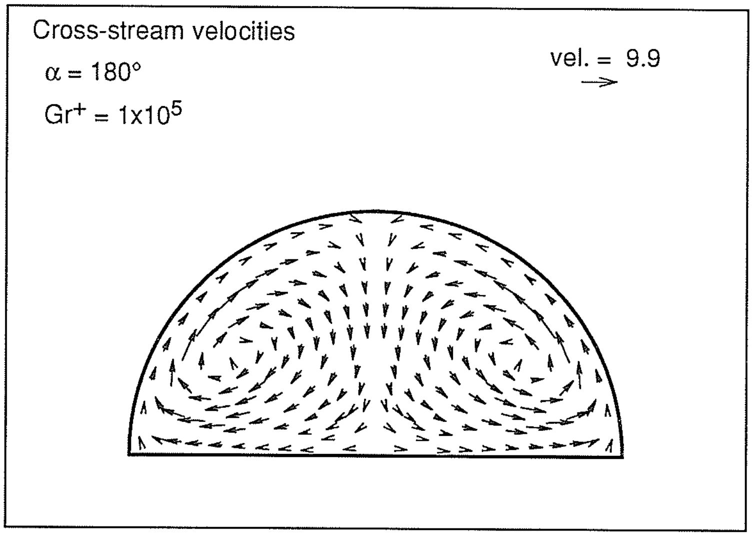


Fig. 5.4(cont) Cross-stream flow pattern, two-cell, α = (e) 180°.

(a)

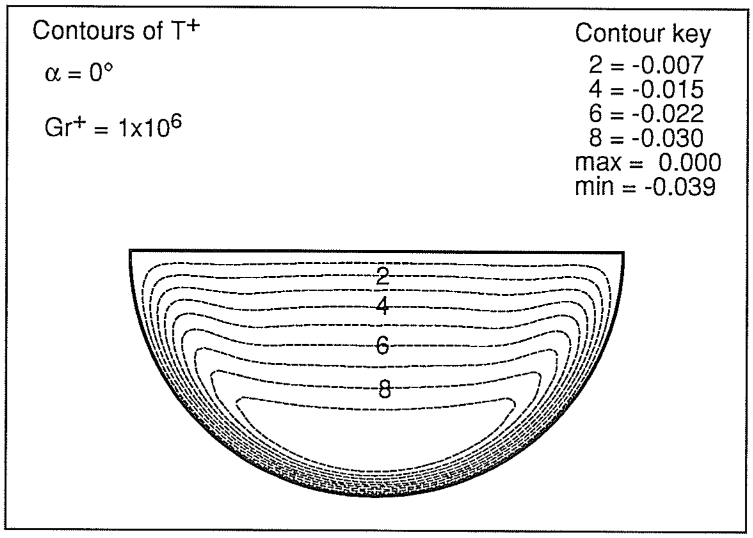


Fig. 5.5 Contour of T^{+}, two-cell, α = (a) 0°.

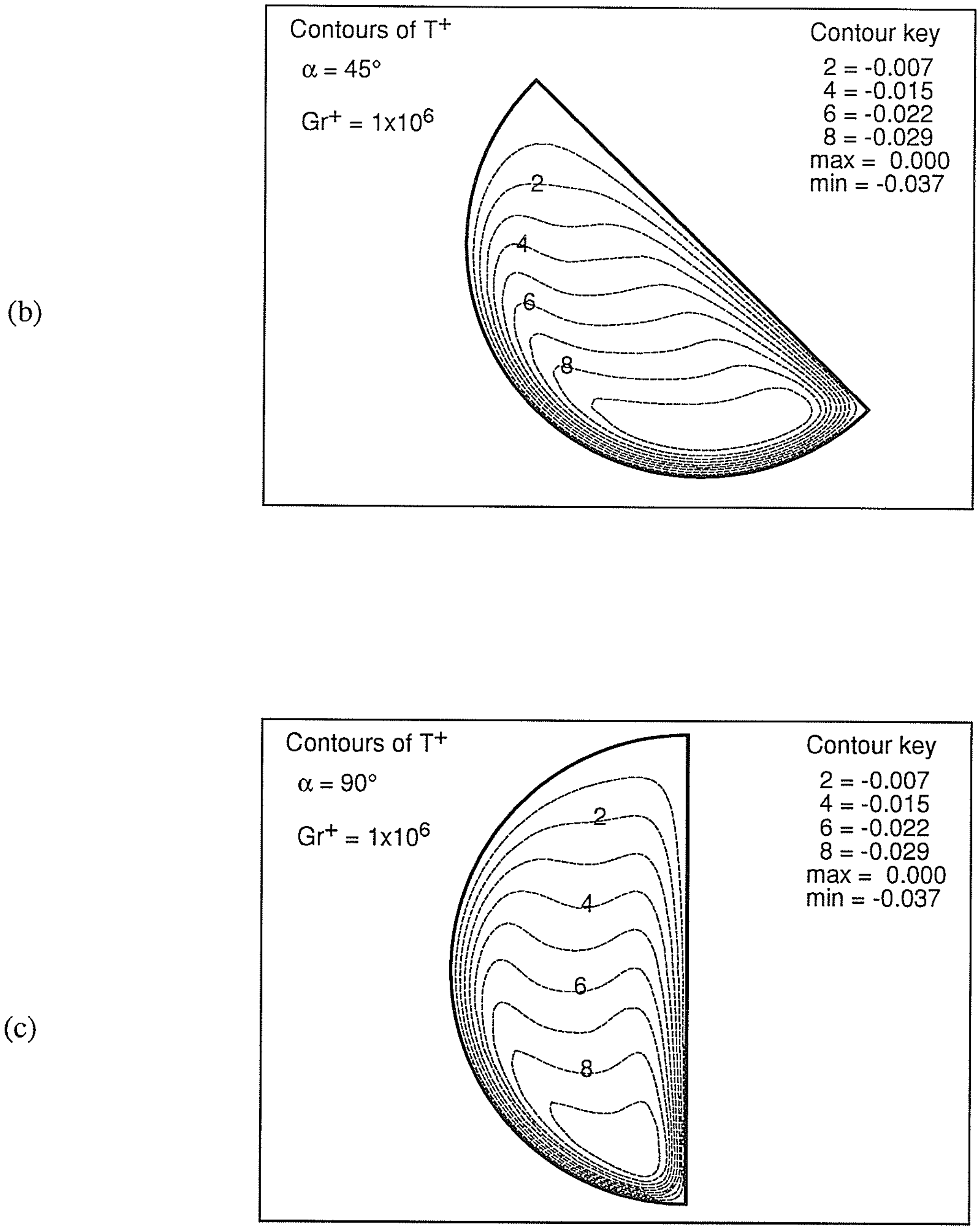
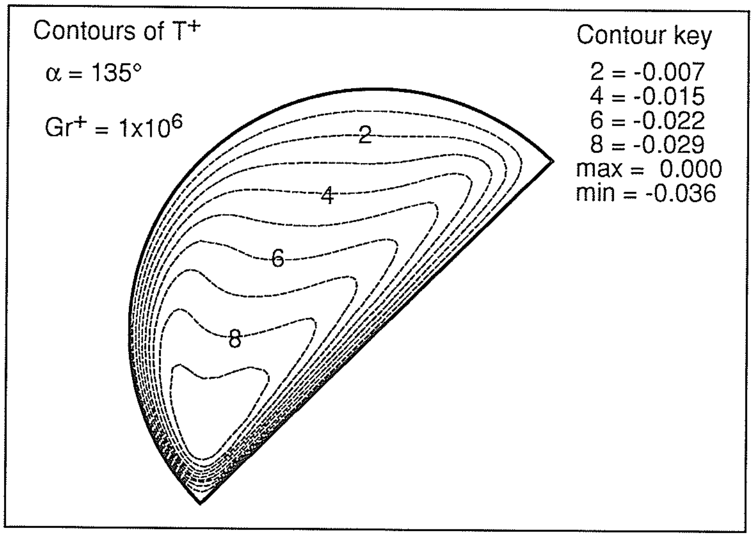


Fig. 5.5(cont) Contour of T^+, two-cell, α = (b) 45°, (c) 90°.

(d)



(e)

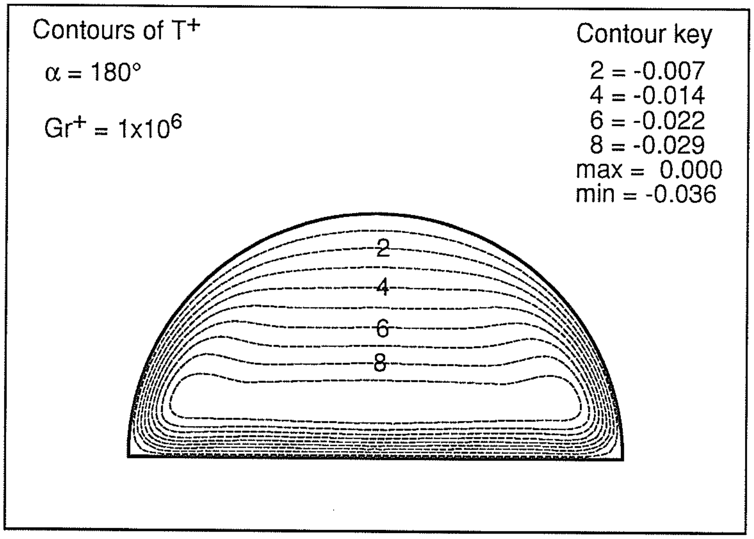


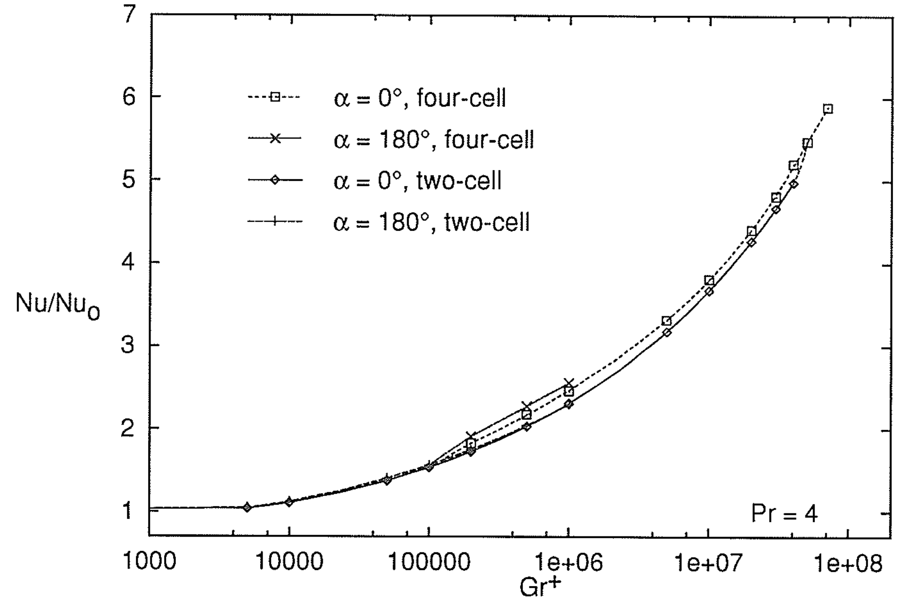
Fig. 5.5(cont) Contour of T^+, two-cell, α = (e) 180°.

Table 5.7 *Nu* and *fRe* of two- and four-cell patterns for $Pr = 4$.

Gr^+	$\alpha = 0°$				$\alpha = 180°$			
	two-cell		**four-cell**		**two-cell**		**four-cell**	
	fRe	***Nu***	***fRe***	***Nu***	***fRe***	***Nu***	***fRe***	***Nu***
0	15.666	4.04644	–	–	15.666	4.046	–	–
$5x10^3$	15.693	4.26122	–	–	15.709	4.295	–	–
$1x10^4$	15.745	4.540	–	–	15.768	4.589	–	–
$5x10^4$	16.080	5.621	–	–	16.106	5.732	–	–
$1x10^5$	16.370	6.270	–	–	16.373	6.396	–	–
$2x10^5$	16.787	7.048	17.077	7.467	16.736	7.160	17.028	7.805
$5x10^5$	17.588	8.298	18.328	8.885	17.399	8.340	18.215	9.297
$1x10^6$	18.421	9.444	19.462	10.059	18.070	9.402	19.227	10.450
$5x10^6$	21.287	12.983	22.815	13.556	–	–	–	–
$1x10^7$	22.998	15.016	24.679	15.576	–	–	–	–
$2x10^7$	25.036	17.454	26.881	18.028	–	–	–	–
$3x10^7$	26.391	19.098	28.339	19.679	–	–	–	–
$4x10^7$	27.431	20.372	29.982	21.288	–	–	–	–
$5x10^7$	–	–	31.017	22.377	–	–	–	–

5.4.2 Four-cell Pattern Results

The nature of the perturbation technique employed in solving this problem is one whereby new solutions are obtained by gradually increased Gr^+. In the cases of non-symmetric cross-stream flow, the solution successfully continued to Gr^+ as high as $2x10^7$ without extra difficulty. For symmetric cases, $\alpha = 0°$ and 180°, the full region solution was attempted in the first place but difficulty in getting converged solutions was encountered for $Gr^+ > 2x10^5$ for $\alpha = 180°$ and for $Gr^+ > 10^7$ for $\alpha = 0°$ hence half region solutions were used to enable proceeding to higher Gr^+. When Gr^+ reached $5x10^7$, for the case of $\alpha = 0°$, it appeared that the solution was only a four-cell pattern instead of the usual two-cell pattern. This four-cell pattern was the only solution for $Gr^+ \geq 5x10^7$. Conversely, when Gr^+ was gradually decreased, the solutions were still four-cell pattern until Gr^+ dropped to 10^5 where the four-cell pattern was no longer a solution. Therefore, there were two possible solutions for $2x10^5 \leq Gr^+ \leq 4x10^7$. The *Nu* and *fRe* results are shown in Table 5.7 and Fig. 5.6. The bifurcation phenomena were tested by feeding the four-cell results to a Gr^+ less than $2x10^5$. It appeared that the converged results were always two-cell patterns which were the same ones obtained by gradually raising Gr^+ from zero in the first place. The four-cell solutions were also fed to the unsymmetric orientations at $Gr^+ > 2x10^5$. The outcome was similar to the previous test due to four-cell result was not established. The coexistence of the two- and four-cell solutions, called dual solution, were found before in rectangular, circular and semicircular ducts, e.g. [21-22], [34], and [46], and extensive discussions are available in [22] and [34].



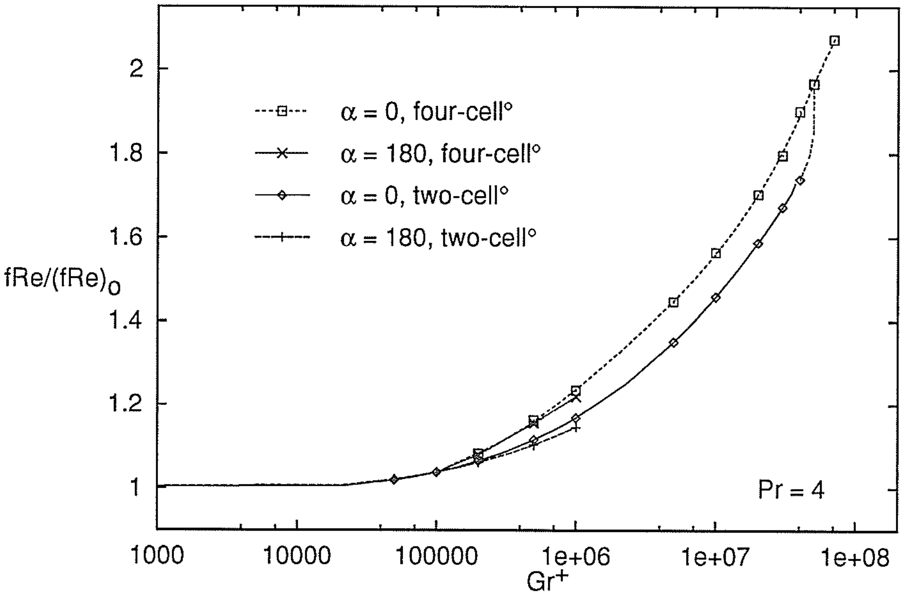


Fig. 5.6 The four- and two-cell results for α = 0° and 180°.

For $\alpha = 180°$, the four-cell solution could not be obtained by the previously described way so that the initial four-cell pattern was prepared from the case of $\alpha = 0°$. After the first four-cell solution was established with $\alpha = 180°$, Gr^+ was varied to get other four-cell solutions. Such transfer process was repeated by taking different solutions from the case $\alpha = 0°$ but the same outcome was observed. The dual solution occurred at the same critical Gr^+ of $2\text{x}10^5$ but the second critical Grashof number could not be reached due to convergence difficulties at high Grashof number.

Fig. 5.6 demonstrates that Nusselt number and *fRe* of four-cell pattern were always higher than those of the two-cell patterns. The differences are about 9 to 11% for the case of $\alpha = 180°$ and about 3 to 7% for $\alpha = 0°$. The four-cell flow patterns for $\alpha = 0°$ and 180° are shown in Figs. 5.7(a) and (b). In both cases, there is an extra pair of cells near the bottom wall which provides additional circulation to the cross-stream flow so that some improvement in Nusselt number was obtained relative to the two-cell pattern.

The formation of the four-cell pattern can be explained as a bifurcation from the two-cell pattern. The two-cell pattern is the original pattern which emerges when the cross-stream flow is slight. This pattern is built up by the rising of hot fluid along both side walls. These two streams turn and run toward each other due to the constraint of the top wall. The downward flow is formed after the collision and combining of these two streams. As a result, two symmetric cross-stream cells are formed. If the heat flux is high enough to encourage the rising of the hot fluid near the middle of bottom wall to encounter the combined downward stream, another collision will occur near the centre of the duct cross-section. This causes a pair of minor cells to be created near the bottom wall. This happens only at a sufficiently high Grashof number such that the upward rising current from the bottom wall is strong enough to maintain the circulation of these minor cells. In Fig. 5.7, each pair of minor cells can be viewed near the bottom walls.

It is reasonable to believe that the four-cell pattern is maintained by the symmetry of cross-stream flow. In this study, no four-cell patterns were found for orientation of $\alpha = 45°$, $90°$ and $135°$ for which the cross-stream flow is not symmetric. In these cases, the direction of the main downward return stream is not normal to the bottom wall. In addition, the sizes of each cells are different. The downward return current is dominated by the larger cell and the flow approaches the bottom wall with an angle other than a right angle. This suggests that any upward rising current from the bottom wall can be easily swept away by the main downward stream which attacks it at an angle. It is for this reason that there are no four-cell patterns for $\alpha = 45°$, $90°$ and $135°$. The symmetry of the cross-stream flow is necessary for bifurcation. This was also observed in [22] and [34] but it was referred to as "a flat wall geometry facing the body force" which corresponds to the case that $\alpha = 0°$ or $180°$ in the present work.

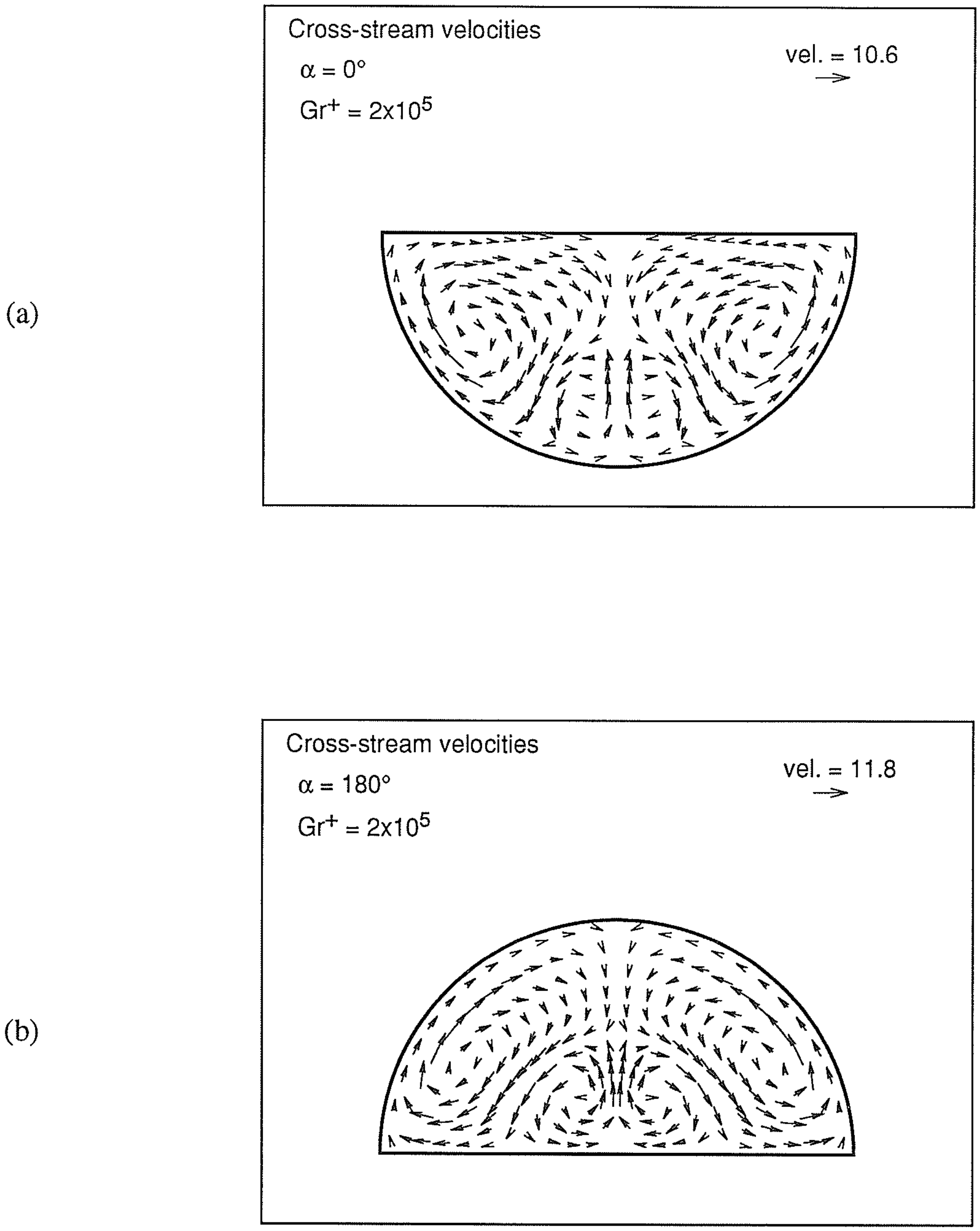


Fig. 5.7 The four-cell pattern for α = (a) 0° and (b) 180°, $Gr^{+} = 2\text{x}10^{5}$.

5.5 Results for Pr = 10 and 50

The results for various Prandtl numbers were useful for exploring the influence of Prandtl number on the flow and heat transfer characteristics. The Nu and fRe results for $Pr = 10$ and 50 are presented in this section where the influence of Prandtl number is illustrated in addition to the effect of α. The further study of the effect of Prandtl number arising from the merging of the data for $Pr = 4$, 10 and 50 is presented in Section 5.6 and 5.7.

The problem was solved similar to the previous section but for $Pr = 10$ and 50 and the numerical results are in Table 5.8 and 5.9. The Nu and fRe for $\alpha = 0°, 45°, 90°,$ 135° and 180° are plotted against Gr^+ in Fig. 5.8 for $Pr = 10$ and Fig. 5.9 for $Pr = 50$. Similar to the case of $Pr = 4$, Nu and fRe for $Pr = 10$ and 50 are maximum when $\alpha =$ 90° or 135° and minimum when $\alpha = 0°$ or 180°. The magnitudes for each pair of α are very close for all range of Gr^+. The case of $\alpha = 45°$ again shows the magnitudes in the middle of the range between maximum and minimum. The differences of Nu for α of 0°and 90° are about 21% for $Pr = 10$ at $Gr^+ = 1\text{x}10^7$ and 21.5% for $Pr = 50$ at $Gr^+ =$ $2\text{x}10^6$. On the fRe side, the differences at the same Gr^+ conditions are about 7% for Pr = 10 and 1.8% for $Pr = 50$.

Table 5.8 *Nu* and *fRe* for all orientations, $Pr = 10$.

Gr^+	α = 0°		α = 45°		α = 90°		α = 115°		α = 135°		α = 180°	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	15.666	4.046	15.748	4.085	15.748	4.085	15.748	4.085	15.748	4.085	15.666	4.046
$1x10^3$	15.669	4.116	15.750	4.147	15.749	4.136	15.749	4.138	15.749	4.145	15.670	4.133
$5x10^3$	15.680	4.659	15.768	4.705	15.767	4.681	15.765	4.648	15.765	4.655	15.691	4.706
$1x10^4$	15.699	5.094	15.794	5.198	15.795	5.233	15.790	5.170	15.787	5.133	15.714	5.165
$5x10^4$	15.815	6.526	15.953	6.852	15.992	7.103	15.979	7.048	15.949	6.909	15.833	6.658
$1x10^5$	15.919	7.354	16.092	7.798	16.171	8.151	16.158	8.117	16.109	7.958	15.929	7.487
$5x10^5$	16.387	9.894	16.670	10.725	16.903	11.405	16.926	11.440	16.833	11.228	16.333	9.963
$1x10^6$	16.733	11.235	17.068	12.417	17.400	13.268	17.461	13.351	17.351	13.112	16.618	11.360
$2x10^6$	17.198	13.023	17.587	14.446	18.040	15.481	18.152	15.614	18.026	15.354	–	–
$5x10^6$	18.036	15.794	18.514	17.761	19.141	19.030	19.332	19.223	19.189	18.948	–	–
$1x10^7$	18.867	18.391	19.437	20.824	20.191	22.256	20.444	22.497	20.289	22.223	–	–
$2x10^7$	19.892	21.504	20.588	24.398	21.442	25.994	21.766	26.302	21.610	26.050	–	–

Table 5.9 Nusselt numbers and *fRe* for all orientations, $Pr = 50$.

Gr^+	$\alpha = 0°$		$\alpha = 45°$		$\alpha = 90°$		$\alpha = 115°$		$\alpha = 135°$		$\alpha = 180°$	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	15.666	4.046	15.748	4.085	15.758	4.085	15.748	4.085	15.748	4.085	15.666	4.046
1x10^{3}	15.666	4.666	15.749	4.709	15.749	4.680	15.749	4.646	15.749	4.657	15.668	4.706
2x10^{3}	15.666	5.106	15.750	5.208	15.750	5.237	15.750	5.170	15.750	5.137	15.669	5.110
5x10^{3}	15.667	5.853	15.753	6.077	15.754	6.225	15.753	6.146	15.752	6.037	15.672	5.958
1x10^{4}	15.669	6.556	15.757	6.891	15.759	7.136	15.758	7.068	15.757	6.919	15.676	6.687
5x10^{4}	15.682	8.740	15.779	9.410	15.789	9.912	15.788	9.893	15.783	9.685	15.690	8.883
1x10^{5}	15.693	9.970	15.797	10.856	15.814	11.502	15.815	11.513	15.807	11.278	15.701	10.114
5x10^{5}	15.745	13.769	15.877	15.442	15.926	16.466	15.937	16.577	15.919	16.293	15.752	13.975
1x10^{6}	15.785	15.963	15.940	18.096	16.013	19.287	16.032	19.428	16.008	19.143	15.790	16.199
2x10^{6}	15.842	18.610	16.030	21.250	16.134	22.608	16.165	22.771	16.134	22.497	–	–
5x10^{6}	–	–	–	–	16.365	27.856	16.418	28.047	16.378	27.806	–	–
7x10^{6}	–	–	–	–	16.475	30.031	16.539	30.235	16.497	30.001	–	–
1x10^{7}	–	–	–	–	16.607	32.469	16.688	32.689	16.644	32.451	–	–

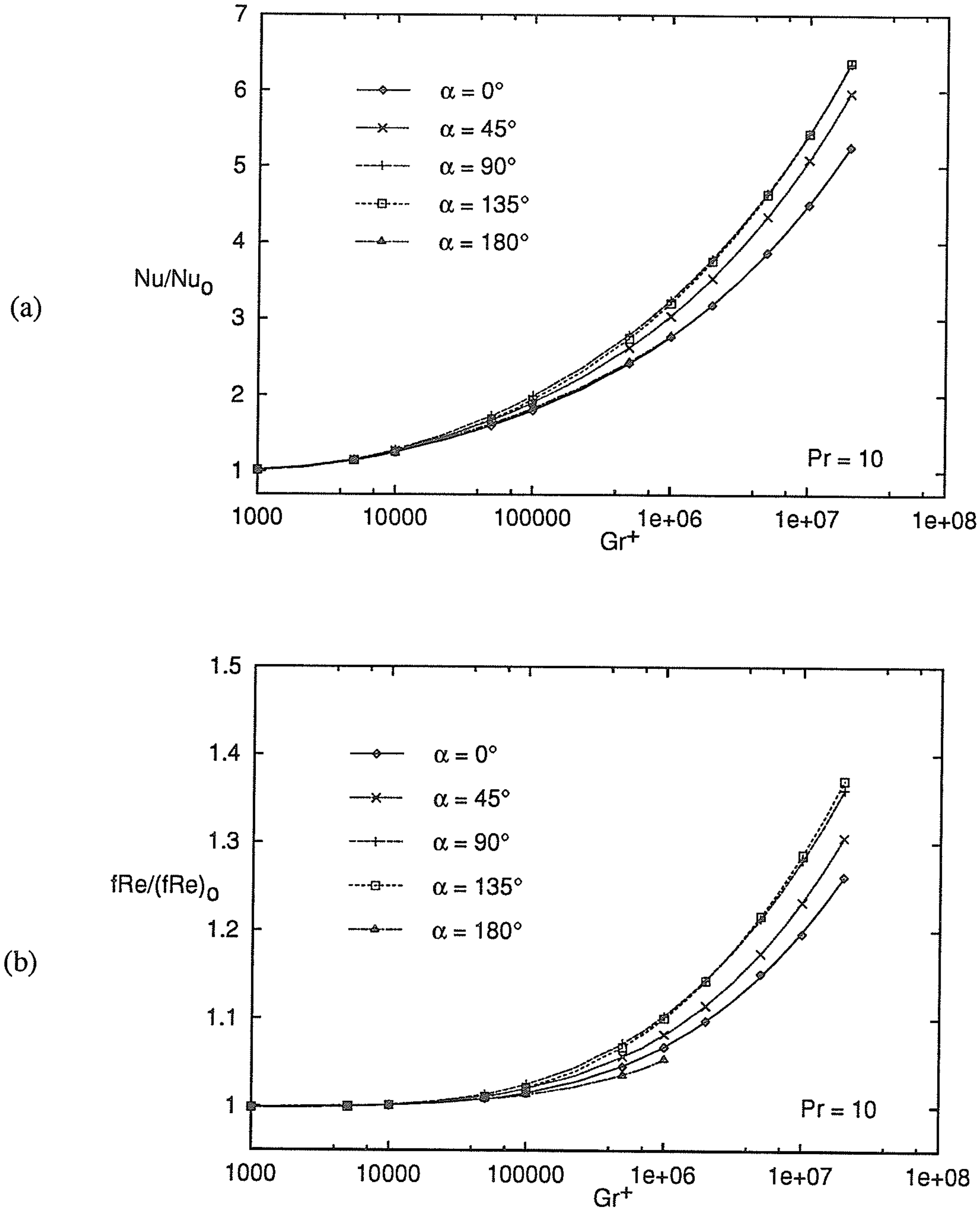


Fig. 5.8 (a) *Nu/Nu*$_o$ and (b) *fRe/(fRe)*$_o$ for *Pr* = 10.

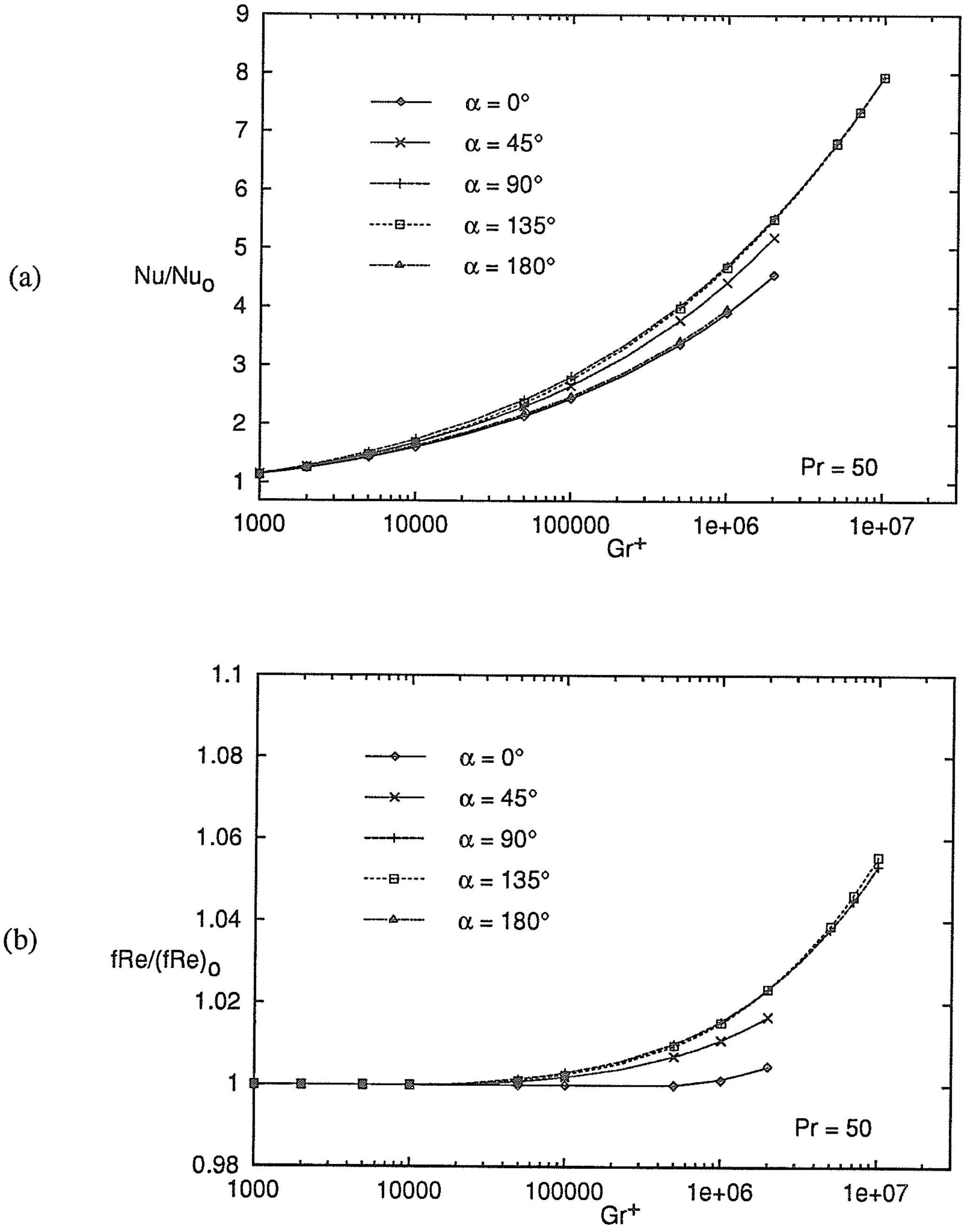


Fig. 5.9 (a) Nu/Nu_o and (b) $fRe/(fRe)_o$ for Pr = 50.

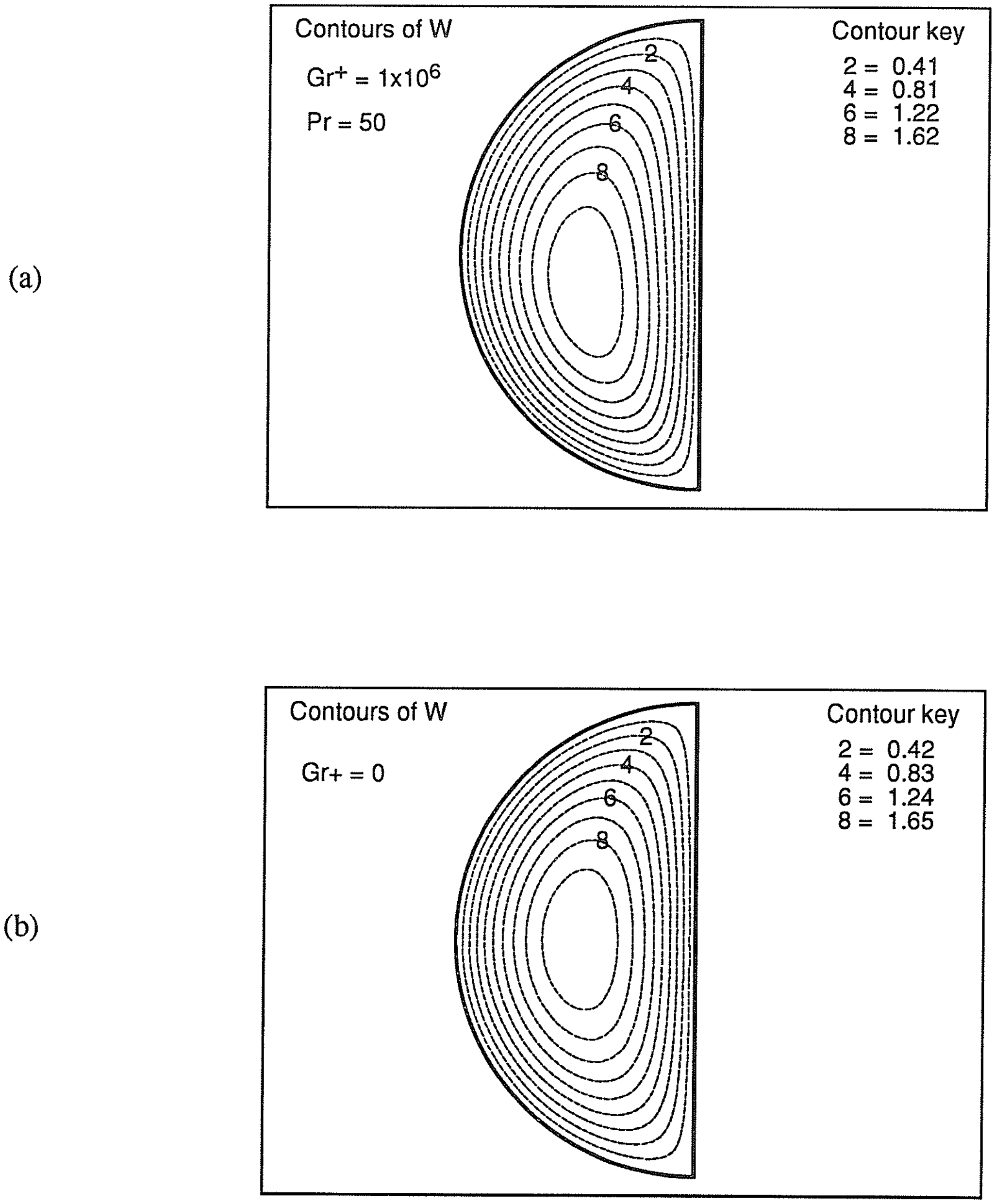


Fig. 5.10 Axial velocity contours for (a) $Pr = 50$, $Gr^+ = 10^6$, (b) $Gr^+ = 0$.

(c)

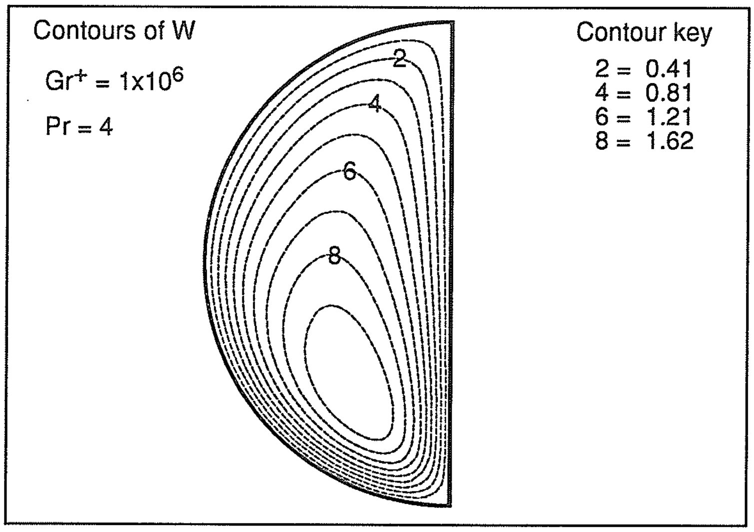


Fig. 5.10(cont) Axial velocity contours for (c) $Pr = 4$, $Gr^+ = 10^6$.

It is interesting to note that the increase of *fRe* due to the buoyancy effect was so small, e.g. 1.053 fold at $Gr^+ = 10^7$ for $\alpha = 90°$ at which the maximum buoyancy effect occurred. This indicates that distortion of the axial velocity fields caused by the buoyancy flow is small due to the very viscous fluid. The contours of the axial velocity for $Pr = 50$ and $Gr^+ = 10^6$ are shown in Fig. 5.10(a) whereas Fig. 5.10(b) is for $Gr^+ = 0$. The similarity of the two contour plots supports the above observation that distortions decrease with increasing *Pr*. A further illustration is provided by Fig. 5.10(c) which is for $Gr^+ = 10^6$ and $Pr = 4$. Here a large amount of distortion can be observed compared to Fig. 5.10(a) and (b).

The *Nu* and *fRe* for $Pr = 10$ and 50 were also computed at $\alpha = 115°$ which is the location where Nusselt number was found maximum at high Gr^+ for the case of $Pr = 4$. The Nu/Nu_o versus α are illustrated in Figs. 5.11(a) and (b) for $Pr = 10$ and 50. For $\alpha = 180°$, where the data are not available, the curves are extrapolated by assuming the same values as at $\alpha = 0°$. The maximum again appears at $\alpha = 115°$ in both cases of *Pr*. At the highest Gr^+, the *Nu* for $\alpha = 115°$ is only 1.2% higher from its neighbours. This is true for both *Pr* and a more precise location of α was not searched for these new *Pr*. The maximums shift from $\alpha = 45°$ at the lowest Gr^+ to $\alpha = 90°$ and 135° as Gr^+ increases. This trend agrees well with the case of $Pr = 4$. The *fRe* results are shown only for $Pr = 10$ in Fig. 5.12. The *fRe* results for $Pr = 50$ is skipped due to its tiny variations (less than 2%) for all orientations. The locus of the maximums for *fRe* is basically similar to the case of *Nu*.

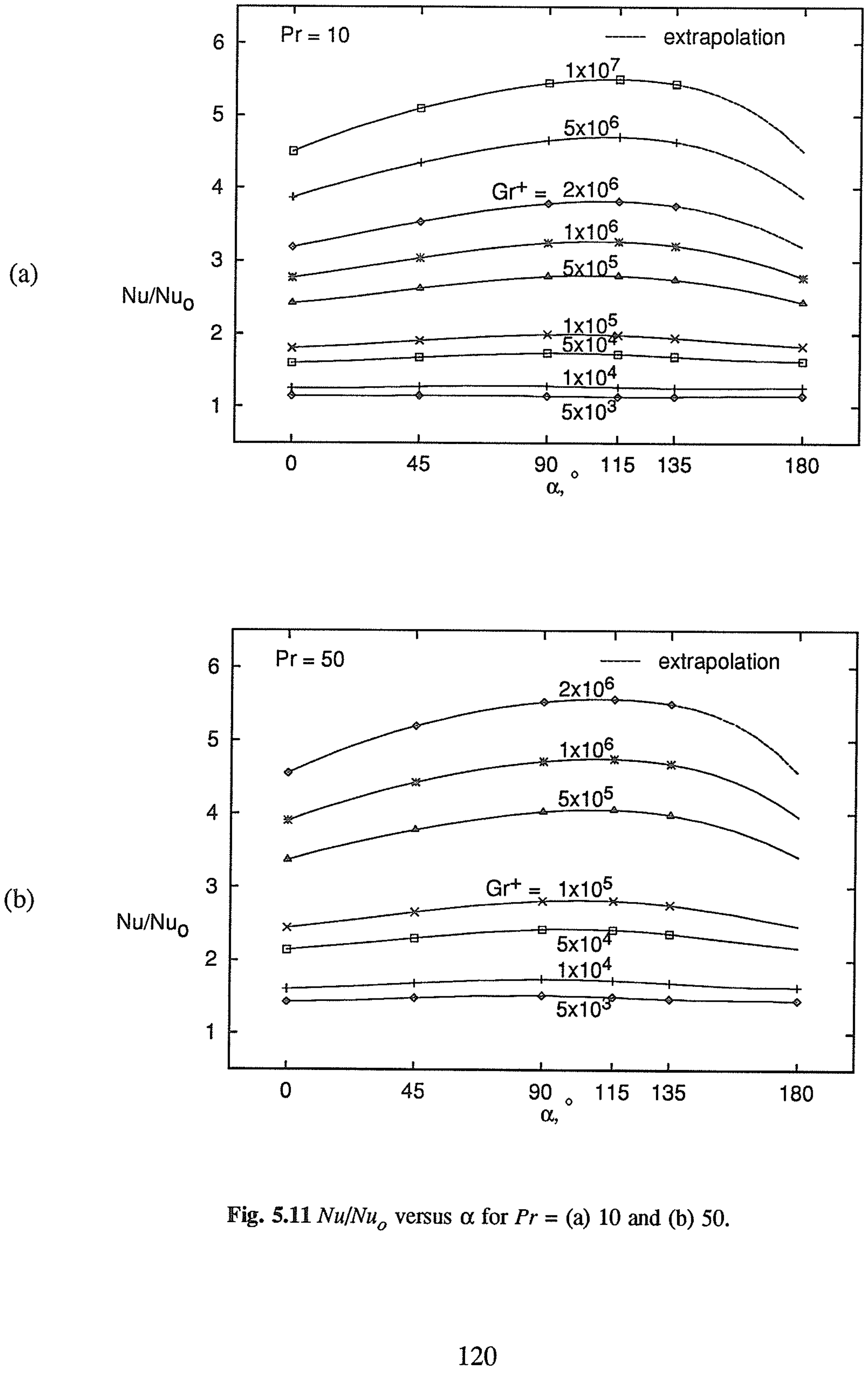


Fig. 5.11 Nu/Nu_o versus α for Pr = (a) 10 and (b) 50.

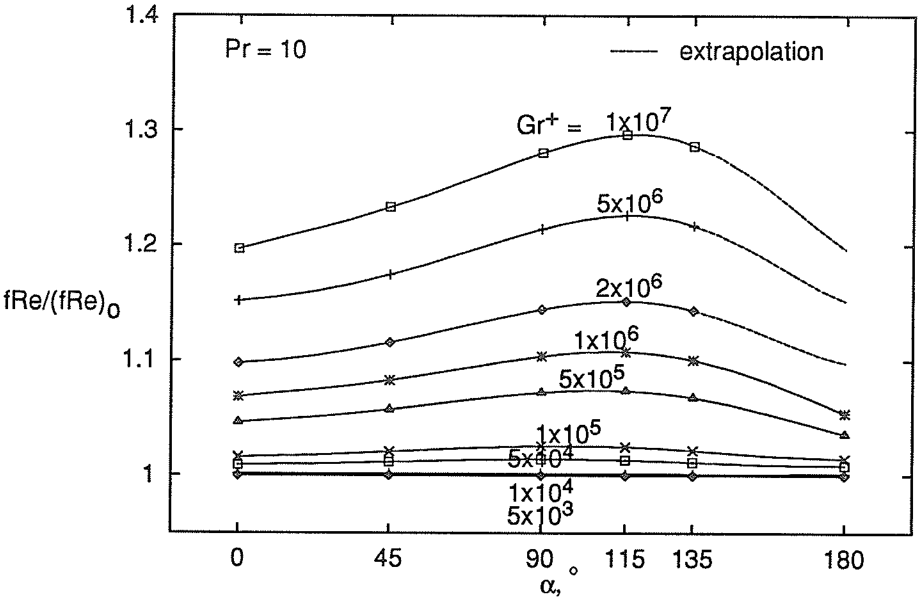


Fig. 5.12 $fRe/(fRe)_o$ versus α for Pr = 10.

5.6 Prandtl Number Effect on Nusselt Number

The Nusselt number results for Pr = 4, 10 and 50 from the previous sections are analyzed in this section. It has been shown in the previous sections that the Nu data form a well defined curve on the Nu–Gr^+ domain for a given Pr. The primary influence of Prandtl number is that the Nusselt number increases with increasing Prandtl number at a given Gr^+. For simplicity, the data for $\alpha = 0°$ and 180° were merged due to their similarities in magnitude and these are plotted in Fig. 5.13(a) which clearly shows, for fixed Gr^+, that Nu increase with increasing Pr.

The analyses of combined convection problem have shown that the fully developed Nusselt number depends on only three dimensionless quantities in term of *ReRa* and *Pr*, e.g. see Morton [5], Mori *et. al.* [8]. Later, Patanka *et. al.* [21] presented a use of Gr^+ as a replacement for *ReRa* by showing that they are equivalent. Thus the variables reduced to Gr^+ and *Pr*. For an ideal fluid, Gr^+ and *Pr* represent the heat input and fluid type while *Nu* represents the inverse of wall-to-fluid temperature drop. In most works, e.g. [18–22], the solution of Nusselt number was done by keeping *Pr* fixed and varying Gr^+ (or *ReRa*). Those results were similar to Fig. 5.14 that a Nu–Gr^+ curve is for a *Pr* value and the curve for a larger *Pr* will lie above that of a lower *Pr*, e.g. see [8], [18], [21], [29–32], etc. This coupled effect of *Pr* can be eliminated if the product Gr^+Pr is used as a sole independent variable for *Nu*. This was originally demonstrated by Lei [45] and Lei and Trupp [46]. When the same data as in Fig. 5.13(a) are plotted against Gr^+Pr in Fig. 5.13(b), the three curves collapse and all the data can be well represented by a single curve. To verify this evidence, the Nusselt number results of the semicircular duct with $\alpha = 180°$ and $Pr = 0.7$ and 5.0 from [22] were carefully duplicated and are plotted in Fig. 5.14(a) in term of Gr^+ and in Fig. 5.14(b) in term of Gr^+Pr. The data for the multiple values of *Pr* again form a single and well defined curve on the Nu–Gr^+Pr domain. To compare the results from [22] and the present results, data from Figs. 5.13(b) and 5.14(b) are shown in Fig. 5.14(c). Excellent agreement of both data confirms not only the comparable accuracy of both data but also the single curve on the Nu–Gr^+Pr domain. Further confirmations were done on other ducts; a circular duct [22] and a rectangular duct [28] with uniform heat flux, and a circular duct with non-uniform heat flux [34] (which included the data from [21] already). These data are plotted against $Gr^{+}Pr$ in Figs. 5.15(a)–(c). The outcome is excellent for the circular duct as can be seen in Fig. 5.15(a). For the square duct, there is some small separation of points in Fig. 5.15(b), but this is somewhat due to the very narrow range of the data so that the plot exaggerates small differences. For the third case, the twisting shape of the original curves in [34] indicates a complicated heat transfer and flow characteristics under the non-uniform heating condition. In spite of such facts, the outcomes of Fig. 5.15(c) confirms $Gr^{+}Pr$ scaling.

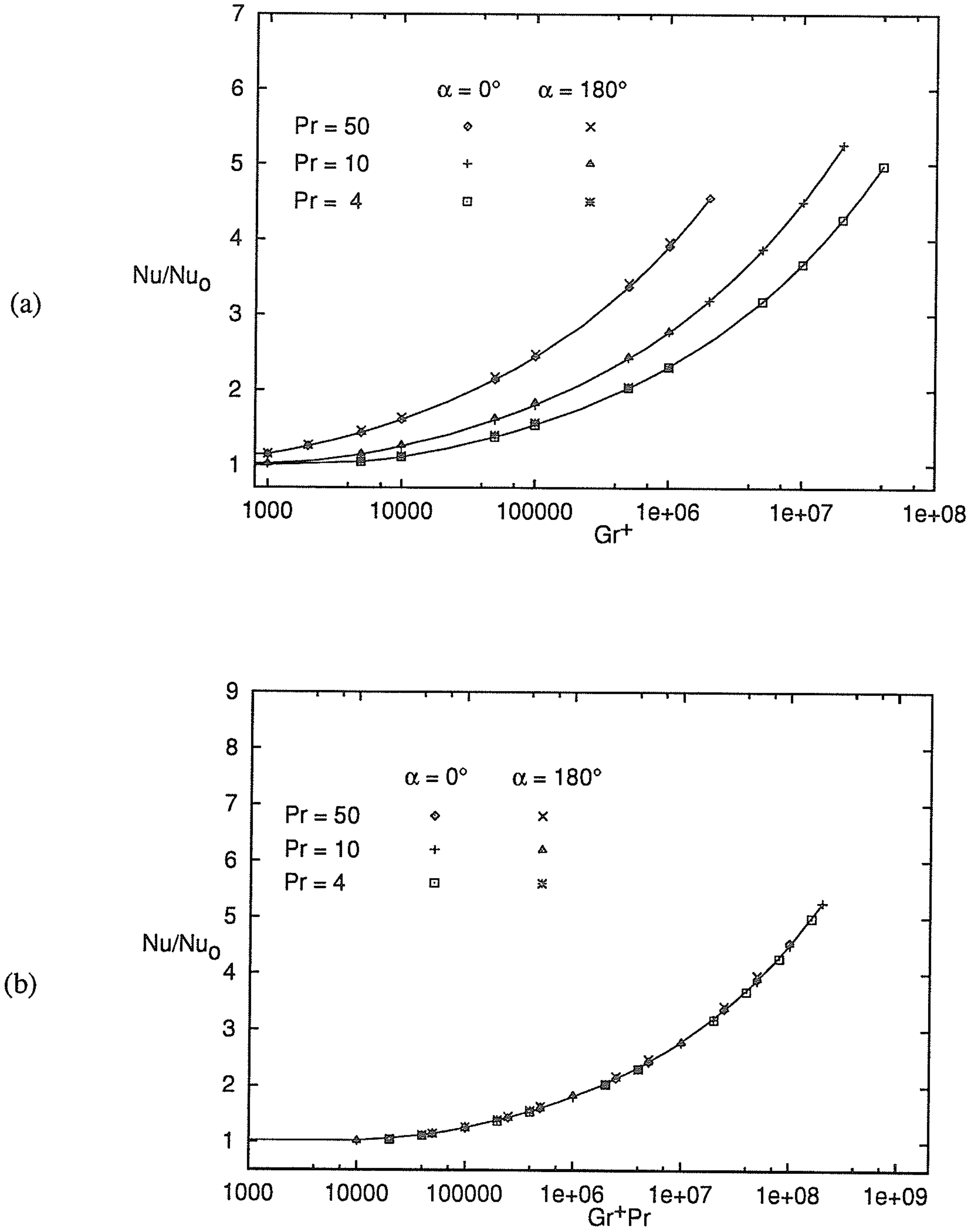


Fig. 5.13 Nu/Nu_o versus (a) Gr^+ and (b) Gr^+Pr, for all Pr.

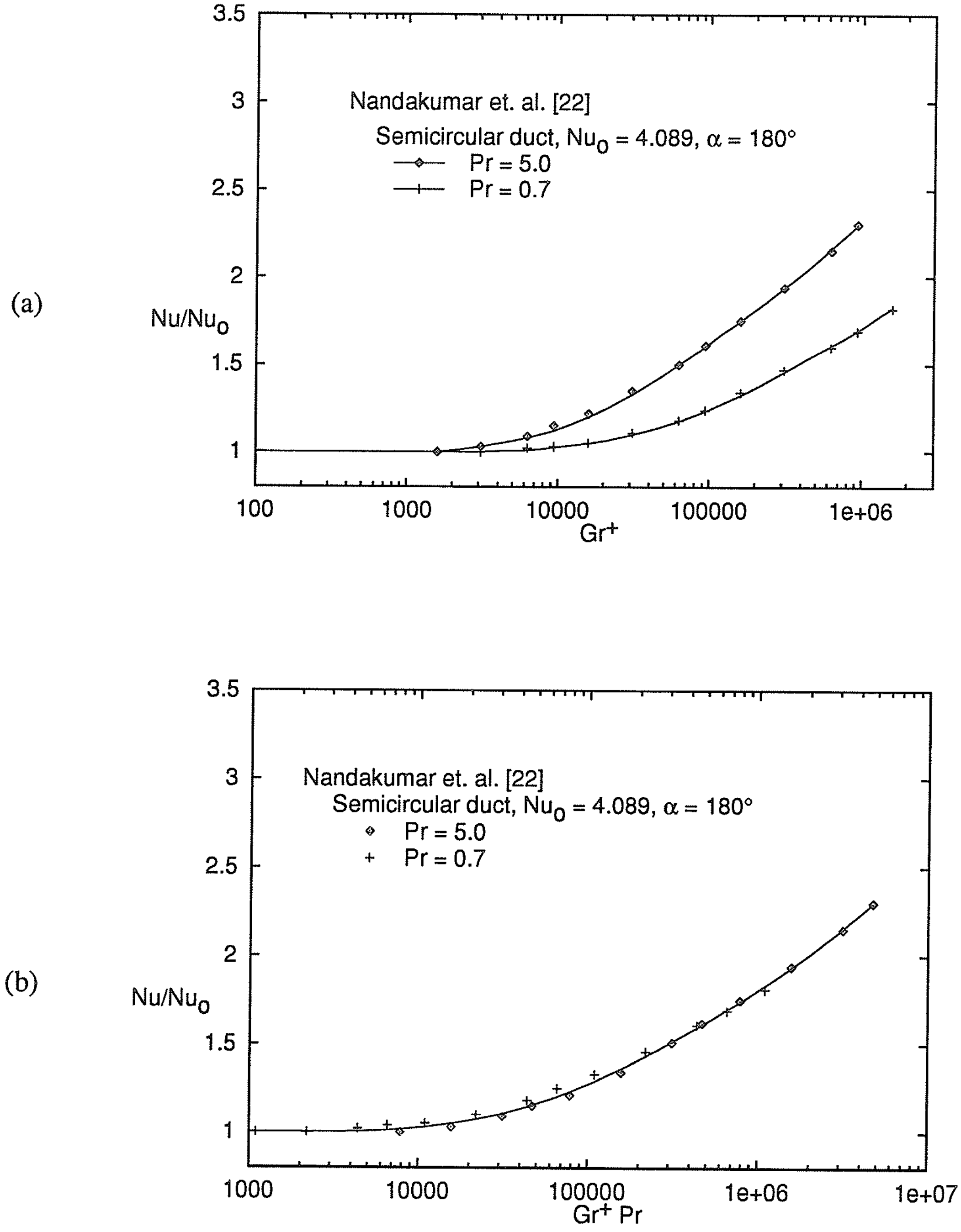


Fig. 5.14 Nu/Nu_o from [22] versus (a) Gr^+, (b) Gr^+Pr.

(c)

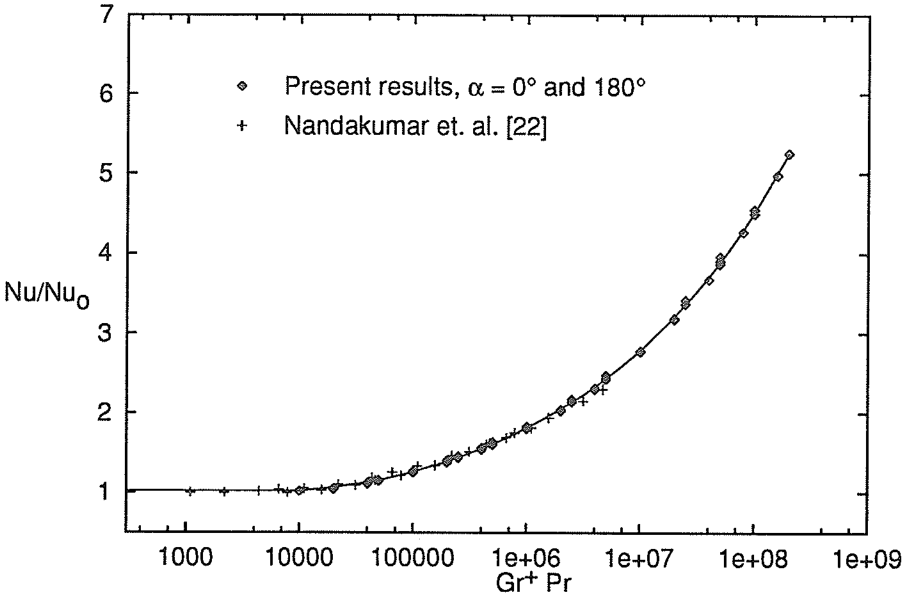


Fig. 5.14(cont) *Nu/Nu$_o$* from [22] (c) comparison to the present results.

(a)

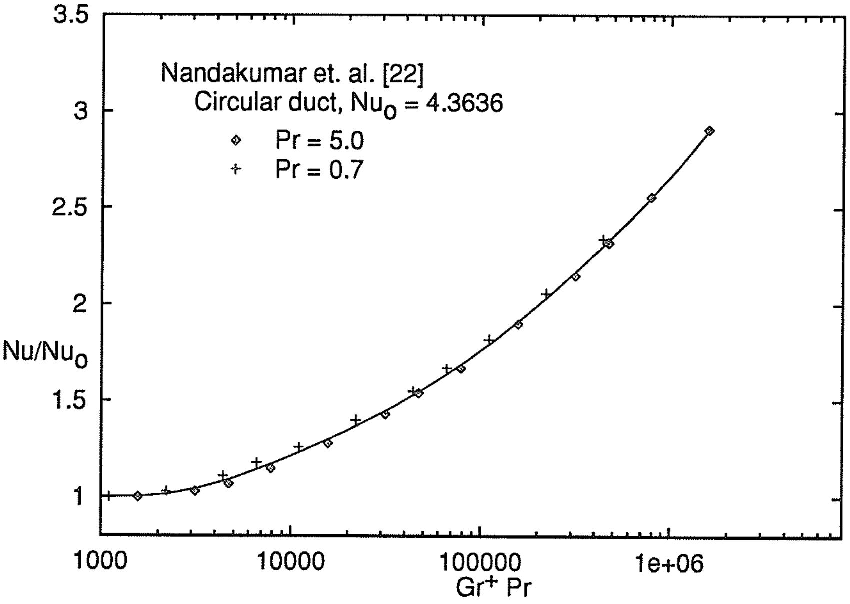
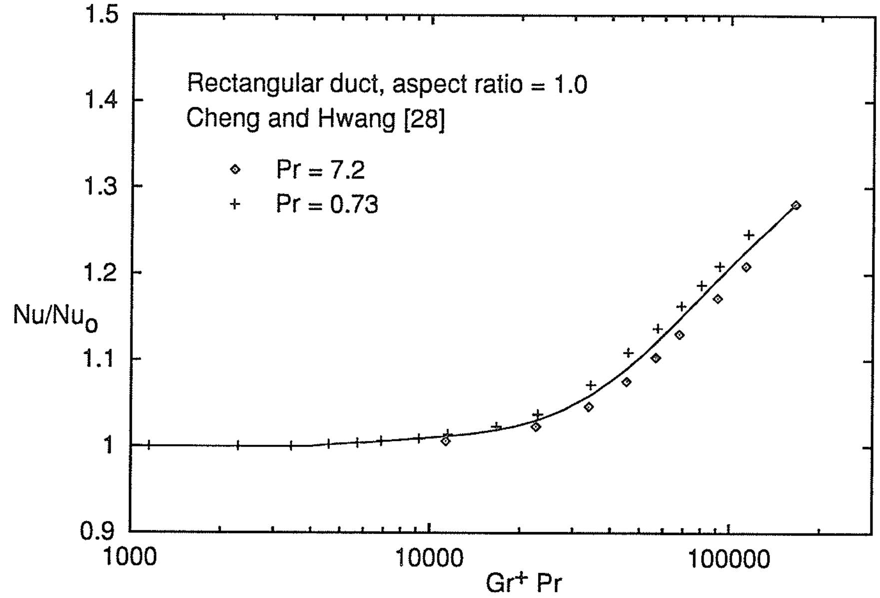


Fig. 5.15 *Nu/Nu$_o$* of (a) circular duct [22].

(b)



(c)

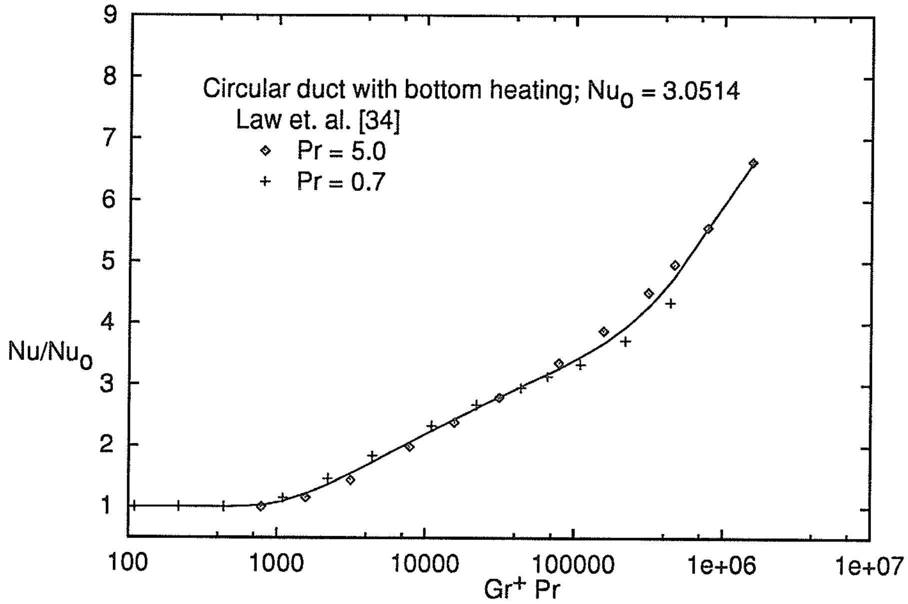


Fig. 5.15(cont) *Nu/Nu$_o$* of (b) rectangular duct [28], and (c) circular duct with non-uniform heat flux [34].

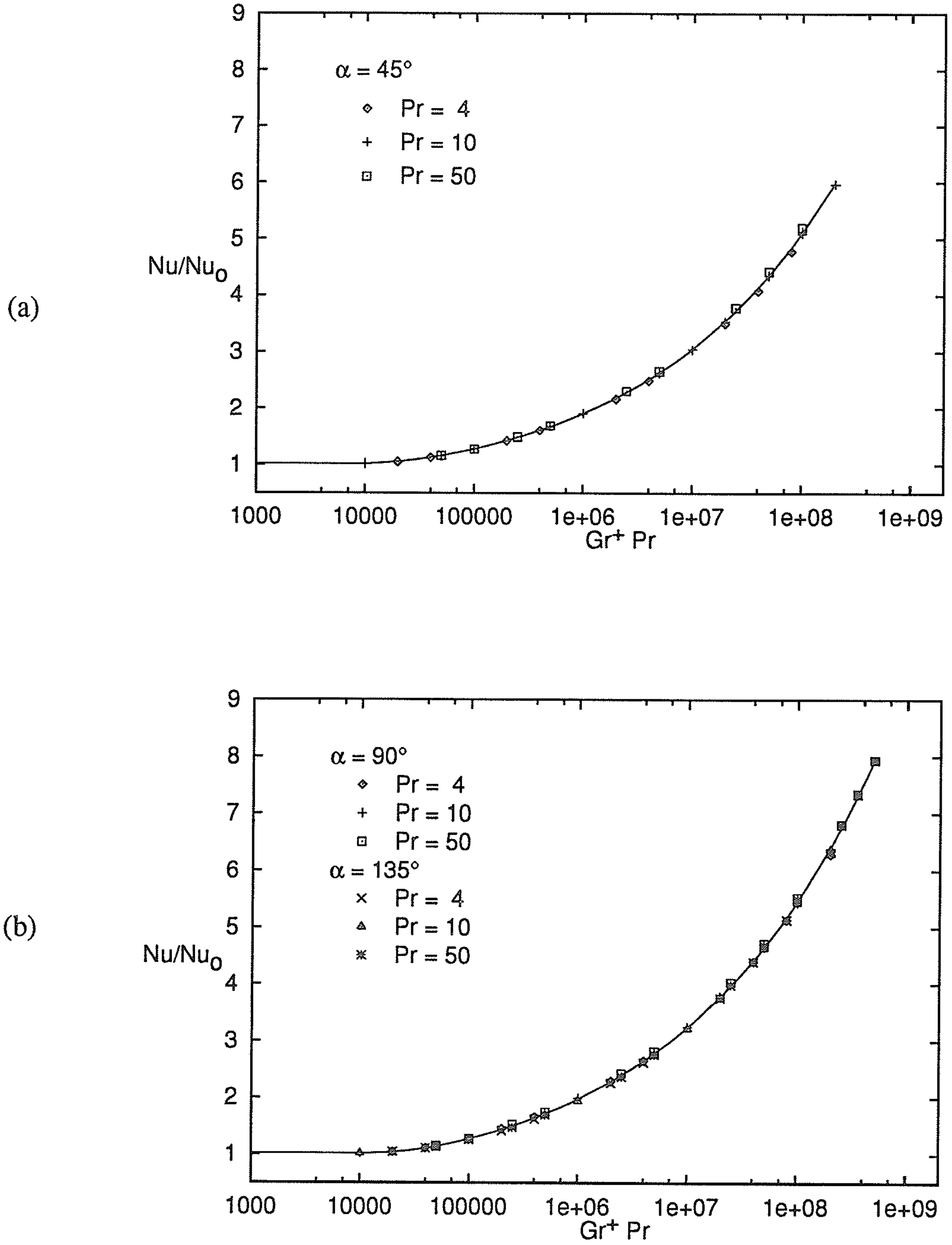


Fig. 5.16 Nu/Nu_o versus $Gr^{+}Pr$ for α = (a) 45°, (b) 90°/135°.

(c)

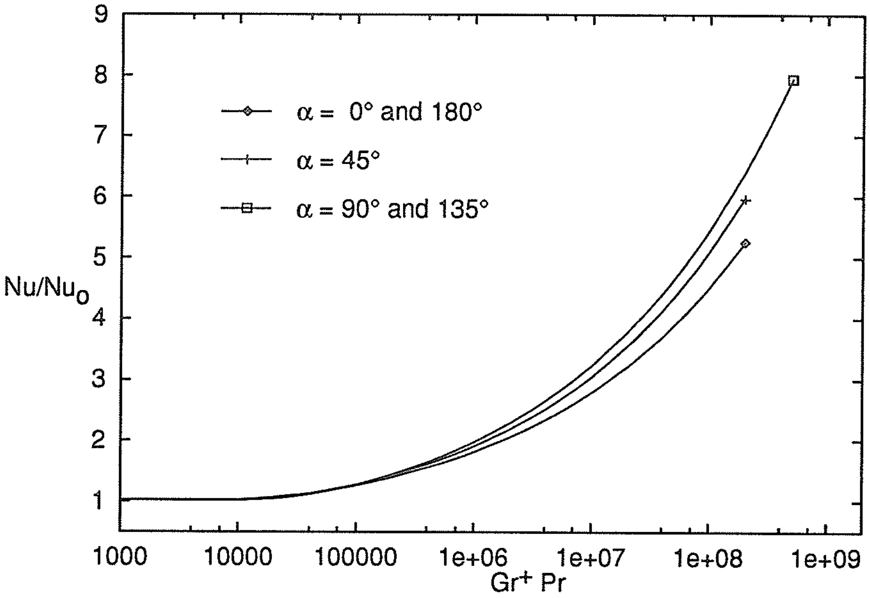


Fig. 5.16(cont) Nu/Nu_o versus Gr^+Pr for (c) all α.

For presentation purposes, the data for α = 90° and 135° were combined due to their almost identical magnitudes. The results for α = 45° and 90°/135° are shown in Figs. 5.16(a) and (b) respectively, and again excellent Gr^+Pr scaling is illustrated. A comparison among the three cases is shown in Fig. 5.16(c) in which the Nusselt number curves arrange in the same sequence as they did on the Nu–Gr^+ domain.

The uniqueness of the Nu–Gr^+Pr relation is very useful if a precise prediction for a specific Prandtl number is required. The lengthy perturbation process can be avoided by computing the Nusselt number from the Nu–Gr^+Pr relation. The Nu data are modelled in a polynomial form as

$$\frac{Nu_i}{Nu_o} = C_0 + C_1 x_i + C_2 x_i^2 + ... + C_n x_i^n \tag{5.1}$$

where i = 1, 2, ..., m which m is the total number of data, and

$$x_i = \log_{10}(Gr^+Pr) \tag{5.2}$$

The residual norm and standard deviation are determined by

$$R = \sum_{i=1}^{m} (C_0 + C_1 x_i + C_2 x_i^2 + ... + C_n x_i^n - \frac{Nu_i}{Nu_o})^2 \tag{5.3}$$

$$\sigma = \sqrt{\frac{R}{m-1}} \tag{5.4}$$

The order of the polynomials was varied from 3 to 9, for all data. It was found that n

= 4 was the best choice in terms of computing cost and accuracy because the residuals only decreased slightly as n was increased from 4 to 9. The coefficients for $n = 4$ and α = 0°, 45°, 90°, 135°, 180°, 0°/180°, and 90°/135° are compiled in Table 5.10. It should be noted here that the data were also tested with the exponential model similar to Chap. 4 but the fit was not as good since each set of data already form a well defined curve which the polynomial modelling was a much better choice.

It is interesting to note that the Gr^+Pr parameter did not surface theoretically in the mathematical model in Chap. 3, but rather it was empirically formulated from the numerical Nusselt number results. Since there is no obvious theoretical basis, it may be too early to generalize that the Nusselt number depends on a sole parameter for a fixed orientation horizontal duct. In addition, the result in [45] and [46] showed a small amount of separation from the unique curve for $Pr = 0.7$. This separation is also noticeable in Fig. 5.15(b) which contains the $Pr \approx 0.7$ data. On the other hand, the result in Fig. 5.14(b) which also contains the data of this Prandtl number did not show this sign. It is possible that the unique $Nu–Gr^+Pr$ relation could somewhat deteriorate as Pr is less than 1. Nevertheless, it is clear that for $4 \leq Pr \leq 50$, the Gr^+Pr works well for the semicircular duct.

Table 5.10 Coefficients of the polynomials in equation 5.1 for the Nu/Nu_o.

α	Coefficients						
	C_0	C_1	C_2	C_3	C_4	σ	σ_{max}
0°	0.95150982E+1	−0.62369480E+1	0.16698433E+1	−0.19990874E+0	0.98561374E−2	0.00269777	0.04544893
45°	0.98366232E+1	−0.65221121E+1	0.17634421E+1	−0.21453426E+0	0.10845645E−1	0.00636744	0.09586126
90°	0.14531336E+2	−0.96409864E+1	0.25125910E+1	−0.29242278E+0	0.13907628E−1	0.00619665	0.12110808
135°	0.12096346E+2	−0.78315638E+1	0.20317778E+1	−0.23848557E+0	0.11737342E−1	0.00438557	0.08410378
180°	0.14866670E+2	−0.10350876E+2	0.28333789E+1	−0.34329864E+0	0.16369740E−1	0.00351722	0.03922880
0° and 180°	0.83017243E+1	−0.54070747E+1	0.14595934E+1	−0.17638511E+0	0.88781484E−2	0.00312848	0.07435869
90° and 135°	0.13313841E+2	−0.87362750E+1	0.22721843E+1	−0.26545417E+0	0.12822485E−1	0.00417036	0.12150593

5.7 Prandtl number effect on *fRe*

The Prandtl number affects *fRe* quite differently from its effect on Nusselt number. For a given Gr^{+}, *fRe* decreases with increasing *Pr* as demonstrated in section 5.6 and in Fig. 5.17(a) where $fRe/(fRe)_o$ vs Gr^{+} is shown for $\alpha = 90°$ as a sample. The higher viscosity of the fluid due to its higher Prandtl number retards the buoyancy flow thus resulting in a less distorted axial velocity field. Therefore *fRe* is not much different from its original forced-convection value. Similar to Nusselt number, *fRe* is governed by *Pr* and Gr^{+}. The coupled effect of *Pr* was overcome by using $Gr^{+}/Pr^{1.8}$ as initially illustrated in [45] and [46]. The present results were test by Gr^{+}/Pr^{n} which *n* was varied from 2.0 to 1.2. The outcome of $n = 2.0$ was the best even though it was only slightly different from that of $n = 1.8$. The data of Fig. 5.17(a) are plotted against Gr^{+}/Pr^{2} in Fig. 5.17(b) where a single curve is formed. Successful scaling is further illustrated in Figs. 5.18(a), (b) and (c) where results are presented for $\alpha = 0°$ and 180°, 45°, and 90° and 135°. The single curves are formed well for each case.

The $fRe/(fRe)_o$ is formulated with an equation similar to eqn. (5.1) where $x_i = \log_{10}(Gr_i^{+}/Pr^{2})$. The coefficients are shown in Table 5.11. The σ and σ_{max} for $fRe/(fRe)_o$ are generally smaller than those for Nu/Nu_o for each α. This is due to the smaller magnitudes of *fRe* ratios rather than other reasons. In fact, both the *Nu* and *fRe* data are represented very well by these polynomial models in terms of the very small standard variations (less than 1% for both cases). The polynomial models were actually used for generating the curves in all of the related figures, e.g. see Figs. 5.18, 5.16(a), and (b).

It is worth noting that even though the data for Pr = 50 are combined with the rest, they share only a small portion in the $fRe/(fRe)_o$–Gr_i^+/Pr^2 relations. This is due to two reasons. First, the data for Pr = 50 were shifted much toward the left when the abscissa was Gr^+/Pr^2 instead of Gr^+ (as compared to the data for smaller Pr). Secondly, the $fRe/(fRe)_o$ magnitudes for Pr = 50 are very close to 1. Therefore the Pr = 50 data locate only within the flat parts of the curves in Fig. 5.18. The curves in $Gr^+/Pr^2 > 10^4$ rely on the data for Pr = 4 and 10 only. Finally, the results from Fig. 5.18 are shown together in Fig. 5.19 to allow comparison. At $Gr^+/Pr^2 \approx 10^6$, the $fRe/(fRe)_o$ ratio is about 1.7 and the difference between the maximum and minimum curves is roughly 8%.

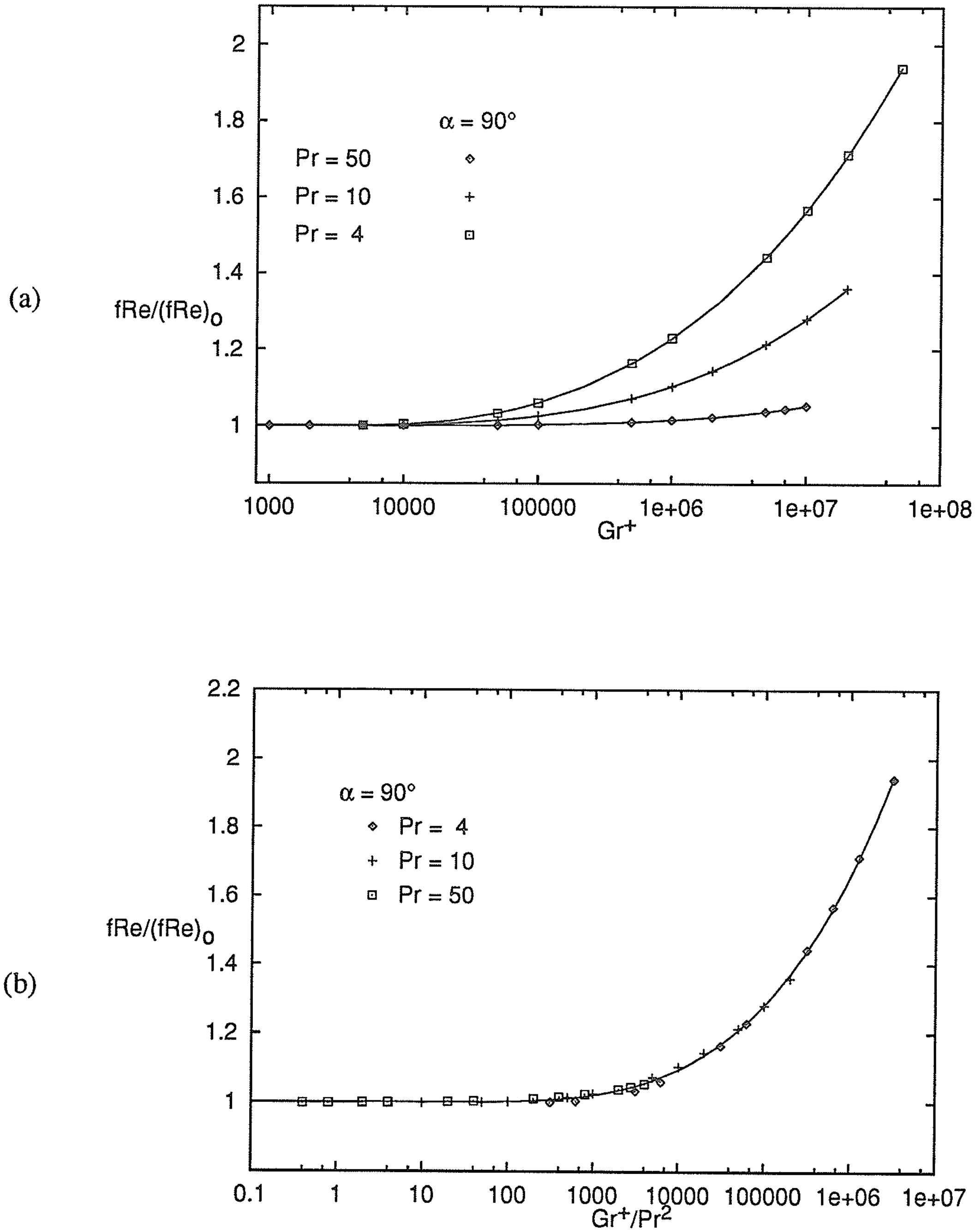


Fig. 5.17 $fRe/(fRe)_o$ versus (a) Gr^+ and (b) Gr^+/Pr^2, for $\alpha = 90°$.

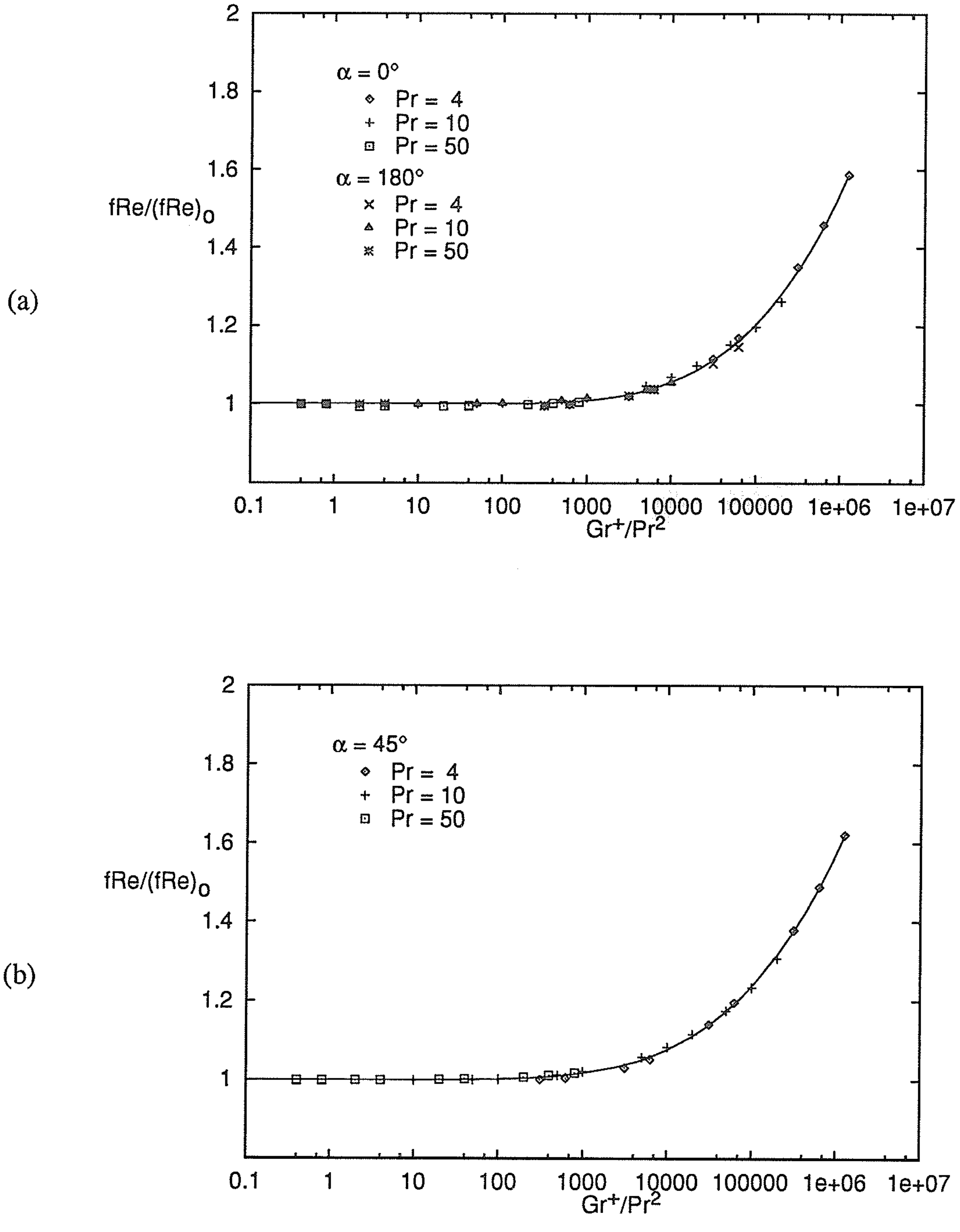


Fig. 5.18 $fRe/(fRe)_o$ versus Gr^+/Pr^2 for α = (a) 0°/180°, (b) 45°.

(c)

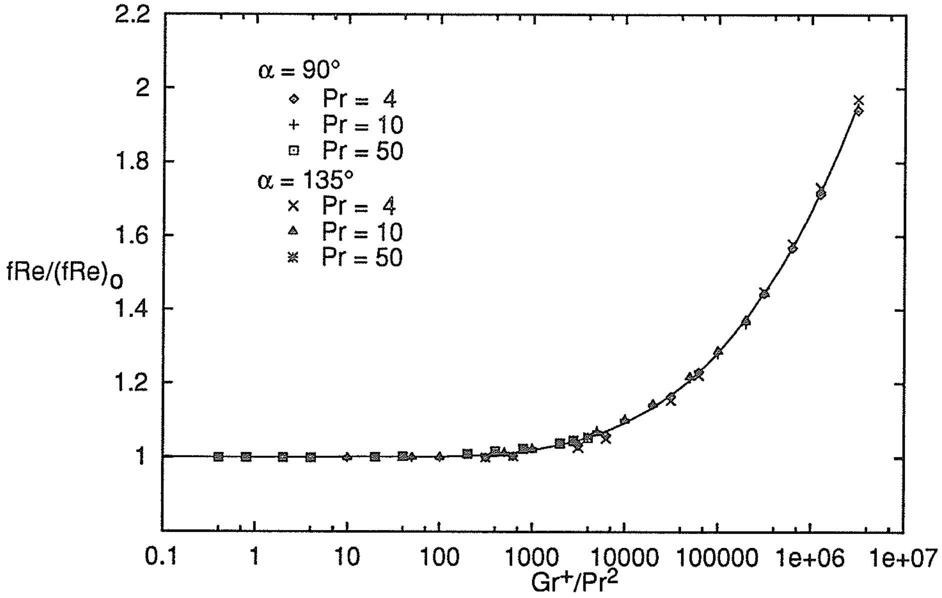


Fig. 5.18(cont) $fRe/(fRe)_o$ versus Gr^+/Pr^2 for α = (c) 90°/135°.

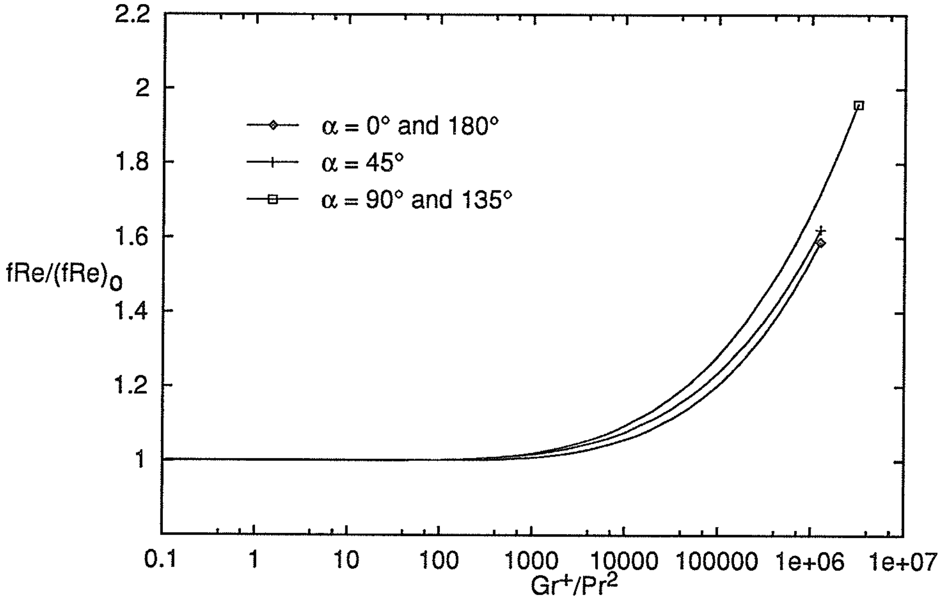


Fig. 5.19 $fRe/(fRe)_o$ versus Gr^+/Pr^2 for all α.

Table 5.11 Coefficients of the polynomials for $fRe/(fRe)_o$.

α	Coefficients						
	C_0	C_1	C_2	C_3	C_4	σ	σ_{max}
0°	0.99533134E+0	−0.89212149E−2	0.14030731E−1	−0.67310238E−2	0.11944874E−2	0.00123837	0.02127804
45°	0.99824711E+0	−0.11880349E−2	0.54225957E−2	−0.37609285E−2	0.92597196E−3	0.00076026	0.00949152
90°	0.99913959E+0	0.33129348E−2	−0.50706989E−3	−0.18385361E−2	0.81410879E−3	0.00106207	0.01474402
135°	0.99889139E+0	0.33843436E−2	0.46165310E−3	−0.25336721E−2	0.91567897E−3	0.00126902	0.01891866
0° and 180°	0.99626326E+0	−0.64666543E−2	0.12547567E−1	−0.66112268E−2	0.12039536E−2	0.00094157	0.01886392
90° and 135°	0.99901549E+0	0.33486392E−2	−0.22708395E−4	−0.21861041E−2	0.86489388E−3	0.00092552	0.02039447

5.8 Comparisons to the Experimental Results

The numerical Nusselt number results for Pr = 4 and α = 45°, 90°, 135° are compared to the experimental results from section 4.6. For α = 180°, the numerical results for Pr = 4 were obtained for Gr^+ up to only 10^6 whereas the experiments were conducted for $Gr^+ > 2\text{x}10^6$ therefore the comparison is not available. However, the numerical results obtained from all Pr values are fairly high compared to the range of the experimental results therefore the comparison for α = 180° is available in term of Gr^+Pr variable.

The comparisons in terms of Gr^+ are shown in Fig. 5.20(a) where the solid curves for the experimental results are generated by the correlations in Table 4.3 and the dash curves for the numerical results are reproduced from the data in Table 5.10. The numerical and the experimental results agreed very well near $Gr^+ = 10^7$ and the difference between both data increases as Gr^+ increases or decreases from 10^7. In the low Gr^+ region, the predictions are underestimations. At $Gr^+ = 2.7\text{x}10^6$, the differences are 11%, 8% and 8% for α = 45°, 90°, and 135°, respectively. In the high Gr^+ region, the numerical results are higher especially at the highest range of the experimental results. However, due to the limits of the numerical results, the comparisons can be done only at $Gr^+ = 4\text{x}10^7$ where the differences for α = 90° and 135° are 6% and 7% based on the experimental results.

(a)

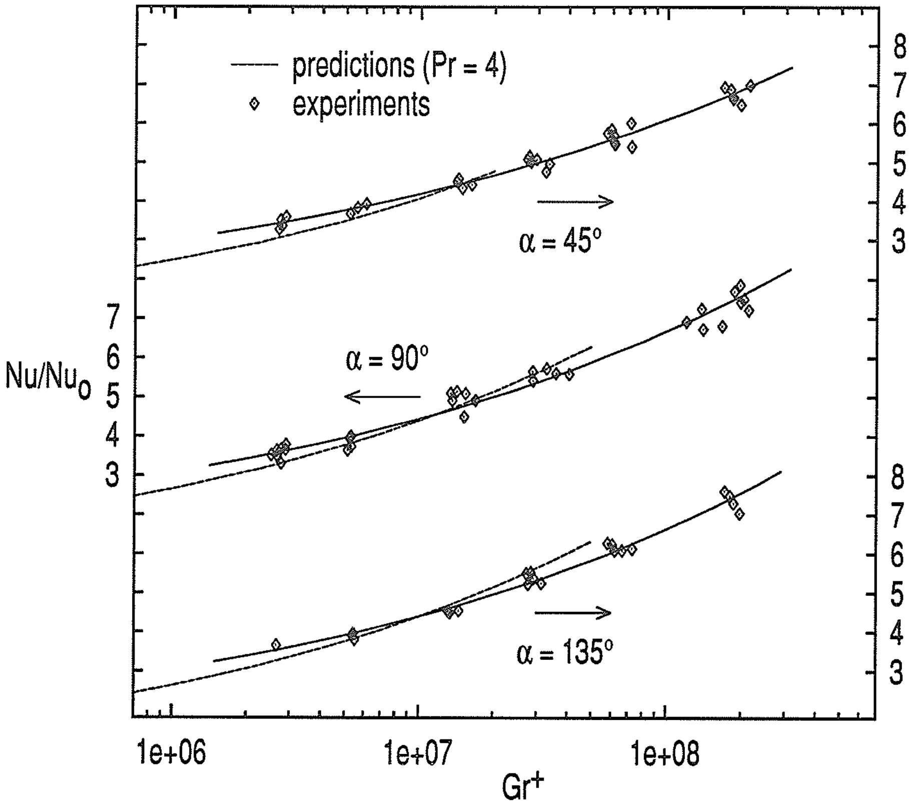


Fig. 5.20 Comparisons to the experimental results in terms of (a) Gr^+

(b)

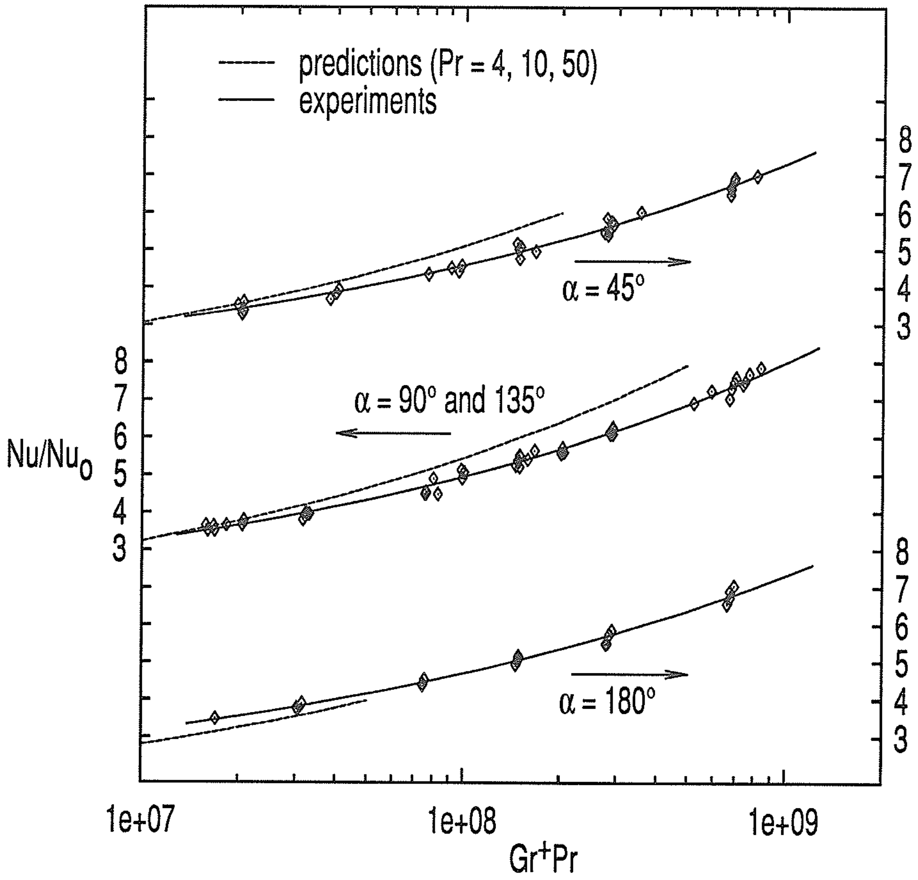


Fig. 5.20(cont) Comparisons to the experimental results in terms of (b) Gr^+Pr.

The numerical results in term of $Gr^{+}Pr$ which include the results for $Pr = 4$, 10, and 50, are compared to the experimental results in Fig. 5.20(b) for $\alpha = 45°$, 90° and 135°, and 180°. This comparison is more general than the previous one in Fig. 5.20(a) due to the variation of Prandtl number within the experimental results are absorbed in the $Gr^{+}Pr$ product. All results show good agreements at the low end of the $Gr^{+}Pr$. In general, as $Gr^{+}Pr$ increases, the curves for the numerical results show a steeper slope and therefore the overestimations are clearly expectable at high $Gr^{+}Pr$ for all α. The intersections of the numerical and experimental data are near $2\text{x}10^{7}$ for $\alpha = 45°$, and 90° and 135°, and near $5\text{x}10^{7}$ for α 180°. At near the intersections, the predictions are about 5% lower for $\alpha = 180°$ and about 3.5% higher for both $\alpha = 45°$, and 90° and 135°. The differences increase as $Gr^{+}Pr$ move further from the intersections. The differences estimated at $Gr^{+}Pr = 2\text{x}10^{8}$ are 14% and 13% overestimations for $\alpha = 45°$, and 90° and 135°, and about 9% underestimation at $Gr^{+}Pr = 2\text{x}10^{7}$ for $\alpha = 180°$.

Overall, the predictions clearly show the trends of overestimation which appear at the lowest $Gr^{+}Pr$ value except for the case of $\alpha = 180°$ where the overestimation did not actually appear but it is expectable if $Gr^{+}Pr$ is further increased. The overestimation is due to the H1 thermal boundary condition assumed in the mathematical model. The H1 condition assumes a uniform peripheral temperature while the experimental results showed the non-uniform temperature which increases with the magnitude of Gr^{+}. On the other hand, the H2 condition assumes a uniform peripheral heat flux. Comparing to the H2 condition, the H1 condition has a higher heat transfer coefficient according to a larger heat transfer potential resulted from the cooler fluid near the bottom wall and the uniform wall temperature. As a result, the Nusselt number for H1 condition should be higher as compared to the H2 condition. The experimental results indicated when the heating rate was small, the wall temperature condition was indeed close to the H1 condition , e.g. about 0.2° at $Gr^{+}Pr \approx 2\text{x}10^{7}$, and the predictions are very close to the experimental results, as appearing in Fig. 5.20(b). The duct wall temperature variation was as large as 3.0-3.7° as indicated in section 4.4 at the largest Gr^{+}. This forced the experimental condition significantly moving away from the H1 toward the H2 condition. This can be confirmed by the increasing amount of the overestimation by the predictions with H1 condition which appears in both Figs. 5.20(a) and (b). It is probably appropriate to conclude that the wall temperature condition for these experiments was H1 at low Grashof number and the prediction with this condition is acceptable up to $Gr^{+}Pr$ of 10^{8}. The further numerical study can be for the H2 condition which should be useful if the application at a higher heating rate is concerned.

In regard to the effect of duct orientation, the experimental results in Chap. 4 show that the duct orientation significantly affected the magnitude of Nusselt number. At $Gr^{+}Pr \approx 10^{9}$, the Nusselt numbers for $\alpha = 90°$ and 135° are about 10% higher compared to $\alpha = 45°$ and 180° and about 40% higher compared to $\alpha = 0°$. At $Gr^{+}Pr \approx 2\text{x}10^{8}$ (maximum $Gr^{+}Pr$ values for the predictions), the predictions (i.e. Fig. 5.16) indicated that Nusselt numbers for $\alpha = 90°$ and 135° are about 7% larger in comparison to $\alpha = 45°$ and about 20% larger in comparison to $\alpha = 0°$ and 180°. The locations of the maximum Nusselt numbers which appeared at $\alpha = 90°$ and 135° for which the Nusselt number magnitudes are very similar agreed very well between the numerical and experimental results. For α = 45°, the predicted value are about 7% lower than the maximum at $Gr^{+}Pr \approx 2\text{x}10^{8}$. The 7% difference agrees very well with the experiments which shows the same difference between α = 90° and 135° and 45° at the same $Gr^{+}Pr$.

Although the predictions have shown the similar Nusselt number magnitudes for α = 0° and 180°, the measured Nusselt numbers for α = 180° are much higher. Actually, the Nusselt numbers for α = 180° were comparatively the same as those for α = 45°. This indicates that the α = 180° position is better than the 0° position for Nusselt number enhancement in practice. Considering the cross-stream flow pattern, the upward curved wall in the 180° orientation allows a smoother path for the rising of the hot fluid near the side wall. Furthermore, the corners which inhibit continuous circulation and the fluid velocity should be low in the corner vicinity. In case of α = 0°, some part of the hot fluid is virtually blocked in the corner. This is in contrast to α = 180° which the corners at the bottom that accommodate cooler fluid instead of hot fluid as in the case of α = 0°. Therefore the wall temperature differences of about 4°–5° C at $Gr \approx 5\text{x}10^{7}$ were measured for α = 0° as compared to about 3° for α = 180°. The mathematical model with uniform wall temperature as H1 boundary condition is certainly not able to imitate this difference and hence the nearly same Nusselt numbers were obtained both orientations.

As mentioned earlier in Chap. 4 for *fRe*, the experimental results should be considered as the average between the thermal developing and fully developed region while the numerical *fRe* results are for the fully developed condition. These results are compared in Fig. 5.21 for α = 45°, 90° and 135°. For α = 45° and 90°, the differences are within about 40% and somewhat larger for $\alpha = 135°$. The experimental results show that the *fRe* were affected by the buoyancy force at $Gr^+ > 2 \times 10^7$ while the numerical results show this effect since the Gr^+ is much smaller. These results indicate that the *fRe* increases when the cross-stream flow becomes stronger similar to the Nusselt number as discussed earlier in this chapter. In addition, the overestimation of *fRe* is also consistent with the Nusselt number predictions when the amount of overestimation increases with a further departing from H1 condition of the peripheral wall temperature.

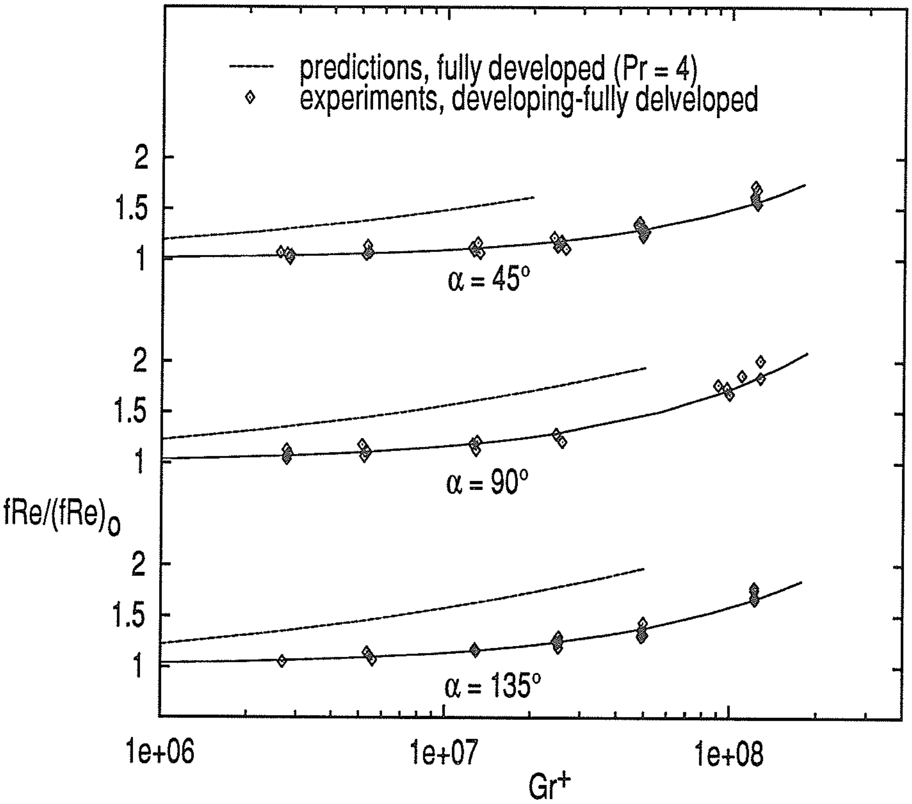


Fig. 5.21 Comparison of the two $fRe/(fRe)_o$ data.

Chapter 6

Circular Sector Ducts

Circular sector ducts are a family of ducts consisting of a countless number of circular sector cross-sectional shapes according to various possible apex angles. The apex angle can be used as the identification for each duct. The flow and heat transfer characteristics of circular sector ducts can vary widely according over the wide range of apex angles. As an element in a multipassage tube, the apex angle is limited to 180°, therefore larger apex angles are omitted. The analyses in this chapter are basically for apex angles of 60°, 90° and 120° in addition to the 180° (semicircular duct) presented in the last chapter. These apex angles correspond to internally finned tubes with equi-spaced, full fin, with 6, 4, 3 and 2 passages. The combined convection characteristics, H1 thermal boundary condition, under the influence of the gravitational orientation for the 60°, 90° and 120° ducts are presented with the data for Pr = 4. For a given orientation with respect to the gravity vector, the Nu and fRe differ due to the shapes of the duct cross section which depends on apex angles. The comparative results in term of the apex angle (2ϕ) for various orientations (α) are presented to demonstrate such results. The effect of Prandtl number is investigated by the association of the data for $Pr = 10$ and 50. Lastly, the unique correlations for Nu and fRe in term of the Gr^+Pr and Gr^+/Pr^2 similar to the last chapter are presented.

6.1 Results for $Pr = 4$

The circular sector duct problems were solved by the same method as described in chapter 5. The accuracy of the solutions were tested similarly to the case of the semicircular duct except that all the problems were solved by the full region solution which experienced no difficulty of convergence. The solutions for $Gr^+ = 0$ were compared to the exact results [35, 36] and the agreements were within about 0.1% for the Nusselt number for all ducts. For fRe the agreements were 0.26% for the 60° duct and 0.15% and 0.16% for the 90° and 120° ducts. Meshes of 30x30, 30x40 and 30x40 were chosen for the 60°, 90° and 120° ducts respectively according to the two reasons; first, the radial grid of 30 was consistent for all ducts including the semicircular duct, secondly, both Nu and fRe were independent of grid sizes with about 3% discrepancies at $Gr^+ = 10^7$ as the meshes reached 40x50, 40x60, and 40x60 for the 60°, 90° and 120° ducts respectively.

Table 6.1 *Nu* and *fRe* for the 60° duct with $Pr = 4$.

Gr^+	α = 0°		α = 90°		α = 180°	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	14.134	3.476	14.134	3.476	14.134	3.476
$5x10^3$	14.137	3.494	14.137	3.494	14.136	3.494
$1x10^4$	14.146	3.547	14.144	3.544	14.143	3.539
$5x10^4$	14.281	4.140	14.262	4.093	14.243	4.039
$1x10^5$	14.445	4.610	14.407	4.545	14.375	4.481
$5x10^5$	15.175	6.034	15.119	6.034	15.091	6.018
$1x10^6$	15.668	6.842	15.668	6.937	15.647	6.931
$5x10^6$	17.489	9.476	17.772	9.859	17.692	9.786
$1x10^7$	18.623	11.035	19.105	11.547	18.940	11.409
$2x10^7$	20.020	12.909	20.728	13.515	20.432	13.338
$5x10^7$	22.383	15.914	23.375	16.516	22.812	16.462

Table 6.2 *Nu* and *fRe* for the 90° duct with $Pr = 4$.

Gr^+	α = 0°		α = 90°		α = 180°	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	14.747	3.739	14.747	3.739	14.747	3.739
$5x10^3$	14.758	3.813	14.756	3.802	14.756	3.808
$1x10^4$	14.785	3.969	14.779	3.940	14.779	3.945
$5x10^4$	15.034	4.875	15.022	4.857	14.994	4.786
$1x10^5$	15.263	5.439	15.277	5.477	15.211	5.354
$5x10^5$	16.194	7.183	16.446	7.506	16.202	7.222
$1x10^6$	16.839	8.200	17.266	8.700	16.912	8.310
$5x10^6$	19.113	11.464	20.111	12.464	19.384	11.688
$1x10^7$	20.493	13.377	21.805	14.606	20.842	13.616
$2x10^7$	22.177	15.683	23.800	17.103	22.562	15.915
$5x10^7$	25.023	19.415	26.959	20.971	25.302	19.630

Table 6.3 *Nu* and *fRe* for the 120° duct with $Pr = 4$.

Gr^+	$\alpha = 0°$		$\alpha = 90°$		$\alpha = 180°$	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	15.177	3.903	15.177	3.903	15.177	3.903
$5x10^3$	15.198	4.041	15.193	4.014	15.196	4.036
$1x10^4$	15.240	4.268	15.229	4.221	15.234	4.251
$5x10^4$	15.542	5.293	15.570	5.367	15.520	5.260
$1x10^5$	15.799	5.910	15.916	6.116	15.777	5.894
$5x10^5$	16.849	7.859	17.390	8.482	16.899	7.955
$1x10^6$	17.568	8.997	18.360	9.851	17.685	9.153
$5x10^6$	20.031	12.606	21.610	14.129	20.402	12.922
$1x10^7$	21.495	14.705	23.914	16.974	22.013	15.107
$2x10^7$	23.305	17.257	26.058	19.713	23.942	17.719
$5x10^7$	–	–	29.452	24.030	27.111	21.908

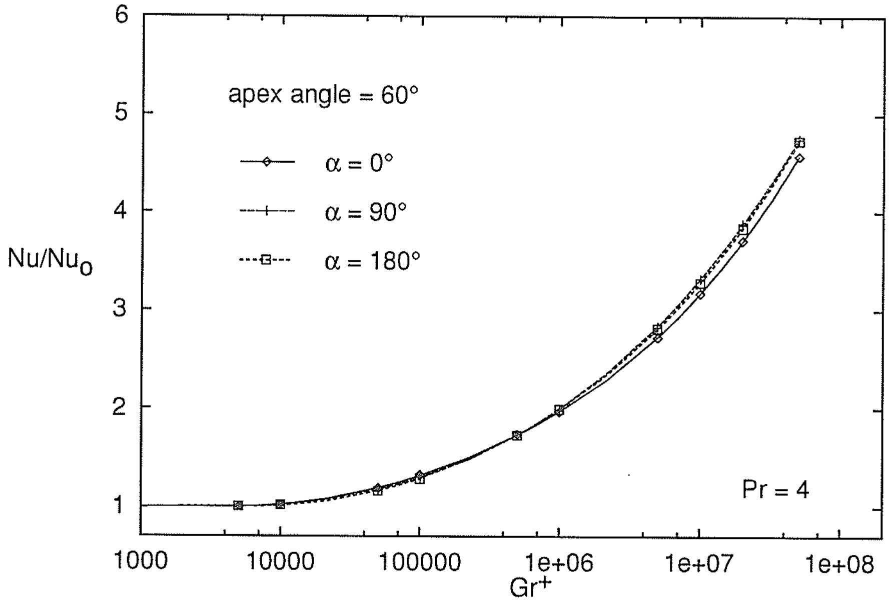
The $Pr = 4$ is for water and therefore the solutions for this Prandtl number should find frequent applications. In addition, the solutions for $Pr = 4$ for the 60°, 90° and 120° ducts were required to complete the data for the study of the whole set of circular sector ducts for which the data for $Pr = 4$ for the semicircular ducts were available already at that time. The Nu and fRe results for all ducts and $\alpha = 0°$, 90° and 180° are compiled in Table 6.1–6.3. In Fig. 6.1(a), (b) and (c) Nu/Nu_o is plotted versus Gr^+.

For the 60° duct, the Nusselt numbers for $\alpha = 90°$ and 180° are almost identical and are larger than those of $\alpha = 0°$. Where $Gr^+ = 2\text{x}10^7$, the difference is 4.7%. In contrast to the 60° duct, the 90° and 120° ducts have the nearly identical Nusselt numbers when $\alpha = 0°$ and 180°, similarly to the semicircular duct. For the 90° and 120° ducts, the 90° orientation shows the maximum Nusselt numbers while the 0° orientation shows the minimum Nusselt numbers for all range of Gr^+. The differences between them are 9% and 14% for the 90° and 120° ducts respectively.

The $fRe/(fRe)_o$ are shown in Fig. 6.2. Similar patterns as for the case of Nusselt number can be observed except that $fRe/(fRe)_o$ for 180° orientation of the 60° duct is somewhat lower than that of $\alpha = 90°$. The differences between the maximum and minimum are 4%, 7%, and 12% at $Gr^+ = 2\text{x}10^7$. For all ducts, the increases of fRe are less than 2 while it is about 5–6 for Nu.

The cross-stream flow patterns are shown for the 90° duct for $\alpha = 0°$, 90°, and 180° for $Gr^+ = 10^5$ are shown in Fig. 6.3. The cross-stream flow comprises two cells similar to the flows in the semicircular duct in Chapter 5. The flow is induced by the rising of the warm fluid near both side walls. The downward stream in the center of the cross section is due to the continuity and the descending of the cooler fluid. All the solutions conform this flow pattern consistently. The isotherms of the fluid are shown in Fig. 6.4 for $Gr^+ = 10^6$ for the same duct with all α. Enclosing the cooler fluid inside, the isotherms emphasize the cool core fluid region surrounded by the warmer fluid. The isotherms also illustrate the descending of the cooler fluid by the dwelling of the low temperature contours in the bottom part of the cross section. The crescent shapes of the top part of the temperature contours reflect the rising of the warm fluid near the side walls and the descending of the cool fluid in the middle.

(a)



(b)

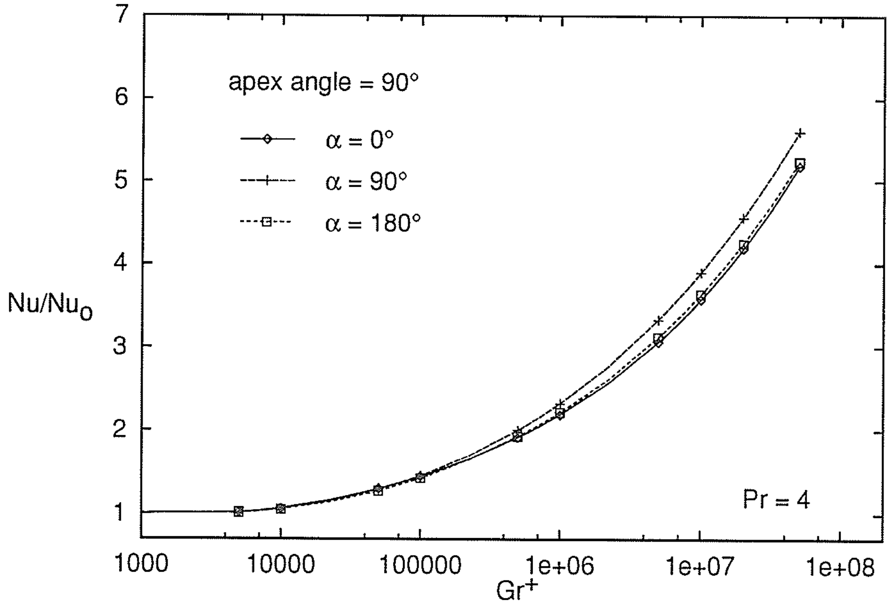


Fig. 6.1 Nusselt number for *Pr* = 4 for the (a) 60°, (b) 90° ducts.

(c)

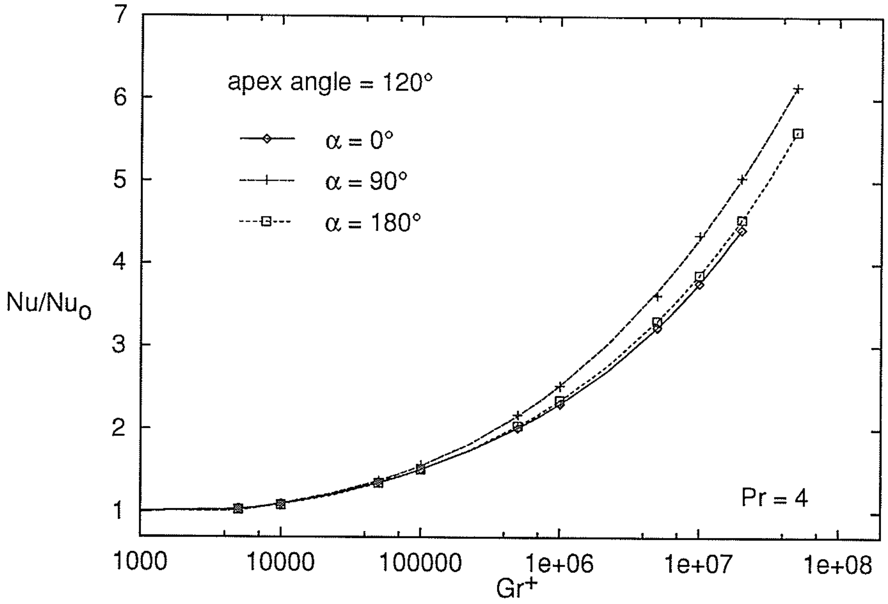


Fig. 6.1(cont) Nusselt number for *Pr* = 4 for the (c) 120° ducts.

(a)

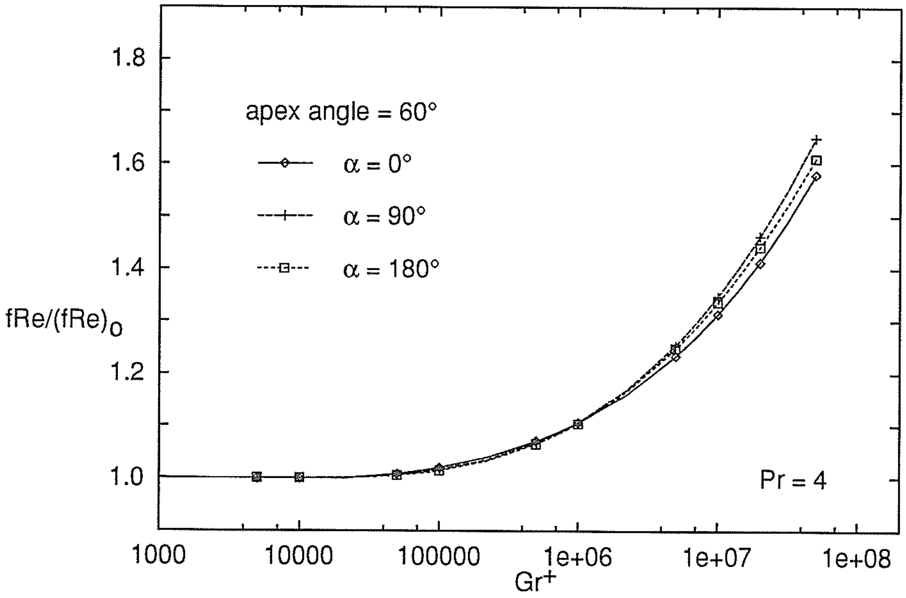
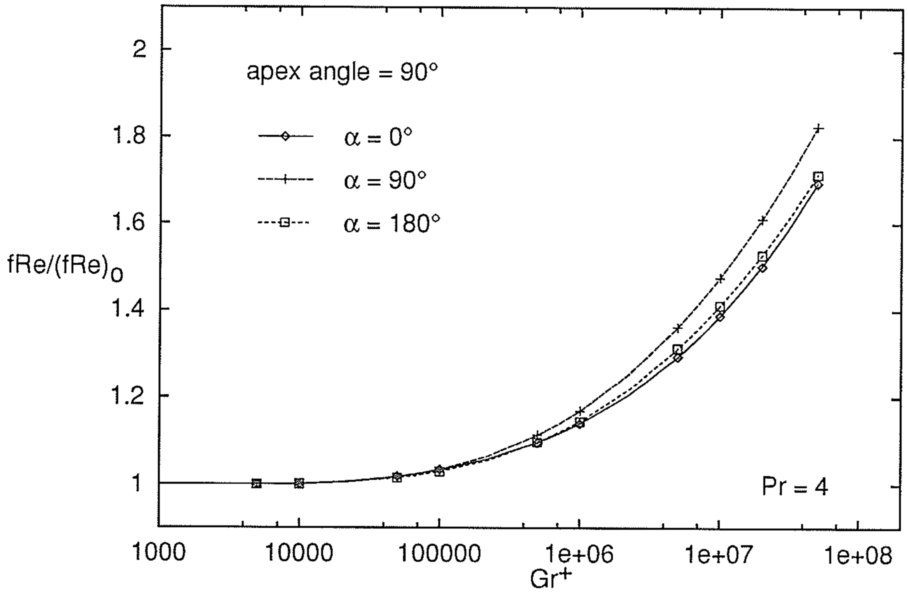


Fig. 6.2 The *fRe* for *Pr* = 4 for the (a) 60° ducts.

(b)



(c)

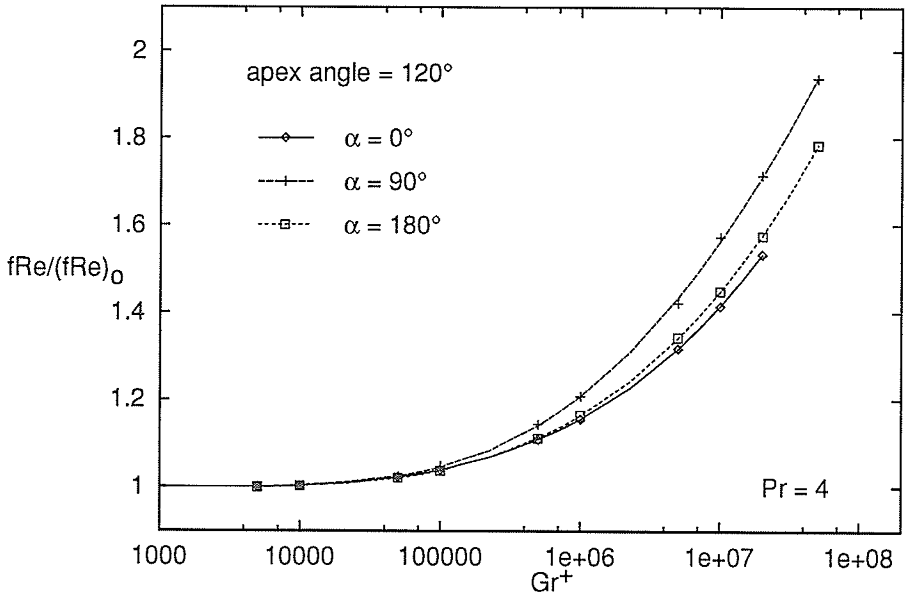
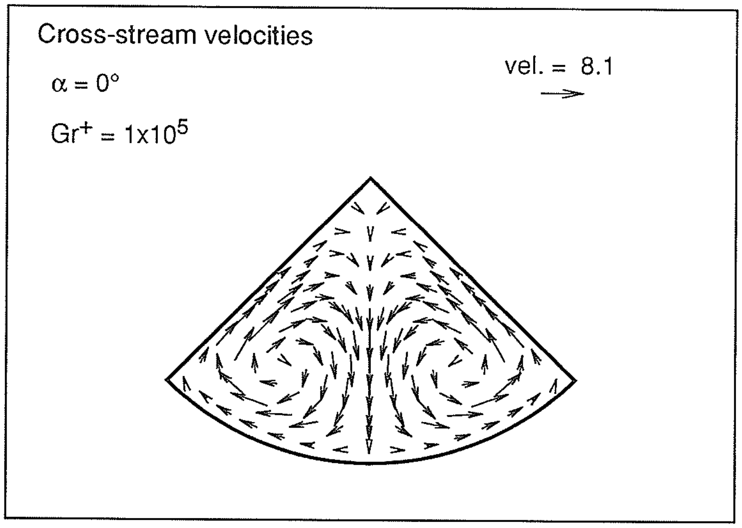


Fig. 6.2(cont) The *fRe* for $Pr = 4$ for the (b) 90°, and (c) 120° ducts.

(a)



(b)

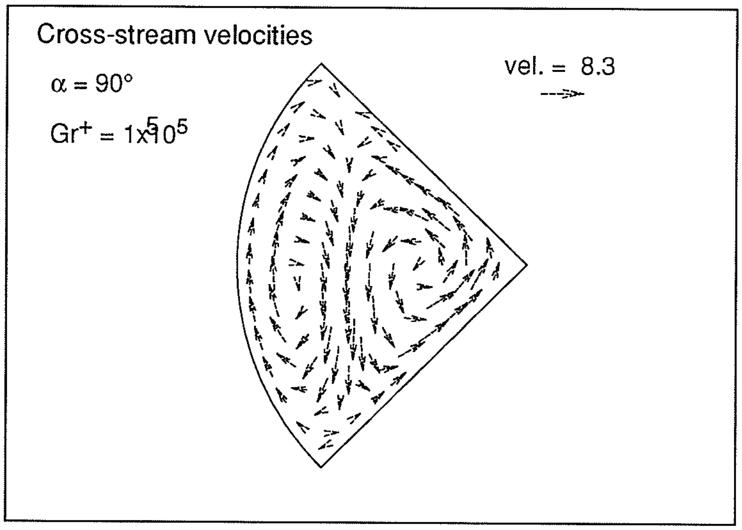


Fig. 6.3 Cross-stream flow patterns for the 90° duct for α = (a) 0°, (b) 90°.

(c)

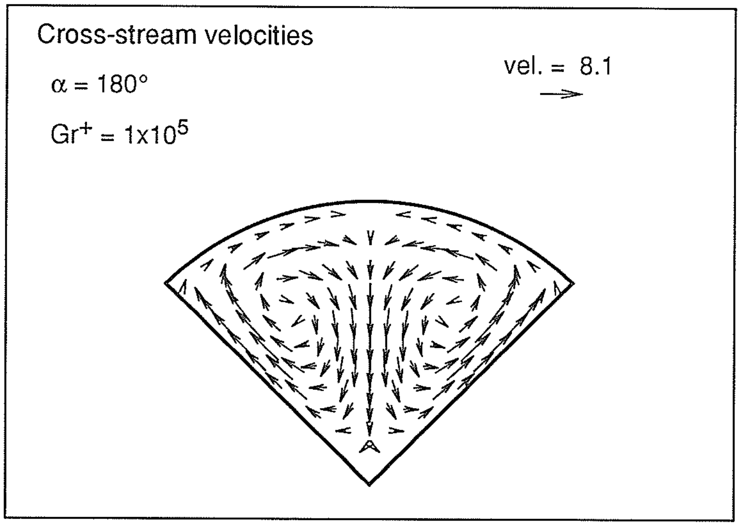


Fig. 6.3(cont) Cross-stream flow patterns for the 90° duct for α = (c) 180°.

(a)

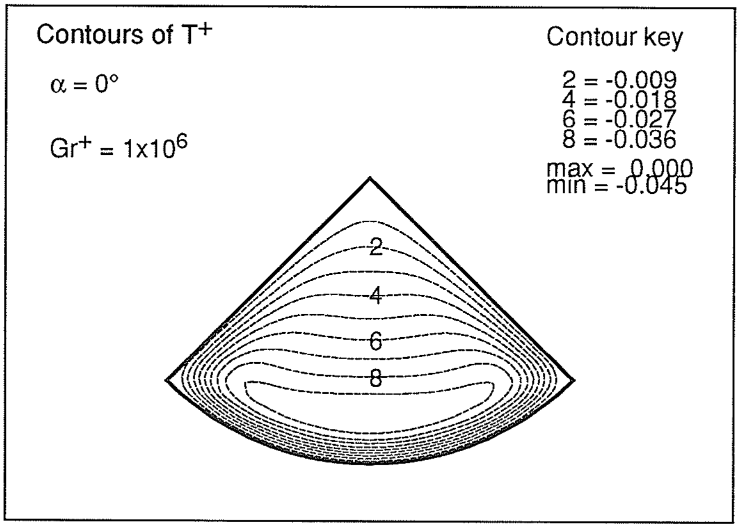
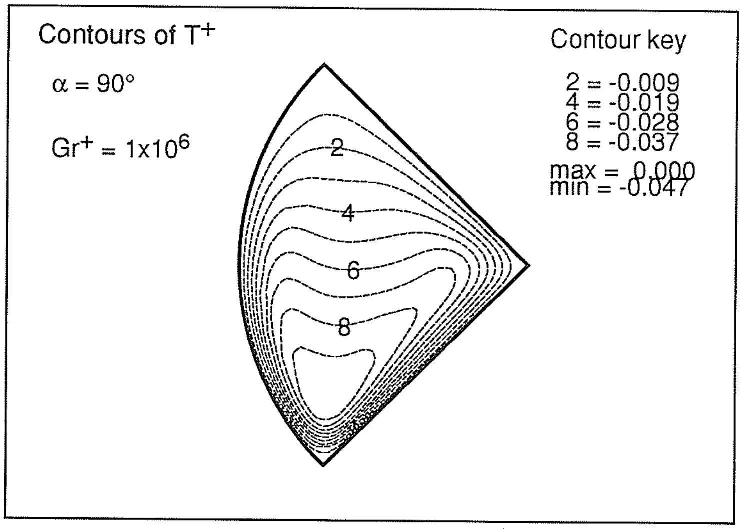


Fig. 6.4 The temperature contours for the 90° duct for α = (a) 0°.

(b)



(c)

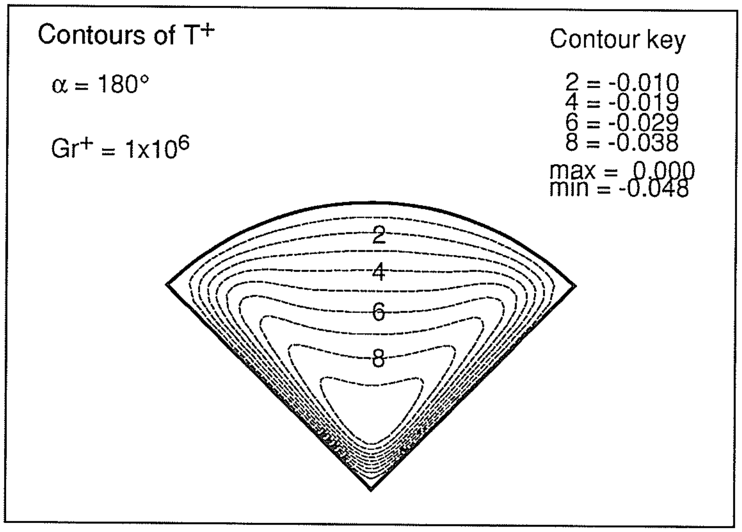


Fig. 6.4(cont) The temperature contours for the 90° duct for α = (a) 90°, (b) 180°.

Buoyancy and orientation effects are of interest in this study. The buoyancy effects are reflected by the magnitudes of the *Nu* and *fRe* ratios, whereas the orientation effects can be observed by comparing these ratios for each α. In other words, the orientation effect exhibits how much difference the buoyancy flow affects the magnitude of *Nu* for each α. Considering the buoyancy effect, the maximum Nusselt number ratios are about 6.3, 6.2, 5.6, and 4.8 at $Gr^+ = 5\text{x}10^7$ for the 180°, 120°, 90°, and 60° ducts respectively whereas the corresponding *fRe* ratios are about 1.8–1.9 for all ducts. The decrease in Nusselt number ratio with decreasing apex angle suggests that the buoyancy effect is more prominent in broader cross sections.

The differences of Nusselt number ratios due to α gradually decreases from about 20% for the semicircular duct to 14%, 9%, and 4.7% for the 120°, 90°, and 60° ducts respectively. The monotonical decrease of these differences in Nusselt numbers also indicates that the combined convection is more effectively affected by the orientation in the broader cross sections. This suggests that the orientation effect should be negligibly small for ducts with apex angle smaller than 60°. In general, cross-stream circulation comprises two cells therefore the duct cross section should be adequately broad to allow the two cells to circulate effectively. A test was conducted using a very narrow duct with apex angle of 10° and the Nu/Nu_o ratio of 1.4 was observed at $Gr^+ = 2\text{x}10^7$ for $Pr = 4$. The Nusselt number ratios are almost the same for all orientations. Therefore the results confirm not only small orientation effect but also small buoyancy effect in very narrow ducts.

Further investigation was conducted using a 30° duct to ensure the above result.

The results for $Pr = 4$ for the 30° duct using a 30x30 mesh are shown in Table 6.4 and Fig. 6.3 for $\alpha = 0°$, 90°, and 180°. The maximum Nusselt number ratio is about 3.4 for $\alpha = 180°$ at $Gr^+ = 5\text{x}10^7$ compared to 6.3, 6.2, 5.6, and 4.8 for the 180° to 60° ducts respectively. Therefore the decrease of buoyancy effect with decreasing apex angle is again confirmed. Concerning the orientation effect, the maximum *Nu* was obtained from $\alpha = 180°$ which is about 10% higher than the others at $Gr^+ = 2\text{x}10^7$. The Nusselt numbers for $\alpha = 0°$ and 90° are similar in magnitudes over the entire range of Gr^+. The orientation effect slightly deviates from the previous observed trend because the effect does not monotonically decrease as the apex angle decrease to smaller than 60°. This will be explained by the so much difference in shapes of the duct cross sections later.

Considering Fig. 6.3, the Nusselt numbers for all α show only little differences until Gr^+ reaches about $5\text{x}10^6$ that the $\alpha = 180°$ surpasses the others for Nusselt number magnitudes. The shifting from the minimum *Nu* to the maximum *Nu* of the 180° orientation actually appears earlier in the 60° duct and the behaviour becomes clear as apex angle decreases to 30°.

The cross-sectional shapes can be roughly classified as broad and narrow shapes for the apex angles larger and smaller than 60° respectively. The narrow cross sections are more like wedge shape and have rather short chord lengths compared to the radius. For the broad cross section ducts, the maximum Nusselt number is always achieved from the 90° orientation where the arc section becomes a side wall. The arc side wall accommodates one of the vortex cells with a rather smooth path for the rising of the warm fluid. The two flat walls on the other side of the duct cross sections accommodate the other cell. This cell is formed by the rising of warm fluid from the lower flat wall to the higher flat wall. The size of the apex angle therefore directly controls the flow pattern of this cell.

For the narrow cross section, observed from the case of apex angle of 30°, the α of 90° is the worst orientation because both the flat walls are rather horizontal and hence there is practically no side wall in the apex vicinity. Flowing along side walls allows the fluid to continuously absorb heat energy and keep rising. For $\alpha = 180°$, the arc top wall provides space for the warm fluid to return to the bottom. The room on the top is important because the flows induced by the side walls need spaces for making turn. The apex at the bottom which does not provide much room for the cool fluid is an additional advantage as discussed earlier in Chapter 5. Since the 0° orientation is the reverse of the 180° orientation, both the advantages for $\alpha = 180°$ become the disadvantages for $\alpha = 0°$. The shapes of the flow domains for the 30° duct drastically change according to the orientation therefore the Nusselt number varied in a lager amount compared to the 60° duct.

Generally, in a sharp apex vicinity, both the axial and cross-sectional fluid velocities are low therefore there is a limit area that allows continuous cross-stream circulation. The awkward increase in Nusselt number magnitude with the increasing Gr^+ indicates the limit buoyancy effect in the narrower duct. For example, the Nusselt number ratios of about 1.3 is reached at Gr^+ about 5×10^5, 1×10^5, 5×10^4, and less than 5×10^4 for the 30° to 180° respectively. Furthermore, the orientation effect is typically smaller in the smaller duct. This can be clearly observed for the 60°–120° in Fig. 6.1.

The orientation effect is large for the 30° duct only at very high Gr^+. At an intermediate Gr^+ value of $5x10^6$, the maximum differences of Nusselt numbers for each orientation are about 5%, 4%, 8%, 11%, and 16% for the 30° to 180° respectively. The 180° orientation for the 30° duct begins to behave differently from other orientations as Gr^+ reaches $5x10^6$. The limit orientation effect in the 30° duct is overcome because the cross-stream current is adequately strong at high heating rates in addition to the exceptional difference in the shapes of the flow areas between α = 180° and the others.

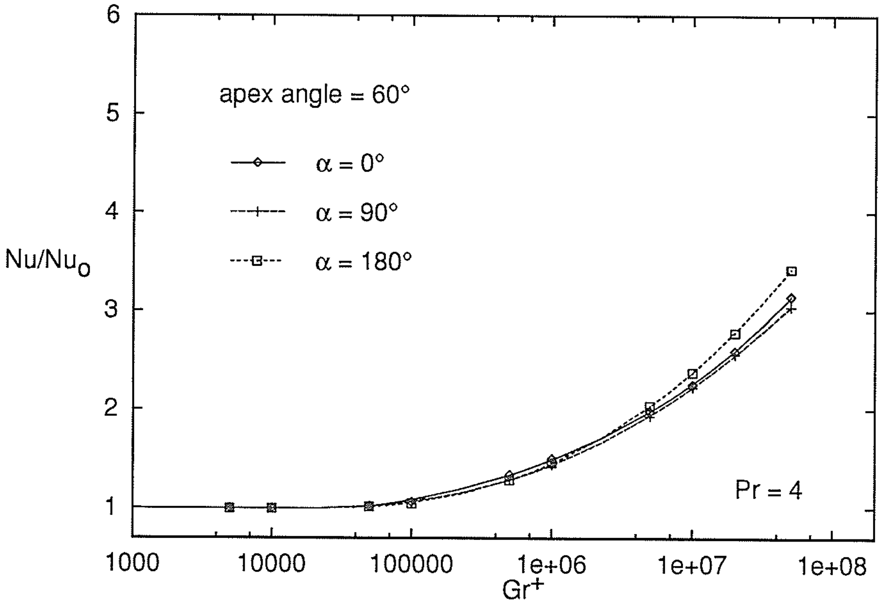


Fig. 6.5 Nusselt number for *Pr* = 4 for the 30° ducts, for α = 0°, 90°, and 180°.

Table 6.4 *Nu* and *fRe* for the 30° duct for $Pr = 4$.

Gr^+	$\alpha = 0°$		$\alpha = 90°$		$\alpha = 180°$	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	13.276	2.997	13.276	2.997	13.276	2.997
$5x10^3$	13.276	2.998	13.276	2.998	13.276	3.000
$1x10^4$	13.277	2.999	13.276	3.000	13.276	3.000
$5x10^4$	13.287	3.059	13.287	3.066	13.282	3.050
$1x10^5$	13.315	3.198	13.310	3.193	13.298	3.153
$5x10^5$	13.599	4.022	13.505	3.874	13.475	3.853
$1x10^6$	13.870	4.512	13.681	4.316	13.677	4.374
$5x10^6$	14.837	5.939	14.463	5.803	14.671	6.124
$1x10^7$	15.435	6.767	15.054	6.681	15.385	7.143
$2x10^7$	16.230	7.794	15.850	7.686	16.299	8.351
$5x10^7$	17.528	9.449	17.225	9.135	17.844	10.289

6.2 Comparisons Among the Circular Sector Ducts

Nusselt numbers for the 60°, 90°, 120° and 180° ducts are shown in Fig. 6.3(a) and (b) for $\alpha = 0°$ and 180°. For a given Gr^+ in both Figs., Nu increases as the apex angle increases. Considering the difference of Nu for a duct compared to the duct of next higher ϕ, the difference is largest for 2ϕ of 30° and 60°. In high Gr^+ region, the difference decreases as the apex angle increases. Small difference for the 120° and 180° ducts, especially at large Gr^+, can be seen for both orientations.

The results show that the narrower duct cross-section yields a smaller Nusselt number. This trend is also true for mixed convection in rectangular ducts and natural convection in rectangular cavities. For mixed convection in rectangular ducts [28], Nusselt number is maximum when the duct aspect ratio of the cross section is 1 and decreases when duct cross-section becomes narrower. The minimum Nusselt number is reached when aspect ratio is zero or infinity.

Since the Nu magnitudes for the 120° and 180° ducts are comparatively the same while the sizes of their cross sections are actually much different, the Nu figure seems to fail in communicating the difference in cross-section in this case. In practice, a better heat transfer performance should lower duct wall temperature toward fluid bulk temperature. The comparison among the ducts with different sizes as in this case can be done by comparing the duct wall temperature drop rather than Nusselt number because it is defined based on the hydraulic diameter which varies according to duct sizes. The

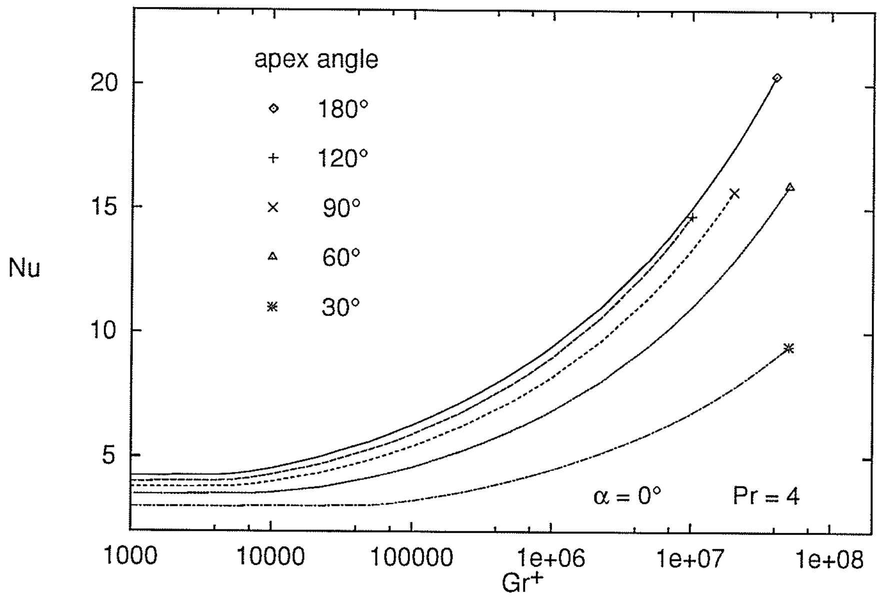
Nusselt number is independent of duct sizes if the eqn. (3.19) is modified as

$$Nu^{+} = -\frac{1}{T_m^{+}} = \frac{S}{D_h} Nu \tag{6.1}$$

where Nu^+ is a modified Nusselt number and S and D_h are duct wet perimeter and hydraulic diameter. The Nu data are transformed to Nu^+ by the ratios D_h/S which are 0.1644, 0.2256, 0.2464, 0.2499 and 0.2377 for the 30° to 180° ducts respectively. For apex angle less than about 110°, the ratio D_h/S decreases monotonically with decreasing apex angle. This makes the ratio D_h/S increase with the decrease of apex angle. The ratio D_h/S approaches zero as the apex angle reaches zero. Since the Nusselt numbers for pure forced convection in circular sector ducts with small apex angles have magnitudes roughly of 2, the magnitudes of Nu^+ become larger than the larger ducts. For the limiting case of zero apex angle, Nu^+ becomes infinity and hence the duct wall temperature is equal to fluid temperature. This is theoretically true because the temperature gradient within the fluid body disappears as the fluid has infinitesimal thickness. For pure forced convection solutions, the magnitudes of Nu^+ decreases as apex angle increases from zero and becomes approximately stable when apex angle is larger than about 60°. The Nu^+ behaviour for small apex angles with pure forced convection condition in which the buoyancy flow is ignored seems to be ambiguous. Therefore the Nu^+ is plotted versus Gr^+ only when the buoyancy effect is significantly large. The Nu^+ is plotted in Fig. 6.6 with the Nusselt number data that are about 10% larger than the corresponding pure forced convection solutions.

In Figs. 6.6(a) and (b), larger differences between the curves for the 120° and 180° ducts can be seen while the spaces between the adjacent curves become uniform. The Nu^+ of the 180° duct compared to the 60° duct is about 28% higher for $\alpha = 0°$ at $Gr^+ = 10^7$, and about 29% higher for $\alpha = 180°$ at $Gr^+ = 10^6$. Since Gr^+ is defined using the duct radius which is the same for all the ducts, it represents the heat input regardless the duct size. Therefore those figures suggest that for a given heat input and the same fluid conditions, the wall temperature of the 180° duct will be about 30% lower than the 60° duct. Based on the 30° duct, at $Gr^+ = 10^7$, the differences of Nu^+ are about 19%, 32%, 43%, and 54% for the 60° to 180° respectively.

(a)



(b)

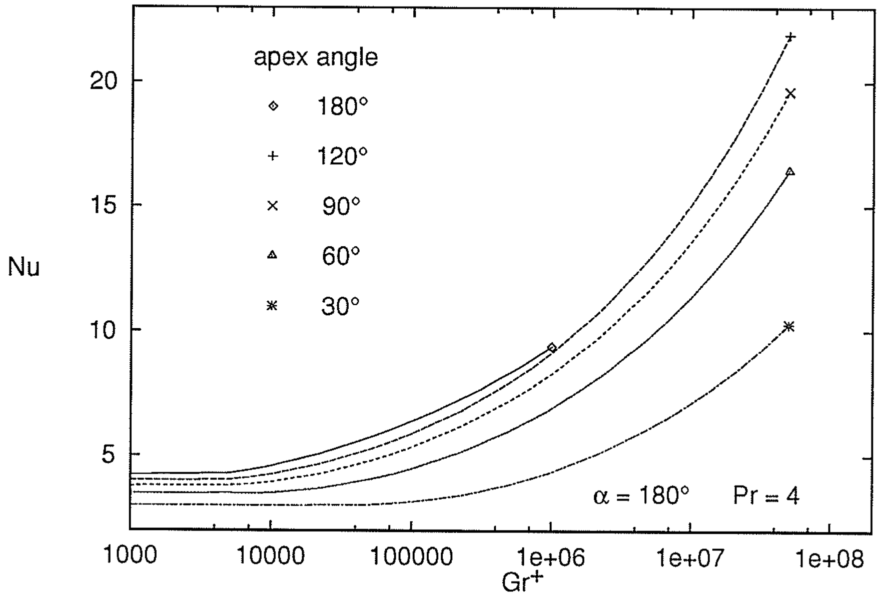


Fig. 6.6 *Nu* for circular sector ducts, apex angle 30°–180°, α = (a) 0°, and (b) 180°.

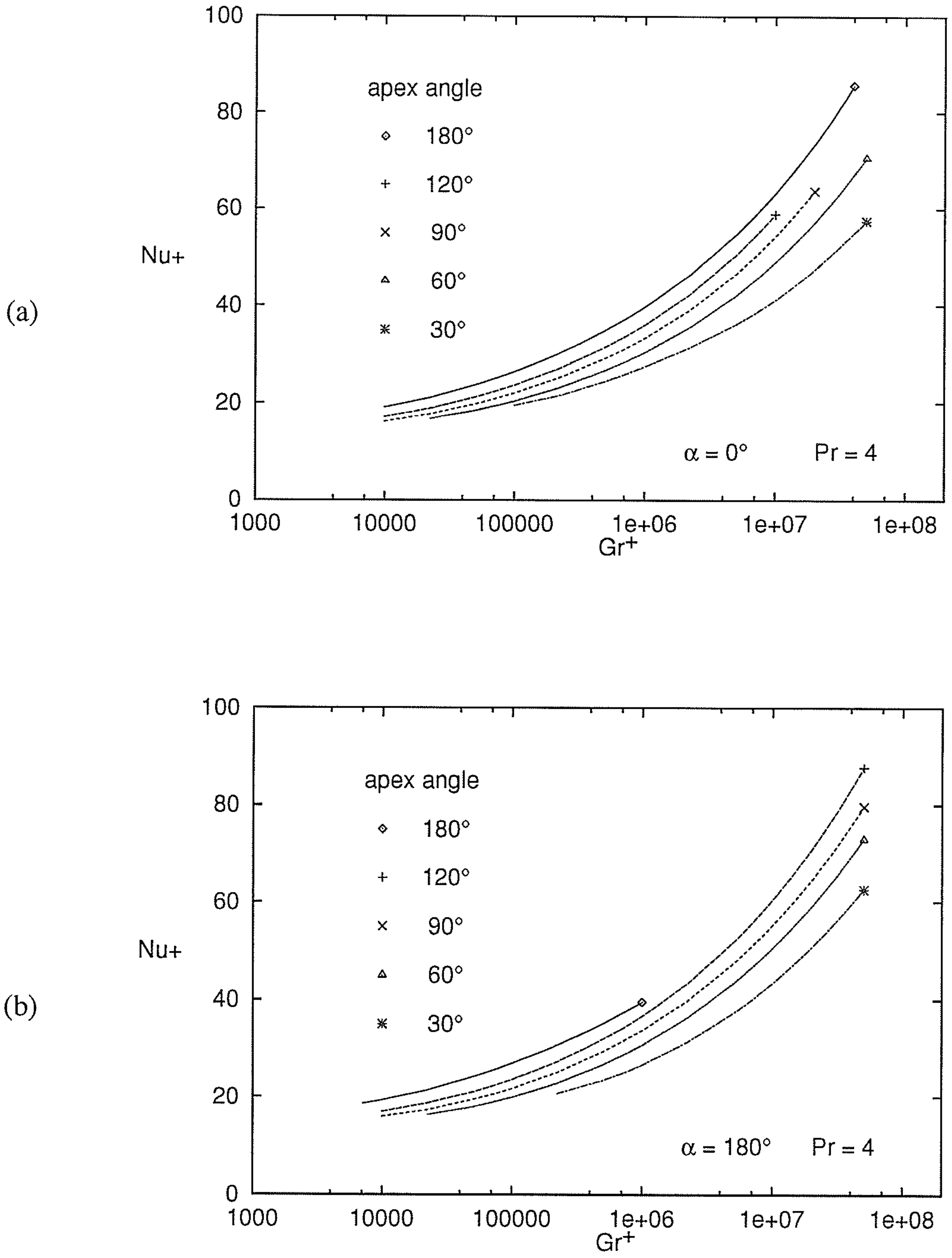


Fig. 6.7 Nu^{+} for circular sector ducts, apex angle 30°–180°, α = (a) 0°, and (b) 180°.

Table 6.5 Nu and fRe for the 60° duct with $Pr = 10$.

Gr^+	$\alpha = 0°$		$\alpha = 90°$		$\alpha = 180°$	
	fRe	Nu	fRe	Nu	fRe	Nu
0	14.134	3.476	14.134	3.476	14.134	3.476
5x10^{3}	14.137	3.581	14.137	3.575	14.136	3.567
1x10^{4}	14.144	3.782	14.142	3.759	14.141	3.731
5x10^{4}	14.205	4.784	14.195	4.713	14.187	4.643
1x10^{5}	14.266	5.372	14.250	5.308	14.240	5.252
5x10^{5}	14.542	7.192	14.534	7.261	14.530	7.233
1x10^{6}	14.755	8.267	14.770	8.428	14.768	8.381
2x10^{6}	15.055	9.583	15.108	9.840	15.099	9.748
5x10^{6}	15.625	11.766	15.757	12.135	15.709	11.962
1x10^{7}	16.232	13.804	16.437	14.204	16.315	14.019
2x10^{7}	17.048	16.181	17.317	16.531	17.059	16.476
5x10^{7}	18.546	19.780	18.877	19.890	–	–

Table 6.6 Nu and fRe for the 90° duct with $Pr = 10$.

Gr^+	$\alpha = 0°$		$\alpha = 90°$		$\alpha = 180°$	
	fRe	Nu	fRe	Nu	fRe	Nu
0	14.747	3.739	14.747	3.739	14.747	3.739
5x10^{3}	14.756	4.049	14.754	4.012	14.754	4.015
1x10^{4}	14.770	4.403	14.767	4.359	14.766	4.335
5x10^{4}	14.864	5.654	14.871	5.705	14.850	5.563
1x10^{5}	14.945	6.369	14.974	6.514	14.931	6.311
5x10^{5}	15.306	8.644	15.468	9.121	15.318	8.697
1x10^{6}	15.576	9.982	15.840	10.639	15.612	10.067
2x10^{6}	15.943	11.598	16.345	12.454	16.008	11.700
5x10^{6}	16.621	14.271	17.249	15.380	16.715	14.360
1x10^{7}	17.325	16.774	18.129	18.022	17.322	16.838
2x10^{7}	18.260	19.724	19.207	21.049	18.260	19.788

Table 6.7 *Nu* and *fRe* for the 120° duct with $Pr = 10$.

Gr^+	α = 0°		α = 90°		α = 180°	
	fRe	***Nu***	***fRe***	***Nu***	***fRe***	***Nu***
0	15.177	3.903	15.177	3.903	15.177	3.903
5x10^3	15.191	4.371	15.189	4.320	15.189	4.348
1x10^4	15.210	4.781	15.208	4.760	15.206	4.746
5x10^4	15.318	6.149	15.357	6.384	15.311	6.134
1x10^5	15.409	6.943	15.501	7.336	15.405	6.966
5x10^5	15.808	9.475	16.143	10.338	15.838	9.624
1x10^6	16.095	10.949	16.603	12.072	16.162	11.166
2x10^6	16.476	12.722	17.209	14.134	16.598	13.024
5x10^6	17.155	15.640	18.259	17.436	17.388	16.076
7x10^6	17.473	16.917	18.721	18.832	17.751	17.393
1x10^7	17.854	18.392	19.259	20.430	18.188	18.911
2x10^7	–	–	20.462	23.891	19.223	22.233

Table 6.8 *Nu* and *fRe* for the 60° duct with $Pr = 50$.

Gr^+	α = 0°		α = 90°		α = 180°	
	fRe	Nu	fRe	Nu	fRe	Nu
0	14.134	3.476	14.134	3.476	14.134	3.476
5x10^3	14.136	4.286	14.135	4.229	14.135	4.163
1x10^4	14.137	4.797	14.137	4.723	14.136	4.647
5x10^4	14.147	6.357	14.145	6.329	14.144	6.285
1x10^5	14.155	7.258	14.153	7.290	14.152	7.250
5x10^5	14.193	10.211	14.193	10.397	14.192	10.285
1x10^6	14.224	11.971	14.227	12.198	14.224	12.035
2x10^6	14.273	14.082	14.277	14.297	14.271	14.137
5x10^6	14.383	17.406	14.386	17.472	14.361	17.576
1x10^7	14.526	20.241	14.518	20.078	14.459	20.752
2x10^7	14.754	23.191	–	–	–	–

Table 6.9 *Nu* and *fRe* for the 90° duct with $Pr = 50$.

Gr^+	$\alpha = 0°$		$\alpha = 90°$		$\alpha = 180°$	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	14.747	3.739	14.747	3.739	14.747	3.739
5x10^3	14.749	5.063	14.749	5.051	14.749	4.962
1x10^4	14.752	5.675	14.752	5.722	14.751	5.576
5x10^4	14.764	7.595	14.768	7.890	14.762	7.573
1x10^5	14.774	8.724	14.783	9.163	14.773	8.734
5x10^5	14.821	12.362	14.853	13.190	14.821	12.387
1x10^6	14.858	14.511	14.910	15.492	14.858	14.510
2x10^6	14.913	17.100	14.990	18.180	14.910	17.071
5x10^6	15.034	21.216	15.149	22.349	15.010	21.234
7x10^6	15.099	22.892	15.228	24.046	15.060	22.999
1x10^7	–	–	15.329	25.920	–	–

Table 6.10 *Nu* and *fRe* for the 120° duct with $Pr = 50$.

Gr^+	$\alpha = 0°$		$\alpha = 90°$		$\alpha = 180°$	
	fRe	*Nu*	*fRe*	*Nu*	*fRe*	*Nu*
0	15.177	3.903	15.177	3.903	15.177	3.903
5x10^3	15.180	5.502	15.180	5.599	15.179	5.465
1x10^4	15.183	6.172	15.185	6.404	15.182	6.153
5x10^4	15.196	8.305	15.208	8.931	15.195	8.383
1x10^5	15.207	9.552	15.228	10.395	15.207	9.687
5x10^5	15.254	13.532	15.324	14.986	15.260	13.863
1x10^6	15.289	15.871	15.398	17.589	15.302	16.317
2x10^6	15.339	18.711	15.502	20.643	15.364	19.250
5x10^6	–	–	15.702	25.438	15.495	23.882
7x10^6	–	–	15.799	27.404	15.565	25.782
1x10^7	–	–	15.921	29.586	15.660	27.892

6.3 Results for Pr = 10 and 50

The *Nu* and *fRe* results according to oriented angles of 0°, 90° and 180° are in Table 6.5–6.7 for Pr = 10 and Table 6.8–6.10 for Pr = 50, for the 60°, 90° and 120° ducts. The results for all the ducts are also shown in Fig. 6.8 for Pr = 10 and Fig. 6.9 for Pr = 50. For each duct, the differences between the maximum and minimum Nusselt numbers decreases with the increase of Pr as can be seen by the closer spaces of the curves in Fig. 6.8 comparing to Fig 6.1 (same vertical scales, except for the 60° duct). This agrees with the discussion in the second last paragraph of Section 6.1; the more viscous fluid reduces the flexibility for the modification of the cross-stream flow by the duct orientation. Therefore the magnitude of the Nusselt number swings within a narrower range. The differences between the maximum and minimum Nusselt numbers for Pr = 50 are 2%, 6.5% and 10% at $Gr^+ = 2\text{x}10^6$ for the 60°, 90° and 120° ducts. For Pr = 10, the results are 3%, 7% and 11% for the same conditions.

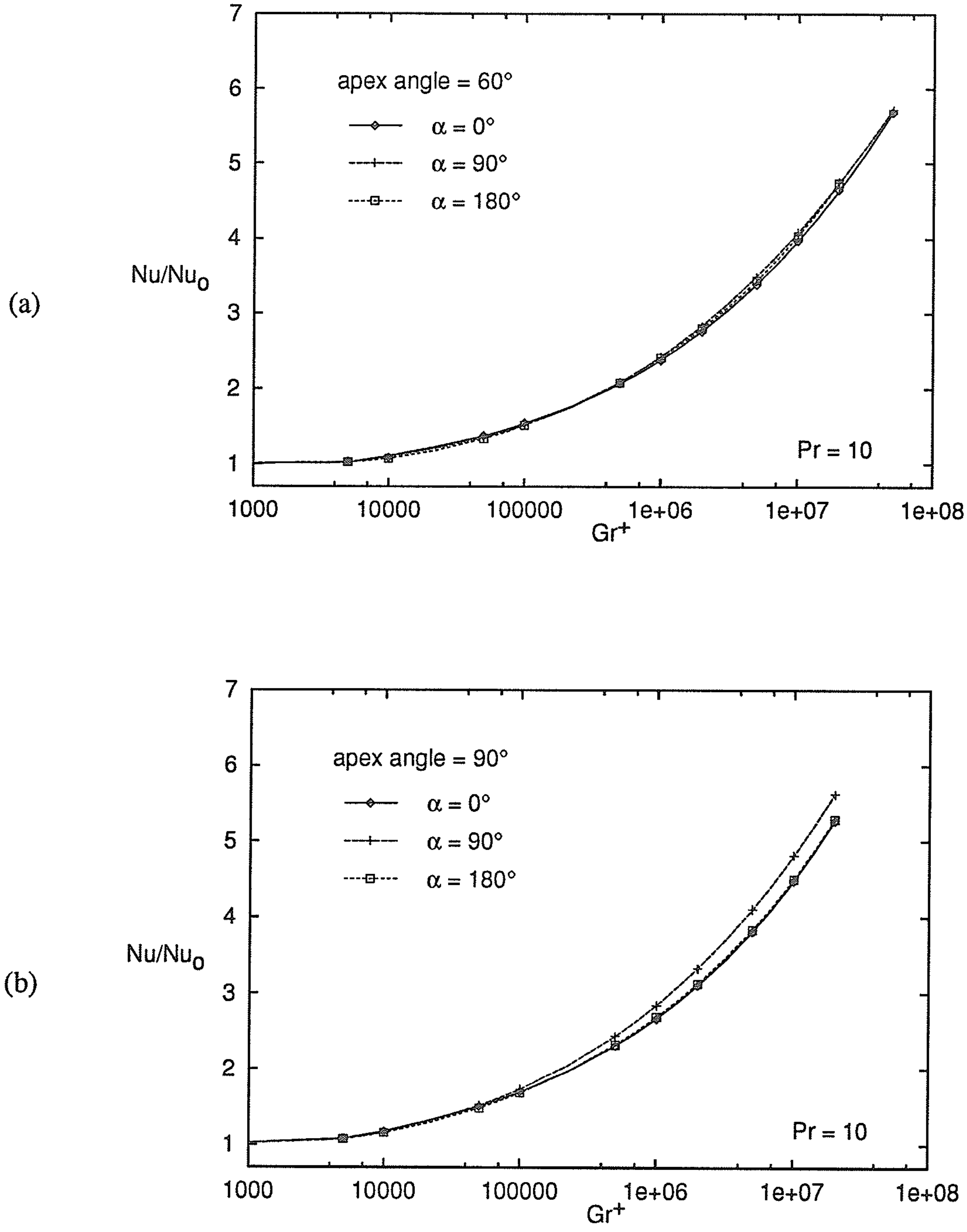


Fig. 6.8 *Nu* ratios for $Pr = 10$, apex angle of (a) 60°, (b) 90°.

(c)

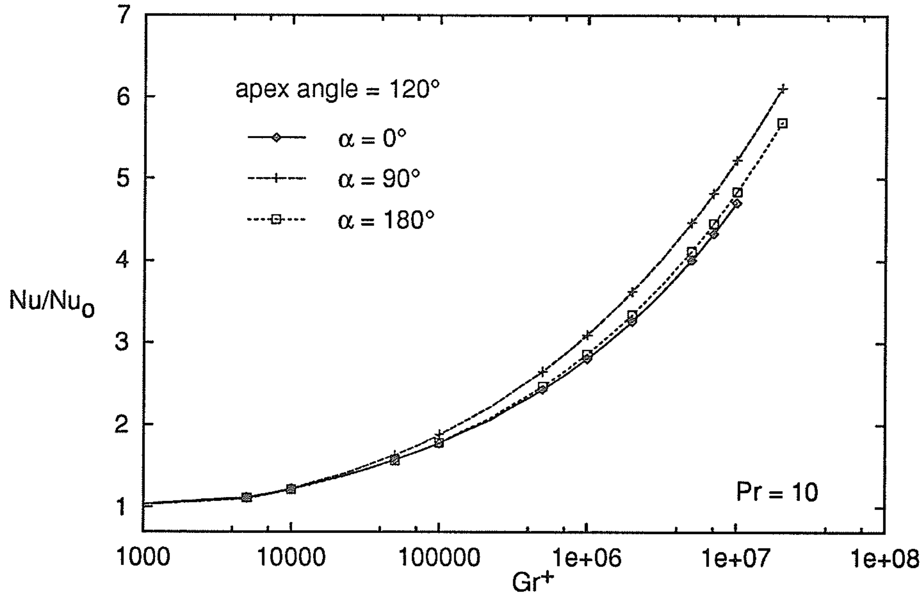


Fig. 6.8(cont) *Nu* ratios for *Pr* = 10, apex angle of (c) 120°.

(a)

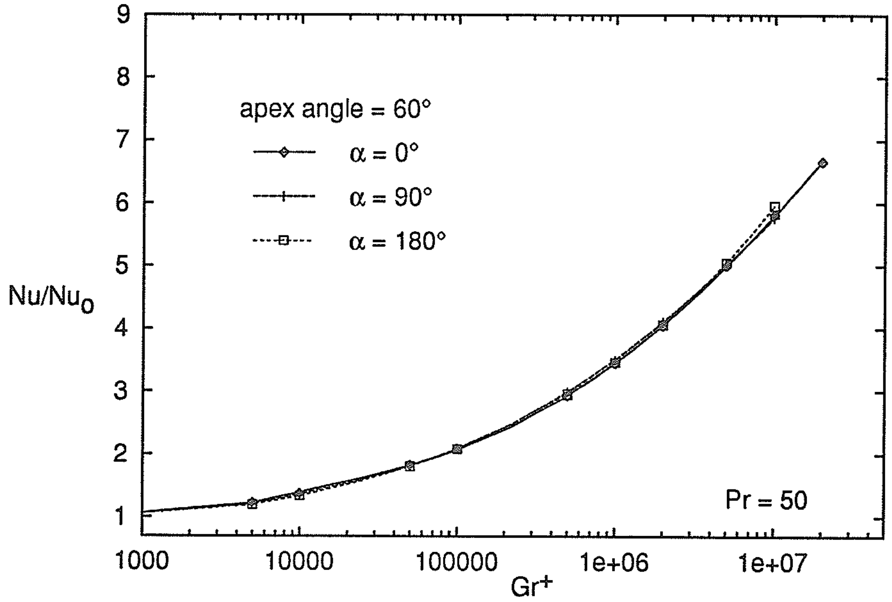
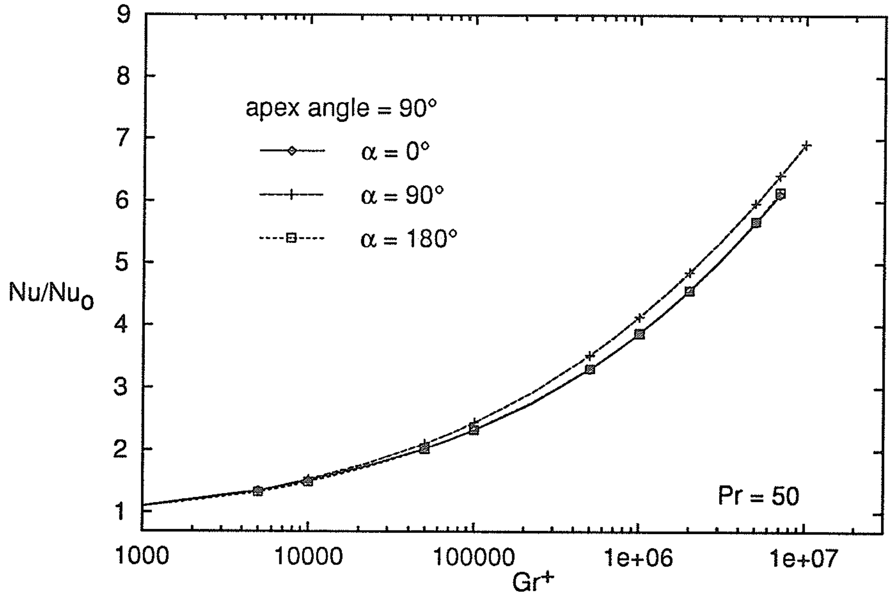


Fig. 6.9 *Nu* ratios for *Pr* = 50, apex angle of (a) 60°.

(b)



(c)

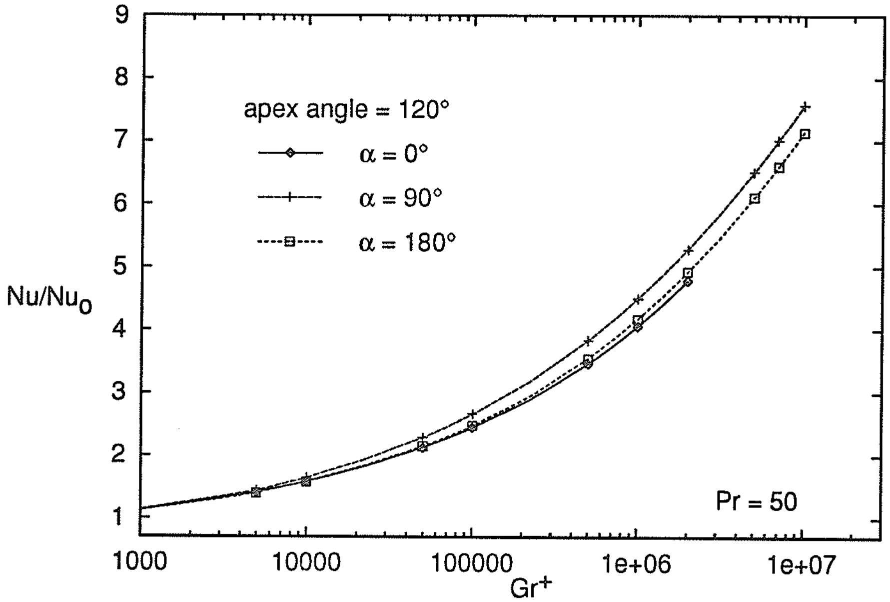


Fig. 6.9(cont) *Nu* ratios for *Pr* = 50, apex angle of (b) 90°, and (c) 120°.

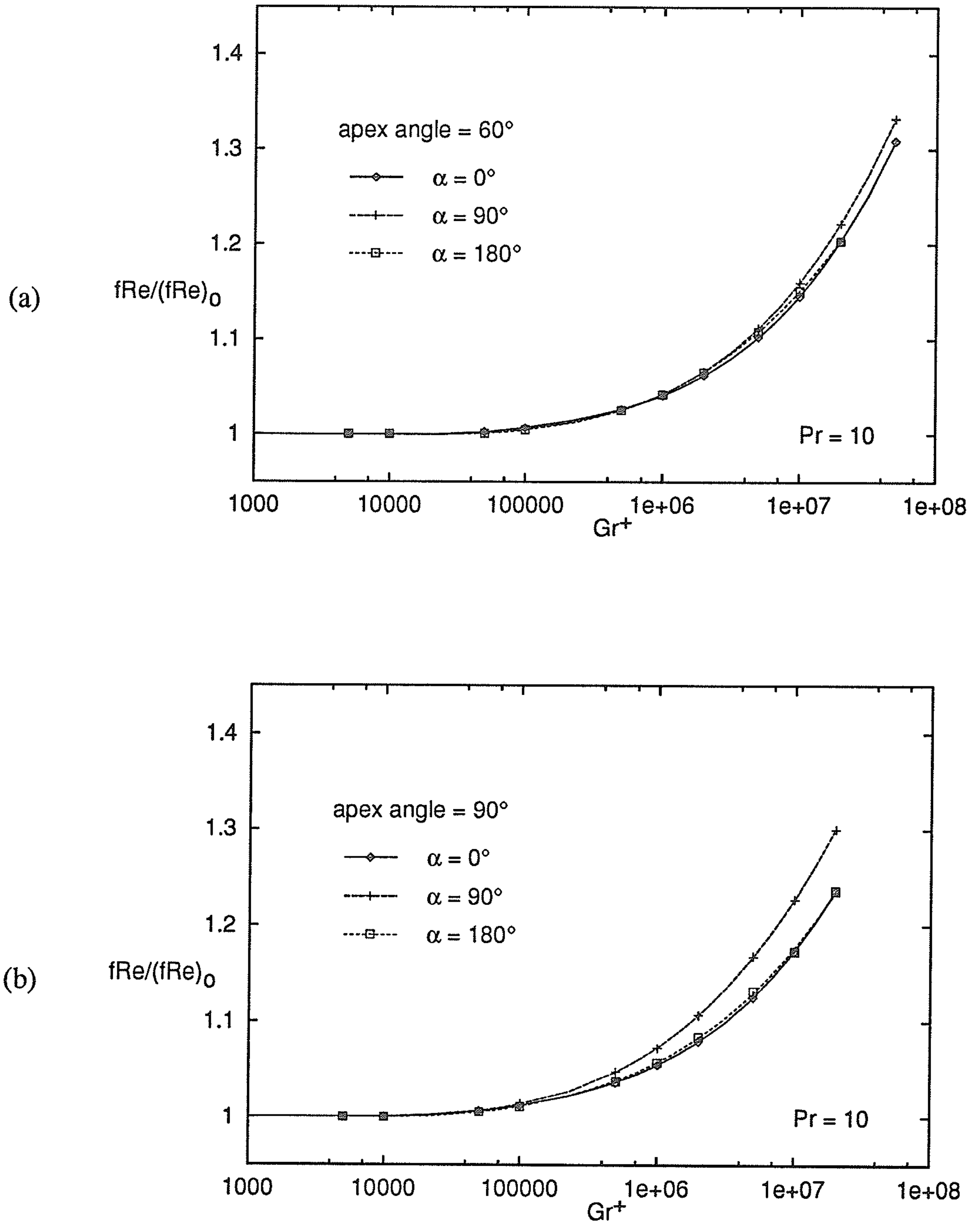


Fig. 6.10 *fRe* ratios for Pr = 10, apex angle of (a) 60°, (b) 90°.

(c)

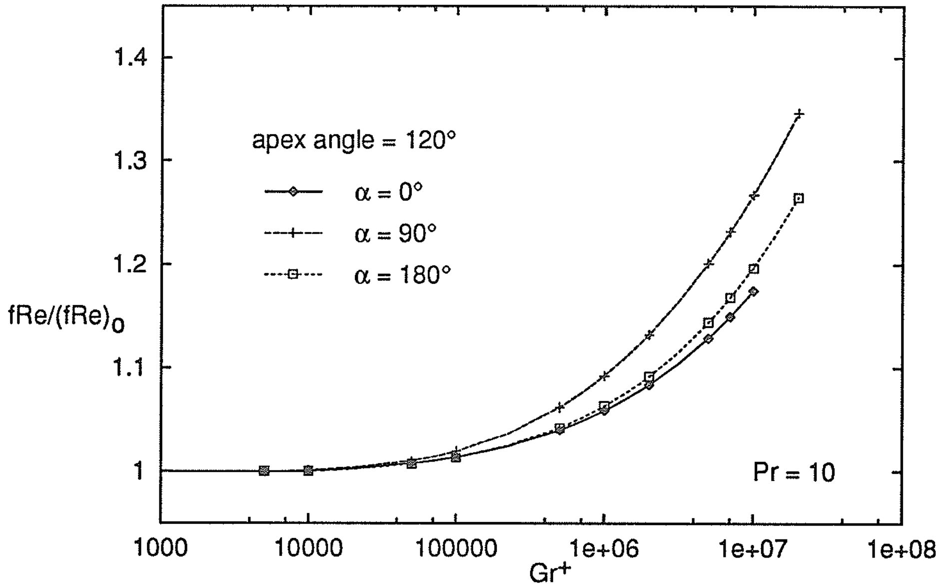


Fig. 6.10 *fRe*(cont) ratios for *Pr* = 10, apex angle of (c) 120°.

(a)

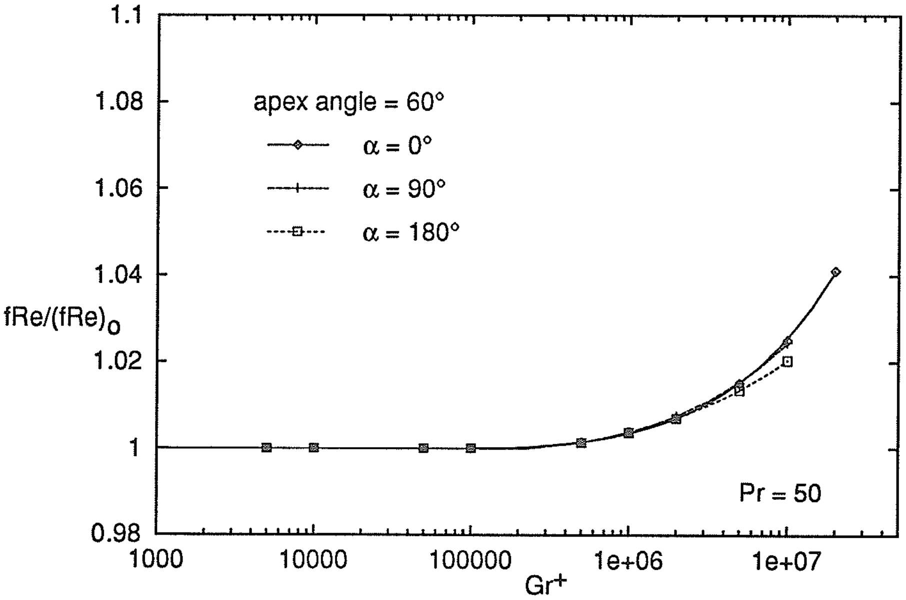
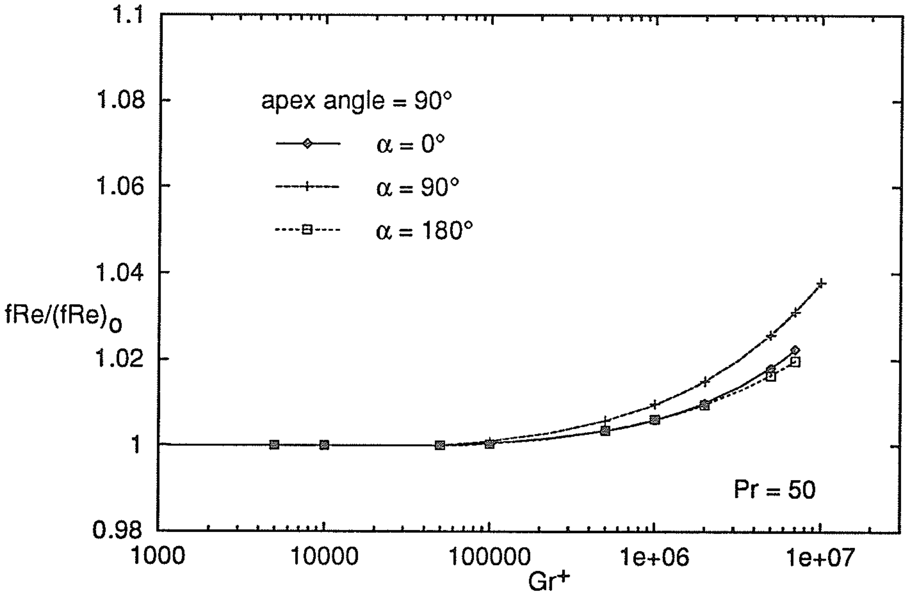


Fig. 6.11 *fRe* ratios for *Pr* = 50, apex angle of (a) 60°.

(b)



(c)

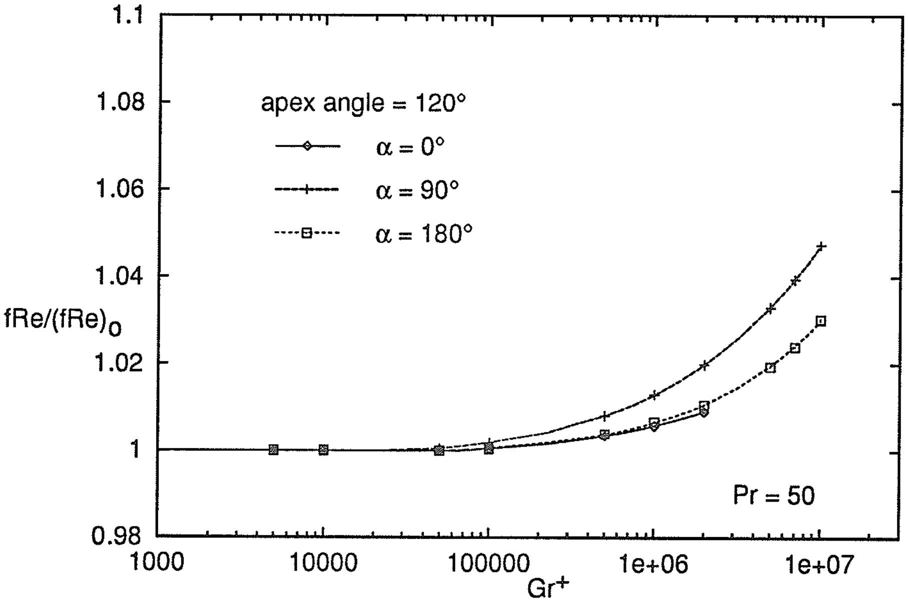


Fig. 6.11 *fRe*(cont) ratios for $Pr = 50$, apex angle of (b) 90°, and (c) 120°.

The $fRe/(fRe)_o$ results for $Pr = 10$ are shown in Fig. 6.10. The increases of fRe are less than the case of $Pr = 4$. For each duct, the maximum and minimum fRe magnitudes are similar to the case of Nusselt number. The maximum difference about 10% can be expected for 120°, however, the fRe of each orientation does not depart much from the $(fRe)_o$. The fRe ratios are about 1.3 at the highest Gr^+. The results for $Pr = 50$ are shown in Fig. 6.11 where the ratios drop to very close to 1 for all ducts. This is similar to the case of semicircular duct which the discussion is in Chapter 5.

6.4 Effect of Prandtl number

The effect of Prandtl number was studied by analyzing the data of $Pr = 4$, 10 and 50. The results for each Pr form a curve on the Nu–Gr^+ plane in the manner that the Nu increases with increasing Pr, e.g. see Fig. 6.12 which is for the 90° duct with $\alpha = 90°$. It has been shown in Section 5.7 that the effect of Pr disappears because the relation Nu–Gr^+Pr is unique. Similar results are observed for the circular sector ducts.

For the 60° duct, the results for all Pr agree very well on the Nu/Nu_o–Gr^+Pr domain. In fact, since Nu varies little with orientation, the results for all orientations and all Pr are plotted in Fig. 6.13 where good agreement can be observed. The Nu/Nu_o–Gr^+Pr relationships in the polynomial form in eqn. 5.1 are presented in Table 6.11 for each orientation separately.

Table 6.11 Coefficients for Nu/Nu_o, eqn. 5.1.

α	Coefficients for 60° duct						
	C_0	C_1	C_2	C_3	C_4	σ	σ_{max}
0°	0.37236269E+1	−0.20716423E+1	0.58588767E+0	−0.79943322E−1	0.49456048E−2	0.00747884	0.10591053
90°	−0.27697589E+1	0.26881159E+1	−0.68895915E+0	0.67425445E−1	−0.12404672E−2	0.00292518	0.04325832
180°	0.17992351E+2	−0.11241168E+2	0.27579254E+1	−0.30567945E+0	0.13667410E−1	0.00248089	0.03503270
For 90° duct							
0°	0.15289681E+2	−0.10175859E+2	0.26737537E+1	−0.31444993E+0	0.14765026E−1	0.00734008	0.11647754
90°	0.59300236E+1	−0.33966246E+1	0.86639363E+0	−0.10562562E+0	0.60286309E−2	0.00286737	0.04114399
180°	0.18895444E+2	−0.12286956E+2	0.31168500E+1	−0.35406167E+0	0.16043163E−1	0.00484728	0.08386671
For 120° duct							
0°	0.14214511E+2	−0.95934025E+1	0.25671693E+1	−0.30715689E+0	0.14703312E−1	0.00518323	0.06363539
90°	0.60423861E+1	−0.36042099E+1	0.94463333E+0	−0.11661205E+0	0.66659136E−2	0.00437286	0.07939668
180°	0.13118928E+2	−0.86365364E+1	0.22744789E+1	−0.26997421E+0	0.13056594E−1	0.00669726	0.11606544

The results for the 90° and 120° ducts are shown in Figs. 6.14 and 6.15. In Figs. 6.13(a) and 6.14(a), the plots are for both $\alpha = 0°$ and 180° due to their similarities in magnitudes and for $\alpha = 90°$ in Figs. 6.13(b) and 6.14(b). The three curves in Fig. 6.12 collapse and only a single curve represents the Nu–Gr^+Pr relation for all Pr data in Fig. 6.14(b). In general, very good agreements between the data for each Prandtl number can be seen in these Figures. The coefficients for Nu/Nu_o–Gr^+Pr relations are also compiled in Table 6.11 for each orientation. The results again confirm the unique Nusselt number distribution on the Gr^+Pr abscissa which is a very useful achievement for combined convection study. In addition, the Nusselt numbers for $\alpha = 90°$ are higher than the case of $\alpha = 0°$ and 180° for both the ducts. The figures of these differences are not so much different from those mentioned in Section 6.1 and 6.3.

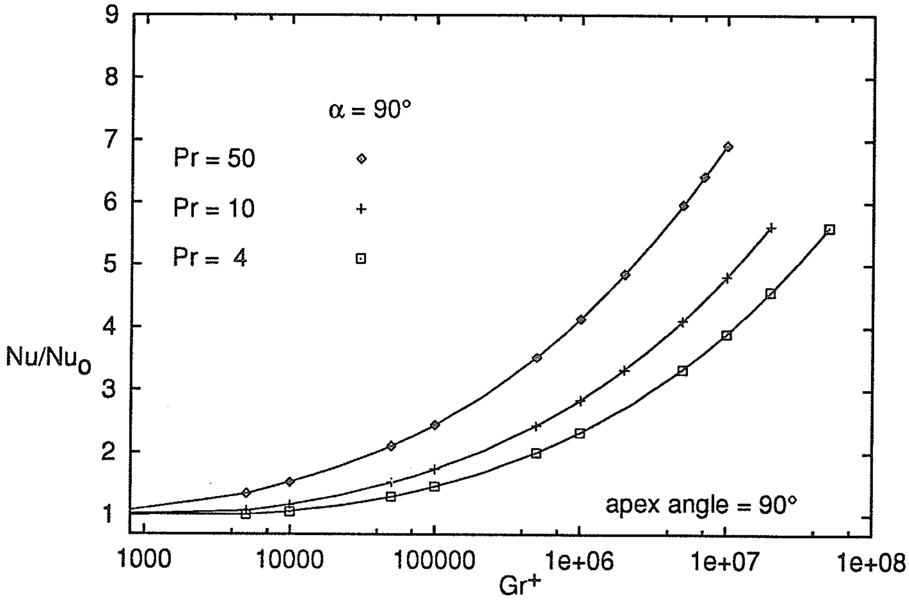


Fig. 6.12 Nu ratios for the 90° duct, $\alpha = 90°$, and all Pr.

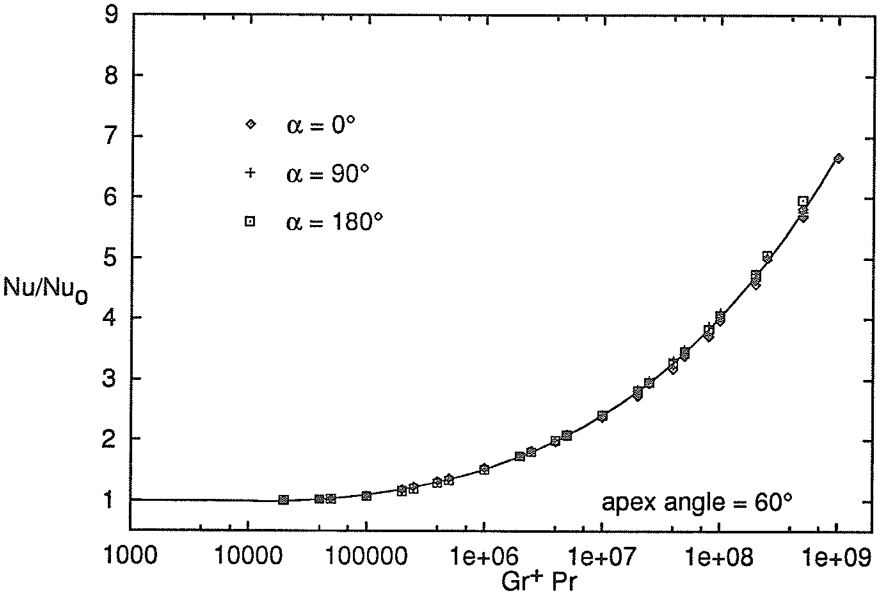


Fig. 6.13 *Nu* ratios, all *Pr* and all α, for the 60° duct.

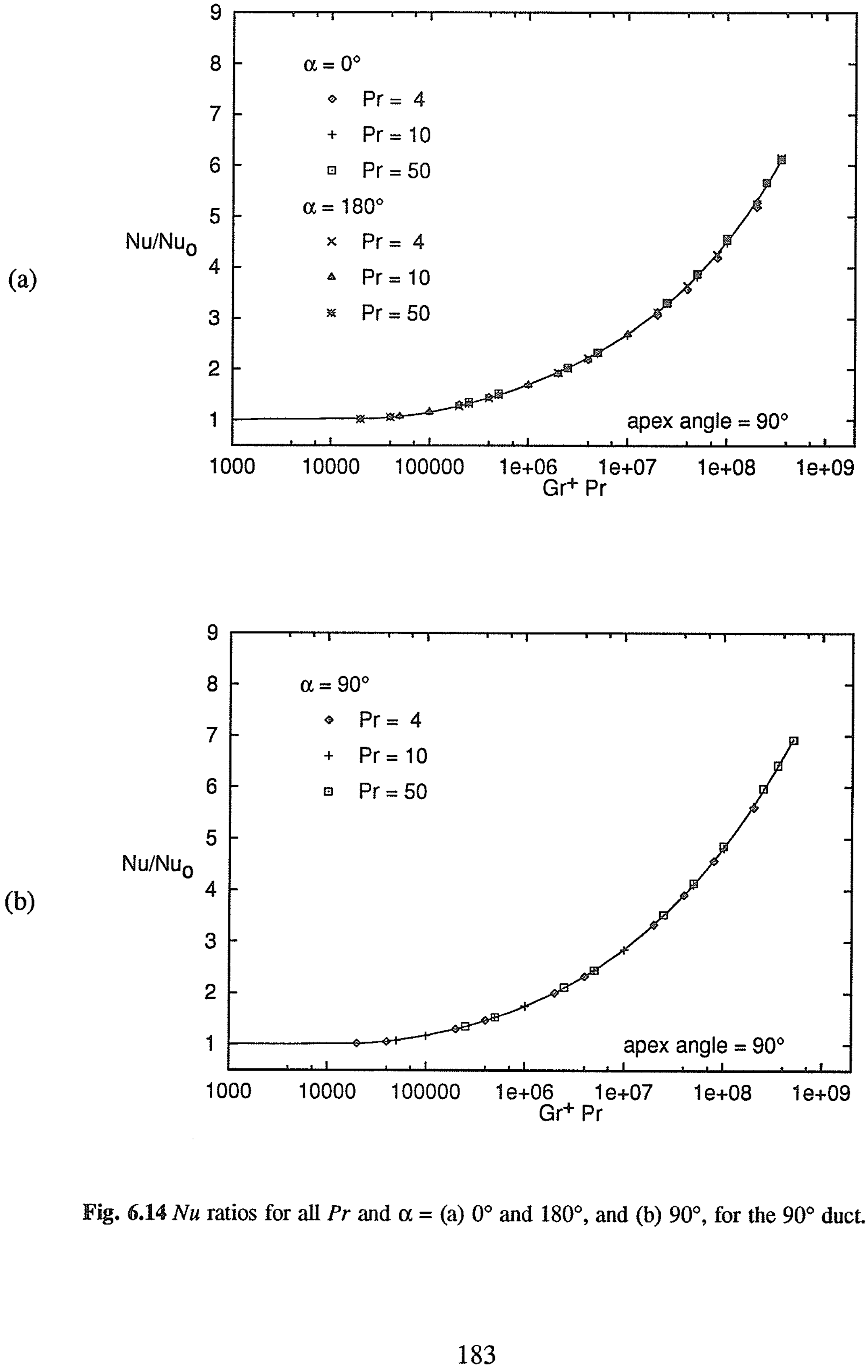
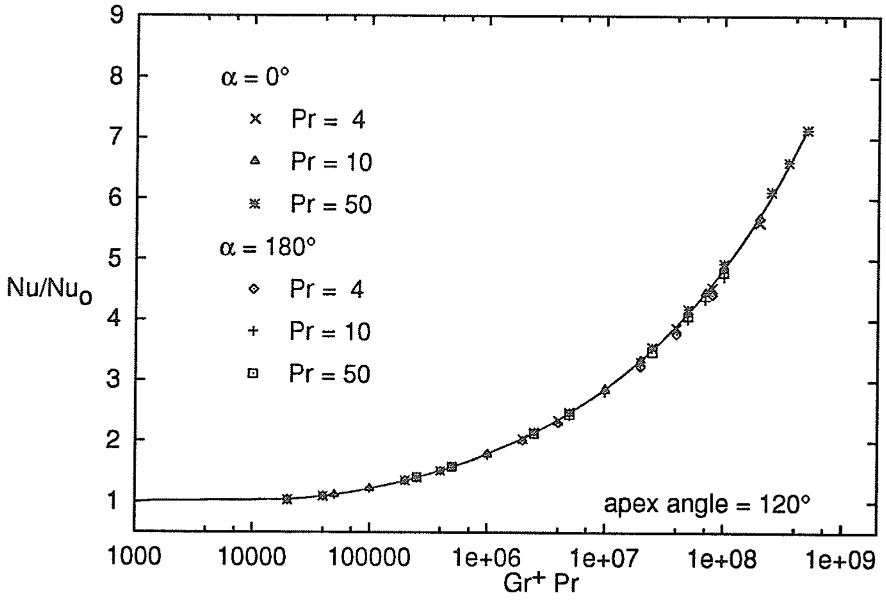


Fig. 6.14 *Nu* ratios for all *Pr* and α = (a) 0° and 180°, and (b) 90°, for the 90° duct.

(a)



(b)

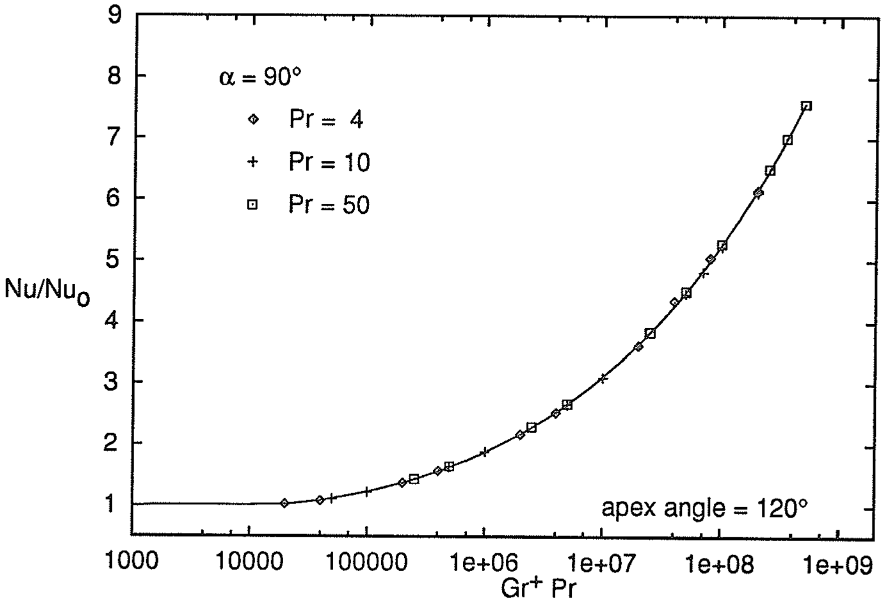


Fig. 6.15 *Nu* ratios for all *Pr* and α = (a) 0° and 180°, and (b) 90°, for the 120° duct.

The effect of Prandtl number on *fRe* for the 60°, 90° and 120° ducts are studied similarly to the case of the semicircular duct in Chapter 5 that the Prandtl number effect can be eliminated if *fRe* is plotted against Gr^+/Pr^2. The $fRe/(fRe)_o$ for the 60° duct is shown in Fig. 6.16 where the data for all α and all Pr are plotted against Gr^+/Pr^2. The separations of the data for each orientation are observable, however, with small differences.

For the 90° duct, the $fRe/(fRe)_o$ is shown in Fig. 6.17(a) for $\alpha = 0°$ and 180° and Fig. 6.17(b) for $\alpha = 90°$. In both Figures, the curves where $Gr^+/Pr^2 > 10^4$ comprise the data for $Pr = 4$ and 10 only because *fRe* ratios for $Pr = 50$ are very close to 1. This is easier to observe in Fig. 6.17(b). The agreements among each Pr data are very good.

For the 120° duct, the results are in Fig. 6.18 in similar fashion as the case of the 90° duct. The outcomes for the 120° duct are also similar to the case of 90° duct except that the *fRe* ratios are slightly larger. For both ducts, the *fRe* for $\alpha = 90°$ is the highest as compared to the other orientations. These results verify the unique $fRe–Gr^+/Pr^2$ relation in addition to the case of semicircular duct in Chapter 5. All the $fRe/(fRe)_o$ data are correlated to the Gr^+/Pr^2 with the eqn. similar to eqn. 5.1 and the results are in Table 6.12.

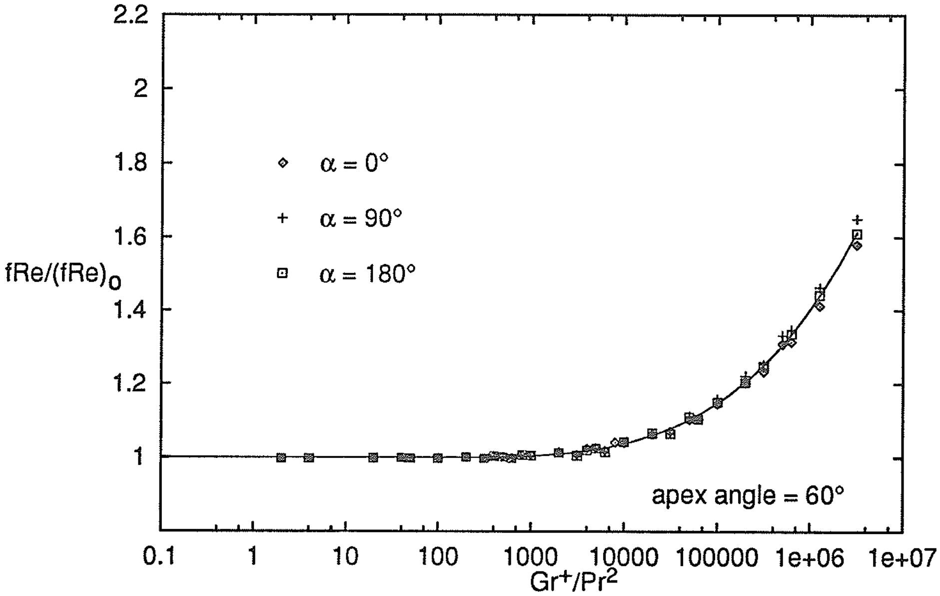


Fig. 6.16 *fRe* ratios for all *Pr* and all α, for the 60° duct.

(a)

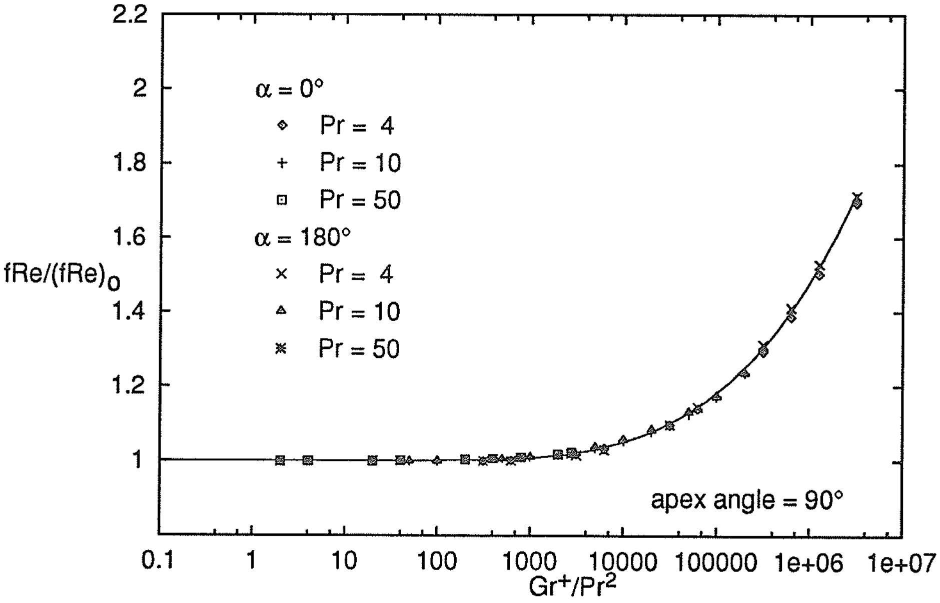


Fig. 6.17 *fRe* ratios for all *Pr* and α = (a) 0° and 180°, for the 90° duct.

(b)

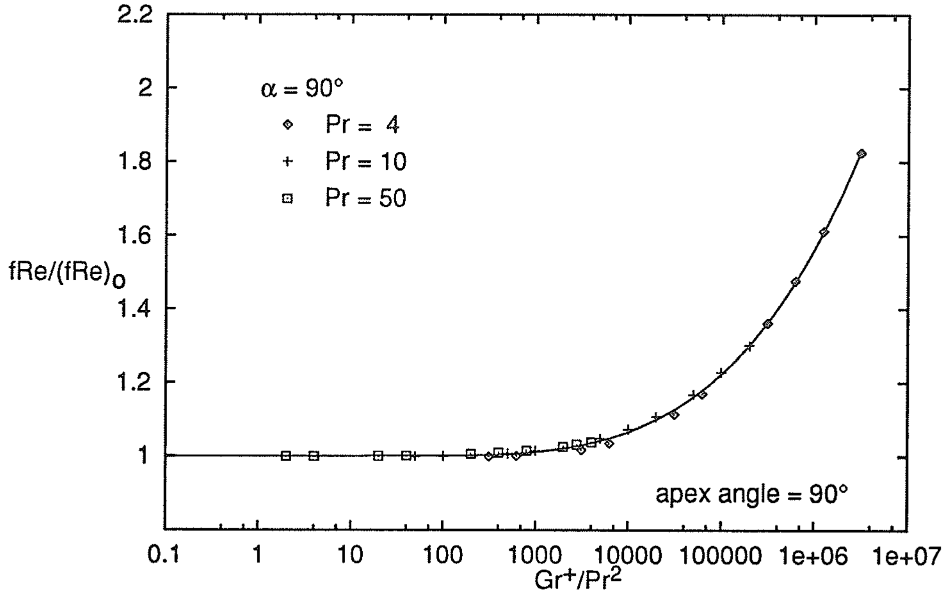


Fig. 6.17(cont) *fRe* ratios for all *Pr* and α = (b) 90°, the 90° duct.

(a)

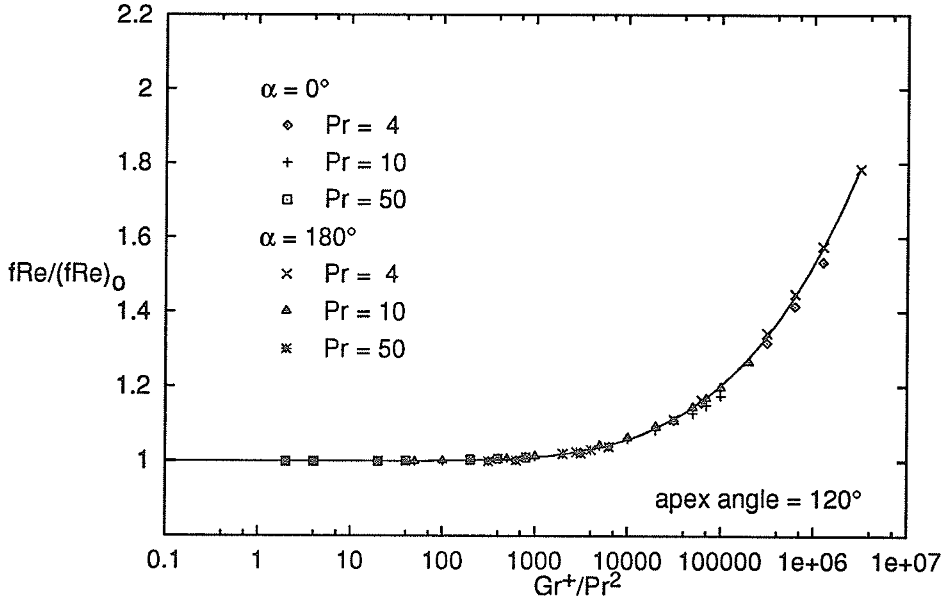


Fig. 6.18 *fRe* ratios for all *Pr* and α = (a) 0° and 180°, the 120° duct.

(b)

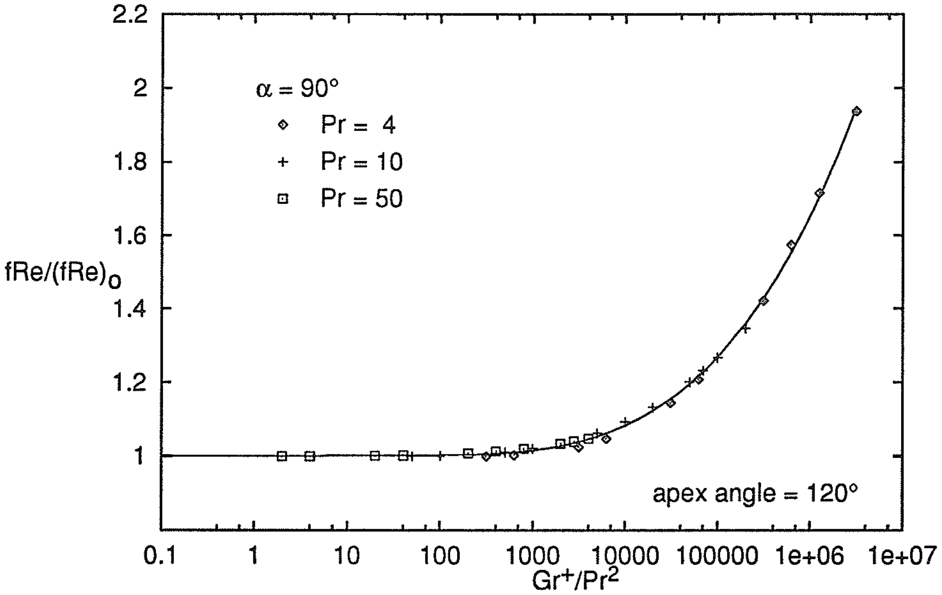


Fig. 6.18(cont) *fRe* ratios for all *Pr* and α = (b) 90°, the 120° duct.

Table 6.12 Coefficients for $fRe/(fRe)_o$, similar to eqn. 5.1.

α	**Coefficients for 60° duct**						
	C_0	C_1	C_2	C_3	C_4	σ	σ_{max}
0°	0.99904241E+0	−0.75210706E−2	0.10195034E−1	−0.49544964E−2	0.87430386E−3	0.00096126	0.01619538
90°	0.99882346E+0	−0.85012493E−2	0.12796952E−1	−0.63306612E−2	0.10682752E−2	0.00114125	0.01360955
180°	0.99745627E+0	−0.40394075E−2	0.89648714E−2	−0.51324150E−2	0.93784386E−3	0.00097588	0.01232653
For 90° duct							
0°	0.10023471E+1	−0.13812856E−1	0.15151148E−1	−0.64804688E−2	0.10777997E−2	0.00049128	0.00531799
90°	0.99592353E+0	0.54514809E−2	0.16518428E−2	−0.33748034E−2	0.92819257E−3	0.00112141	0.01413986
180°	0.99770647E+0	−0.84874606E−3	0.66255275E−2	−0.46348601E−2	0.96498352E−3	0.00103086	0.01457469
For 120° duct							
0°	0.10039440E+1	−0.19096670E−1	0.19437540E−1	−0.77441066E−2	0.12164718E−2	0.00087966	0.01208072
90°	0.99202664E+0	0.17431339E−1	−0.69345821E−2	−0.12554769E−2	0.83096566E−3	0.00150423	0.01983553
180°	0.99928886E+0	−0.55749857E−2	0.10140762E−1	−0.56221079E−2	0.10883432E−2	0.00075322	0.01203267

Chapter 7

Concluding Remarks

The studies of combined convection in this thesis consists of two main topics. The first part is a major part dealing with a semicircular duct both theoretically and experimentally. The second part deals with the rest of the set of circular sector ducts by theoretical study. In both parts, the effect of duct cross-sectional orientation was exhaustively studied in addition to the study of the effect of Prandtl number. The second part also includes a generic view of the circular sector ducts according to the size of the apex angle associating with the buoyancy force effect. The results of these studies are summarized in this chapter along with the remarks and suggestion for further study.

7.1 Summaries

The first three subsections are the summaries according to the results in Chapter 4, 5, and 6. Due to the similarity of the effect of Prandtl number for all the ducts, the summaries for these results are combined in the last subsection.

7.1.1 Experimental Results for the Semicircular Duct

The experiments for combined convection in the semicircular duct were conducted for four orientations, $\alpha = 45°$, $90°$, $135°$ and $180°$, for investigating the effect of the duct cross-sectional orientation on the fully developed Nusselt number. The average experimental ranges were within 490–1550 for Re_m, $1\text{x}10^6$–$5\text{x}10^7$ for Gr_m, and 4.2–7.6 for Pr_m. Examination of the streamwise wall temperatures and local Nusselt number showed that the fully developed conditions were obtained for $X > 30D_h$ or $x^* > 0.01$.

The wall temperature drops (the difference between duct wall temperature and fluid bulk temperature) showed a peak at the inlet of the heated section. The peak was followed by a uniform temperature drop which occupied a large portion of the duct length. The peak temperature drop suggested the developing of the combined convection near the inlet while the uniform temperature drop indicated that the temperature drop was fully developed. The fully developed region also implied that the heat transfer mechanism reached a constant level which was not changed as the fluid proceeded to the outlet. The local Nusselt number distribution was approximately the reversion of the wall temperature drop and the peak temperature drop became a sag in Nusselt number profile.

In the developing region, the local Nusselt number decreased to the minimum over a first few stations. The effects of Reynolds number were observed for a fixed Gr of about 10^7 and three Reynolds numbers of about 500, 1000, and 1500. The effects of

Grashof number were observed for a fixed Re of about 1000 and three Grashof numbers of 5×10^6, 1×10^7, and 5×10^7. The effects of both Reynolds and Grashof numbers were negligibly small for the dimensional entrance lengths (X). The effects were somewhat larger for the dimensionless entrance lengths (x^*). For a fixed Gr of about 10^7, decreasing Re was observed to increase the entrance length in terms of x^*. The effect of α on the entrance lengths was not noticeable.

The fully developed Nusselt number was obtained by the length mean average of six local Nusselt numbers at the downstream end. For all α, fully developed regions were observed to occupy about 11 station in the downstream side where local Nusselt number varied within the average of 2–4% compared to the fully developed values. For each α, Nu depended on Gr^+ in an exponential fashion. Increases in Nusselt number ratios up to eight folds were observed at $Gr^+ \approx 2 \times 10^8$ while it was about three folds at $Gr^+ \approx 10^6$. The Nusselt numbers for $\alpha = 90°$ and 135° were very close in magnitude while that for $\alpha = 45°$ was lower, about 10% lower at $Gr^+ \approx 2 \times 10^8$. For $\alpha = 45°$ and 180°, Nusselt numbers were quite similar in magnitudes.

The Nusselt number was also plotted against the variable Gr^+Pr and an improved correlation of the data in the Nu–Gr^+Pr mode was observed. Similar to the case of Gr^+ variable, at Gr^+Pr about 10^9, Nusselt numbers for α of 90° and 135° are about 10% higher than those for $\alpha = 45°$ and 180° and about 40% higher than that for $\alpha = 0°$.

Regarding friction factor, it was found that fRe was maximum for $\alpha = 90°$, while those of 45° and 180° were the lowest. The 135° orientation showed a moderate fRe

which was closer to the case of $\alpha = 45°$ rather than 90°. The lowest *fRe* was observed for $\alpha = 0°$. For all α, the maximum *fRe* compared to the pure forced convection were less than two folds. The *fRe* was obtained from the pressure drop across the duct inlet and outlet therefore it included both the developing and fully developed regions.

7.1.2 Numerical Results for the Semicircular Duct

Numerical results were obtained for $Pr = 4$ and $\alpha = 0°, 45°, 90°, 135°$ and 180°. For $\alpha = 0°$ and 180°, the cross-stream flow was symmetric and could be two- or four-cell pattern while for $\alpha = 45°, 90°$, and 135°, it was not symmetric and the pattern was only two-cell. The two-cell pattern was the only common pattern and therefore it was used to allow comparisons for *Nu* and *fRe* among all orientations. The Nusselt numbers were the highest for $\alpha = 90°$ and 135° which had very small differences in magnitudes. Similarly for $\alpha = 0°$ and 180°, the Nusselt number magnitudes were almost the same but they were the lowest, up to 20% compared to the case of $\alpha = 90°$ or 135°. The Nusselt numbers for $\alpha = 45°$ were approximately in the middle between the highest and the lowest. The fluid temperature cross-stream isotherms at the lowest level were observed to be smaller for $\alpha = 90°$ and 135° compared to similar isotherms for $\alpha = 0°$ and 180°. The smaller area bounded by the isotherm indicated that the cooler part of the fluid was efficiently used and the fluid temperature became more homogenous. This appeared to relate to the shape of the duct as well. For $\alpha = 45°, 90°$ and 135°, the sharp corner of the duct was turned to the bottom which contained the cooler fluid. This confined space seemed to force the hotter fluid downward to mix with the cool core fluid more effectively. This would be a reason to explain why all the non-symmetric orientations had higher Nusselt numbers. For a given Gr^+, the maximum Nusselt number appeared between $\alpha \approx 90°$ and $135°$. The maximum was at $\alpha = 115°$ for high Gr^+, however, it was only little higher than that of $\alpha = 90°$ or $135°$.

The four-cell pattern was an additional solution for symmetric orientations when Gr^+ was sufficiently high. The four-cell pattern started to appear where $Gr^+ \geq 2\text{x}10^5$. For $\alpha = 0°$, the two-cell solution disappeared where $Gr^+ \geq 5\text{x}10^7$. Therefore, there were two possible solutions within the range $2\text{x}10^5 \leq Gr^+ \leq 4\text{x}10^7$. The second critical Gr^+ could not be obtained for $\alpha = 180°$ due to convergence difficulty. The four-cell solutions were higher, about 9–11% for $\alpha = 0°$ and 3–7% for $\alpha = 180°$. The four-cell pattern occurred only where Gr^+ was sufficiently high, unlike the two-cell pattern that appear naturally at low Gr^+.

In general, the *fRe* product behaved similar to *Nu* in regard to the influence of duct orientation. The enhancement of Nusselt number is due to the buoyancy induced flow which actually distorts the axial velocity field as well. The *fRe* product increases as the axial velocity field is further distorted. Therefore the conditions producing a higher Nusselt number is always likely to generate a higher *fRe*. The Nusselt number enhancement is obtained by paying a higher price for the axial pressure drop, however, the gain in Nusselt number is much higher. For all cases, the increase in *fRe* was less than two folds compared to factors of 5–6 for Nusselt number.

7.1.3 Circular Sector Ducts

Circular sector ducts are identified by their apex angles. The results for $Pr = 4$ were obtained for 60°, 90° and 120° ducts in addition to the previous results for the semicircular duct. The results showed that cross-sectional orientation affected Nusselt number more for the larger ducts. The effect was almost negligible for the 60° duct. For the 90° and 120° ducts, the 90° orientation gave the maximum Nusselt numbers while those for 0° or 180° were minimum. The differences between the maximum and minimum were 4.7%, 9%, and 11.5% for the 60°, 90° and 120° duct, respectively. Since the differences were not large, solutions were determined only for three orientations. The decrease of the orientation effect with the decreasing apex angle suggests that the cross-stream flow requires a broad cross section in order to become effective. The confined cross-sectional flow domain in the 60° duct limited the effect of the buoyancy flow therefore the Nusselt number was observed to be fairly insensitive to orientation.

A comparison of Nusselt number among the 60°, 90°, 120° and 180° ducts with a fixed orientation showed that Nusselt number increased with increasing apex angle. A modified Nusselt number which was inversely proportional to the duct wall mean temperature drop was introduced. The result of the comparison was similar to the case of the original Nusselt number except that the difference of the modified Nusselt number between the 180° and 120° duct was larger. This comparison implies that the smaller duct wall is hotter if the ducts are operated with the same heat input.

7.1.4 Effect of Prandtl Number

For all four ducts, the results for Pr = 10, and 50 showed that Nu increased and fRe decreased with increasing Pr at a given Gr^+. In general, all the results for Pr = 10 and 50 had the same trend as the Pr = 4 results regarding the effect of duct orientation. The 90° or 135° orientation always yielded the highest Nu and fRe while the 0° and 180° orientations were always the lowest. For the 180° duct, the differences between the maximum and minimum were about 20% for all cases of Pr. The increase of fRe was small for the higher Prandtl number fluid. The fRe ratio was about 1.3 for Pr = 10 and 1.05 for Pr = 50. The axial velocity contours for Pr = 50 and $Gr^+ = 1\text{x}10^6$ showed almost no difference from the case of $Gr^+ = 0$. This revealed why the fRe ratio for Pr = 50 was very close to 1.

On the Nu or Nu/Nu_o and Gr^+ domain, the solutions for each Pr formed a curve separately. Therefore, there were three curves for Pr = 4, 10, and 50. When the same Nusselt number data were plotted on the Nu–Gr^+Pr domain, the data for all Pr formed a unique curve. This was true for all ducts. Hence there is a unique relationship between Nu and Gr^+Pr for a given α. The validity of this relation was also true for the rectangular and circular ducts which the data were published by other authors. Similarly, the unique relationship existed for fRe when it was plotted with the Gr^+/Pr^2 variable.

7.2 Remarks and Suggestions for Further Studies

There are some interesting points that arose during the course of the experimental and theoretical studies in this thesis. The followings should be worth further studies:

1. Regarding comparison of the experimental and numerical results in Chapter 5, predictions with the H1 thermal boundary condition compared reasonably well in the lower range of Gr^+ where the actual duct wall temperature was almost uniform. However, the amount of overestimation was large in the high Gr^+ range where the actual wall temperature variation in the experiment was as large as 3°–4° C. This was due to the H1 condition supplying more heat flux at the bottom than at the top of the cross section according to the constant wall temperature. This results in a larger heat transfer coefficient as compared to the H2 condition which has a lower wall temperature at the bottom. The Nusselt number predicted with H2 condition should be smaller than that predicted with the H1 condition and therefore it should be closer to the experimental results in the high Gr^+ region.

2. The results in Chapter 5 and 6 suggest that the orientation effect is most remarkable in semicircular ducts. Considering the numerical and experimental results, a semicircular duct orienting at $\alpha = 90°$ possibly yielded the extra gain in Nusselt number magnitude up to 20–40% compared to other orientations. A circular tube with two semicircular passages seating with the angle α of 90° seems capable to make use

of the buoyancy and orientation effects effectively.

3. Partitioning in a semicircular cross section has two advantages over the partitioning in circular cross sections. First, the flat wall can be conveniently attached to sheet materials to achieve a good thermal contact. Secondly, the number of interior walls is smaller for semicircular ducts compared to circular ducts partitioned with the same apex angle. The heat transfer performances of the passage possessing interior wall should deteriorate due to the indirect exposing to the applied heat flux. The 60° and 90° circular sector cross sections are two potential component passages that has considerably large buoyancy effect. Two alternates for partitioning in a semicircular cross section can be two 90° passages or three 60° passages. The latter case has two drawbacks; more interior walls, and smaller orientation effect.

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Appendix 1

Experimental Data for $\alpha = 45°$

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                                                    XP045-01

INPUT ELECTRIC POWER =  330.0 W                HEAT RATE GAINED BY WATER =  334.7 W                HEAT BALANCE ERROR = -1.41%
MASS FLOW RATE = 53.2320 G/S         PRESSURE DROP = 1.3725 MM H2O         FRICTION FACTOR = 0.013897          FREM =  21.1350
REM = 1520.8      GRM  = 0.10965E+07    UPSTREAM BULK TEMPERATURE = 15.60 DEG C    DOWN STREAM BULK TEMPERATURE = 17.11 DEG C
PRM =   7.684     RAM  = 0.84255E+07    INLET BULK TEMPERATURE     = 15.60 DEG C    OUTLET BULK TEMPERATURE       = 17.10 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR       RA            Z        ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                                 A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                             T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  16.31  16.28  16.28  16.29  15.60    1491.1  7.87  0.787E+07  0.00000     40.42  41.98  42.14  41.63  41.67  41.65
 1     1.5  16.45  16.42  16.42  16.43  15.61    1491.3  7.87  0.788E+07  0.00004     33.59  35.13  34.89  34.59  34.62  34.61
 2     2.5  16.56  16.51  16.52  16.53  15.61    1491.4  7.87  0.788E+07  0.00007     30.09  31.57  31.19  30.98  31.01  30.99
 3     5.5  16.86  16.79  16.82  16.83  15.62    1491.8  7.87  0.788E+07  0.00015     22.92  24.22  23.66  23.59  23.60  23.59
 4    15.5  17.18  17.11  17.06  17.12  15.65    1493.0  7.86  0.791E+07  0.00043     18.58  19.50  20.19  19.40  19.42  19.41
 5    25.5  17.30  17.35  17.30  17.32  15.68    1494.3  7.85  0.793E+07  0.00071     17.60  17.07  17.60  17.42  17.43  17.42
 6    45.5  17.42  17.41  17.27  17.36  15.75    1496.8  7.84  0.798E+07  0.00128     17.05  17.16  18.73  17.61  17.64  17.63
 7    75.5  17.66  17.71  17.43  17.60  15.84    1500.5  7.81  0.805E+07  0.00212     15.70  15.23  17.96  16.21  16.30  16.25
 8   105.5  17.84  18.08  17.67  17.87  15.94    1504.3  7.79  0.812E+07  0.00296     14.93  13.27  16.41  14.76  14.87  14.81
 9   135.5  18.07  18.19  18.03  18.10  16.04    1508.1  7.76  0.819E+07  0.00381     13.96  13.21  14.27  13.80  13.81  13.81
10   165.2  18.32  18.40  18.23  18.32  16.13    1511.9  7.74  0.826E+07  0.00464     12.97  12.53  13.52  12.99  13.01  13.00
11   205.2  18.31  18.59  18.21  18.37  16.26    1517.0  7.71  0.836E+07  0.00577     13.89  12.17  14.60  13.47  13.55  13.51
12   245.2  18.52  18.63  18.29  18.48  16.39    1522.2  7.68  0.845E+07  0.00690     13.34  12.68  14.94  13.59  13.65  13.62
13   275.2  18.52  18.74  18.35  18.54  16.48    1526.1  7.65  0.852E+07  0.00775     13.97  12.56  15.21  13.83  13.91  13.87
14   305.2  18.47  18.66  18.35  18.50  16.58    1530.0  7.63  0.860E+07  0.00860     15.00  13.50  16.04  14.77  14.84  14.81
15   333.3  18.82  19.02  18.68  18.84  16.67    1533.7  7.61  0.866E+07  0.00940     13.22  12.07  14.10  13.07  13.13  13.10
16   363.3  18.86  19.09  18.72  18.89  16.77    1537.6  7.58  0.874E+07  0.01025     13.58  12.22  14.55  13.38  13.45  13.41
17   383.3  18.87  19.08  18.77  18.91  16.83    1540.3  7.57  0.879E+07  0.01082     13.89  12.62  14.65  13.67  13.72  13.69
18   403.3  18.98  19.19  18.81  19.00  16.89    1542.6  7.55  0.883E+07  0.01139     13.58  12.33  14.80  13.49  13.57  13.53
19   423.3  19.12  19.31  18.85  19.09  16.96    1544.8  7.54  0.888E+07  0.01195     13.14  12.05  14.99  13.29  13.39  13.34
20   443.3  19.07  19.36  18.98  19.14  17.02    1547.1  7.53  0.892E+07  0.01252     13.83  12.12  14.46  13.40  13.47  13.43
21   463.3  19.19  19.44  19.00  19.21  17.09    1549.3  7.52  0.896E+07  0.01309     13.45  12.02  14.82  13.33  13.43  13.38
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  18.95  19.18  18.80  18.98  16.86    1541.0  7.56  0.880E+07  0.01106     13.54  12.24  14.59  13.38  13.45  13.42
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                                                    XP045-02

INPUT ELECTRIC POWER =  285.0 W                HEAT RATE GAINED BY WATER =  283.1 W                HEAT BALANCE ERROR =  0.66%
MASS FLOW RATE = 16.9880 G/S         PRESSURE DROP = 0.4535 MM H2O         FRICTION FACTOR = 0.045079          FREM =  22.4064
REM =  497.0      GRM  = 0.10335E+07    UPSTREAM BULK TEMPERATURE = 15.32 DEG C    DOWN STREAM BULK TEMPERATURE = 19.32 DEG C
PRM =   7.472     RAM  = 0.77216E+07    INLET BULK TEMPERATURE     = 15.33 DEG C    OUTLET BULK TEMPERATURE       = 19.31 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR       RA            Z        ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                                 A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                             T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  16.35  16.37  16.29  16.33  15.33     472.5  7.94  0.649E+07  0.00000     23.60  23.20  25.14  24.14  24.27  24.20
 1     1.5  16.52  16.54  16.46  16.50  15.34     472.7  7.94  0.650E+07  0.00013     20.52  20.10  21.55  20.81  20.93  20.87
 2     2.5  16.63  16.66  16.58  16.62  15.35     472.8  7.94  0.650E+07  0.00022     18.82  18.40  19.62  19.00  19.12  19.06
 3     5.5  16.97  17.02  16.93  16.97  15.38     473.1  7.93  0.652E+07  0.00048     15.09  14.68  15.46  15.07  15.08  15.07
 4    15.5  17.46  17.51  17.34  17.44  15.46     474.1  7.91  0.657E+07  0.00136     12.04  11.78  12.82  12.20  12.21  12.20
 5    25.5  17.63  17.85  17.68  17.72  15.54     475.2  7.89  0.662E+07  0.00224     11.53  10.45  11.26  11.06  11.08  11.07
 6    45.5  17.86  17.96  17.72  17.85  15.71     477.3  7.84  0.673E+07  0.00400     11.22  10.72  12.03  11.29  11.32  11.31
 7    75.5  17.88  18.10  17.65  17.88  15.97     480.5  7.78  0.689E+07  0.00664     12.61  11.29  14.32  12.62  12.74  12.68
 8   105.5  18.07  18.19  17.84  18.03  16.22     483.7  7.72  0.705E+07  0.00930     13.05  12.21  14.89  13.29  13.38  13.34
 9   135.5  18.24  18.41  18.14  18.26  16.48     487.0  7.65  0.721E+07  0.01196     13.66  12.44  14.48  13.47  13.52  13.50
10   165.2  18.38  18.62  18.34  18.45  16.73     490.3  7.59  0.737E+07  0.01460     14.59  12.70  14.89  13.99  14.06  14.02
11   205.2  18.69  18.93  18.59  18.74  17.07     494.3  7.52  0.758E+07  0.01816     14.78  12.92  15.75  14.39  14.49  14.44
12   245.2  19.07  19.24  18.84  19.05  17.41     498.1  7.45  0.778E+07  0.02172     14.43  13.12  16.73  14.61  14.76  14.69
13   275.2  19.18  19.36  19.02  19.19  17.67     501.0  7.41  0.793E+07  0.02440     15.79  14.18  17.74  15.77  15.90  15.84
14   305.2  19.36  19.57  19.29  19.41  17.92     503.9  7.36  0.808E+07  0.02707     16.63  14.50  17.43  16.09  16.19  16.14
15   333.3  19.82  20.03  19.69  19.85  18.16     506.7  7.31  0.823E+07  0.02959     14.44  12.77  15.65  14.19  14.29  14.24
16   363.3  20.07  20.31  19.89  20.09  18.42     509.7  7.27  0.838E+07  0.03227     14.43  12.61  16.22  14.27  14.42  14.34
17   383.3  20.21  20.42  20.04  20.22  18.59     511.7  7.23  0.849E+07  0.03406     14.74  13.04  16.37  14.59  14.72  14.66
18   403.3  20.43  20.64  20.26  20.44  18.76     513.7  7.20  0.860E+07  0.03586     14.28  12.64  15.92  14.15  14.28  14.21
19   423.3  20.61  20.81  20.47  20.63  18.93     515.8  7.17  0.870E+07  0.03765     14.16  12.66  15.48  14.00  14.10  14.05
20   443.3  20.69  20.93  20.54  20.72  19.10     517.9  7.14  0.881E+07  0.03945     14.97  13.02  16.52  14.70  14.84  14.77
21   463.3  20.87  21.07  20.67  20.87  19.27     519.9  7.11  0.892E+07  0.04125     14.89  13.24  17.01  14.89  15.05  14.97
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  20.30  20.52  20.15  20.33  18.66     512.6  7.22  0.853E+07  0.03481     14.50  12.79  16.03  14.32  14.44  14.38
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                                                    XP045-03

INPUT ELECTRIC POWER =  320.0 W                HEAT RATE GAINED BY WATER =  321.8 W                HEAT BALANCE ERROR = -0.56%
MASS FLOW RATE = 35.0380 G/S         PRESSURE DROP = 0.9292 MM H2O         FRICTION FACTOR = 0.021715          FREM =  21.9682
REM = 1011.6      GRM  = 0.11061E+07    UPSTREAM BULK TEMPERATURE = 15.65 DEG C    DOWN STREAM BULK TEMPERATURE = 17.85 DEG C
PRM =   7.585     RAM  = 0.83894E+07    INLET BULK TEMPERATURE     = 15.65 DEG C    OUTLET BULK TEMPERATURE       = 17.85 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR       RA            Z        ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                                 A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                             T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  16.53  16.55  16.47  16.51  15.65     982.8  7.86  0.761E+07  0.00000     31.26  30.65  33.66  32.10  32.31  32.20
 1     1.5  16.68  16.70  16.62  16.66  15.66     982.9  7.86  0.761E+07  0.00006     26.93  26.29  28.50  27.36  27.55  27.46
 2     2.5  16.78  16.81  16.73  16.77  15.66     983.1  7.86  0.761E+07  0.00011     24.58  23.94  25.78  24.84  25.02  24.93
 3     5.5  17.08  17.13  17.04  17.09  15.68     983.4  7.85  0.762E+07  0.00023     19.48  18.88  20.03  19.45  19.46  19.46
 4    15.5  17.52  17.56  17.39  17.49  15.73     984.6  7.84  0.766E+07  0.00066     15.27  14.90  16.39  15.50  15.52  15.51
 5    25.5  17.81  17.96  17.85  17.87  15.77     985.8  7.83  0.769E+07  0.00109     13.45  12.50  13.17  13.03  13.04  13.03
 6    45.5  18.03  18.13  17.94  18.03  15.87     988.2  7.81  0.775E+07  0.00194     12.65  12.09  13.19  12.63  12.64  12.64
 7    75.5  18.16  18.27  17.87  18.10  16.01     991.9  7.77  0.785E+07  0.00322     12.72  12.09  14.65  13.07  13.16  13.11
 8   105.5  18.18  18.36  17.96  18.16  16.15     995.6  7.74  0.795E+07  0.00451     13.46  12.34  15.11  13.54  13.64  13.59
 9   135.5  18.29  18.52  18.14  18.32  16.29     999.3  7.70  0.805E+07  0.00579     13.61  12.22  14.75  13.45  13.53  13.49
10   165.2  18.43  18.62  18.40  18.49  16.43    1002.9  7.67  0.815E+07  0.00707     13.61  12.44  13.84  13.26  13.29  13.28
11   205.2  18.58  18.82  18.43  18.61  16.61    1008.0  7.62  0.829E+07  0.00879     13.86  12.39  15.04  13.68  13.76  13.72
12   245.2  18.79  18.96  18.57  18.77  16.80    1013.0  7.57  0.843E+07  0.01051     13.68  12.63  15.45  13.83  13.92  13.87
13   275.2  18.79  19.08  18.68  18.85  16.94    1016.4  7.54  0.852E+07  0.01181     14.72  12.76  15.65  14.27  14.38  14.33
14   305.2  18.81  19.13  18.74  18.89  17.08    1019.7  7.52  0.862E+07  0.01310     15.81  13.32  16.45  15.07  15.20  15.13
15   333.3  19.21  19.47  19.07  19.25  17.21    1022.7  7.49  0.870E+07  0.01431     13.68  12.06  14.66  13.38  13.47  13.42
16   363.3  19.24  19.53  19.11  19.29  17.35    1025.9  7.47  0.880E+07  0.01560     14.41  12.50  15.55  14.04  14.15  14.10
17   383.3  19.43  19.63  19.21  19.42  17.45    1028.1  7.45  0.886E+07  0.01647     13.75  12.46  15.44  13.78  13.88  13.83
18   403.3  19.54  19.76  19.31  19.54  17.54    1030.3  7.43  0.893E+07  0.01733     13.63  12.30  15.38  13.65  13.77  13.71
19   423.3  19.67  19.87  19.46  19.67  17.63    1032.5  7.41  0.899E+07  0.01819     13.36  12.20  14.90  13.40  13.49  13.44
20   443.3  19.63  19.87  19.48  19.66  17.73    1034.7  7.39  0.905E+07  0.01906     14.33  12.73  15.51  14.09  14.19  14.14
21   463.3  19.75  19.92  19.56  19.74  17.82    1036.9  7.38  0.912E+07  0.01992     14.11  12.95  15.69  14.17  14.25  14.21
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  19.45  19.69  19.27  19.47  17.49    1029.1  7.44  0.889E+07  0.01683     13.86  12.37  15.24  13.72  13.82  13.77
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                                               XP045-04

INPUT ELECTRIC POWER =  285.0 W             HEAT RATE GAINED BY WATER =  285.1 W            HEAT BALANCE ERROR = -0.04%
MASS FLOW RATE = 16.9880 G/S          PRESSURE DROP = 0.4450 MM H2O          FRICTION FACTOR = 0.044231          FREM =  22.1981
REM =  501.9     GRM  = 0.10866E+07    UPSTREAM BULK TEMPERATURE = 15.73 DEG C    DOWN STREAM BULK TEMPERATURE = 19.76 DEG C
PRM =  7.392     RAM  = 0.80315E+07    INLET BULK TEMPERATURE    = 15.74 DEG C    OUTLET BULK TEMPERATURE      = 19.75 DEG C
_____________________________________________________________________________________________________________________________
STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE    PR       RA         Z        ------------ NUSSELT NUMBER -----------
TION  CM      A      B      C   AVER-    (C)                                            A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                         T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  16.72  16.76  16.65  16.70  15.74     477.6  7.84  0.679E+07  0.00000    24.80  23.79  26.49  25.18  25.39  25.29
 1     1.5  16.87  16.93  16.82  16.87  15.75     477.7  7.83  0.680E+07  0.00013    21.61  20.54  22.75  21.71  21.91  21.81
 2     2.5  16.98  17.05  16.93  16.98  15.76     477.8  7.83  0.680E+07  0.00022    19.85  18.77  20.73  19.82  20.02  19.92
 3     5.5  17.31  17.41  17.27  17.33  15.79     478.1  7.83  0.682E+07  0.00048    15.95  14.92  16.37  15.72  15.75  15.73
 4    15.5  17.79  17.90  17.73  17.81  15.87     479.2  7.80  0.687E+07  0.00136    12.60  11.95  13.06  12.52  12.53  12.53
 5    25.5  18.08  18.29  18.07  18.15  15.96     480.3  7.78  0.693E+07  0.00224    11.39  10.37  11.45  11.05  11.07  11.06
 6    45.5  18.25  18.41  18.11  18.25  16.13     482.5  7.74  0.704E+07  0.00401    11.41  10.63  12.25  11.39  11.43  11.41
 7    75.5  18.32  18.49  18.09  18.30  16.39     485.7  7.68  0.720E+07  0.00666    12.49  11.50  14.16  12.63  12.72  12.67
 8   105.5  18.40  18.64  18.23  18.42  16.64     489.1  7.61  0.736E+07  0.00932    13.75  12.11  15.19  13.57  13.69  13.63
 9   135.5  18.63  18.86  18.63  18.71  16.90     492.3  7.55  0.753E+07  0.01199    13.97  12.35  13.93  13.37  13.42  13.40
10   165.2  18.98  19.18  18.85  19.00  17.15     495.2  7.50  0.768E+07  0.01463    13.19  11.93  14.23  13.05  13.12  13.08
11   205.2  19.19  19.37  19.09  19.22  17.49     499.0  7.44  0.788E+07  0.01818    14.20  12.85  15.08  13.98  14.04  14.01
12   245.2  19.35  19.52  19.12  19.33  17.84     502.9  7.37  0.809E+07  0.02175    15.94  14.35  18.76  16.15  16.35  16.25
13   275.2  19.52  19.74  19.46  19.57  18.09     505.9  7.33  0.824E+07  0.02442    16.93  14.60  17.62  16.28  16.38  16.33
14   305.2  19.75  19.97  19.57  19.76  18.35     508.9  7.28  0.840E+07  0.02711    17.20  14.90  19.71  17.05  17.27  17.16
15   333.3  20.15  20.42  20.02  20.20  18.59     511.8  7.23  0.855E+07  0.02962    15.43  13.14  16.81  14.97  15.13  15.05
16   363.3  20.41  20.64  20.33  20.46  18.85     514.9  7.18  0.871E+07  0.03231    15.43  13.38  16.18  14.90  15.00  14.95
17   383.3  20.65  20.81  20.49  20.65  19.02     516.9  7.15  0.882E+07  0.03410    14.73  13.41  16.35  14.73  14.83  14.78
18   403.3  20.88  21.04  20.65  20.86  19.19     519.0  7.12  0.893E+07  0.03590    14.23  12.99  16.45  14.42  14.56  14.49
19   423.3  21.06  21.26  20.91  21.07  19.36     521.1  7.09  0.904E+07  0.03770    14.17  12.67  15.49  14.02  14.11  14.07
20   443.3  21.13  21.32  20.98  21.14  19.53     523.3  7.06  0.915E+07  0.03950    14.99  13.45  16.54  14.89  14.99  14.94
21   463.3  21.26  21.46  21.17  21.30  19.70     525.4  7.02  0.926E+07  0.04130    15.46  13.65  16.33  15.06  15.15  15.10
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  20.71  20.91  20.56  20.73  19.09     517.8  7.14  0.887E+07  0.03485    14.83  13.17  16.31  14.66  14.77  14.71
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                                               XP045-05

INPUT ELECTRIC POWER =  585.0 W             HEAT RATE GAINED BY WATER =  571.0 W            HEAT BALANCE ERROR =  2.40%
MASS FLOW RATE = 52.3660 G/S          PRESSURE DROP = 1.3743 MM H2O          FRICTION FACTOR = 0.014377          FREM =  21.9849
REM = 1529.1     GRM  = 0.20658E+07    UPSTREAM BULK TEMPERATURE = 15.93 DEG C    DOWN STREAM BULK TEMPERATURE = 18.54 DEG C
PRM =  7.488     RAM  = 0.15469E+08    INLET BULK TEMPERATURE    = 15.93 DEG C    OUTLET BULK TEMPERATURE      = 18.54 DEG C
_____________________________________________________________________________________________________________________________
STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE    PR       RA         Z        ------------ NUSSELT NUMBER -----------
TION  CM      A      B      C   AVER-    (C)                                            A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                         T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  17.14  17.13  17.01  17.08  15.93    1479.5  7.79  0.138E+08  0.00000    40.24  40.32  45.12  42.06  42.70  42.38
 1     1.5  17.37  17.37  17.22  17.32  15.94    1479.8  7.79  0.139E+08  0.00004    33.82  33.89  37.82  35.23  35.84  35.53
 2     2.5  17.54  17.53  17.37  17.48  15.94    1480.0  7.79  0.139E+08  0.00007    30.46  30.53  34.02  31.68  32.26  31.97
 3     5.5  18.03  18.02  17.82  17.96  15.96    1480.7  7.78  0.139E+08  0.00016    23.47  23.54  26.14  24.32  24.38  24.35
 4    15.5  18.46  18.63  18.29  18.46  16.02    1482.8  7.77  0.139E+08  0.00044    19.89  18.54  21.35  19.86  19.92  19.89
 5    25.5  18.81  18.96  18.79  18.86  16.07    1485.0  7.75  0.140E+08  0.00073    17.71  16.79  17.82  17.43  17.44  17.43
 6    45.5  18.97  19.13  18.83  18.98  16.18    1489.3  7.73  0.142E+08  0.00130    17.42  16.44  18.34  17.36  17.40  17.38
 7    75.5  19.37  19.54  19.10  19.34  16.35    1495.9  7.68  0.144E+08  0.00216    16.04  15.20  17.62  16.23  16.29  16.26
 8   105.5  19.51  19.86  19.62  19.66  16.52    1502.6  7.64  0.146E+08  0.00302    16.18  14.49  15.60  15.39  15.42  15.41
 9   135.5  19.85  20.08  19.63  19.85  16.68    1509.3  7.60  0.148E+08  0.00389    15.29  14.27  16.42  15.27  15.33  15.30
10   165.2  20.09  20.51  20.07  20.23  16.85    1516.0  7.56  0.150E+08  0.00474    14.91  13.22  15.02  14.33  14.38  14.36
11   205.2  20.19  20.59  19.98  20.26  17.07    1523.6  7.52  0.153E+08  0.00589    15.49  13.73  16.61  15.18  15.28  15.23
12   245.2  20.46  20.79  20.24  20.50  17.29    1531.2  7.48  0.155E+08  0.00705    15.29  13.81  16.41  15.09  15.17  15.13
13   275.2  20.57  20.97  20.36  20.63  17.46    1537.0  7.45  0.157E+08  0.00791    15.53  13.76  16.69  15.23  15.33  15.28
14   305.2  20.53  20.97  20.36  20.62  17.63    1542.9  7.41  0.159E+08  0.00878    16.65  14.46  17.70  16.16  16.27  16.21
15   333.3  21.14  21.59  20.86  21.20  17.78    1548.4  7.38  0.161E+08  0.00959    14.36  12.67  15.69  14.13  14.24  14.19
16   363.3  21.07  21.53  20.78  21.13  17.95    1554.3  7.35  0.163E+08  0.01046    15.46  13.47  17.03  15.18  15.32  15.25
17   383.3  21.21  21.64  20.88  21.24  18.06    1558.3  7.33  0.165E+08  0.01104    15.34  13.46  17.13  15.16  15.31  15.24
18   403.3  21.32  21.76  20.98  21.36  18.17    1562.3  7.31  0.166E+08  0.01161    15.31  13.44  17.16  15.15  15.30  15.23
19   423.3  21.44  21.87  21.19  21.50  18.28    1566.3  7.29  0.167E+08  0.01219    15.25  13.46  16.56  14.98  15.09  15.04
20   443.3  21.53  21.93  21.21  21.56  18.39    1570.4  7.27  0.169E+08  0.01277    15.39  13.62  17.15  15.25  15.39  15.32
21   463.3  21.53  22.02  21.23  21.59  18.51    1574.4  7.25  0.170E+08  0.01335    15.92  13.70  17.70  15.60  15.78  15.69
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  21.29  21.72  20.98  21.33  18.11    1560.0  7.32  0.165E+08  0.01128    15.19  13.35  16.79  14.98  15.11  15.04
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                                               XP045-06

INPUT ELECTRIC POWER =  565.0 W             HEAT RATE GAINED BY WATER =  548.4 W            HEAT BALANCE ERROR =  2.94%
MASS FLOW RATE = 34.3160 G/S          PRESSURE DROP = 0.9037 MM H2O          FRICTION FACTOR = 0.022012          FREM =  22.3940
REM = 1017.3     GRM  = 0.21222E+07    UPSTREAM BULK TEMPERATURE = 15.98 DEG C    DOWN STREAM BULK TEMPERATURE = 19.81 DEG C
PRM =  7.363     RAM  = 0.15626E+08    INLET BULK TEMPERATURE    = 15.99 DEG C    OUTLET BULK TEMPERATURE      = 19.81 DEG C
_____________________________________________________________________________________________________________________________
STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE    PR       RA         Z        ------------ NUSSELT NUMBER -----------
TION  CM      A      B      C   AVER-    (C)                                            A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                         T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  17.38  17.40  17.26  17.33  15.99     971.0  7.78  0.134E+08  0.00000    33.46  32.94  36.62  34.61  34.91  34.76
 1     1.5  17.63  17.66  17.51  17.59  16.00     971.3  7.77  0.134E+08  0.00007    28.64  28.11  30.82  29.32  29.60  29.46
 2     2.5  17.80  17.83  17.69  17.76  16.01     971.5  7.77  0.134E+08  0.00011    26.05  25.52  27.78  26.53  26.78  26.66
 3     5.5  18.31  18.36  18.21  18.29  16.03     972.1  7.76  0.134E+08  0.00024    20.50  20.01  21.44  20.63  20.65  20.64
 4    15.5  19.01  19.19  18.79  19.00  16.11     974.2  7.74  0.135E+08  0.00068    16.08  15.12  17.41  16.15  16.20  16.18
 5    25.5  19.48  19.63  19.41  19.50  16.20     976.3  7.72  0.136E+08  0.00111    14.19  13.57  14.51  14.08  14.09  14.08
 6    45.5  19.63  19.86  19.50  19.66  16.36     980.5  7.68  0.138E+08  0.00199    14.21  13.31  14.82  14.09  14.11  14.10
 7    75.5  19.87  20.09  19.49  19.82  16.60     986.9  7.62  0.141E+08  0.00330    14.23  13.32  16.12  14.47  14.56  14.51
 8   105.5  19.96  20.31  19.62  19.96  16.85     993.4  7.56  0.144E+08  0.00462    14.96  13.42  16.75  14.92  15.04  14.98
 9   135.5  20.18  20.57  20.02  20.26  17.09     998.9  7.51  0.147E+08  0.00594    15.03  13.35  15.85  14.67  14.74  14.70
10   165.2  20.43  20.84  20.35  20.54  17.33    1004.3  7.47  0.150E+08  0.00724    15.00  13.22  15.39  14.48  14.54  14.51
11   205.2  20.58  21.04  20.43  20.69  17.66    1011.8  7.41  0.153E+08  0.00901    15.87  13.73  16.72  15.33  15.44  15.38
12   245.2  21.01  21.41  20.68  21.03  17.99    1019.4  7.35  0.157E+08  0.01077    15.32  13.55  17.18  15.21  15.35  15.28
13   275.2  21.07  21.53  20.86  21.15  18.23    1025.2  7.30  0.160E+08  0.01210    16.30  14.04  17.64  15.85  15.99  15.92
14   305.2  21.19  21.58  20.97  21.25  18.47    1031.0  7.25  0.163E+08  0.01342    17.02  14.91  18.57  16.70  16.83  16.77
15   333.3  21.70  22.16  21.48  21.78  18.70    1036.5  7.21  0.166E+08  0.01467    15.44  13.40  16.67  15.05  15.17  15.11
16   363.3  21.84  22.20  21.56  21.87  18.95    1042.5  7.17  0.169E+08  0.01600    15.96  14.21  17.69  15.83  15.95  15.89
17   383.3  21.98  22.32  21.65  21.98  19.11    1046.5  7.13  0.171E+08  0.01689    16.09  14.41  18.20  16.09  16.23  16.16
18   403.3  22.22  22.54  21.87  22.21  19.27    1050.5  7.10  0.173E+08  0.01778    15.69  14.12  17.77  15.72  15.86  15.79
19   423.3  22.44  22.82  22.19  22.49  19.44    1054.6  7.07  0.175E+08  0.01867    15.35  13.66  16.74  15.14  15.25  15.20
20   443.3  22.47  22.88  22.16  22.50  19.60    1058.7  7.04  0.177E+08  0.01956    16.07  14.05  18.06  15.89  16.06  15.97
21   463.3  22.64  23.06  22.34  22.68  19.76    1062.8  7.01  0.179E+08  0.02045    16.01  14.01  17.91  15.81  15.97  15.89
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  22.11  22.49  21.82  22.14  19.18    1048.2  7.12  0.172E+08  0.01726    15.77  13.98  17.52  15.62  15.75  15.69
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                                                        XP045-07

INPUT ELECTRIC POWER =  485.0 W            HEAT RATE GAINED BY WATER =  473.9 W            HEAT BALANCE ERROR =  2.28%
MASS FLOW RATE = 16.2660 G/S         PRESSURE DROP = 0.4416 MM H2O         FRICTION FACTOR = 0.047861         FREM =  23.8212
REM =  497.7     GRM   = 0.20983E+07    UPSTREAM BULK TEMPERATURE = 15.76 DEG C    DOWN STREAM BULK TEMPERATURE = 22.74 DEG C
PRM =  7.108     RAM   = 0.14915E+08    INLET BULK TEMPERATURE    = 15.77 DEG C    OUTLET BULK TEMPERATURE      = 22.74 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB      RE     PR      RA          Z       ------------ NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                         A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                     T      H     T+H
---------------------------------------------------------------------------------------------------------------------------
 0    0.1  17.37  17.41  17.28  17.35  15.77    457.7  7.83  0.113E+08  0.00000   25.23  24.55  26.67  25.58  25.78  25.68
 1    1.5  17.63  17.69  17.54  17.62  15.79    457.9  7.82  0.113E+08  0.00014   21.90  21.19  23.03  22.08  22.29  22.18
 2    2.5  17.81  17.89  17.72  17.80  15.81    458.1  7.82  0.114E+08  0.00023   20.07  19.36  21.05  20.18  20.38  20.28
 3    5.5  18.36  18.47  18.26  18.36  15.85    458.6  7.81  0.114E+08  0.00051   16.06  15.38  16.72  16.03  16.05  16.04
 4   15.5  19.01  19.25  18.90  19.05  16.00    460.4  7.77  0.116E+08  0.00142   13.38  12.39  13.89  13.19  13.22  13.21
 5   25.5  19.37  19.74  19.29  19.47  16.15    462.2  7.74  0.117E+08  0.00235   12.51  11.21  12.80  12.13  12.18  12.16
 6   45.5  19.63  19.86  19.39  19.63  16.45    465.9  7.66  0.120E+08  0.00419   12.62  11.80  13.67  12.65  12.70  12.67
 7   75.5  19.82  20.09  19.49  19.80  16.89    471.4  7.55  0.125E+08  0.00698   13.74  12.55  15.47  13.82  13.92  13.87
 8  105.5  20.07  20.48  19.73  20.09  17.34    476.1  7.47  0.129E+08  0.00976   14.71  12.78  16.75  14.57  14.75  14.66
 9  135.5  20.52  20.79  20.24  20.52  17.78    481.0  7.38  0.134E+08  0.01255   14.67  13.31  16.29  14.66  14.76  14.71
10  165.2  20.87  21.23  20.68  20.93  18.23    485.9  7.30  0.138E+08  0.01532   15.12  13.31  16.29  14.80  14.91  14.85
11  205.2  21.25  21.65  21.04  21.31  18.82    492.7  7.19  0.145E+08  0.01906   16.45  14.12  17.97  16.02  16.18  16.10
12  245.2  21.84  22.18  21.52  21.85  19.41    499.6  7.08  0.151E+08  0.02281   16.42  14.41  18.93  16.38  16.59  16.48
13  275.2  22.13  22.53  21.97  22.21  19.86    505.0  6.99  0.156E+08  0.02563   17.58  14.94  18.92  16.98  17.15  17.06
14  305.2  22.53  22.92  22.31  22.58  20.31    510.4  6.91  0.161E+08  0.02846   17.92  15.25  19.91  17.48  17.69  17.59
15  333.3  23.20  23.61  22.99  23.27  20.72    515.7  6.83  0.165E+08  0.03112   16.06  13.77  17.55  15.64  15.79  15.71
16  363.3  23.57  23.98  23.29  23.61  21.17    521.4  6.75  0.170E+08  0.03397   16.57  14.14  18.74  16.27  16.48  16.37
17  383.3  23.87  24.22  23.65  23.91  21.47    525.2  6.69  0.174E+08  0.03587   16.50  14.43  18.18  16.22  16.37  16.29
18  403.3  24.22  24.55  23.99  24.25  21.76    529.2  6.64  0.177E+08  0.03778   16.13  14.23  17.82  15.93  16.06  15.99
19  423.3  24.55  24.87  24.31  24.58  22.06    532.8  6.59  0.180E+08  0.03968   15.92  14.10  17.61  15.74  15.88  15.81
20  443.3  24.76  25.12  24.49  24.79  22.36    536.2  6.54  0.184E+08  0.04158   16.52  14.33  18.58  16.29  16.48  16.38
21  463.3  24.98  25.41  24.73  25.04  22.66    539.7  6.49  0.187E+08  0.04349   17.00  14.36  19.04  16.58  16.80  16.69
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  24.03  24.39  23.79  24.07  21.59    526.7  6.67  0.175E+08  0.03667   16.28  14.17  18.08  16.01  16.18  16.09
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                                                        XP045-08

INPUT ELECTRIC POWER =  985.0 W            HEAT RATE GAINED BY WATER =  960.4 W            HEAT BALANCE ERROR =  2.50%
MASS FLOW RATE = 31.4280 G/S         PRESSURE DROP = 0.7877 MM H2O         FRICTION FACTOR = 0.022862         FREM =  22.8180
REM =  998.1     GRM   = 0.49351E+07    UPSTREAM BULK TEMPERATURE = 17.13 DEG C    DOWN STREAM BULK TEMPERATURE = 24.46 DEG C
PRM =  6.818     RAM   = 0.33649E+08    INLET BULK TEMPERATURE    = 17.14 DEG C    OUTLET BULK TEMPERATURE      = 24.45 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB      RE     PR      RA          Z       ------------ NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                         A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                     T      H     T+H
---------------------------------------------------------------------------------------------------------------------------
 0    0.1  19.50  19.58  19.36  19.47  17.14    915.8  7.51  0.258E+08  0.00000   34.48  33.42  36.67  35.00  35.31  35.15
 1    1.5  19.94  20.04  19.79  19.91  17.16    916.3  7.50  0.259E+08  0.00007   29.36  28.29  30.99  29.60  29.91  29.76
 2    2.5  20.24  20.36  20.09  20.22  17.18    916.6  7.50  0.259E+08  0.00012   26.63  25.57  28.00  26.76  27.05  26.91
 3    5.5  21.13  21.32  20.97  21.14  17.23    917.6  7.49  0.260E+08  0.00026   20.82  19.86  21.72  20.77  20.80  20.79
 4   15.5  22.17  22.63  21.85  22.21  17.38    920.9  7.46  0.263E+08  0.00074   17.00  15.50  18.20  16.83  16.90  16.86
 5   25.5  22.83  23.29  22.67  22.93  17.54    924.1  7.43  0.266E+08  0.00122   15.35  14.12  15.83  15.06  15.10  15.08
 6   45.5  23.01  23.41  22.62  23.01  17.85    930.7  7.37  0.273E+08  0.00218   15.73  14.60  17.04  15.73  15.79  15.76
 7   75.5  23.31  23.76  22.72  23.26  18.32    940.8  7.28  0.282E+08  0.00362   16.26  14.91  18.41  16.41  16.53  16.47
 8  105.5  23.52  24.32  23.07  23.64  18.79    951.1  7.20  0.292E+08  0.00507   17.12  14.63  18.90  16.70  16.88  16.79
 9  135.5  24.13  24.74  23.68  24.18  19.25    961.6  7.11  0.302E+08  0.00652   16.60  14.75  18.26  16.41  16.54  16.47
10  165.2  24.37  25.12  24.02  24.50  19.72    972.3  7.02  0.312E+08  0.00796   17.37  14.95  18.76  16.88  17.03  16.95
11  205.2  24.58  25.43  24.10  24.70  20.34    987.0  6.90  0.326E+08  0.00991   19.01  15.85  21.45  18.48  18.77  18.63
12  245.2  25.44  26.08  24.81  25.44  20.96   1002.2  6.79  0.340E+08  0.01186   17.97  15.75  20.93  17.97  18.22  18.09
13  275.2  25.73  26.48  25.36  25.86  21.43   1013.9  6.70  0.351E+08  0.01333   18.70  15.94  20.49  18.18  18.38  18.28
14  305.2  25.97  26.76  25.59  26.11  21.90   1025.7  6.61  0.362E+08  0.01480   19.75  16.54  21.74  19.10  19.34  19.22
15  333.3  26.81  27.69  26.46  26.98  22.34   1035.6  6.54  0.372E+08  0.01618   17.96  14.99  19.48  17.27  17.48  17.37
16  363.3  27.17  27.97  26.69  27.28  22.80   1046.3  6.47  0.382E+08  0.01766   18.38  15.51  20.61  17.92  18.17  18.04
17  383.3  27.42  28.13  26.81  27.45  23.12   1053.6  6.42  0.389E+08  0.01864   18.60  15.98  21.68  18.47  18.76  18.61
18  403.3  27.62  28.34  26.99  27.65  23.43   1061.0  6.37  0.396E+08  0.01963   19.09  16.28  22.45  18.94  19.27  19.11
19  423.3  27.99  28.77  27.43  28.06  23.74   1068.4  6.32  0.403E+08  0.02062   18.83  15.91  21.66  18.50  18.80  18.65
20  443.3  28.27  29.04  27.66  28.32  24.05   1076.0  6.27  0.410E+08  0.02161   18.96  16.03  22.15  18.72  19.05  18.88
21  463.3  28.72  29.39  28.24  28.78  24.36   1083.7  6.22  0.418E+08  0.02260   18.35  15.89  20.58  18.07  18.27  18.17
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  27.55  28.32  27.01  27.63  23.25   1056.8  6.40  0.392E+08  0.01905   18.64  15.79  21.34  18.30  18.59  18.44
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                                                        XP045-09

INPUT ELECTRIC POWER = 1250.0 W            HEAT RATE GAINED BY WATER = 1207.6 W            HEAT BALANCE ERROR =  3.39%
MASS FLOW RATE = 50.2000 G/S         PRESSURE DROP = 1.2907 MM H2O         FRICTION FACTOR = 0.014688         FREM =  22.3555
REM = 1522.0     GRM   = 0.51455E+07    UPSTREAM BULK TEMPERATURE = 15.98 DEG C    DOWN STREAM BULK TEMPERATURE = 21.74 DEG C
PRM =  7.181     RAM   = 0.36952E+08    INLET BULK TEMPERATURE    = 15.99 DEG C    OUTLET BULK TEMPERATURE      = 21.74 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB      RE     PR      RA          Z       ------------ NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                         A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                     T      H     T+H
---------------------------------------------------------------------------------------------------------------------------
 0    0.1  18.47  18.45  18.23  18.36  15.99   1420.5  7.78  0.294E+08  0.00000   41.39  41.68  45.87  43.22  43.70  43.46
 1    1.5  18.96  18.93  18.69  18.85  16.01   1421.1  7.77  0.295E+08  0.00004   34.78  35.07  38.23  36.13  36.58  36.36
 2    2.5  19.29  19.26  19.01  19.18  16.02   1421.6  7.77  0.295E+08  0.00007   31.33  31.61  34.29  32.46  32.88  32.67
 3    5.5  20.31  20.26  19.97  20.18  16.06   1423.0  7.76  0.296E+08  0.00016   24.14  24.40  26.20  24.88  24.91  24.90
 4   15.5  21.23  21.73  20.79  21.25  16.18   1427.6  7.73  0.299E+08  0.00046   20.31  18.48  22.25  20.23  20.35  20.29
 5   25.5  21.94  22.29  21.68  21.97  16.30   1432.2  7.70  0.303E+08  0.00076   18.19  17.11  19.07  18.08  18.12  18.10
 6   45.5  22.07  22.41  21.67  22.05  16.55   1441.6  7.64  0.309E+08  0.00136   18.54  17.47  19.99  18.61  18.67  18.64
 7   75.5  22.75  23.20  22.16  22.70  16.92   1455.4  7.55  0.319E+08  0.00226   17.54  16.28  19.51  17.68  17.78  17.73
 8  105.5  23.07  23.87  22.46  23.13  17.28   1467.5  7.48  0.328E+08  0.00316   17.66  15.52  19.77  17.48  17.65  17.56
 9  135.5  23.68  24.29  23.13  23.70  17.65   1479.9  7.41  0.338E+08  0.00406   16.93  15.38  18.63  16.88  16.98  16.93
10  165.2  23.98  24.73  23.58  24.10  18.02   1492.3  7.34  0.347E+08  0.00496   17.12  15.19  18.35  16.78  16.88  16.83
11  205.2  23.92  24.82  23.49  24.07  18.51   1509.3  7.25  0.360E+08  0.00617   18.84  16.15  20.45  18.30  18.48  18.39
12  245.2  24.56  25.41  24.03  24.66  19.00   1526.8  7.16  0.373E+08  0.00738   18.31  15.87  20.23  17.96  18.14  18.05
13  275.2  24.79  25.76  24.30  24.95  19.36   1540.1  7.09  0.383E+08  0.00829   18.75  15.91  20.60  18.21  18.42  18.32
14  305.2  24.91  25.81  24.42  25.05  19.73   1553.7  7.02  0.393E+08  0.00921   19.62  16.71  21.66  19.11  19.33  19.22
15  333.3  25.70  26.79  25.23  25.91  20.08   1566.6  6.95  0.403E+08  0.01007   18.05  15.11  19.71  17.41  17.62  17.52
16  363.3  25.83  26.75  25.19  25.92  20.45   1580.7  6.88  0.413E+08  0.01098   18.82  16.08  21.38  18.51  18.76  18.63
17  383.3  26.04  26.90  25.31  26.08  20.69   1590.2  6.84  0.420E+08  0.01160   18.95  16.32  21.93  18.79  19.07  18.93
18  403.3  26.28  27.17  25.55  26.34  20.94   1599.8  6.79  0.427E+08  0.01221   18.94  16.24  21.95  18.76  19.04  18.90
19  423.3  26.49  27.38  25.76  26.54  21.18   1609.5  6.75  0.434E+08  0.01282   19.07  16.33  22.10  18.88  19.17  19.02
20  443.3  26.59  27.58  25.88  26.69  21.43   1619.4  6.70  0.442E+08  0.01344   19.57  16.43  22.72  19.23  19.57  19.40
21  463.3  26.99  27.79  26.24  27.01  21.67   1629.4  6.65  0.449E+08  0.01406   19.01  16.52  22.13  18.95  19.22  19.09
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  26.16  27.10  25.49  26.25  20.79   1594.4  6.82  0.423E+08  0.01185   18.90  16.08  21.63  18.60  18.87  18.73
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                                                      XP045-10

INPUT ELECTRIC POWER =   545.0 W                   HEAT RATE GAINED BY WATER =   531.1 W                 HEAT BALANCE ERROR =   2.54%
MASS FLOW RATE = 13.1350 G/S           PRESSURE DROP = 0.2950 MM H2O          FRICTION FACTOR = 0.048923           FREM =  24.3521
REM =   497.8     GRM   = 0.51270E+07    UPSTREAM BULK TEMPERATURE = 23.74 DEG C    DOWN STREAM BULK TEMPERATURE = 33.44 DEG C
PRM =   5.611     RAM   = 0.28766E+08    INLET BULK TEMPERATURE    = 23.75 DEG C    OUTLET BULK TEMPERATURE      = 33.43 DEG C
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STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA           Z         ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C    AVER-  (C)                                                  A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                                 T       H     T+H
--------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  25.37   25.41   25.25   25.33  23.75     446.7  6.32  0.223E+08   0.00001     27.40   26.68   29.64   28.07   28.34   28.20
 1     1.5  25.66   25.72   25.54   25.63  23.78     447.0  6.31  0.224E+08   0.00017     23.59   22.83   25.23   23.96   24.22   24.09
 2     2.5  25.86   25.93   25.74   25.84  23.80     447.2  6.31  0.224E+08   0.00029     21.52   20.77   22.88   21.76   22.01   21.89
 3     5.5  26.46   26.57   26.34   26.46  23.87     447.8  6.30  0.225E+08   0.00064     17.04   16.34   17.88   17.06   17.09   17.08
 4    15.5  26.99   27.24   26.74   26.99  24.07     449.9  6.27  0.227E+08   0.00181     15.16   13.93   16.54   15.14   15.21   15.17
 5    25.5  27.47   27.84   27.22   27.51  24.28     452.1  6.24  0.230E+08   0.00298     13.83   12.39   15.04   13.67   13.75   13.71
 6    45.5  27.61   27.97   27.36   27.64  24.69     456.4  6.17  0.235E+08   0.00531     15.12   13.48   16.57   14.95   15.06   15.00
 7    75.5  27.96   28.30   27.63   27.96  25.31     463.0  6.07  0.244E+08   0.00883     16.67   14.75   19.02   16.63   16.81   16.72
 8   105.5  28.36   28.83   27.97   28.39  25.93     469.8  5.98  0.252E+08   0.01236     18.15   15.16   21.61   17.93   18.31   18.12
 9   135.5  28.91   29.29   28.62   28.94  26.55     476.8  5.88  0.261E+08   0.01590     18.65   16.01   21.20   18.38   18.62   18.50
10   165.2  29.41   29.85   29.14   29.47  27.16     483.4  5.79  0.269E+08   0.01941     19.52   16.33   22.14   19.03   19.33   19.18
11   205.2  30.20   30.65   29.89   30.25  27.99     491.6  5.69  0.280E+08   0.02415     19.81   16.46   23.05   19.40   19.77   19.59
12   245.2  31.32   31.74   31.00   31.35  28.81     500.1  5.58  0.291E+08   0.02889     17.47   14.92   20.00   17.22   17.46   17.34
13   275.2  31.90   32.27   31.63   31.93  29.43     506.7  5.50  0.299E+08   0.03246     17.70   15.41   19.85   17.46   17.65   17.56
14   305.2  32.35   32.77   32.06   32.39  30.05     513.4  5.43  0.308E+08   0.03604     18.98   16.03   21.71   18.62   18.91   18.76
15   333.3  33.02   33.45   32.77   33.08  30.63     519.9  5.35  0.316E+08   0.03939     18.22   15.46   20.35   17.78   18.01   17.90
16   363.3  33.76   34.14   33.44   33.78  31.25     527.0  5.28  0.325E+08   0.04299     17.37   15.06   19.88   17.21   17.44   17.33
17   383.3  34.09   34.49   33.85   34.14  31.66     531.8  5.22  0.331E+08   0.04539     17.92   15.35   19.88   17.52   17.72   17.62
18   403.3  34.48   34.82   34.12   34.47  32.08     536.4  5.17  0.337E+08   0.04781     18.08   15.84   21.22   18.12   18.38   18.25
19   423.3  34.92   35.39   34.68   35.00  32.49     540.7  5.13  0.342E+08   0.05024     17.83   14.96   19.77   17.29   17.52   17.40
20   443.3  35.24   35.75   35.01   35.33  32.90     545.1  5.08  0.348E+08   0.05268     18.54   15.21   20.60   17.83   18.12   17.98
21   463.3  35.68   36.22   35.37   35.76  33.32     549.6  5.03  0.353E+08   0.05513     18.32   14.89   21.04   17.72   18.08   17.90
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  34.25   34.67   33.98   34.30  31.84     533.5  5.20  0.333E+08   0.04642     17.99   15.31   20.28   17.63   17.86   17.75
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                                                      XP045-11

INPUT ELECTRIC POWER =   875.0 W                   HEAT RATE GAINED BY WATER =   841.5 W                 HEAT BALANCE ERROR =   3.83%
MASS FLOW RATE = 15.5440 G/S           PRESSURE DROP = 0.3870 MM H2O          FRICTION FACTOR = 0.045903           FREM =  23.4677
REM =   511.2     GRM   = 0.49426E+07    UPSTREAM BULK TEMPERATURE = 15.76 DEG C    DOWN STREAM BULK TEMPERATURE = 28.74 DEG C
PRM =   6.556     RAM   = 0.32406E+08    INLET BULK TEMPERATURE    = 15.78 DEG C    OUTLET BULK TEMPERATURE      = 28.73 DEG C
--------------------------------------------------------------------------------------------------------------------------------------
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA           Z         ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C    AVER-  (C)                                                  A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                                 T       H     T+H
--------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  18.41   18.48   16.24   18.36  15.78     437.4  7.83  0.201E+08   0.00000     27.15   26.45   29.08   27.71   27.94   27.82
 1     1.5  18.86   18.96   18.69   18.82  15.82     437.9  7.82  0.202E+08   0.00014     23.54   22.80   24.94   23.83   24.05   23.94
 2     2.5  19.16   19.28   19.00   19.14  15.85     438.2  7.81  0.202E+08   0.00024     21.56   20.82   22.71   21.74   21.95   21.84
 3     5.5  20.08   20.26   19.92   20.09  15.93     439.2  7.79  0.204E+08   0.00053     17.22   16.51   17.91   17.20   17.21   17.20
 4    15.5  21.01   21.50   20.73   21.08  16.21     442.4  7.72  0.209E+08   0.00149     14.89   13.50   15.78   14.66   14.72   14.69
 5    25.5  21.66   22.18   21.46   21.77  16.48     445.6  7.65  0.214E+08   0.00246     13.79   12.53   14.36   13.51   13.56   13.54
 6    45.5  21.96   22.41   21.56   21.98  17.04     451.9  7.53  0.224E+08   0.00440     14.47   13.26   15.75   14.42   14.50   14.46
 7    75.5  22.42   22.98   21.88   22.43  17.86     460.5  7.37  0.239E+08   0.00732     15.62   13.91   17.70   15.59   15.74   15.67
 8   105.5  22.85   23.59   22.29   22.91  18.69     469.4  7.21  0.254E+08   0.01025     17.07   14.48   19.74   16.83   17.10   16.96
 9   135.5  23.63   24.24   23.19   23.69  19.52     478.7  7.06  0.270E+08   0.01319     17.25   15.01   19.31   17.01   17.19   17.10
10   165.2  24.37   25.12   24.02   24.50  20.34     488.2  6.90  0.286E+08   0.01612     17.56   14.78   19.20   16.98   17.18   17.08
11   205.2  25.19   25.87   24.77   25.28  21.45     501.7  6.70  0.308E+08   0.02009     18.80   15.92   21.18   18.38   18.63   18.51
12   245.2  26.44   27.02   25.92   26.46  22.55     514.6  6.51  0.330E+08   0.02408     18.05   15.72   20.84   17.96   18.20   18.08
13   275.2  27.12   27.81   26.69   27.21  23.38     524.2  6.38  0.346E+08   0.02708     18.74   15.83   21.19   18.32   18.59   18.46
14   305.2  27.74   28.37   27.32   27.81  24.21     534.1  6.25  0.363E+08   0.03009     19.80   16.81   22.48   19.42   19.70   19.56
15   333.3  28.81   29.54   28.47   28.94  24.98     543.7  6.12  0.379E+08   0.03292     18.29   15.34   20.07   17.68   17.90   17.79
16   363.3  29.54   30.31   28.98   29.61  25.81     554.4  5.99  0.397E+08   0.03596     18.69   15.53   22.04   18.37   18.75   18.56
17   383.3  30.09   30.69   29.64   30.14  26.37     561.8  5.91  0.409E+08   0.03800     18.71   16.09   21.28   18.45   18.69   18.57
18   403.3  30.69   31.36   30.23   30.76  26.92     569.2  5.82  0.421E+08   0.04004     18.45   15.68   21.02   18.12   18.38   18.25
19   423.3  31.43   32.05   31.01   31.49  27.47     575.6  5.75  0.432E+08   0.04206     17.56   15.17   19.65   17.27   17.46   17.36
20   443.3  31.84   32.51   31.39   31.91  28.02     582.2  5.68  0.444E+08   0.04408     18.18   15.48   20.61   17.85   18.09   17.97
21   463.3  32.28   33.08   31.92   32.43  28.57     588.9  5.61  0.455E+08   0.04611     18.72   15.37   20.74   18.00   18.28   18.14
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  30.40   31.08   29.95   30.48  26.60     564.5  5.88  0.414E+08   0.03884     18.31   15.55   20.78   17.96   18.21   18.08
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                                                      XP045-12

INPUT ELECTRIC POWER = 1180.0 W                    HEAT RATE GAINED BY WATER = 1142.6 W                  HEAT BALANCE ERROR =   3.17%
MASS FLOW RATE = 40.8140 G/S           PRESSURE DROP = 0.8934 MM H2O          FRICTION FACTOR = 0.015353           FREM =  23.1197
REM = 1505.8      GRM   = 0.10079E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 30.64 DEG C
PRM =   5.775     RAM   = 0.58204E+08    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 30.64 DEG C
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STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA           Z         ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C    AVER-  (C)                                                  A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                                 T       H     T+H
--------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.03   26.03   25.78   25.93  23.94    1393.9  6.29  0.485E+08   0.00000     45.56   45.47   51.64   47.82   48.58   48.20
 1     1.5  26.50   26.50   26.22   26.40  23.96    1394.5  6.29  0.486E+08   0.00006     37.49   37.40   42.02   39.07   39.74   39.40
 2     2.5  26.82   26.83   26.53   26.72  23.98    1395.0  6.28  0.486E+08   0.00009     33.41   33.33   37.24   34.69   35.30   35.00
 3     5.5  27.79   27.81   27.44   27.68  24.02    1396.3  6.28  0.487E+08   0.00021     25.19   25.11   27.76   25.96   26.02   25.99
 4    15.5  28.54   29.04   28.19   28.59  24.16    1400.9  6.25  0.491E+08   0.00058     21.72   19.47   23.57   21.46   21.59   21.52
 5    25.5  29.20   29.73   28.88   29.27  24.30    1405.5  6.23  0.495E+08   0.00096     19.41   17.51   20.76   19.13   19.22   19.18
 6    45.5  29.38   29.86   29.03   29.42  24.59    1414.7  6.19  0.503E+08   0.00171     19.82   18.04   21.40   19.66   19.75   19.70
 7    75.5  29.84   30.36   29.19   29.79  25.02    1428.9  6.12  0.516E+08   0.00284     19.69   17.78   22.75   19.87   20.07   19.97
 8   105.5  30.14   31.01   29.63   30.26  25.45    1443.3  6.05  0.528E+08   0.00397     20.21   17.05   22.65   19.70   19.97   19.83
 9   135.5  30.91   31.63   30.51   31.01  25.88    1458.0  5.98  0.541E+08   0.00511     18.83   16.46   20.43   18.43   18.58   18.50
10   165.2  31.02   31.91   30.59   31.17  26.30    1472.8  5.92  0.553E+08   0.00624     20.06   16.88   22.06   19.43   19.67   19.55
11   205.2  31.42   32.26   30.78   31.49  26.87    1493.2  5.83  0.571E+08   0.00776     20.77   17.53   24.19   20.47   20.83   20.65
12   245.2  32.09   32.97   31.61   32.22  27.44    1510.6  5.76  0.586E+08   0.00928     20.29   17.09   22.64   19.74   20.01   19.87
13   275.2  32.46   33.32   32.02   32.60  27.87    1523.9  5.70  0.598E+08   0.01042     20.57   17.30   22.72   19.94   20.19   20.07
14   305.2  32.68   33.49   32.12   32.76  28.30    1537.4  5.65  0.610E+08   0.01156     21.49   18.13   24.68   21.10   21.44   21.27
15   333.3  33.13   34.12   32.49   33.25  28.70    1550.3  5.60  0.622E+08   0.01264     21.24   17.36   24.81   20.69   21.14   20.91
16   363.3  33.37   34.31   32.77   33.48  29.13    1564.3  5.54  0.635E+08   0.01378     22.19   18.17   25.82   21.61   22.06   21.83
17   383.3  33.81   34.61   33.24   33.89  29.42    1573.8  5.51  0.643E+08   0.01455     21.38   18.11   24.58   21.02   21.36   21.19
18   403.3  34.20   34.98   33.68   34.29  29.70    1583.4  5.47  0.652E+08   0.01532     20.88   17.78   23.62   20.48   20.76   20.62
19   423.3  34.70   35.50   34.13   34.78  29.99    1593.1  5.43  0.660E+08   0.01608     19.91   17.02   22.67   19.60   19.87   19.73
20   443.3  34.79   35.75   34.28   34.94  30.27    1603.0  5.40  0.669E+08   0.01685     20.77   17.12   23.42   20.10   20.44   20.27
21   463.3  35.34   36.14   34.76   35.41  30.56    1612.9  5.36  0.678E+08   0.01762     19.59   16.80   22.33   19.31   19.57   19.44
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  34.00   34.88   33.43   34.10  29.54    1578.0  5.49  0.647E+08   0.01487     21.06   17.59   24.15   20.58   20.94   20.76
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                                                XP045-13

INPUT ELECTRIC POWER = 1065.0 W             HEAT RATE GAINED BY WATER = 1015.0 W             HEAT BALANCE ERROR =  4.70%
MASS FLOW RATE = 26.3740 G/S          PRESSURE DROP = 0.5746 MM H2O        FRICTION FACTOR = 0.023637         FREM =  23.5491
REM =  996.3     GRM   = 0.96939E+07    UPSTREAM BULK TEMPERATURE = 23.82 DEG C    DOWN STREAM BULK TEMPERATURE = 33.05 DEG C
PRM =  5.630     RAM   = 0.54577E+08    INLET BULK TEMPERATURE    = 23.83 DEG C    OUTLET BULK TEMPERATURE      = 33.04 DEG C

STA-  Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA         Z        ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                         A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                      T      H      T+H
------------------------------------------------------------------------------------------------------------------------------
 0     0.1 26.14  26.17  25.90  26.05  23.83     898.5  6.31  0.428E+08  0.00000   36.65  36.24  40.82  38.20  38.64  38.42
 1     1.5 26.61  26.65  26.37  26.53  23.86     899.1  6.30  0.429E+08  0.00009   30.76  30.35  33.66  31.73  32.11  31.92
 2     2.5 26.93  26.98  26.70  26.86  23.88     899.5  6.30  0.430E+08  0.00015   27.69  27.30  30.02  28.41  28.76  28.59
 3     5.5 27.91  27.97  27.67  27.85  23.94     900.7  6.29  0.431E+08  0.00032   21.31  20.96  22.68  21.62  21.65  21.64
 4    15.5 28.76  29.16  28.42  28.78  24.14     904.8  6.26  0.436E+08  0.00090   18.27  16.83  19.74  18.20  18.28  18.24
 5    25.5 29.37  29.84  29.05  29.42  24.33     908.8  6.23  0.441E+08  0.00148   16.75  15.32  17.90  16.59  16.66  16.62
 6    45.5 29.55  30.02  29.08  29.55  24.73     917.1  6.17  0.451E+08  0.00265   17.49  15.93  19.36  17.48  17.59  17.53
 7    75.5 29.89  30.52  29.41  29.94  25.32     929.8  6.07  0.466E+08  0.00440   18.40  16.18  20.57  18.20  18.38  18.29
 8   105.5 30.36  31.23  29.74  30.44  25.91     942.8  5.98  0.481E+08  0.00616   18.88  15.80  21.91  18.53  18.86  18.70
 9   135.5 30.85  31.52  30.29  30.89  26.49     956.2  5.89  0.497E+08  0.00792   19.29  16.73  22.14  19.13  19.38  19.26
10   165.2 31.07  31.85  30.53  31.15  27.08     968.9  5.80  0.512E+08  0.00967   21.00  17.58  24.28  20.59  20.95  20.77
11   205.2 31.64  32.54  31.11  31.76  27.86     984.5  5.70  0.531E+08  0.01202   22.15  17.91  25.79  21.47  21.95  21.71
12   245.2 32.76  33.52  32.22  32.84  28.65    1000.7  5.60  0.551E+08  0.01438   20.33  17.16  23.40  19.97  20.29  20.13
13   275.2 33.23  34.10  32.80  33.38  29.24    1013.2  5.53  0.567E+08  0.01616   20.90  17.17  23.44  20.17  20.50  20.34
14   305.2 33.63  34.44  33.12  33.73  29.83    1025.9  5.45  0.582E+08  0.01794   21.94  18.08  25.35  21.38  21.79  21.59
15   333.3 34.19  35.07  33.73  34.33  30.38    1038.2  5.39  0.597E+08  0.01961   21.86  17.75  24.87  21.08  21.49  21.29
16   363.3 34.70  35.64  34.28  34.87  30.97    1051.6  5.31  0.613E+08  0.02140   22.29  17.81  25.14  21.31  21.75  21.53
17   383.3 35.31  35.89  34.63  35.28  31.36    1060.8  5.26  0.624E+08  0.02259   21.04  18.35  25.44  21.23  21.61  21.42
18   403.3 35.59  36.27  35.07  35.64  31.76    1070.1  5.21  0.636E+08  0.02379   21.62  18.40  25.07  21.35  21.70  21.53
19   423.3 36.14  36.89  35.74  36.26  32.15    1078.5  5.17  0.646E+08  0.02499   20.78  17.47  23.06  20.17  20.44  20.30
20   443.3 36.46  37.32  36.01  36.59  32.54    1086.8  5.12  0.656E+08  0.02621   21.13  17.35  23.91  20.44  20.80  20.62
21   463.3 36.90  37.84  36.37  37.04  32.93    1095.2  5.07  0.665E+08  0.02742   20.87  16.85  24.07  20.16  20.60  20.38
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 35.40  36.18  34.91  35.50  31.53    1064.3  5.24  0.629E+08  0.02310   21.45  17.85  24.58  20.93  21.30  21.11
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                                                xp045-14

INPUT ELECTRIC POWER = 1055.0 W             HEAT RATE GAINED BY WATER = 1018.0 W             HEAT BALANCE ERROR =  3.50%
MASS FLOW RATE = 26.3740 G/S          PRESSURE DROP = 0.5780 MM H2O        FRICTION FACTOR = 0.023775         FREM =  23.7759
REM = 1000.0     GRM   = 0.98454E+07    UPSTREAM BULK TEMPERATURE = 23.99 DEG C    DOWN STREAM BULK TEMPERATURE = 33.24 DEG C
PRM =  5.607     RAM   = 0.55205E+08    INLET BULK TEMPERATURE    = 24.00 DEG C    OUTLET BULK TEMPERATURE      = 33.24 DEG C

STA-  Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA         Z        ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                         A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                      T      H      T+H
------------------------------------------------------------------------------------------------------------------------------
 0     0.1 26.28  26.35  26.03  26.20  24.00     901.9  6.28  0.434E+08  0.00000   37.10  36.00  41.82  38.55  39.18  38.87
 1     1.5 26.75  26.84  26.48  26.67  24.03     902.5  6.28  0.434E+08  0.00009   31.19  30.10  34.60  32.06  32.62  32.34
 2     2.5 27.06  27.18  26.79  27.00  24.05     902.9  6.27  0.435E+08  0.00015   28.11  27.04  30.92  28.73  29.25  28.99
 3     5.5 28.02  28.19  27.72  27.98  24.11     904.1  6.26  0.436E+08  0.00032   21.67  20.73  23.44  21.89  21.95  21.92
 4    15.5 28.76  29.38  28.53  28.89  24.30     908.2  6.23  0.441E+08  0.00090   19.00  16.67  20.05  18.46  18.58  18.52
 5    25.5 29.54  29.96  29.22  29.57  24.50     912.3  6.20  0.446E+08  0.00148   16.80  15.52  17.95  16.70  16.76  16.73
 6    45.5 29.66  30.19  29.31  29.72  24.90     920.7  6.14  0.456E+08  0.00265   17.75  15.98  15.18  17.53  17.63  17.58
 7    75.5 29.95  30.52  29.36  29.94  25.49     933.5  6.05  0.471E+08  0.00440   18.92  16.77  21.83  18.95  19.17  19.06
 8   105.5 30.36  31.23  29.86  30.48  26.08     946.7  5.95  0.487E+06  0.00616   19.69  16.38  22.33  19.15  19.46  19.31
 9   135.5 31.07  31.79  30.62  31.16  26.67     960.2  5.86  0.503E+08  0.00792   19.13  16.43  21.31  18.74  18.96  18.85
10   165.2 31.46  32.29  31.03  31.60  27.25     972.4  5.78  0.518E+08  0.00967   19.99  16.69  22.26  19.37  19.65  19.51
11   205.2 32.20  32.98  31.50  32.23  28.04     988.2  5.68  0.537E+08  0.01203   20.20  16.99  24.28  20.06  20.49  20.28
12   245.2 32.98  33.69  32.39  33.02  28.83    1004.5  5.58  0.558E+08  0.01439   20.18  17.25  23.55  20.00  20.33  20.17
13   275.2 33.51  34.27  33.03  33.60  29.42    1017.1  5.51  0.573E+08  0.01617   20.47  17.28  23.21  20.02  20.32  20.17
14   305.2 33.85  34.67  33.34  33.95  30.01    1030.0  5.43  0.589E+08  0.01795   21.78  17.96  25.13  21.22  21.63  21.42
15   333.3 34.47  35.41  34.01  34.63  30.57    1042.4  5.36  0.604E+08  0.01962   21.41  17.25  24.28  20.57  20.98  20.77
16   363.3 35.03  35.86  34.61  35.17  31.16    1056.0  5.29  0.621E+08  0.02140   21.51  17.73  24.14  20.79  21.13  20.96
17   383.3 35.59  36.23  34.96  35.59  31.55    1065.2  5.24  0.632E+08  0.02260   20.63  17.81  24.43  20.61  20.96  20.79
18   403.3 35.93  36.66  35.46  36.01  31.95    1074.3  5.19  0.643E+08  0.02380   20.90  17.67  23.68  20.45  20.75  20.60
19   423.3 36.53  37.28  36.02  36.61  32.34    1082.5  5.14  0.652E+08  0.02501   19.85  16.82  22.58  19.47  19.75  19.61
20   443.3 36.80  37.60  36.28  36.89  32.73    1090.9  5.10  0.662E+08  0.02622   20.43  17.07  23.40  19.96  20.30  20.13
21   463.3 37.24  38.07  36.65  37.32  33.13    1099.4  5.05  0.672E+08  0.02744   20.18  16.78  23.56  19.79  20.17  19.98
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 35.72  36.51  35.22  35.82  31.72    1068.6  5.22  0.636E+08  0.02311   20.79  17.39  23.75  20.31  20.64  20.48
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                                                XP045-15

INPUT ELECTRIC POWER =  995.0 W             HEAT RATE GAINED BY WATER =  965.9 W             HEAT BALANCE ERROR =  2.93%
MASS FLOW RATE = 20.5980 G/S          PRESSURE DROP = 0.4569 MM H2O        FRICTION FACTOR = 0.030800         FREM =  24.5650
REM =  797.6     GRM   = 0.10006E+08    UPSTREAM BULK TEMPERATURE = 23.99 DEG C    DOWN STREAM BULK TEMPERATURE = 35.23 DEG C
PRM =  5.482     RAM   = 0.54850E+08    INLET BULK TEMPERATURE    = 24.00 DEG C    OUTLET BULK TEMPERATURE      = 35.22 DEG C

STA-  Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA         Z        ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                         A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                      T      H      T+H
------------------------------------------------------------------------------------------------------------------------------
 0     0.1 26.37  26.47  26.17  26.32  24.00     704.5  6.28  0.412E+08  0.00000   33.92  32.65  37.11  34.73  35.20  34.96
 1     1.5 26.83  26.95  26.61  26.78  24.04     705.0  6.27  0.412E+08  0.00011   28.84  27.56  31.25  29.28  29.72  29.50
 2     2.5 27.14  27.29  26.91  27.10  24.06     705.4  6.27  0.413E+08  0.00019   26.14  24.88  28.17  26.41  26.84  26.63
 3     5.5 28.07  28.31  27.83  28.07  24.13     706.6  6.26  0.415E+08  0.00041   20.41  19.26  21.76  20.43  20.48  20.45
 4    15.5 28.87  29.44  28.53  28.95  24.37     710.4  6.22  0.420E+08  0.00115   17.85  15.86  19.33  17.56  17.68  17.62
 5    25.5 29.54  30.01  29.16  29.57  24.61     714.4  6.18  0.426E+08  0.00190   16.30  14.87  17.65  16.19  16.27  16.23
 6    45.5 29.66  30.19  29.19  29.68  25.09     722.3  6.11  0.438E+08  0.00339   17.55  15.73  19.54  17.47  17.61  17.54
 7    75.5 29.95  30.58  29.41  29.98  25.81     734.6  5.99  0.455E+08  0.00564   19.34  16.79  22.23  19.20  19.45  19.32
 8   105.5 30.31  31.23  29.80  30.44  26.53     747.4  5.88  0.473E+08  0.00790   21.16  17.01  24.42  20.41  20.86  20.63
 9   135.5 31.13  31.91  30.68  31.24  27.25     759.3  5.78  0.491E+08  0.01016   20.56  17.12  23.25  19.99  20.31  20.15
10   165.2 31.74  32.63  31.37  31.91  27.96     770.4  5.69  0.508E+08  0.01240   21.06  17.06  23.36  20.15  20.49  20.32
11   205.2 32.76  33.54  32.22  32.84  28.91     785.9  5.57  0.531E+08  0.01542   20.69  17.19  24.03  20.25  20.64  20.45
12   245.2 33.81  34.52  33.28  33.87  29.87     802.0  5.45  0.555E+08  0.01846   20.14  17.06  23.25  19.83  20.15  19.99
13   275.2 34.40  35.16  33.97  34.51  30.59     814.5  5.36  0.574E+08  0.02074   20.78  17.35  23.41  20.21  20.51  20.36
14   305.2 34.91  35.61  34.46  34.99  31.31     827.4  5.27  0.593E+08  0.02303   21.98  18.37  25.12  21.47  21.82  21.65
15   333.3 35.69  36.53  35.29  35.84  31.98     839.6  5.18  0.611E+08  0.02519   21.29  17.36  23.86  20.48  20.84  20.66
16   363.3 36.47  37.25  36.01  36.58  32.70     851.4  5.10  0.628E+08  0.02751   20.88  17.31  23.83  20.32  20.67  20.50
17   383.3 36.86  37.51  36.29  36.89  33.18     859.4  5.05  0.639E+08  0.02907   21.36  18.16  25.29  21.21  21.61  21.41
18   403.3 37.27  37.94  36.79  37.33  33.66     867.6  4.99  0.651E+08  0.03064   21.77  18.35  25.05  21.38  21.72  21.55
19   423.3 38.03  38.67  37.58  38.09  34.13     876.0  4.93  0.663E+08  0.03221   20.17  17.30  22.77  19.83  20.08  19.95
20   443.3 38.36  39.17  37.89  38.47  34.61     884.5  4.88  0.675E+08  0.03379   20.95  17.22  23.90  20.32  20.69  20.51
21   463.3 38.91  39.78  38.49  39.06  35.09     893.2  4.82  0.687E+08  0.03537   20.54  16.71  23.06  19.75  20.10  19.93
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 37.11  37.84  36.64  37.20  33.38     863.1  5.02  0.644E+08  0.02973   21.07  17.62  24.12  20.59  20.94  20.76
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                                             XP045-16

INPUT ELECTRIC POWER =  865.0 W              HEAT RATE GAINED BY WATER =  830.2 W              HEAT BALANCE ERROR =  4.02%
MASS FLOW RATE = 12.2970 G/S           PRESSURE DROP = 0.2626 MM H2O          FRICTION FACTOR = 0.049621          FREM =  24.8573
REM =   500.9     GRM   = 0.10103E+08     UPSTREAM BULK TEMPERATURE = 23.85 DEG C     DOWN STREAM BULK TEMPERATURE = 40.04 DEG C
PRM =   5.188     RAM   = 0.52416E+08     INLET BULK TEMPERATURE    = 23.87 DEG C     OUTLET BULK TEMPERATURE      = 40.03 DEG C
_________________________________________________________________________________________________________________________________
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------ NUSSELT NUMBER -----------
TION  CM       A       B       C    AVER-  (C)                                                A      B      C    ----- AVERAGE -----
NO.                                  AGE                                                                          T      H      T+H
---------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.20   26.31   26.02   26.16  23.87     419.3  6.30  0.351E+08  0.00001      29.75  28.36  32.25  30.27  30.65  30.46
 1     1.5  26.62   26.78   26.44   26.60  23.92     419.8  6.29  0.352E+08  0.00019      25.61  24.17  27.45  25.80  26.17  25.99
 2     2.5  26.91   27.11   26.73   26.91  23.96     420.1  6.29  0.353E+08  0.00031      23.37  21.94  24.90  23.42  23.78  23.60
 3     5.5  27.79   28.08   27.61   27.83  24.06     421.1  6.27  0.355E+08  0.00069      18.51  17.18  19.46  18.33  18.38  18.36
 4    15.5  28.59   29.04   28.19   28.61  24.41     424.4  6.22  0.362E+08  0.00193      16.48  14.88  18.22  16.42  16.53  16.47
 5    25.5  29.26   29.79   28.88   29.31  24.75     427.8  6.16  0.369E+08  0.00318      15.31  13.69  16.69  15.13  15.23  15.18
 6    45.5  29.55   30.08   29.14   29.59  25.44     434.8  6.05  0.383E+08  0.00569      16.76  14.85  18.62  16.60  16.74  16.67
 7    75.5  30.23   30.86   29.58   30.22  26.47     445.6  5.89  0.406E+08  0.00946      18.30  15.68  22.14  18.34  18.71  18.52
 8   105.5  31.03   31.78   30.41   31.07  27.51     455.7  5.75  0.427E+08  0.01325      19.47  16.03  23.61  19.22  19.71  19.46
 9   135.5  31.96   32.63   31.46   32.01  28.54     465.5  5.62  0.449E+08  0.01705      20.00  16.74  23.47  19.69  20.07  19.88
10   165.2  32.96   33.74   32.54   33.08  29.57     475.7  5.49  0.470E+08  0.02082      20.09  16.35  22.95  19.42  19.80  19.61
11   205.2  34.31   34.93   33.78   34.34  30.94     490.0  5.31  0.501E+08  0.02592      20.20  17.07  23.96  20.03  20.41  20.22
12   245.2  35.97   36.53   35.46   35.99  32.32     504.6  5.15  0.532E+08  0.03107      18.58  16.12  21.64  18.51  18.78  18.65
13   275.2  36.78   37.55   36.42   36.92  33.36     514.9  5.03  0.553E+08  0.03499      19.73  16.13  22.10  18.99  19.32  19.16
14   305.2  37.62   38.28   37.19   37.70  34.39     525.7  4.91  0.575E+08  0.03893      20.87  17.33  24.10  20.39  20.77  20.58
15   333.3  38.80   39.54   38.42   38.92  35.36     536.2  4.79  0.596E+08  0.04266      19.55  16.07  21.96  18.88  19.20  19.04
16   363.3  39.85   40.53   39.36   39.91  36.39     547.9  4.67  0.620E+08  0.04668      19.41  16.23  22.65  19.07  19.43  19.25
17   383.3  40.42   40.97   39.84   40.41  37.08     555.6  4.60  0.636E+08  0.04935      20.09  17.22  24.31  20.14  20.54  20.34
18   403.3  41.06   41.73   40.69   41.16  37.77     562.8  4.54  0.651E+08  0.05198      20.37  16.89  22.89  19.74  20.05  19.90
19   423.3  41.85   42.57   41.48   41.97  38.46     570.1  4.47  0.667E+08  0.05462      19.72  16.25  22.11  19.05  19.36  19.21
20   443.3  42.54   43.31   42.12   42.66  39.15     577.7  4.41  0.684E+08  0.05726      19.69  16.06  22.46  19.04  19.40  19.22
21   463.3  43.19   44.09   42.83   43.37  39.84     585.5  4.34  0.701E+08  0.05991      19.87  15.66  22.26  18.86  19.26  19.06
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  40.75   41.44   40.32   40.84  37.37     558.4  4.58  0.642E+08  0.05042      19.81  16.45  22.73  19.32  19.66  19.49
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                                             XP045-17

INPUT ELECTRIC POWER = 1080.0 W              HEAT RATE GAINED BY WATER = 1052.1 W              HEAT BALANCE ERROR =  2.58%
MASS FLOW RATE = 13.3780 G/S           PRESSURE DROP = 0.3205 MM H2O          FRICTION FACTOR = 0.051258          FREM =  25.4930
REM =   497.3     GRM   = 0.95243E+07     UPSTREAM BULK TEMPERATURE = 18.23 DEG C     DOWN STREAM BULK TEMPERATURE = 37.09 DEG C
PRM =   5.728     RAM   = 0.54551E+08     INLET BULK TEMPERATURE    = 18.25 DEG C     OUTLET BULK TEMPERATURE      = 37.07 DEG C
_________________________________________________________________________________________________________________________________
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------ NUSSELT NUMBER -----------
TION  CM       A       B       C    AVER-  (C)                                                A      B      C    ----- AVERAGE -----
NO.                                  AGE                                                                          T      H      T+H
---------------------------------------------------------------------------------------------------------------------------------
 0     0.1  21.43   21.58   21.20   21.38  18.25     399.9  7.30  0.308E+08  0.00001      27.97  26.75  30.20  28.46  28.78  28.62
 1     1.5  21.97   22.18   21.74   21.95  18.31     400.4  7.28  0.309E+08  0.00017      24.27  22.99  25.92  24.46  24.78  24.62
 2     2.5  22.35   22.59   22.11   22.34  18.35     400.8  7.28  0.310E+08  0.00028      22.25  20.56  23.61  22.30  22.61  22.45
 3     5.5  23.47   23.83   23.24   23.51  18.47     401.9  7.25  0.313E+08  0.00062      17.78  16.57  18.63  17.62  17.66  17.64
 4    15.5  24.44   25.22   24.07   24.58  18.87     405.7  7.18  0.322E+08  0.00175      15.94  13.99  17.07  15.56  15.67  15.61
 5    25.5  25.23   25.96   24.89   25.36  19.28     409.6  7.10  0.332E+08  0.00288      14.88  13.27  15.79  14.57  14.64  14.61
 6    45.5  25.62   26.30   25.07   25.66  20.08     417.5  6.95  0.351E+08  0.00516      15.97  14.21  17.71  15.84  15.96  15.90
 7    75.5  26.35   27.08   25.67   26.37  21.28     430.0  6.73  0.381E+08  0.00859      17.40  15.20  20.08  17.33  17.56  17.45
 8   105.5  27.19   28.22   26.46   27.29  22.49     442.3  6.52  0.411E+08  0.01204      18.69  15.34  22.12  18.31  18.72  18.51
 9   135.5  28.29   29.13   27.68   28.37  23.69     454.3  6.33  0.440E+08  0.01550      19.04  16.12  21.96  18.74  19.04  18.89
10   165.2  29.63   30.46   29.09   29.73  24.88     466.9  6.14  0.471E+08  0.01895      18.40  15.67  20.79  18.05  18.29  18.17
11   205.2  30.87   31.76   30.22   30.95  26.49     485.0  5.89  0.515E+08  0.02364      19.90  16.52  23.33  19.53  19.92  19.72
12   245.2  32.54   33.36   31.89   32.59  28.10     501.8  5.67  0.557E+08  0.02833      19.53  16.50  22.88  19.29  19.63  19.46
13   275.2  33.57   34.49   33.14   33.73  29.30     514.6  5.52  0.589E+08  0.03186      20.28  16.68  22.54  19.53  19.83  19.68
14   305.2  34.46   35.39   33.96   34.60  30.50     528.0  5.37  0.622E+08  0.03541      21.81  17.67  25.01  21.06  21.50  21.28
15   333.3  35.97   36.92   35.52   36.13  31.63     541.3  5.23  0.655E+08  0.03875      19.86  16.29  22.16  19.12  19.44  19.28
16   363.3  36.92   37.86   36.40   37.06  32.84     554.5  5.09  0.687E+08  0.04238      21.03  17.08  24.09  20.32  20.73  20.53
17   383.3  37.75   38.52   37.18   37.81  33.64     563.3  4.99  0.709E+08  0.04483      20.84  17.56  24.21  20.51  20.87  20.69
18   403.3  38.49   39.33   37.97   38.60  34.44     572.5  4.90  0.730E+08  0.04730      21.12  17.47  24.25  20.58  20.95  20.76
19   423.3  39.52   40.34   38.92   39.60  35.25     582.0  4.81  0.753E+08  0.04978      19.94  16.73  23.20  19.60  19.96  19.78
20   443.3  40.14   41.01   39.51   40.22  36.05     591.8  4.71  0.776E+08  0.05229      20.81  17.15  24.58  20.40  20.85  20.62
21   463.3  40.91   41.85   40.33   41.03  36.85     601.9  4.62  0.799E+08  0.05481      20.92  16.99  24.43  20.33  20.78  20.56
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  38.13   39.00   37.58   38.24  33.97     567.6  4.95  0.718E+08  0.04589      20.60  17.05  23.75  20.09  20.47  20.28
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                                             XP045-18

INPUT ELECTRIC POWER = 1930.0 W              HEAT RATE GAINED BY WATER = 1848.6 W              HEAT BALANCE ERROR =  4.22%
MASS FLOW RATE = 38.6480 G/S           PRESSURE DROP = 0.8934 MM H2O          FRICTION FACTOR = 0.017107          FREM =  25.5998
REM =  1496.5     GRM   = 0.19150E+08     UPSTREAM BULK TEMPERATURE = 23.88 DEG C     DOWN STREAM BULK TEMPERATURE = 35.34 DEG C
PRM =   5.482     RAM   = 0.10498E+09     INLET BULK TEMPERATURE    = 23.89 DEG C     OUTLET BULK TEMPERATURE      = 35.34 DEG C
_________________________________________________________________________________________________________________________________
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------ NUSSELT NUMBER -----------
TION  CM       A       B       C    AVER-  (C)                                                A      B      C    ----- AVERAGE -----
NO.                                  AGE                                                                          T      H      T+H
---------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.54   27.60   27.10   27.38  23.89    1318.4  6.30  0.783E+08  0.00000      42.19  41.54  47.92  44.14  44.89  44.51
 1     1.5  28.29   28.37   27.81   28.13  23.93    1319.4  6.29  0.784E+08  0.00006      35.30  34.66  39.61  36.62  37.30  36.96
 2     2.5  28.80   28.90   28.30   28.65  23.95    1320.2  6.29  0.785E+08  0.00010      31.73  31.11  35.38  32.77  33.40  33.08
 3     5.5  30.34   30.49   29.77   30.20  24.02    1322.4  6.28  0.789E+08  0.00022      24.34  23.80  26.79  24.91  24.98  24.94
 4    15.5  31.31   32.31   30.64   31.42  24.27    1329.8  6.24  0.800E+08  0.00061      21.83  19.12  24.12  21.49  21.69  21.59
 5    25.5  32.33   33.12   31.82   32.42  24.51    1337.2  6.20  0.811E+08  0.00101      19.65  17.86  21.04  19.43  19.52  19.47
 6    45.5  32.54   33.36   31.87   32.59  25.00    1352.4  6.12  0.833E+08  0.00181      20.35  18.36  22.34  20.22  20.35  20.29
 7    75.5  33.05   34.02   32.31   33.12  25.73    1375.9  6.01  0.868E+08  0.00301      20.95  18.50  23.32  20.74  20.92  20.83
 8   105.5  33.76   35.18   32.86   33.93  26.47    1400.2  5.89  0.903E+08  0.00421      20.99  17.55  23.92  20.49  20.82  20.65
 9   135.5  34.63   35.85   33.62   34.70  27.20    1423.3  5.79  0.938E+08  0.00541      20.56  17.65  23.80  20.37  20.67  20.52
10   165.2  34.73   36.19   33.82   34.91  27.92    1444.5  5.69  0.970E+08  0.00661      22.39  18.45  25.88  21.82  22.24  22.03
11   205.2  35.31   36.71   34.28   35.43  28.90    1474.1  5.57  0.102E+09  0.00822      23.73  19.49  28.26  23.29  23.83  23.56
12   245.2  36.53   37.86   35.68   36.69  29.88    1504.9  5.45  0.106E+09  0.00984      22.83  19.01  26.17  22.29  22.67  22.48
13   275.2  36.89   38.38   36.08   37.12  30.61    1528.9  5.36  0.110E+09  0.01105      24.12  19.50  27.69  23.28  23.77  23.52
14   305.2  37.35   38.73   36.46   37.51  31.34    1553.7  5.26  0.114E+09  0.01228      25.19  20.49  29.56  24.52  25.08  24.80
15   333.3  38.24   39.88   37.42   38.51  32.03    1576.8  5.18  0.117E+09  0.01343      24.30  19.23  28.04  23.29  23.86  23.57
16   363.3  38.97   40.47   38.07   39.17  32.76    1599.4  5.09  0.120E+09  0.01467      24.30  19.55  28.39  23.52  24.08  23.80
17   383.3  39.53   40.75   38.51   39.59  33.25    1614.8  5.04  0.123E+09  0.01550      23.99  20.08  28.65  23.73  24.24  23.99
18   403.3  39.99   41.34   39.08   40.14  33.74    1630.6  4.98  0.125E+09  0.01633      24.04  19.79  28.16  23.50  24.00  23.75
19   423.3  40.74   42.12   39.81   40.89  34.23    1646.6  4.92  0.127E+09  0.01717      23.04  19.02  26.90  22.53  22.99  22.76
20   443.3  41.09   42.47   40.23   41.26  34.71    1663.0  4.87  0.130E+09  0.01801      23.54  19.35  27.18  22.91  23.36  23.13
21   463.3  41.74   43.03   40.72   41.83  35.20    1679.7  4.81  0.132E+09  0.01886      22.91  19.15  27.17  22.61  23.08  22.84
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  39.76   41.17   38.85   39.93  33.45    1621.9  5.01  0.124E+09  0.01585      23.87  19.50  27.89  23.25  23.75  23.50
_________________________________________________________________________________________________________________________________
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                                                    XP045-19

INPUT ELECTRIC POWER = 1695.0 W              HEAT RATE GAINED BY WATER = 1594.7 W              HEAT BALANCE ERROR =  5.92%
MASS FLOW RATE = 24.9300 G/S         PRESSURE DROP = 0.6002 MM H2O        FRICTION FACTOR = 0.027599         FREM =  27.7541
REM = 1005.6      GRM   = 0.18818E+08    UPSTREAM BULK TEMPERATURE = 23.82 DEG C    DOWN STREAM BULK TEMPERATURE = 39.16 DEG C
PRM =  5.245      RAM   = 0.98696E+08    INLET BULK TEMPERATURE    = 23.84 DEG C    OUTLET BULK TEMPERATURE      = 39.15 DEG C
-----------------------------------------------------------------------------------------------------------------------------
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA          Z         ------------ NUSSELT NUMBER -----------
TION  CM      A      B      C    AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T       H      T+H
-----------------------------------------------------------------------------------------------------------------------------
  0     0.1  27.43  27.53  27.04  27.30  23.84     849.5  6.31  0.673E+08  0.00000     37.00  36.01  41.55  38.43  39.03  38.73
  1     1.5  28.13  28.27  27.72  28.01  23.89     850.4  6.30  0.675E+08  0.00009     31.29  30.30  34.66  32.18  32.73  32.45
  2     2.5  28.61  28.78  28.19  28.51  23.92     851.0  6.29  0.676E+08  0.00015     28.28  27.31  31.11  28.93  29.45  29.19
  3     5.5  30.07  30.32  29.60  29.99  24.02     852.9  6.28  0.680E+08  0.00034     21.95  21.08  23.78  22.21  22.27  22.24
  4    15.5  31.09  31.92  30.48  31.16  24.35     859.3  6.23  0.693E+08  0.00095     19.67  17.52  21.63  19.46  19.60  19.53
  5    25.5  32.05  32.89  31.49  32.14  24.67     865.8  6.17  0.706E+08  0.00157     17.96  16.12  19.44  17.74  17.84  17.79
  6    45.5  32.27  33.14  31.64  32.35  25.32     879.0  6.07  0.732E+08  0.00280     19.06  16.94  20.94  18.84  18.98  18.91
  7    75.5  32.99  33.96  32.14  33.03  26.30     899.7  5.92  0.772E+08  0.00467     19.74  17.25  22.63  19.63  19.87  19.75
  8   105.5  33.59  34.96  32.64  33.73  27.28     919.7  5.78  0.812E+08  0.00653     20.90  17.16  24.61  20.44  20.89  20.66
  9   135.5  34.52  35.68  33.62  34.61  28.26     938.4  5.65  0.851E+08  0.00840     21.02  17.72  24.56  20.73  21.10  20.92
 10   165.2  35.07  36.36  34.21  35.21  29.23     957.6  5.53  0.890E+08  0.01026     22.49  18.42  26.38  21.95  22.43  22.19
 11   205.2  36.03  37.26  35.06  36.12  30.54     984.8  5.36  0.945E+08  0.01278     23.81  19.46  28.93  23.45  24.07  23.76
 12   245.2  37.58  38.75  36.74  37.69  31.85    1013.5  5.20  0.100E+09  0.01530     22.73  18.89  26.65  22.31  22.76  22.54
 13   275.2  38.34  39.67  37.64  38.55  32.83    1033.0  5.09  0.104E+09  0.01723     23.60  19.01  27.03  22.73  23.21  22.97
 14   305.2  39.07  40.29  38.24  39.20  33.81    1053.3  4.97  0.108E+09  0.01917     24.66  20.01  29.23  24.05  24.64  24.35
 15   333.3  40.02  41.50  39.21  40.24  34.72    1073.0  4.87  0.112E+09  0.02100     24.46  19.10  28.88  23.46  24.15  23.80
 16   363.3  41.07  42.36  40.19  41.21  35.70    1094.8  4.75  0.116E+09  0.02297     24.07  19.39  28.79  23.47  24.08  23.78
 17   383.3  41.58  42.65  40.67  41.64  36.36    1109.9  4.68  0.119E+09  0.02429     24.66  20.48  29.87  24.42  25.00  24.71
 18   403.3  42.17  43.35  41.36  42.29  37.01    1124.9  4.61  0.122E+09  0.02561     24.93  20.30  29.58  24.35  24.94  24.64
 19   423.3  43.18  44.46  42.49  43.38  37.66    1138.6  4.55  0.125E+09  0.02691     23.28  18.91  26.64  22.49  22.94  22.72
 20   443.3  43.66  44.98  42.79  43.81  38.32    1152.7  4.49  0.128E+09  0.02821     24.04  19.26  28.70  23.37  24.00  23.69
 21   463.3  44.48  45.80  43.61  44.63  38.97    1167.1  4.42  0.131E+09  0.02951     23.28  18.77  27.62  22.65  23.22  22.94
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
      391.6  41.95  43.22  41.12  42.09  36.63    1115.6  4.66  0.120E+09  0.02483     24.24  19.57  28.74  23.59  24.19  23.89
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                                                    XP045-20

INPUT ELECTRIC POWER = 1810.0 W              HEAT RATE GAINED BY WATER = 1738.9 W              HEAT BALANCE ERROR =  3.93%
MASS FLOW RATE = 29.9840 G/S         PRESSURE DROP = 0.7042 MM H2O        FRICTION FACTOR = 0.022391         FREM =  26.6897
REM = 1192.0      GRM   = 0.19599E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 37.78 DEG C
PRM =  5.328      RAM   = 0.10443E+09    INLET BULK TEMPERATURE    = 23.89 DEG C    OUTLET BULK TEMPERATURE      = 37.77 DEG C
-----------------------------------------------------------------------------------------------------------------------------
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA          Z         ------------ NUSSELT NUMBER -----------
TION  CM      A      B      C    AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T       H      T+H
-----------------------------------------------------------------------------------------------------------------------------
  0     0.1  27.68  27.81  27.29  27.56  23.89    1022.9  6.30  0.736E+08  0.00000     38.20  37.00  42.62  39.50  40.11  39.81
  1     1.5  28.42  28.59  28.01  28.32  23.94    1023.9  6.29  0.738E+08  0.00008     32.28  31.08  35.55  33.06  33.62  33.34
  2     2.5  28.93  29.14  28.50  28.84  23.97    1024.6  6.29  0.739E+08  0.00013     29.16  27.99  31.90  29.72  30.24  29.98
  3     5.5  30.46  30.77  29.99  30.40  24.06    1026.7  6.27  0.743E+08  0.00028     22.61  21.56  24.39  22.80  22.86  22.83
  4    15.5  31.48  32.48  30.92  31.63  24.35    1033.6  6.22  0.756E+08  0.00079     20.29  17.80  22.01  19.88  20.03  19.96
  5    25.5  32.50  33.39  31.98  32.63  24.65    1040.7  6.18  0.768E+08  0.00130     18.40  16.52  19.70  18.11  18.21  18.16
  6    45.5  32.60  33.58  31.98  32.72  25.24    1055.1  6.08  0.794E+08  0.00233     19.61  17.30  21.40  19.29  19.44  19.36
  7    75.5  33.27  34.34  32.42  33.34  26.13    1077.5  5.94  0.834E+08  0.00388     20.16  17.53  22.90  19.96  20.20  20.08
  8   105.5  33.87  35.41  32.92  34.06  27.02    1100.2  5.81  0.874E+08  0.00543     20.98  17.13  24.36  20.40  20.83  20.61
  9   135.5  34.79  35.96  33.89  34.88  27.90    1120.2  5.70  0.912E+08  0.00698     20.82  17.81  23.95  20.55  20.86  20.71
 10   165.2  35.12  36.63  34.32  35.36  28.78    1140.9  5.59  0.950E+08  0.00853     22.59  18.24  25.87  21.78  22.23  22.01
 11   205.2  36.09  37.43  35.12  36.21  29.97    1169.9  5.44  0.100E+09  0.01061     23.33  19.14  27.73  22.87  23.40  23.13
 12   245.2  37.31  38.58  36.46  37.45  31.15    1200.4  5.29  0.106E+09  0.01271     23.14  19.16  26.82  22.61  23.04  22.83
 13   275.2  37.89  39.39  37.19  38.16  32.04    1223.6  5.18  0.110E+09  0.01429     24.27  19.34  27.57  23.22  23.73  23.48
 14   305.2  38.62  39.96  37.80  38.79  32.93    1244.9  5.07  0.114E+09  0.01589     24.90  20.18  29.10  24.18  24.73  24.45
 15   333.3  39.57  41.17  38.82  39.85  33.76    1265.6  4.98  0.118E+09  0.01740     24.34  19.10  27.98  23.23  23.81  23.52
 16   363.3  40.57  41.97  39.80  40.78  34.65    1288.5  4.88  0.122E+09  0.01902     23.83  19.27  27.40  23.02  23.50  23.26
 17   383.3  41.08  42.37  40.12  41.19  35.24    1304.2  4.81  0.124E+09  0.02011     24.12  19.76  28.91  23.69  24.26  23.98
 18   403.3  41.72  42.96  40.81  41.83  35.83    1320.3  4.74  0.127E+09  0.02121     23.90  19.74  28.30  23.47  23.98  23.72
 19   423.3  42.63  43.91  41.87  42.80  36.43    1336.8  4.67  0.130E+09  0.02231     22.65  18.78  25.80  22.04  22.41  22.22
 20   443.3  43.04  44.48  42.12  43.21  37.02    1353.1  4.60  0.133E+09  0.02341     23.30  18.81  27.49  22.65  23.20  22.92
 21   463.3  43.81  45.24  42.83  43.96  37.61    1368.0  4.55  0.136E+09  0.02448     22.62  18.37  26.83  22.07  22.61  22.34
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
      391.6  41.44  42.81  40.59  41.61  35.49    1311.4  4.78  0.126E+09  0.02058     23.69  19.25  27.65  23.01  23.53  23.27
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                                                    XP045-21

INPUT ELECTRIC POWER = 1650.0 W              HEAT RATE GAINED BY WATER = 1599.5 W              HEAT BALANCE ERROR =  3.06%
MASS FLOW RATE = 24.5690 G/S         PRESSURE DROP = 0.5610 MM H2O        FRICTION FACTOR = 0.026558         FREM =  26.4653
REM =  996.5      GRM   = 0.19201E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 39.54 DEG C
PRM =  5.214      RAM   = 0.10011E+09    INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 39.53 DEG C
-----------------------------------------------------------------------------------------------------------------------------
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA          Z         ------------ NUSSELT NUMBER -----------
TION  CM      A      B      C    AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T       H      T+H
-----------------------------------------------------------------------------------------------------------------------------
  0     0.1  27.65  27.82  27.26  27.54  23.95     839.3  6.29  0.680E+08  0.00000     36.00  34.45  40.27  37.10  37.75  37.42
  1     1.5  28.35  28.59  27.94  28.27  24.00     840.2  6.28  0.682E+08  0.00009     30.59  29.02  33.79  31.20  31.80  31.50
  2     2.5  28.84  29.12  28.41  28.77  24.03     840.9  6.27  0.683E+08  0.00016     27.72  26.18  30.41  28.11  28.68  28.40
  3     5.5  30.29  30.71  29.82  30.27  24.13     842.8  6.26  0.687E+08  0.00034     21.62  20.23  23.40  21.68  21.75  21.71
  4    15.5  31.20  32.26  30.64  31.37  24.47     849.2  6.21  0.700E+08  0.00097     19.75  17.07  21.53  19.27  19.45  19.36
  5    25.5  32.27  33.17  31.82  32.42  24.80     855.7  6.15  0.713E+08  0.00159     17.78  15.87  18.94  17.44  17.53  17.48
  6    45.5  32.43  33.36  31.82  32.54  25.46     869.1  6.05  0.740E+08  0.00285     19.04  16.80  20.88  18.76  18.91  18.83
  7    75.5  33.05  34.07  32.08  33.07  26.46     890.0  5.89  0.781E+08  0.00474     20.09  17.39  23.54  20.03  20.34  20.19
  8   105.5  33.59  35.02  32.64  33.75  27.46     909.6  5.75  0.821E+08  0.00663     21.54  17.47  25.49  21.00  21.50  21.25
  9   135.5  34.52  35.74  33.73  34.66  28.45     928.4  5.63  0.861E+08  0.00853     21.74  18.09  24.99  21.23  21.61  21.42
 10   165.2  35.29  36.63  34.54  35.49  29.44     947.9  5.50  0.901E+08  0.01042     22.49  18.28  25.80  21.75  22.19  21.97
 11   205.2  36.31  37.65  35.34  36.43  30.77     975.4  5.34  0.958E+08  0.01297     23.66  19.06  28.70  23.15  23.81  23.48
 12   245.2  37.86  39.08  37.02  37.99  32.10    1003.8  5.17  0.102E+09  0.01554     22.69  18.72  26.59  22.20  22.66  22.43
 13   275.2  38.67  39.94  37.97  38.86  33.10    1023.5  5.06  0.106E+09  0.01750     23.39  19.04  26.74  22.61  23.06  22.83
 14   305.2  39.46  40.68  38.69  39.61  34.09    1044.0  4.94  0.110E+09  0.01947     24.26  19.75  28.27  23.58  24.09  23.84
 15   333.3  40.57  42.06  39.77  40.80  35.03    1064.0  4.83  0.114E+09  0.02133     23.40  18.45  27.38  22.48  23.08  22.78
 16   363.3  41.68  43.03  40.86  41.86  36.03    1086.2  4.72  0.118E+09  0.02333     22.89  18.48  26.76  22.19  22.71  22.45
 17   383.3  42.19  43.38  41.22  42.26  36.69    1101.6  4.64  0.121E+09  0.02468     23.47  19.32  28.50  23.17  23.76  23.47
 18   403.3  42.95  44.13  42.08  43.06  37.36    1115.7  4.57  0.124E+09  0.02600     23.06  19.03  27.28  22.63  23.12  22.88
 19   423.3  43.85  45.13  43.21  44.06  38.02    1129.6  4.51  0.127E+09  0.02732     22.10  18.13  24.82  21.32  21.68  21.50
 20   443.3  44.27  45.66  43.46  44.46  38.69    1144.0  4.45  0.130E+09  0.02864     23.05  18.46  26.94  22.28  22.82  22.55
 21   463.3  45.09  46.42  44.28  45.26  39.35    1158.6  4.39  0.133E+09  0.02996     22.39  18.18  26.05  21.73  22.21  21.97
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
      391.6  42.59  43.90  41.77  42.75  36.97    1106.9  4.62  0.122E+09  0.02521     22.99  18.64  26.95  22.34  22.86  22.60
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                                                          XP045-22

INPUT ELECTRIC POWER = 1505.0 W              HEAT RATE GAINED BY WATER = 1436.8 W               HEAT BALANCE ERROR =  4.53%
MASS FLOW RATE = 19.1540 G/S          PRESSURE DROP = 0.4552 MM H2O          FRICTION FACTOR = 0.035439          FREM =  28.1852
REM =   795.3     GRM   = 0.18561E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 41.92 DEG C
PRM =   5.075     RAM   = 0.94191E+08    INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 41.91 DEG C
---------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR      RA           Z          ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                                 A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                              T      H      T+H
---------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.49  27.67  27.15  27.41  23.96      654.4   6.29  0.611E+08  0.00000     33.88  32.18  37.46  34.66  35.25  34.95
 1     1.5  28.14  28.41  27.79  28.09  24.01      655.2   6.28  0.613E+08  0.00012     28.95  27.22  31.68  29.32  29.88  29.60
 2     2.5  28.60  28.91  28.23  28.56  24.05      655.8   6.27  0.614E+08  0.00020     26.30  24.60  28.64  26.50  27.04  26.77
 3     5.5  29.96  30.43  29.54  29.98  24.16      657.5   6.25  0.618E+08  0.00044     20.65  19.09  22.22  20.57  20.65  20.61
 4    15.5  30.92  31.86  30.37  31.05  24.55      663.3   6.19  0.631E+08  0.00124     18.74  16.33  20.53  18.37  18.53  18.45
 5    25.5  31.88  32.78  31.43  32.03  24.93      669.2   6.13  0.645E+08  0.00204     17.17  15.20  18.35  16.80  16.91  16.85
 6    45.5  32.10  33.03  31.59  32.24  25.70      681.3   6.01  0.673E+08  0.00365     18.60  16.25  20.22  18.21  18.36  18.28
 7    75.5  32.78  33.74  31.86  32.79  26.85      700.4   5.83  0.717E+08  0.00608     20.03  17.24  23.69  19.98  20.32  20.15
 8   105.5  33.48  34.79  32.58  33.62  27.99      716.9   5.69  0.757E+08  0.00851     21.61  17.43  25.83  21.07  21.62  21.35
 9   135.5  34.57  35.74  33.84  34.72  29.14      734.3   5.54  0.798E+08  0.01095     21.77  17.92  25.17  21.21  21.62  21.42
10   165.2  35.57  36.80  34.93  35.76  30.28      752.4   5.40  0.841E+08  0.01338     22.30  18.08  25.37  21.50  21.92  21.71
11   205.2  37.03  38.15  36.17  37.12  31.81      778.1   5.20  0.902E+08  0.01667     22.51  18.54  26.95  22.14  22.67  22.40
12   245.2  38.63  39.75  37.97  38.78  33.34      801.8   5.03  0.957E+08  0.02001     22.13  18.27  25.32  21.52  21.91  21.71
13   275.2  39.56  40.72  38.92  39.73  34.49      820.5   4.89  0.999E+08  0.02255     23.03  18.73  26.38  22.27  22.71  22.49
14   305.2  40.46  41.62  39.81  40.63  35.64      840.1   4.76  0.104E+09  0.02511     24.17  19.46  27.95  23.34  23.86  23.60
15   333.3  41.91  43.18  41.16  42.08  36.72      859.3   4.64  0.109E+09  0.02753     22.37  17.96  26.12  21.64  22.15  21.89
16   363.3  42.90  44.19  42.20  43.10  37.87      878.2   4.53  0.113E+09  0.03007     23.00  18.30  26.72  22.13  22.67  22.40
17   383.3  43.58  44.66  42.72  43.66  38.63      891.0   4.46  0.116E+09  0.03176     23.35  19.18  28.27  23.02  23.60  23.31
18   403.3  44.34  45.47  43.70  44.51  39.40      904.2   4.39  0.119E+09  0.03346     23.34  19.01  26.84  22.61  23.06  22.83
19   423.3  45.46  46.58  44.83  45.62  40.17      917.7   4.31  0.123E+09  0.03516     21.79  17.97  24.72  21.13  21.49  21.31
20   443.3  45.99  47.22  45.24  46.15  40.93      931.7   4.24  0.126E+09  0.03687     22.73  18.29  26.72  22.05  22.58  22.31
21   463.3  46.82  48.10  46.12  47.01  41.70      946.2   4.17  0.129E+09  0.03859     22.45  17.95  26.01  21.63  22.13  21.88
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  44.03  45.22  43.31  44.19  38.95      897.0   4.43  0.118E+09  0.03247     22.76  18.45  26.56  22.09  22.59  22.34
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                                                          XP045-23

INPUT ELECTRIC POWER = 2340.0 W              HEAT RATE GAINED BY WATER = 2246.2 W               HEAT BALANCE ERROR =  4.01%
MASS FLOW RATE = 27.0960 G/S          PRESSURE DROP = 0.6922 MM H2O          FRICTION FACTOR = 0.026990          FREM =  26.9820
REM =   999.7     GRM   = 0.19815E+08    UPSTREAM BULK TEMPERATURE = 17.35 DEG C    DOWN STREAM BULK TEMPERATURE = 37.22 DEG C
PRM =   5.775     RAM   = 0.11442E+09    INLET BULK TEMPERATURE    = 17.37 DEG C    OUTLET BULK TEMPERATURE      = 37.21 DEG C
---------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR      RA           Z          ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                                 A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                              T      H      T+H
---------------------------------------------------------------------------------------------------------------------------------
 0     0.1  22.35  22.59  21.90  22.24  17.37      793.7   7.46  0.615E+08  0.00000     38.22  36.46  42.00  39.08  39.67  39.38
 1     1.5  23.31  23.65  22.85  23.24  17.43      794.9   7.45  0.618E+08  0.00008     32.36  30.59  35.14  32.76  33.31  33.03
 2     2.5  23.97  24.38  23.50  23.93  17.48      795.6   7.44  0.620E+08  0.00014     29.27  27.54  31.58  29.47  29.99  29.73
 3     5.5  25.96  26.57  25.45  25.99  17.60      797.9   7.42  0.626E+08  0.00031     22.74  21.19  24.22  22.65  22.72  22.68
 4    15.5  27.38  28.82  26.74  27.65  18.03      805.7   7.34  0.646E+08  0.00086     20.30  17.58  21.77  19.73  19.89  19.81
 5    25.5  28.76  29.96  28.16  28.96  18.45      813.6   7.26  0.667E+08  0.00142     18.40  16.48  19.52  18.04  18.13  18.09
 6    45.5  28.94  30.19  28.14  29.09  19.30      829.9   7.10  0.709E+08  0.00254     19.61  17.37  21.39  19.31  19.46  19.39
 7    75.5  29.89  31.29  28.85  30.01  20.57      855.7   6.86  0.775E+08  0.00423     20.21  17.57  22.76  19.96  20.18  20.07
 8   105.5  30.64  32.56  29.30  30.83  21.84      883.1   6.62  0.844E+08  0.00593     21.34  17.52  25.17  20.88  21.35  21.11
 9   135.5  31.74  33.46  30.62  31.94  23.10      908.1   6.42  0.909E+08  0.00764     21.70  18.09  24.92  21.20  21.57  21.39
10   165.2  32.46  34.41  31.26  32.71  24.36      934.3   6.22  0.977E+08  0.00935     23.06  18.59  27.10  22.38  22.92  22.65
11   205.2  33.42  35.21  32.22  33.62  26.05      972.0   5.96  0.107E+09  0.01166     25.26  20.33  30.17  24.61  25.25  24.93
12   245.2  35.42  37.08  34.29  35.60  27.75     1009.1   5.72  0.117E+09  0.01398     24.15  19.85  28.33  23.61  24.11  23.86
13   275.2  36.51  38.33  35.64  36.82  29.02     1036.0   5.56  0.124E+09  0.01572     24.68  19.85  27.91  23.67  24.15  23.91
14   305.2  37.35  39.01  36.24  37.53  30.29     1064.4   5.40  0.132E+09  0.01748     26.09  21.14  30.96  25.44  26.06  25.75
15   333.3  38.80  40.83  37.75  39.13  31.47     1092.5   5.25  0.139E+09  0.01912     25.09  19.64  29.29  24.02  24.67  24.35
16   363.3  40.07  41.92  38.91  40.30  32.74     1121.0   5.10  0.146E+09  0.02092     25.00  19.98  29.74  24.26  24.91  24.58
17   383.3  40.64  42.37  39.45  40.82  33.59     1139.9   5.00  0.151E+09  0.02213     25.94  20.82  31.20  25.29  25.99  25.64
18   403.3  41.61  43.35  40.53  41.83  34.44     1159.4   4.90  0.156E+09  0.02335     25.43  20.47  29.95  24.68  25.28  24.98
19   423.3  42.85  44.57  41.82  43.08  35.28     1179.6   4.80  0.161E+09  0.02458     24.06  19.60  27.86  23.35  23.84  23.59
20   443.3  43.48  45.32  42.29  43.70  36.13     1200.6   4.70  0.166E+09  0.02582     24.70  19.76  29.49  24.00  24.65  24.32
21   463.3  44.31  46.31  43.06  44.56  36.98     1221.8   4.61  0.171E+09  0.02707     24.71  19.43  29.81  23.91  24.65  24.28
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  41.24  43.06  40.12  41.48  33.94     1148.8   4.96  0.153E+09  0.02266     25.04  20.04  29.59  24.26  24.89  24.58
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                                                          XP045-24

INPUT ELECTRIC POWER = 1245.0 W              HEAT RATE GAINED BY WATER = 1200.1 W               HEAT BALANCE ERROR =  3.60%
MASS FLOW RATE = 11.2120 G/S          PRESSURE DROP = 0.2523 MM H2O          FRICTION FACTOR = 0.057238          FREM =  28.7910
REM =   503.0     GRM   = 0.19567E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 49.55 DEG C
PRM =   4.635     RAM   = 0.90695E+08    INLET BULK TEMPERATURE    = 23.91 DEG C    OUTLET BULK TEMPERATURE      = 49.53 DEG C
---------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR      RA           Z          ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                                 A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                              T      H      T+H
---------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.49  27.72  27.12  27.41  23.91      382.7   6.29  0.509E+08  0.00001     27.94  26.25  31.17  28.59  29.13  28.86
 1     1.5  28.06  28.38  27.68  28.01  23.99      383.4   6.28  0.511E+08  0.00020     24.58  22.76  27.12  24.85  25.39  25.12
 2     2.5  28.45  28.84  28.06  28.43  24.05      383.8   6.27  0.513E+08  0.00034     22.69  20.85  24.89  22.79  23.33  23.06
 3     5.5  29.62  30.21  29.21  29.68  24.21      385.3   6.25  0.517E+08  0.00075     18.45  16.66  19.97  18.26  18.36  18.31
 4    15.5  30.53  31.52  30.03  30.69  24.76      390.1   6.16  0.534E+08  0.00212     17.26  14.74  18.92  16.80  16.97  16.89
 5    25.5  31.55  32.39  31.10  31.68  25.30      395.1   6.07  0.550E+08  0.00349     15.94  14.05  17.18  15.62  15.72  15.67
 6    45.5  31.93  32.86  31.42  32.07  26.40      405.5   5.90  0.584E+08  0.00625     17.94  15.37  19.77  17.50  17.69  17.60
 7    75.5  33.11  33.96  32.19  33.09  28.04      420.0   5.68  0.633E+08  0.01041     19.52  16.71  23.80  19.60  20.01  19.80
 8   105.5  34.31  35.46  33.47  34.41  29.68      434.7   5.47  0.684E+08  0.01458     21.27  17.04  25.97  20.81  21.43  21.12
 9   135.5  35.79  36.85  35.12  35.92  31.31      450.5   5.27  0.737E+08  0.01878     21.93  17.75  25.84  21.33  21.84  21.59
10   165.2  37.56  38.58  36.93  37.69  32.94      465.6   5.07  0.787E+08  0.02300     21.17  17.35  24.49  20.59  21.00  20.80
11   205.2  39.48  40.54  38.79  39.60  35.12      486.5   4.82  0.855E+08  0.02878     22.35  17.97  26.55  21.73  22.29  22.01
12   245.2  41.74  42.81  41.03  41.86  37.31      508.7   4.58  0.926E+08  0.03464     21.86  17.61  26.00  21.28  21.82  21.55
13   275.2  43.23  44.28  42.58  43.36  38.95      524.7   4.43  0.981E+06  0.03897     22.55  18.09  26.55  21.85  22.40  22.13
14   305.2  44.62  45.63  44.04  44.76  40.59      541.7   4.28  0.104E+09  0.04334     23.88  19.07  27.84  23.04  23.60  23.32
15   333.3  46.51  47.66  45.97  46.71  42.12      558.2   4.14  0.110E+09  0.04746     21.87  17.34  24.93  20.90  21.38  21.14
16   363.3  47.99  49.13  47.38  48.17  43.76      574.4   4.01  0.115E+09  0.05188     22.60  17.81  26.42  21.70  22.28  21.99
17   383.3  48.91  49.91  48.27  49.03  44.86      585.7   3.93  0.119E+09  0.05484     23.54  18.88  27.99  22.87  23.47  23.17
18   403.3  50.19  51.22  49.60  50.34  45.95      597.5   3.84  0.123E+09  0.05782     22.44  18.08  26.09  21.71  22.20  21.96
19   423.3  51.39  52.48  50.74  51.54  47.04      609.6   3.76  0.127E+09  0.06081     21.87  17.49  25.72  21.16  21.69  21.42
20   443.3  52.18  53.32  51.52  52.34  48.14      621.1   3.68  0.132E+09  0.06380     23.44  18.29  28.02  22.56  23.25  22.90
21   463.3  53.11  54.37  52.52  53.33  49.23      633.1   3.60  0.136E+09  0.06680     24.43  18.42  28.76  23.08  23.87  23.47
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  49.53  50.62  48.91  49.69  45.31      591.1   3.89  0.121E+09  0.05610     22.63  17.98  26.53  21.82  22.38  22.10
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XP045-25

```
INPUT ELECTRIC POWER = 3345.0 W            HEAT RATE GAINED BY WATER = 3208.2 W            HEAT BALANCE ERROR =  4.09%
MASS FLOW RATE = 34.3160 G/S        PRESSURE DROP = 0.8917 MM H2O        FRICTION FACTOR = 0.021608        FREM =  32.2616
REM = 1493.0     GRM   = 0.47779E+08    UPSTREAM BULK TEMPERATURE = 24.04 DEG C    DOWN STREAM BULK TEMPERATURE = 46.46 DEG C
PRM =  4.605     RAM   = 0.22959E+09    INLET BULK TEMPERATURE    = 24.07 DEG C    OUTLET BULK TEMPERATURE      = 46.44 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE      PR      RA          Z       ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                            A      B      C    ----- AVERAGE -----
NO.                                AGE                                                                       T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  30.03  30.30  29.36  29.84  24.07    1175.3  6.27  0.137E+09  0.00000    44.80  42.88  50.47  46.24  47.15  46.70
 1     1.5  31.25  31.63  30.51  31.09  24.14    1177.2  6.26  0.138E+09  0.00007    37.54  35.65  41.88  38.39  39.24  38.81
 2     2.5  32.09  32.54  31.31  31.95  24.18    1178.5  6.25  0.138E+09  0.00011    33.76  31.94  37.48  34.37  35.16  34.76
 3     5.5  34.62  35.29  33.69  34.54  24.33    1182.4  6.23  0.139E+09  0.00025    25.94  24.33  28.49  26.14  26.25  26.20
 4    15.5  35.85  37.72  34.82  36.13  24.81    1195.4  6.15  0.143E+09  0.00069    24.13  20.64  26.63  23.54  23.80  23.67
 5    25.5  37.36  39.00  36.47  37.61  25.28    1208.8  6.08  0.147E+09  0.00114    22.04  19.41  23.80  21.60  21.75  21.67
 6    45.5  37.48  39.19  36.38  37.69  26.24    1236.5  5.93  0.155E+09  0.00204    23.64  20.50  26.19  23.21  23.44  23.32
 7    75.5  38.59  40.61  37.43  38.88  27.67    1275.9  5.73  0.166E+09  0.00340    24.25  20.46  27.12  23.63  23.94  23.79
 8   105.5  39.76  42.37  37.98  40.04  29.10    1314.4  5.55  0.178E+09  0.00476    24.76  19.90  29.74  24.14  24.80  24.47
 9   135.5  40.96  43.29  39.44  41.23  30.53    1355.3  5.37  0.190E+09  0.00613    25.23  20.62  29.52  24.59  25.12  24.86
10   165.2  41.72  44.47  40.27  42.16  31.95    1397.9  5.19  0.203E+09  0.00749    26.84  20.94  31.51  25.70  26.43  26.07
11   205.2  42.98  45.59  41.24  43.27  33.86    1451.4  4.97  0.218E+09  0.00936    28.62  22.24  35.37  27.73  28.74  28.24
12   245.2  44.95  47.42  43.32  45.23  35.77    1509.1  4.75  0.234E+09  0.01126    28.29  22.29  34.41  27.45  28.33  27.89
13   275.2  46.17  48.84  44.86  46.63  37.20    1553.8  4.59  0.247E+09  0.01270    28.85  22.23  33.79  27.46  28.29  27.87
14   305.2  46.95  49.42  45.49  47.29  38.63    1596.2  4.46  0.259E+09  0.01411    31.03  23.93  37.62  29.82  30.86  30.34
15   333.3  48.96  51.73  47.48  49.39  39.97    1638.1  4.33  0.272E+09  0.01545    28.66  21.89  34.28  27.34  28.28  27.81
16   363.3  50.32  52.97  48.67  50.65  41.41    1685.2  4.20  0.286E+09  0.01688    28.80  22.21  35.36  27.77  28.79  28.28
17   383.3  51.08  53.26  49.32  51.22  42.36    1715.4  4.12  0.295E+09  0.01784    29.40  23.51  36.84  28.93  29.92  29.43
18   403.3  52.09  54.45  50.55  52.36  43.32    1744.1  4.05  0.304E+09  0.01880    29.16  22.98  35.36  28.28  29.17  28.72
19   423.3  53.38  55.87  52.02  53.76  44.27    1773.9  3.97  0.313E+09  0.01977    28.02  22.01  32.94  26.91  27.66  27.28
20   443.3  53.97  56.57  52.42  54.32  45.23    1804.6  3.90  0.322E+09  0.02074    29.16  22.47  35.44  28.04  29.03  28.53
21   463.3  55.28  57.62  53.75  55.55  46.18    1836.5  3.82  0.332E+09  0.02171    27.97  22.24  33.61  27.15  27.94  27.55
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  51.63  54.14  50.08  51.95  42.76    1726.9  4.09  0.299E+09  0.01825    28.87  22.51  35.04  27.88  28.81  28.34
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XP045-26

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INPUT ELECTRIC POWER = 3000.0 W            HEAT RATE GAINED BY WATER = 2903.8 W            HEAT BALANCE ERROR =  3.21%
MASS FLOW RATE = 26.3740 G/S        PRESSURE DROP = 0.6718 MM H2O        FRICTION FACTOR = 0.027540        FREM =  32.8148
REM = 1191.6     GRM   = 0.48340E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 50.27 DEG C
PRM =  4.599     RAM   = 0.22231E+09    INLET BULK TEMPERATURE    = 23.90 DEG C    OUTLET BULK TEMPERATURE      = 50.26 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE      PR      RA          Z       ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                            A      B      C    ----- AVERAGE -----
NO.                                AGE                                                                       T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.78  30.15  29.06  29.60  23.91     900.0  6.30  0.123E+09  0.00000    41.20  38.72  46.92  42.47  43.44  42.95
 1     1.5  30.92  31.44  30.16  30.79  23.99     901.7  6.28  0.124E+09  0.00009    34.89  32.42  39.17  35.52  36.41  35.96
 2     2.5  31.70  32.34  30.92  31.62  24.04     902.8  6.27  0.124E+09  0.00015    31.56  29.15  35.16  31.91  32.76  32.34
 3     5.5  34.06  35.01  33.19  34.09  24.21     906.3  6.25  0.125E+09  0.00032    24.53  22.37  26.90  24.46  24.60  24.53
 4    15.5  35.30  37.21  34.37  35.63  24.78     918.1  6.16  0.129E+09  0.00090    22.92  19.41  25.14  22.24  22.49  22.36
 5    25.5  36.80  38.45  36.03  37.09  25.34     930.2  6.07  0.133E+09  0.00149    21.02  18.38  22.53  20.50  20.64  20.57
 6    45.5  37.14  38.81  36.16  37.37  26.46     955.4  5.89  0.142E+09  0.00266    22.50  19.47  24.78  22.03  22.25  22.14
 7    75.5  38.21  40.06  36.66  38.31  28.15     990.3  5.67  0.154E+09  0.00443    23.81  20.10  28.14  23.57  24.02  23.79
 8   105.5  39.15  41.76  37.59  39.50  29.83    1026.1  5.45  0.167E+09  0.00620    25.60  20.01  30.76  24.68  25.46  25.07
 9   135.5  40.68  42.96  39.11  40.92  31.52    1064.5  5.24  0.180E+09  0.00799    25.93  20.77  31.30  25.28  26.00  25.64
10   165.2  42.00  44.53  40.61  42.38  33.19    1100.7  5.04  0.192E+09  0.00979    26.86  20.87  31.91  25.75  26.54  26.15
11   205.2  43.64  46.04  41.85  43.84  35.44    1151.9  4.78  0.209E+09  0.01225    28.67  22.19  36.69  27.99  29.18  28.59
12   245.2  46.17  48.42  44.54  46.38  37.69    1205.1  4.54  0.227E+09  0.01473    27.58  21.80  34.13  26.92  27.84  27.38
13   275.2  47.67  50.18  46.48  48.11  39.37    1244.3  4.39  0.241E+09  0.01658    28.13  21.58  32.84  26.70  27.52  27.11
14   305.2  48.78  51.03  47.22  49.01  41.06    1286.2  4.23  0.256E+09  0.01844    30.11  23.31  37.73  29.24  30.39  29.81
15   333.3  50.90  53.47  49.55  51.31  42.64    1324.7  4.10  0.269E+09  0.02019    28.07  21.41  33.55  26.75  27.68  27.21
16   363.3  52.37  54.80  51.01  52.73  44.33    1364.7  3.97  0.284E+09  0.02208    28.72  22.06  34.57  27.51  28.45  27.98
17   383.3  53.24  55.38  51.59  53.41  45.45    1392.7  3.88  0.294E+09  0.02334    29.59  23.22  37.53  28.98  30.11  29.55
18   403.3  54.54  56.74  53.33  54.87  46.57    1421.8  3.79  0.304E+09  0.02461    28.87  22.64  34.05  27.73  28.52  28.13
19   423.3  55.94  58.21  54.64  56.26  47.70    1450.0  3.71  0.314E+09  0.02588    27.88  21.86  33.10  26.83  27.61  27.22
20   443.3  56.64  59.08  55.25  56.99  48.82    1478.7  3.63  0.325E+09  0.02715    29.34  22.35  35.68  28.07  29.12  28.60
21   463.3  58.06  60.26  56.42  58.25  49.95    1508.5  3.55  0.335E+09  0.02843    28.21  22.20  35.35  27.58  28.59  28.08
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  53.94  56.28  52.56  54.26  45.92    1405.4  3.85  0.298E+09  0.02387    28.74  22.26  34.74  27.65  28.58  28.11
```

XP045-27

```
INPUT ELECTRIC POWER = 2755.0 W            HEAT RATE GAINED BY WATER = 2612.3 W            HEAT BALANCE ERROR =  5.18%
MASS FLOW RATE = 21.3200 G/S        PRESSURE DROP = 0.5354 MM H2O        FRICTION FACTOR = 0.033565        FREM =  33.3179
REM =  992.6     GRM   = 0.47543E+08    UPSTREAM BULK TEMPERATURE = 23.99 DEG C    DOWN STREAM BULK TEMPERATURE = 53.37 DEG C
PRM =  4.451     RAM   = 0.21163E+09    INLET BULK TEMPERATURE    = 24.02 DEG C    OUTLET BULK TEMPERATURE      = 53.34 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE      PR      RA          Z       ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                            A      B      C    ----- AVERAGE -----
NO.                                AGE                                                                       T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.58  30.00  28.96  29.46  24.02     729.5  6.28  0.111E+09  0.00000    39.14  36.40  44.00  40.02  40.89  40.45
 1     1.5  30.64  31.23  30.00  30.58  24.11     731.0  6.26  0.112E+09  0.00011    33.32  30.56  36.91  33.61  34.43  34.02
 2     2.5  31.37  32.08  30.72  31.36  24.18     732.0  6.25  0.112E+09  0.00018    30.22  27.51  33.22  30.27  31.04  30.66
 3     5.5  33.56  34.62  32.87  33.68  24.36     735.2  6.22  0.114E+09  0.00040    23.62  21.18  25.55  23.31  23.45  23.38
 4    15.5  34.86  36.70  33.98  35.18  24.99     745.9  6.12  0.118E+09  0.00112    21.99  18.53  24.12  21.29  21.55  21.42
 5    25.5  36.36  38.01  35.64  36.67  25.61     756.9  6.03  0.122E+09  0.00184    20.17  17.48  21.60  19.60  19.75  19.68
 6    45.5  36.70  38.36  35.66  36.91  26.87     779.9  5.83  0.130E+09  0.00329    21.97  18.79  24.56  21.51  21.77  21.64
 7    75.5  37.93  39.78  36.60  38.10  28.74     810.5  5.59  0.142E+09  0.00548    23.42  19.48  27.37  22.98  23.42  23.20
 8   105.5  39.21  41.70  37.64  39.52  30.62     843.6  5.36  0.155E+09  0.00768    24.94  19.33  30.49  24.07  24.92  24.50
 9   135.5  40.79  42.91  39.33  41.01  32.50     877.7  5.13  0.168E+09  0.00991    25.69  20.48  31.18  25.04  25.79  25.41
10   165.2  42.39  44.86  41.22  42.82  34.35     910.7  4.91  0.181E+09  0.01215    26.41  20.20  30.92  25.06  25.84  25.45
11   205.2  44.59  46.76  43.13  44.83  36.86     959.2  4.62  0.198E+09  0.01523    27.25  21.29  33.62  26.45  27.38  26.92
12   245.2  47.22  49.37  45.72  47.44  39.36    1005.6  4.39  0.217E+09  0.01827    26.68  20.97  33.00  25.98  26.88  26.43
13   275.2  49.00  51.18  47.76  49.31  41.23    1043.4  4.22  0.231E+09  0.02058    26.93  21.02  32.07  25.88  26.67  26.28
14   305.2  50.12  52.15  48.89  50.39  43.11    1079.7  4.06  0.246E+09  0.02289    29.74  23.05  36.03  28.64  29.61  29.12
15   333.3  52.45  54.92  51.23  52.87  44.87    1114.0  3.92  0.260E+09  0.02508    27.39  20.66  32.66  25.97  26.90  26.44
16   363.3  54.14  56.41  52.85  54.47  46.74    1153.0  3.78  0.275E+09  0.02743    27.97  21.41  33.90  26.80  27.76  27.28
17   383.3  55.19  57.12  53.70  55.34  48.00    1178.2  3.69  0.285E+09  0.02900    28.72  22.65  36.21  28.14  29.19  28.67
18   403.3  56.61  58.69  55.34  56.88  49.25    1204.3  3.60  0.296E+09  0.03058    28.01  21.83  33.84  27.02  27.90  27.46
19   423.3  58.16  60.32  56.87  58.45  50.50    1231.6  3.51  0.307E+09  0.03217    26.87  20.94  32.28  25.87  26.70  26.29
20   443.3  58.93  61.27  57.64  59.28  51.75    1260.1  3.43  0.318E+09  0.03377    28.61  21.58  34.83  27.27  28.34  27.80
21   463.3  60.40  62.55  59.21  60.72  53.00    1284.3  3.36  0.328E+09  0.03534    27.70  21.46  33.03  26.55  27.40  26.97
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  55.91  58.12  54.61  56.21  48.52    1190.2  3.66  0.290E+09  0.02967    27.93  21.51  33.95  26.84  27.80  27.32
```

```
                                                    XP045-28

INPUT ELECTRIC POWER = 2755.0 W            HEAT RATE GAINED BY WATER = 2617.6 W            HEAT BALANCE ERROR =  4.99%
MASS FLOW RATE = 21.3200 G/S          PRESSURE DROP = 0.5456 MM H2O          FRICTION FACTOR = 0.034205          FREM =  33.9364
REM =   992.1     GRM   = 0.47570E+08     UPSTREAM BULK TEMPERATURE = 23.93 DEG C     DOWN STREAM BULK TEMPERATURE = 53.37 DEG C
PRM =   4.454     RAM   = 0.21187E+09     INLET BULK TEMPERATURE    = 23.96 DEG C     OUTLET BULK TEMPERATURE      = 53.35 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR       RA         Z          ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                             A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                        T      H      T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.60  30.00  29.01  29.48  23.97     728.6  6.29  0.111E+09  0.00000     38.69  36.14  43.23  39.54  40.32  39.93
 1     1.5  30.67  31.23  30.06  30.61  24.06     730.1  6.27  0.112E+09  0.00011     32.96  30.39  36.27  33.24  33.97  33.61
 2     2.5  31.41  32.08  30.79  31.39  24.12     731.1  6.26  0.112E+09  0.00018     29.90  27.38  32.65  29.95  30.65  30.30
 3     5.5  33.62  34.62  32.98  33.74  24.31     734.3  6.23  0.113E+09  0.00040     23.39  21.11  25.12  23.09  23.21  23.15
 4    15.5  34.91  36.70  34.04  35.22  24.94     745.0  6.13  0.118E+09  0.00112     21.80  18.48  23.88  21.15  21.39  21.27
 5    25.5  36.41  38.06  35.64  36.71  25.56     756.0  6.03  0.122E+09  0.00184     20.01  17.37  21.53  19.48  19.64  19.56
 6    45.5  36.76  38.42  35.88  37.02  26.82     779.0  5.84  0.130E+09  0.00329     21.78  18.66  23.88  21.22  21.44  21.33
 7    75.5  37.98  39.89  36.66  38.18  28.70     809.7  5.60  0.142E+09  0.00548     23.21  19.25  27.08  22.74  23.18  22.96
 8   105.5  39.26  41.76  37.76  39.59  30.58     842.8  5.36  0.155E+09  0.00768     24.72  19.20  29.90  23.81  24.61  24.21
 9   135.5  40.91  43.07  39.44  41.14  32.46     877.1  5.13  0.169E+09  0.00991     25.29  20.13  30.58  24.61  25.34  24.97
10   165.2  42.50  44.86  41.22  42.86  34.32     910.1  4.91  0.181E+09  0.01215     25.99  20.17  30.83  24.90  25.67  25.28
11   205.2  44.54  46.71  42.96  44.74  36.83     958.6  4.62  0.199E+09  0.01523     27.40  21.39  34.44  26.72  27.74  27.23
12   245.2  47.22  49.42  45.77  47.47  39.33    1005.1  4.39  0.217E+09  0.01827     26.66  20.84  32.66  25.84  26.72  26.28
13   275.2  49.00  51.24  47.98  49.41  41.21    1042.9  4.22  0.232E+09  0.02058     26.91  20.90  30.98  25.58  26.26  25.92
14   305.2  50.12  52.15  48.89  50.39  43.09    1079.4  4.06  0.246E+09  0.02289     29.73  23.06  36.00  28.63  29.60  29.11
15   333.3  52.51  54.92  51.34  52.92  44.86    1113.7  3.93  0.260E+09  0.02508     27.20  20.67  32.10  25.80  26.66  26.23
16   363.3  54.26  56.47  52.96  54.56  46.74    1152.8  3.78  0.275E+09  0.02743     27.58  21.31  33.31  26.50  27.40  26.95
17   383.3  55.30  57.12  53.81  55.41  47.99    1178.1  3.69  0.286E+09  0.02900     28.31  22.67  35.55  27.89  28.84  28.37
18   403.3  56.66  58.69  55.45  56.93  49.24    1204.2  3.60  0.296E+09  0.03058     27.84  21.87  33.28  26.86  27.66  27.26
19   423.3  58.21  60.32  56.98  58.51  50.50    1231.6  3.51  0.307E+09  0.03217     26.72  20.98  31.78  25.74  26.49  26.12
20   443.3  58.93  61.27  57.64  59.28  51.75    1260.2  3.43  0.318E+09  0.03377     28.67  21.62  34.91  27.33  28.40  27.86
21   463.3  60.40  62.55  59.21  60.72  53.00    1284.4  3.36  0.329E+09  0.03534     27.76  21.51  33.11  26.62  27.46  27.04
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  55.98  58.13  54.70  56.27  48.51    1190.1  3.66  0.291E+09  0.02967     27.72  21.52  33.49  26.69  27.58  27.13
```

```
                                                    XP045-29

INPUT ELECTRIC POWER = 2405.0 W            HEAT RATE GAINED BY WATER = 2334.6 W            HEAT BALANCE ERROR =  2.93%
MASS FLOW RATE = 16.2660 G/S          PRESSURE DROP = 0.4228 MM H2O          FRICTION FACTOR = 0.045493          FREM =  36.1085
REM =   793.7     GRM   = 0.48654E+08     UPSTREAM BULK TEMPERATURE = 23.88 DEG C     DOWN STREAM BULK TEMPERATURE = 58.28 DEG C
PRM =   4.230     RAM   = 0.20581E+09     INLET BULK TEMPERATURE    = 23.92 DEG C     OUTLET BULK TEMPERATURE      = 58.26 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR       RA         Z          ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                             A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                        T      H      T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.74  30.20  29.08  29.60  23.92     555.2  6.29  0.990E+08  0.00000     33.40  30.94  37.67  34.19  34.92  34.56
 1     1.5  30.68  31.33  30.03  30.63  24.02     556.6  6.28  0.996E+08  0.00014     29.20  26.59  32.38  29.42  30.13  29.78
 2     2.5  31.33  32.11  30.68  31.34  24.10     557.5  6.26  0.100E+09  0.00024     26.86  24.24  29.51  26.84  27.53  27.18
 3     5.5  33.28  34.46  32.64  33.46  24.32     560.3  6.23  0.101E+09  0.00052     21.66  19.16  23.32  21.24  21.38  21.31
 4    15.5  34.58  36.36  33.76  34.90  25.05     569.9  6.11  0.106E+09  0.00146     20.35  17.14  22.26  19.68  19.92  19.80
 5    25.5  36.02  37.62  35.26  36.30  25.78     579.8  6.00  0.110E+09  0.00241     18.91  16.36  20.43  18.41  18.57  18.49
 6    45.5  36.26  38.03  35.44  36.57  27.25     599.6  5.78  0.119E+09  0.00432     21.42  17.89  23.55  20.68  20.95  20.82
 7    75.5  37.87  39.62  36.43  37.97  29.45     627.6  5.50  0.132E+09  0.00719     22.78  18.87  27.47  22.51  23.04  22.77
 8   105.5  39.37  41.70  37.87  39.65  31.64     658.3  5.23  0.145E+09  0.01009     24.71  18.99  30.69  23.87  24.80  24.33
 9  .135.5  41.29  43.29  40.00  41.53  33.84     687.7  4.97  0.158E+09  0.01304     25.48  20.09  30.84  24.70  25.47  25.09
10   165.2  43.44  45.53  42.22  43.73  36.02     719.0  4.72  0.172E+09  0.01602     25.45  19.86  30.44  24.49  25.25  24.87
11   205.2  46.09  48.09  44.68  46.29  38.95     761.2  4.43  0.191E+09  0.02003     26.27  20.52  32.73  25.57  26.51  26.04
12   245.2  49.17  51.26  47.78  49.40  41.88     806.4  4.16  0.212E+09  0.02406     25.62  19.91  31.65  24.82  25.72  25.27
13   275.2  51.11  53.18  50.14  51.48  44.08     837.9  3.99  0.226E+09  0.02710     26.43  20.41  30.64  25.11  25.83  25.47
14   305.2  52.61  54.49  51.46  52.85  46.28     872.0  3.81  0.242E+09  0.03018     29.22  22.54  35.74  28.15  29.16  28.66
15   333.3  55.39  57.72  54.42  55.84  48.33     904.2  3.67  0.257E+09  0.03307     26.13  19.66  30.33  24.57  25.38  24.97
16   363.3  57.41  59.52  56.25  57.73  50.53     940.2  3.51  0.274E+09  0.03619     26.73  20.45  32.16  25.55  26.45  26.00
17   383.3  58.63  60.36  57.25  58.74  52.00     965.3  3.41  0.286E+09  0.03828     27.67  21.95  34.92  27.19  28.18  27.68
18   403.3  60.12  62.15  58.96  60.41  53.46     986.7  3.33  0.297E+09  0.04034     27.51  21.07  33.32  26.36  27.30  26.83
19   423.3  61.87  63.88  60.66  62.14  54.93    1009.1  3.25  0.308E+09  0.04241     26.30  20.39  31.85  25.32  26.18  25.75
20   443.3  62.77  64.90  61.59  63.09  56.39    1032.5  3.17  0.319E+09  0.04449     28.56  21.42  35.03  27.21  28.34  27.78
21   463.3  64.13  66.28  62.99  64.47  57.86    1055.7  3.10  0.330E+09  0.04663     28.96  21.59  35.39  27.49  28.64  28.07
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  59.37  61.42  58.19  59.66  52.61     973.0  3.39  0.290E+09  0.03913     27.15  20.82  32.94  26.03  26.97  26.50
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                                                    XP045-30

INPUT ELECTRIC POWER = 3500.0 W            HEAT RATE GAINED BY WATER = 3330.7 W            HEAT BALANCE ERROR =  4.84%
MASS FLOW RATE = 22.7640 G/S          PRESSURE DROP = 0.6513 MM H2O          FRICTION FACTOR = 0.035869          FREM =  35.3071
REM =   984.3     GRM   = 0.48693E+08     UPSTREAM BULK TEMPERATURE = 17.41 DEG C     DOWN STREAM BULK TEMPERATURE = 52.48 DEG C
PRM =   4.840     RAM   = 0.23568E+09     INLET BULK TEMPERATURE    = 17.44 DEG C     OUTLET BULK TEMPERATURE      = 52.46 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR       RA         Z          ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                             A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                        T      H      T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  24.95  25.47  24.09  24.75  17.45     667.9  7.45  0.917E+08  0.00000     37.54  35.12  42.42  38.61  39.38  38.99
 1     1.5  26.30  27.03  25.45  26.19  17.55     669.6  7.43  0.925E+08  0.00010     32.22  29.75  35.68  32.62  33.33  32.98
 2     2.5  27.23  28.10  26.39  27.19  17.63     670.7  7.41  0.930E+08  0.00017     29.35  26.90  32.15  29.47  30.14  29.80
 3     5.5  30.01  31.32  29.21  30.18  17.85     674.2  7.37  0.946E+08  0.00036     23.16  20.91  24.79  22.84  22.95  22.90
 4    15.5  31.70  34.00  30.48  32.06  18.60     685.9  7.23  0.100E+09  0.00103     21.45  18.25  23.66  20.88  21.12  21.00
 5    25.5  33.39  35.51  32.59  33.83  19.35     698.1  7.09  0.106E+09  0.00169     19.97  17.36  21.17  19.36  19.50  19.43
 6    45.5  33.76  35.86  32.48  34.04  20.84     723.8  6.81  0.117E+09  0.00304     21.62  18.60  24.00  21.17  21.41  21.29
 7    75.5  35.16  37.39  33.42  35.32  23.08     762.6  6.43  0.135E+09  0.00507     23.01  19.41  26.87  22.70  23.10  22.90
 8   105.5  36.59  39.69  34.75  37.01  25.32     802.6  6.07  0.153E+09  0.00712     24.54  19.23  29.32  23.65  24.36  24.01
 9   135.5  38.52  41.18  36.78  38.83  27.56     844.6  5.74  0.172E+09  0.00919     25.11  20.19  29.83  24.41  25.04  24.73
10   165.2  40.22  43.19  38.61  40.67  29.78     884.7  5.46  0.191E+09  0.01125     26.21  20.40  31.01  25.12  25.87  25.50
11   205.2  42.53  45.32  40.57  42.81  32.77     942.3  5.09  0.217E+09  0.01407     27.83  21.66  34.85  27.08  28.11  27.59
12   245.2  45.73  48.64  44.21  46.19  35.76    1000.8  4.75  0.243E+09  0.01698     27.05  20.92  31.90  25.84  26.62  26.23
13   275.2  47.67  50.63  46.26  48.18  38.00    1046.3  4.51  0.263E+09  0.01917     27.75  21.24  32.50  26.34  27.16  26.75
14   305.2  48.84  51.64  47.28  49.25  40.24    1092.3  4.31  0.285E+09  0.02133     31.07  23.43  37.96  29.64  30.82  30.23
15   333.3  51.67  54.81  50.00  52.16  42.34    1137.5  4.12  0.306E+09  0.02338     28.51  21.34  34.74  27.09  28.19  27.64
16   363.3  53.70  56.63  52.18  54.17  44.58    1183.3  3.95  0.328E+09  0.02559     29.06  21.98  34.85  27.63  28.63  28.13
17   383.3  54.86  57.34  53.03  55.08  46.08    1215.9  3.83  0.343E+09  0.02707     30.09  23.46  37.97  29.35  30.51  29.93
18   403.3  56.55  59.25  54.94  56.91  47.57    1248.8  3.72  0.359E+09  0.02856     29.34  22.56  35.73  28.20  29.21  28.71
19   423.3  58.27  61.10  56.93  58.76  49.06    1281.7  3.62  0.375E+09  0.03005     28.57  21.84  33.43  27.10  27.95  27.52
20   443.3  59.32  62.16  57.48  59.65  50.56    1316.4  3.51  0.392E+09  0.03155     29.95  22.61  37.90  28.84  30.15  29.50
21   463.3  60.96  63.62  59.21  61.26  52.05    1352.0  3.41  0.408E+09  0.03306     29.37  22.63  36.58  28.42  29.53  28.97
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  55.73  58.55  54.09  56.12  46.70    1230.6  3.79  0.351E+09  0.02770     29.25  22.30  35.77  28.04  29.11  28.57
```

Appendix 2

Experimental Data for $\alpha = 90°$

```
                                                            XP090-01

INPUT ELECTRIC POWER =   170.0 W                HEAT RATE GAINED BY WATER =   168.2 W                 HEAT BALANCE ERROR =  1.08%
MASS FLOW RATE = 52.9430 G/S          PRESSURE DROP = 0.0000 MM H2O          FRICTION FACTOR = 0.000000          FREM =    0.0000
REM = 1776.7      GRM   = 0.10651E+07     UPSTREAM BULK TEMPERATURE = 22.78 DEG C     DOWN STREAM BULK TEMPERATURE = 23.54 DEG C
PRM =   6.412     RAM   = 0.68299E+07     INLET BULK TEMPERATURE     = 22.78 DEG C     OUTLET BULK TEMPERATURE       = 23.54 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C    AVER-   (C)                                                A       B       C     ----- AVERAGE -----
NO.                                 AGE                                                                             T       H       T+H
---------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.28   23.29   23.24   23.26   22.78     1761.8  6.47  0.668E+07  0.00000     28.40   27.67   31.08   29.39   29.56   29.47
 1     1.5  23.33   23.35   23.30   23.32   22.79     1761.9  6.47  0.668E+07  0.00004     25.90   25.04   27.56   26.37   26.52   26.45
 2     2.5  23.36   23.39   23.34   23.36   22.79     1762.0  6.47  0.668E+07  0.00007     24.42   23.51   25.57   24.63   24.77   24.70
 3     5.5  23.47   23.50   23.46   23.48   22.79     1762.1  6.47  0.668E+07  0.00016     20.83   19.85   21.01   20.55   20.56   20.56
 4    15.5  23.56   23.58   23.52   23.55   22.81     1762.8  6.47  0.669E+07  0.00045     18.80   18.13   19.84   18.90   18.92   18.91
 5    25.5  23.62   23.63   23.62   23.62   22.83     1763.4  6.47  0.670E+07  0.00074     17.74   17.49   17.74   17.65   17.66   17.65
 6    45.5  23.68   23.69   23.68   23.68   22.86     1764.7  6.46  0.671E+07  0.00131     17.11   16.89   17.11   17.04   17.04   17.04
 7    75.5  23.69   23.81   23.72   23.74   22.91     1766.6  6.45  0.673E+07  0.00218     17.81   15.51   17.20   16.78   16.84   16.81
 8   105.5  23.85   23.93   23.85   23.88   22.95     1768.5  6.45  0.675E+07  0.00304     15.68   14.42   15.68   15.24   15.26   15.25
 9   135.5  23.91   24.02   24.02   23.98   23.00     1770.4  6.44  0.677E+07  0.00391     15.56   13.85   13.85   14.37   14.42   14.40
10   165.2  23.98   24.07   24.08   24.04   23.05     1772.3  6.43  0.679E+07  0.00477     15.15   13.82   13.67   14.18   14.21   14.20
11   205.2  23.97   24.09   24.04   24.04   23.12     1774.9  6.42  0.681E+07  0.00592     16.39   14.34   15.12   15.24   15.28   15.26
12   245.2  24.06   24.18   24.08   24.11   23.18     1777.4  6.41  0.684E+07  0.00708     15.94   14.00   15.55   15.11   15.16   15.14
13   275.2  24.12   24.25   24.13   24.17   23.23     1779.4  6.40  0.686E+07  0.00795     15.72   13.75   15.52   14.94   15.00   14.97
14   305.2  24.13   24.31   24.26   24.23   23.28     1781.3  6.39  0.688E+07  0.00881     16.41   13.65   14.35   14.72   14.80   14.76
15   333.3  24.26   24.39   24.33   24.33   23.32     1783.1  6.39  0.689E+07  0.00963     15.05   13.10   13.97   14.00   14.04   14.02
16   363.3  24.28   24.42   24.35   24.35   23.37     1785.1  6.38  0.691E+07  0.01049     15.40   13.36   14.35   14.32   14.37   14.34
17   383.3  24.32   24.44   24.37   24.37   23.41     1786.4  6.37  0.693E+07  0.01107     15.38   13.56   14.58   14.47   14.51   14.49
18   403.3  24.33   24.55   24.38   24.42   23.44     1787.7  6.37  0.694E+07  0.01165     15.65   12.60   14.91   14.26   14.39   14.32
19   423.3  24.44   24.54   24.43   24.47   23.47     1789.0  6.36  0.695E+07  0.01223     14.47   13.11   14.63   14.04   14.07   14.05
20   443.3  24.37   24.51   24.43   24.44   23.50     1790.3  6.36  0.696E+07  0.01281     16.22   13.97   15.05   15.02   15.08   15.05
21   463.3  24.48   24.49   24.51   24.49   23.53     1791.6  6.35  0.698E+07  0.01339     14.77   14.69   14.35   14.60   14.61   14.60
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  24.33   24.48   24.38   24.40   23.42     1786.9  6.37  0.693E+07  0.01131     15.36   13.28   14.58   14.35   14.41   14.38
```

```
                                                            XP090-02

INPUT ELECTRIC POWER =   165.0 W                HEAT RATE GAINED BY WATER =   170.2 W                 HEAT BALANCE ERROR = -3.16%
MASS FLOW RATE = 29.2620 G/S          PRESSURE DROP = 0.7127 MM H2O          FRICTION FACTOR = 0.023848          FREM =   23.5711
REM =   988.4     GRM   = 0.11040E+07     UPSTREAM BULK TEMPERATURE = 22.76 DEG C     DOWN STREAM BULK TEMPERATURE = 24.15 DEG C
PRM =   6.367     RAM   = 0.70290E+07     INLET BULK TEMPERATURE     = 22.76 DEG C     OUTLET BULK TEMPERATURE       = 24.15 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C    AVER-   (C)                                                A       B       C     ----- AVERAGE -----
NO.                                 AGE                                                                             T       H       T+H
---------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.34   23.38   23.39   23.38   22.76      973.2  6.48  0.675E+07  0.00000     24.22   22.85   22.43   22.97   22.98   22.98
 1     1.5  23.42   23.47   23.47   23.46   22.76      973.3  6.48  0.675E+07  0.00008     21.55   20.05   20.10   20.44   20.45   20.45
 2     2.5  23.47   23.53   23.52   23.51   22.76      973.3  6.48  0.675E+07  0.00013     20.02   18.48   18.75   19.00   19.00   19.00
 3     5.5  23.63   23.72   23.68   23.68   22.77      973.5  6.47  0.676E+07  0.00029     16.52   14.98   15.62   15.68   15.70   15.69
 4    15.5  23.89   23.98   23.85   23.91   22.80      974.2  6.47  0.677E+07  0.00081     13.08   12.09   13.57   12.89   12.92   12.90
 5    25.5  24.01   24.07   24.06   24.04   22.83      974.8  6.46  0.678E+07  0.00133     12.11   11.51   11.57   11.72   11.73   11.73
 6    45.5  24.07   24.19   24.12   24.13   22.89      976.1  6.46  0.681E+07  0.00238     12.09   10.95   11.55   11.51   11.53   11.52
 7    75.5  24.08   24.09   23.94   24.04   22.98      978.0  6.44  0.684E+07  0.00394     12.95   12.82   14.74   13.45   13.50   13.48
 8   105.5  23.96   24.09   24.02   24.02   23.07      980.0  6.43  0.688E+07  0.00551     15.94   13.86   15.00   14.89   14.93   14.91
 9   135.5  24.07   24.18   24.18   24.15   23.16      981.9  6.41  0.691E+07  0.00708     15.55   13.86   13.86   14.38   14.42   14.40
10   165.2  24.14   24.29   24.30   24.24   23.25      983.9  6.40  0.695E+07  0.00863     15.82   13.63   13.48   14.24   14.31   14.27
11   205.2  24.14   24.32   24.21   24.22   23.37      986.5  6.38  0.699E+07  0.01072     18.36   14.93   16.79   16.57   16.69   16.63
12   245.2  24.28   24.41   24.36   24.35   23.48      989.1  6.36  0.704E+07  0.01282     17.77   15.41   16.19   16.40   16.45   16.43
13   275.2  24.34   24.47   24.41   24.41   23.57      991.1  6.35  0.708E+07  0.01439     18.41   15.79   16.94   16.98   17.04   17.01
14   305.2  24.47   24.53   24.48   24.49   23.66      993.1  6.33  0.711E+07  0.01596     17.64   16.40   17.40   17.13   17.15   17.14
15   333.3  24.59   24.78   24.72   24.70   23.75      995.0  6.32  0.715E+07  0.01743     16.83   13.67   14.53   14.89   15.01   14.95
16   363.3  24.62   24.81   24.74   24.72   23.84      997.0  6.31  0.718E+07  0.01901     18.14   14.53   15.69   15.98   16.12   16.05
17   383.3  24.76   25.00   24.87   24.88   23.89      998.3  6.30  0.721E+07  0.02006     16.36   12.82   14.58   14.44   14.59   14.52
18   403.3  24.89   24.99   24.93   24.94   23.95      999.7  6.29  0.723E+07  0.02111     15.16   13.62   14.47   14.39   14.42   14.40
19   423.3  24.88   25.09   24.98   24.99   24.01     1001.0  6.28  0.726E+07  0.02216     16.29   13.11   14.61   14.55   14.67   14.61
20   443.3  24.98   25.12   24.99   25.03   24.07     1002.4  6.27  0.728E+07  0.02321     15.56   13.50   15.46   14.78   14.84   14.81
21   463.3  24.98   25.19   25.01   25.06   24.13     1003.7  6.26  0.731E+07  0.02426     16.64   13.40   16.12   15.25   15.39   15.32
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  24.79   24.97   24.87   24.88   23.92      998.9  6.29  0.722E+07  0.02050     16.39   13.54   14.89   14.84   14.94   14.89
```

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                                                            XP090-03

INPUT ELECTRIC POWER =   165.0 W                HEAT RATE GAINED BY WATER =   175.3 W                 HEAT BALANCE ERROR = -6.22%
MASS FLOW RATE = 41.5360 G/S          PRESSURE DROP = 0.9633 MM H2O          FRICTION FACTOR = 0.015999          FREM =   22.3355
REM = 1396.1      GRM   = 0.11164E+07     UPSTREAM BULK TEMPERATURE = 22.73 DEG C     DOWN STREAM BULK TEMPERATURE = 23.74 DEG C
PRM =   6.401     RAM   = 0.71466E+07     INLET BULK TEMPERATURE     = 22.73 DEG C     OUTLET BULK TEMPERATURE       = 23.74 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C    AVER-   (C)                                                A       B       C     ----- AVERAGE -----
NO.                                 AGE                                                                             T       H       T+H
---------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.27   23.26   23.24   23.25   22.73     1380.5  6.48  0.694E+07  0.00000     27.21   27.66   28.86   27.95   28.15   28.05
 1     1.5  23.33   23.32   23.30   23.32   22.73     1380.6  6.48  0.694E+07  0.00006     24.28   24.79   25.95   25.02   25.24   25.13
 2     2.5  23.38   23.37   23.34   23.36   22.73     1380.7  6.48  0.694E+07  0.00009     22.60   23.13   24.27   23.33   23.56   23.45
 3     5.5  23.52   23.50   23.46   23.49   22.74     1380.9  6.48  0.695E+07  0.00020     18.72   19.26   20.30   19.41   19.43   19.42
 4    15.5  23.67   23.76   23.63   23.68   22.76     1361.5  6.48  0.695E+07  0.00057     16.17   14.73   16.90   15.88   15.93   15.91
 5    25.5  23.73   23.85   23.84   23.81   22.78     1382.2  6.47  0.696E+07  0.00094     15.49   13.72   13.86   14.31   14.36   14.34
 6    45.5  23.84   23.86   23.84   23.85   22.83     1383.5  6.47  0.698E+07  0.00167     14.37   14.22   14.37   14.32   14.32   14.32
 7    75.5  23.75   23.87   23.78   23.80   22.89     1385.5  6.46  0.701E+07  0.00278     17.03   14.99   16.50   16.13   16.17   16.15
 8   105.5  23.79   23.93   23.85   23.86   22.96     1387.5  6.45  0.703E+07  0.00388     17.44   15.05   16.35   16.22   16.28   16.25
 9   135.5  23.85   23.96   23.96   23.92   23.02     1389.5  6.44  0.706E+07  0.00498     17.62   15.54   15.54   16.18   16.24   16.21
10   165.2  23.98   24.01   24.02   24.00   23.08     1391.5  6.42  0.709E+07  0.00608     16.36   15.77   15.59   15.90   15.91   15.91
11   205.2  23.97   24.09   24.10   24.06   23.17     1394.1  6.41  0.712E+07  0.00755     18.23   15.82   15.72   16.51   16.59   16.55
12   245.2  24.12   24.29   24.25   24.22   23.26     1396.8  6.40  0.716E+07  0.00903     16.99   14.08   14.71   15.16   15.26   15.21
13   275.2  24.18   24.31   24.24   24.24   23.32     1398.8  6.39  0.718E+07  0.01013     17.06   14.84   15.83   15.86   15.91   15.88
14   305.2  24.24   24.42   24.37   24.34   23.39     1400.9  6.38  0.721E+07  0.01124     17.01   14.17   14.89   15.27   15.36   15.31
15   333.3  24.37   24.56   24.50   24.48   23.45     1402.8  6.37  0.723E+07  0.01227     15.87   13.10   13.86   14.19   14.28   14.23
16   363.3  24.45   24.59   24.57   24.54   23.51     1404.8  6.36  0.726E+07  0.01338     15.55   13.55   13.76   14.23   14.29   14.26
17   383.3  24.54   24.66   24.59   24.60   23.55     1406.2  6.35  0.728E+07  0.01412     14.83   13.19   14.11   14.01   14.04   14.03
18   403.3  24.61   24.66   24.66   24.64   23.60     1407.5  6.34  0.730E+07  0.01486     14.40   13.72   13.79   13.96   13.97   13.97
19   423.3  24.61   24.65   24.65   24.64   23.64     1408.9  6.34  0.732E+07  0.01560     15.12   14.46   14.46   14.67   14.68   14.68
20   443.3  24.59   24.73   24.66   24.66   23.68     1410.3  6.33  0.733E+07  0.01633     16.12   13.90   15.01   14.96   15.01   14.98
21   463.3  24.59   24.77   24.62   24.66   23.73     1411.6  6.32  0.735E+07  0.01707     16.81   14.03   16.29   15.61   15.71   15.66
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  24.53   24.64   24.60   24.59   23.57     1406.7  6.35  0.729E+07  0.01443     15.31   13.65   14.17   14.34   14.38   14.36
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                                                         XP090-04

INPUT ELECTRIC POWER =   305.0 W                 HEAT RATE GAINED BY WATER =   315.3 W                 HEAT BALANCE ERROR = -3.38%
MASS FLOW RATE = 25.6520 G/S            PRESSURE DROP = 0.0000 MM H2O             FRICTION FACTOR = 0.000000          FREM =    0.0000
REM =   740.4     GRM   = 0.10823E+07     UPSTREAM BULK TEMPERATURE = 15.27 DEG C     DOWN STREAM BULK TEMPERATURE = 18.21 DEG C
PRM =   7.588     RAM   = 0.82120E+07     INLET BULK TEMPERATURE    = 15.27 DEG C     OUTLET BULK TEMPERATURE      = 18.21 DEG C
-------------------------------------------------------------------------------------------------------------------------------------
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C    AVER-   (C)                                                A       B       C     ----- AVERAGE -----
NO.                                 AGE                                                                               T       H     T+H
-------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  16.38   16.42   16.40   16.40   15.27     712.4   7.95   0.719E+07   0.00000     24.12   23.30   23.80   23.78   23.76   23.77
 1     1.5  16.54   16.60   16.57   16.57   15.28     712.6   7.95   0.720E+07   0.00009     21.30   20.40   20.80   20.85   20.82   20.84
 2     2.5  16.65   16.71   16.69   16.68   15.29     712.7   7.95   0.720E+07   0.00015     19.71   18.79   19.13   19.22   19.19   19.21
 3     5.5  16.97   17.07   17.04   17.03   15.30     713.1   7.95   0.721E+07   0.00032     16.10   15.19   15.43   15.56   15.57   15.57
 4    15.5  17.46   17.62   17.45   17.51   15.37     714.2   7.93   0.726E+07   0.00090     12.82   11.93   12.89   12.53   12.55   12.54
 5    25.5  17.81   17.91   17.74   17.82   15.43     715.4   7.91   0.730E+07   0.00148     11.30   10.84   11.62   11.24   11.25   11.25
 6    45.5  17.81   17.96   17.83   17.86   15.56     717.7   7.88   0.738E+07   0.00265     11.92   11.15   11.80   11.62   11.63   11.62
 7    75.5  17.77   17.93   17.71   17.80   15.74     721.2   7.84   0.751E+07   0.00439     13.25   12.24   13.66   13.02   13.05   13.04
 8   105.5  17.79   17.97   17.73   17.83   15.93     724.8   7.79   0.764E+07   0.00615     14.43   13.13   14.92   14.12   14.16   14.14
 9   135.5  17.91   18.08   18.03   18.00   16.12     728.3   7.74   0.777E+07   0.00790     15.00   13.68   14.03   14.21   14.24   14.22
10   165.2  17.99   18.23   18.18   18.13   16.31     731.9   7.70   0.790E+07   0.00965     15.90   13.89   14.30   14.65   14.70   14.67
11   205.2  18.03   18.32   18.21   18.18   16.56     736.8   7.63   0.808E+07   0.01200     18.18   15.20   16.22   16.44   16.53   16.49
12   245.2  18.46   18.79   18.62   18.63   16.81     741.8   7.57   0.826E+07   0.01436     16.16   13.45   14.73   14.70   14.78   14.74
13   275.2  18.68   18.97   18.79   18.81   17.00     745.1   7.53   0.839E+07   0.01613     15.83   13.55   14.85   14.68   14.74   14.71
14   305.2  18.75   19.02   18.91   18.89   17.18     748.2   7.50   0.851E+07   0.01790     17.04   14.56   15.50   15.64   15.70   15.67
15   333.3  19.09   19.42   19.24   19.25   17.36     751.2   7.46   0.862E+07   0.01955     15.38   12.97   14.20   14.12   14.18   14.15
16   363.3  19.19   19.53   19.33   19.35   17.55     754.4   7.43   0.875E+07   0.02132     16.25   13.43   14.94   14.78   14.87   14.83
17   383.3  19.32   19.58   19.49   19.46   17.67     756.6   7.41   0.883E+07   0.02250     16.22   14.00   14.68   14.91   14.97   14.94
18   403.3  19.43   19.70   19.53   19.55   17.80     758.7   7.38   0.892E+07   0.02369     16.36   14.02   15.36   15.18   15.24   15.21
19   423.3  19.56   19.81   19.63   19.67   17.92     760.9   7.36   0.900E+07   0.02487     16.27   14.12   15.58   15.27   15.32   15.30
20   443.3  19.63   19.92   19.71   19.75   18.05     763.1   7.33   0.909E+07   0.02605     16.87   14.22   16.08   15.64   15.72   15.68
21   463.3  19.69   20.03   19.78   19.84   18.17     765.3   7.31   0.917E+07   0.02724     17.51   14.32   16.60   16.03   16.15   16.09
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  19.37   19.66   19.49   19.51   17.72     757.5   7.40   0.887E+07   0.02300     16.22   13.79   15.14   14.98   15.05   15.02
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                                                         XP090-05

INPUT ELECTRIC POWER =   185.0 W                 HEAT RATE GAINED BY WATER =   193.3 W                 HEAT BALANCE ERROR = -4.47%
MASS FLOW RATE = 53.0880 G/S            PRESSURE DROP = 0.0000 MM H2O             FRICTION FACTOR = 0.000000          FREM =    0.0000
REM =  1778.3     GRM   = 0.12158E+07     UPSTREAM BULK TEMPERATURE = 22.64 DEG C     DOWN STREAM BULK TEMPERATURE = 23.52 DEG C
PRM =   6.426     RAM   = 0.78120E+07     INLET BULK TEMPERATURE    = 22.65 DEG C     OUTLET BULK TEMPERATURE      = 23.52 DEG C
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STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C    AVER-   (C)                                                A       B       C     ----- AVERAGE -----
NO.                                 AGE                                                                               T       H     T+H
-------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.19   23.22   23.24   23.22   22.65    1761.2   6.49   0.762E+07   0.00000     29.67   27.88   27.33   28.04   28.05   28.05
 1     1.5  23.25   23.30   23.30   23.28   22.65    1761.3   6.49   0.762E+07   0.00004     26.89   24.84   24.91   25.38   25.39   25.38
 2     2.5  23.29   23.35   23.34   23.33   22.65    1761.4   6.49   0.762E+07   0.00007     25.25   23.11   23.48   23.82   23.83   23.83
 3     5.5  23.41   23.50   23.46   23.46   22.66    1761.6   6.49   0.762E+07   0.00016     21.35   19.11   20.03   20.12   20.16   20.14
 4    15.5  23.50   23.64   23.52   23.55   22.67    1762.3   6.49   0.763E+07   0.00045     19.53   16.72   19.15   18.38   18.47   18.42
 5    25.5  23.62   23.63   23.67   23.64   22.69    1763.0   6.49   0.764E+07   0.00073     17.46   17.25   16.47   17.05   17.06   17.06
 6    45.5  23.68   23.80   23.73   23.74   22.73    1764.5   6.48   0.765E+07   0.00131     17.02   15.07   16.08   16.02   16.06   16.04
 7    75.5  23.69   23.81   23.72   23.74   22.79    1766.7   6.47   0.768E+07   0.00217     17.75   15.73   17.22   16.85   16.90   16.88
 8   105.5  23.74   23.87   23.74   23.78   22.84    1768.9   6.46   0.770E+07   0.00304     17.97   15.64   17.97   17.12   17.19   17.16
 9   135.5  23.85   23.91   23.91   23.89   22.90    1771.0   6.45   0.773E+07   0.00390     16.92   15.99   15.99   16.29   16.30   16.29
10   165.2  23.87   24.01   24.02   23.97   22.95    1773.2   6.45   0.775E+07   0.00475     17.63   15.23   15.07   15.89   15.98   15.93
11   205.2  23.97   24.04   23.99   24.00   23.03    1776.1   6.43   0.779E+07   0.00591     17.05   15.92   16.75   16.56   16.57   16.57
12   245.2  24.06   24.18   24.08   24.11   23.10    1779.1   6.42   0.782E+07   0.00706     16.78   14.89   16.40   15.98   16.03   16.00
13   275.2  24.12   24.25   24.24   24.21   23.16    1781.3   6.41   0.785E+07   0.00792     16.69   14.74   14.81   15.36   15.41   15.39
14   305.2  24.19   24.31   24.26   24.25   23.21    1783.5   6.40   0.787E+07   0.00879     16.50   14.74   15.45   15.53   15.56   15.54
15   333.3  24.26   24.45   24.33   24.34   23.26    1785.6   6.40   0.790E+07   0.00960     16.26   13.59   15.15   14.92   15.00   14.96
16   363.3  24.28   24.48   24.35   24.37   23.32    1787.8   6.39   0.792E+07   0.01046     16.73   13.92   15.64   15.34   15.43   15.38
17   383.3  24.37   24.55   24.42   24.45   23.36    1789.3   6.38   0.794E+07   0.01104     15.87   13.51   15.13   14.77   14.84   14.80
18   403.3  24.44   24.55   24.54   24.51   23.39    1790.8   6.38   0.795E+07   0.01162     15.34   13.94   14.01   14.40   14.43   14.42
19   423.3  24.44   24.54   24.54   24.51   23.43    1792.3   6.37   0.797E+07   0.01220     15.99   14.55   14.55   15.00   15.03   15.01
20   443.3  24.48   24.56   24.54   24.53   23.47    1793.8   6.36   0.799E+07   0.01277     15.96   14.74   14.97   15.21   15.23   15.22
21   463.3  24.43   24.57   24.46   24.49   23.51    1795.3   6.36   0.801E+07   0.01335     17.47   15.10   16.96   16.44   16.51   16.48
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  24.38   24.52   24.45   24.45   23.37    1790.0   6.38   0.794E+07   0.01128     16.02   14.04   14.91   14.94   14.99   14.97
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                                                         XP090-06

INPUT ELECTRIC POWER =   285.0 W                 HEAT RATE GAINED BY WATER =   295.0 W                 HEAT BALANCE ERROR = -3.52%
MASS FLOW RATE = 16.9880 G/S            PRESSURE DROP = 0.0000 MM H2O             FRICTION FACTOR = 0.000000          FREM =    0.0000
REM =   498.0     GRM   = 0.10861E+07     UPSTREAM BULK TEMPERATURE = 15.32 DEG C     DOWN STREAM BULK TEMPERATURE = 19.48 DEG C
PRM =   7.456     RAM   = 0.80981E+07     INLET BULK TEMPERATURE    = 15.33 DEG C     OUTLET BULK TEMPERATURE      = 19.48 DEG C
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STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C    AVER-   (C)                                                A       B       C     ----- AVERAGE -----
NO.                                 AGE                                                                               T       H     T+H
-------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  16.55   16.57   16.51   16.53   15.33     472.5   7.94   0.677E+07   0.00000     20.56   20.26   21.26   20.82   20.84   20.83
 1     1.5  16.71   16.73   16.68   16.70   15.34     472.7   7.94   0.677E+07   0.00013     18.39   18.06   18.74   18.47   18.48   18.48
 2     2.5  16.81   16.84   16.80   16.82   15.35     472.8   7.93   0.678E+07   0.00022     17.14   16.80   17.32   17.14   17.15   17.14
 3     5.5  17.14   17.18   17.16   17.16   15.38     473.1   7.93   0.680E+07   0.00048     14.25   13.90   14.12   14.09   14.09   14.09
 4    15.5  17.57   17.73   17.51   17.60   15.47     474.2   7.91   0.685E+07   0.00136     11.91   11.07   12.30   11.74   11.76   11.75
 5    25.5  17.75   17.96   17.91   17.87   15.55     475.3   7.88   0.691E+07   0.00224     11.43   10.43   10.67   10.83   10.84   10.83
 6    45.5  17.86   18.02   17.88   17.92   15.73     477.5   7.84   0.702E+07   0.00400     11.78   10.97   11.65   11.46   11.47   11.46
 7    75.5  17.88   18.04   17.87   17.93   16.00     480.8   7.77   0.719E+07   0.00665     13.33   12.24   13.36   12.96   12.98   12.97
 8   105.5  17.96   18.08   17.96   18.00   16.26     484.2   7.71   0.737E+07   0.00930     14.79   13.75   14.79   14.43   14.45   14.44
 9   135.5  18.13   18.41   18.25   18.26   16.53     487.6   7.64   0.754E+07   0.01196     15.65   13.29   14.54   14.43   14.49   14.46
10   165.2  18.27   18.57   18.46   18.43   16.79     491.0   7.57   0.772E+07   0.01461     16.95   14.09   15.03   15.26   15.35   15.31
11   205.2  18.53   18.76   18.65   18.65   17.15     495.1   7.50   0.794E+07   0.01817     18.07   15.46   16.61   16.65   16.71   16.68
12   245.2  18.91   19.29   19.18   19.13   17.50     499.1   7.44   0.816E+07   0.02173     17.75   13.91   14.87   15.35   15.51   15.43
13   275.2  19.29   19.58   19.46   19.44   17.76     502.1   7.39   0.832E+07   0.02440     16.31   13.76   14.71   14.85   14.93   14.89
14   305.2  19.47   19.80   19.63   19.63   18.03     505.2   7.34   0.849E+07   0.02708     17.29   14.09   15.61   15.55   15.66   15.61
15   333.3  19.82   20.14   19.91   19.96   18.28     508.1   7.29   0.865E+07   0.02960     16.21   13.36   15.27   14.85   14.94   14.90
16   363.3  19.96   20.31   20.11   20.13   18.54     511.2   7.24   0.882E+07   0.03228     17.58   14.10   15.90   15.73   15.86   15.79
17   383.3  20.15   20.42   20.32   20.30   18.72     513.3   7.21   0.894E+07   0.03408     17.43   14.69   15.55   15.81   15.89   15.85
18   403.3  20.43   20.64   20.54   20.54   18.90     515.5   7.17   0.905E+07   0.03587     16.27   14.25   15.17   15.19   15.23   15.21
19   423.3  20.61   20.81   20.69   20.70   19.08     517.6   7.14   0.917E+07   0.03767     16.20   14.33   15.42   15.28   15.32   15.30
20   443.3  20.69   20.98   20.82   20.83   19.25     519.8   7.11   0.928E+07   0.03947     17.31   14.36   15.90   15.77   15.86   15.81
21   463.3  20.75   21.15   20.78   20.89   19.43     522.0   7.07   0.940E+07   0.04127     18.82   14.44   18.44   16.99   17.23   17.11
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  20.28   20.55   20.40   20.41   18.80     514.3   7.19   0.898E+07   0.03483     16.83   14.18   15.53   15.44   15.52   15.48
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                                                         XP090-07

INPUT ELECTRIC POWER =   305.0 W               HEAT RATE GAINED BY WATER =   319.6 W               HEAT BALANCE ERROR = -4.80%
MASS FLOW RATE = 41.5360 G/S           PRESSURE DROP = 0.9497 MM H2O          FRICTION FACTOR = 0.015771          FREM =  22.3058
REM = 1414.4      GRM   = 0.21351E+07     UPSTREAM BULK TEMPERATURE = 22.89 DEG C     DOWN STREAM BULK TEMPERATURE = 24.73 DEG C
PRM =   6.310     RAM   = 0.13473E+08     INLET BULK TEMPERATURE     = 22.89 DEG C     OUTLET BULK TEMPERATURE        = 24.73 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                                  A      B      C    ----- AVERAGE -----
NO.                                AGE                                                                               T      H     T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.73  23.72  23.66  23.70  22.89    1385.5  6.46  0.128E+08  0.00000     31.73  31.98  34.47  32.96  33.16  33.06
 1     1.5  23.85  23.84  23.79  23.82  22.90    1385.7  6.45  0.128E+08  0.00006     27.88  28.16  29.97  28.80  29.00  28.90
 2     2.5  23.94  23.93  23.87  23.91  22.90    1385.8  6.45  0.128E+08  0.00009     25.73  26.01  27.50  26.49  26.69  26.59
 3     5.5  24.19  24.17  24.12  24.16  22.91    1386.1  6.45  0.128E+08  0.00020     20.89  21.17  22.04  21.36  21.37  21.36
 4    15.5  24.38  24.60  24.36  24.45  22.95    1387.3  6.45  0.128E+08  0.00057     18.63  16.18  19.00  17.84  17.93  17.89
 5    25.5  24.57  24.68  24.61  24.62  22.99    1388.6  6.44  0.129E+08  0.00094     16.92  15.81  16.46  16.38  16.40  16.39
 6    45.5  24.73  24.80  24.74  24.76  23.07    1391.0  6.43  0.129E+08  0.00167     16.02  15.41  15.97  15.79  15.80  15.80
 7    75.5  24.80  24.87  24.73  24.80  23.19    1394.6  6.41  0.130E+08  0.00278     16.53  15.87  17.30  16.55  16.57  16.56
 8   105.5  24.85  25.10  24.85  24.93  23.30    1398.3  6.39  0.131E+08  0.00388     17.25  14.85  17.25  16.36  16.45  16.41
 9   135.5  25.02  25.18  25.13  25.11  23.42    1402.0  6.37  0.132E+08  0.00499     16.71  15.13  15.62  15.80  15.82  15.81
10   165.2  25.14  25.40  25.31  25.28  23.54    1405.7  6.35  0.133E+08  0.00608     16.65  14.31  15.08  15.29  15.35  15.32
11   205.2  25.14  25.43  25.27  25.28  23.70    1410.7  6.33  0.134E+08  0.00756     18.46  15.38  16.90  16.82  16.91  16.86
12   245.2  25.33  25.52  25.37  25.41  23.85    1415.7  6.30  0.135E+08  0.00904     17.99  15.95  17.59  17.13  17.17  17.15
13   275.2  25.46  25.70  25.63  25.60  23.97    1419.5  6.28  0.136E+08  0.01015     17.93  15.39  16.01  16.37  16.44  16.41
14   305.2  25.58  25.87  25.76  25.74  24.09    1423.3  6.27  0.137E+08  0.01126     17.87  14.96  15.91  16.16  16.25  16.20
15   333.3  25.64  25.96  25.78  25.79  24.20    1426.9  6.25  0.138E+08  0.01230     18.40  15.14  16.79  16.67  16.78  16.73
16   363.3  25.78  26.08  26.02  25.96  24.32    1430.8  6.23  0.139E+08  0.01341     18.20  15.05  15.59  16.17  16.28  16.23
17   383.3  25.87  26.23  26.03  26.04  24.40    1433.3  6.22  0.139E+08  0.01415     18.00  14.51  16.23  16.12  16.25  16.19
18   403.3  26.01  26.28  26.16  26.15  24.47    1435.9  6.21  0.140E+08  0.01489     17.36  14.74  15.76  15.88  15.95  15.91
19   423.3  26.11  26.32  26.32  26.25  24.55    1438.5  6.19  0.141E+08  0.01563     17.11  15.02  15.02  15.66  15.72  15.69
20   443.3  26.15  26.47  26.21  26.28  24.63    1441.1  6.18  0.141E+08  0.01637     17.49  14.48  16.82  16.16  16.26  16.21
21   463.3  26.21  26.56  26.24  26.34  24.71    1443.8  6.17  0.142E+08  0.01711     17.69  14.35  17.37  16.33  16.47  16.40
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  25.93  26.22  26.09  26.08  24.43    1434.4  6.21  0.140E+08  0.01446     17.76  14.82  16.03  16.11  16.21  16.16
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                                                         XP090-08

INPUT ELECTRIC POWER =   295.0 W               HEAT RATE GAINED BY WATER =   309.2 W               HEAT BALANCE ERROR = -4.83%
MASS FLOW RATE = 29.2620 G/S           PRESSURE DROP = 0.6871 MM H2O          FRICTION FACTOR = 0.022988          FREM =  23.1440
REM = 1006.8      GRM   = 0.21443E+07     UPSTREAM BULK TEMPERATURE = 23.00 DEG C     DOWN STREAM BULK TEMPERATURE = 25.53 DEG C
PRM =   6.238     RAM   = 0.13376E+08     INLET BULK TEMPERATURE     = 23.00 DEG C     OUTLET BULK TEMPERATURE        = 25.53 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                                  A      B      C    ----- AVERAGE -----
NO.                                AGE                                                                               T      H     T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.89  23.90  23.82  23.86  23.00     978.5  6.44  0.124E+08  0.00000     29.21  28.71  31.59  30.02  30.28  30.15
 1     1.5  24.03  24.05  23.96  24.01  23.01     978.7  6.44  0.124E+08  0.00008     25.42  24.89  27.20  25.93  26.18  26.05
 2     2.5  24.12  24.15  24.06  24.10  23.02     978.8  6.44  0.125E+08  0.00013     23.33  22.79  24.82  23.70  23.94  23.82
 3     5.5  24.41  24.45  24.34  24.40  23.03     979.1  6.43  0.125E+08  0.00029     18.71  18.20  19.66  18.84  18.86  18.85
 4    15.5  24.72  24.94  24.69  24.78  23.09     980.3  6.42  0.125E+08  0.00081     15.82  13.92  16.10  15.22  15.28  15.25
 5    25.5  24.96  25.12  25.06  25.04  23.14     981.5  6.42  0.125E+08  0.00133     14.21  13.01  13.47  13.55  13.56  13.55
 6    45.5  25.06  25.19  25.13  25.13  23.25     983.9  6.40  0.126E+08  0.00238     14.22  13.29  13.72  13.73  13.74  13.74
 7    75.5  25.08  25.14  25.06  25.09  23.41     987.4  6.37  0.127E+08  0.00395     15.45  14.91  15.61  15.32  15.32  15.32
 8   105.5  25.07  25.32  25.13  25.17  23.57     991.0  6.35  0.129E+08  0.00552     17.17  14.72  16.56  16.08  16.15  16.12
 9   135.5  25.24  25.52  25.41  25.39  23.73     994.7  6.32  0.130E+08  0.00709     17.11  14.44  15.40  15.58  15.65  15.61
10   165.2  25.42  25.62  25.58  25.54  23.89     998.3  6.30  0.131E+08  0.00864     16.91  14.90  15.24  15.63  15.68  15.66
11   205.2  25.42  25.76  25.61  25.59  24.11    1003.2  6.26  0.133E+08  0.01074     19.69  15.58  17.20  17.33  17.49  17.41
12   245.2  25.78  25.97  25.81  25.85  24.33    1008.2  6.23  0.134E+08  0.01284     17.71  15.67  17.31  16.85  16.90  16.87
13   275.2  25.79  26.14  26.02  25.99  24.49    1011.9  6.20  0.135E+08  0.01442     19.75  15.51  16.75  17.16  17.34  17.25
14   305.2  25.97  26.26  26.15  26.12  24.65    1015.7  6.18  0.137E+08  0.01600     19.50  16.00  17.12  17.42  17.54  17.48
15   333.3  26.20  26.57  26.51  26.43  24.80    1019.3  6.15  0.138E+08  0.01748     18.36  14.50  15.02  15.79  15.96  15.87
16   363.3  26.39  26.69  26.53  26.54  24.96    1023.1  6.13  0.139E+08  0.01906     18.00  14.83  16.40  16.31  16.41  16.36
17   383.3  26.53  26.78  26.64  26.65  25.07    1025.7  6.11  0.140E+08  0.02012     17.55  14.99  16.31  16.21  16.28  16.25
18   403.3  26.67  26.89  26.72  26.76  25.18    1028.2  6.09  0.141E+08  0.02117     17.18  14.95  16.68  16.21  16.27  16.24
19   423.3  26.71  26.99  26.88  26.86  25.29    1030.8  6.08  0.142E+08  0.02223     18.00  15.07  16.12  16.31  16.40  16.35
20   443.3  26.77  27.08  26.88  26.91  25.39    1033.5  6.06  0.142E+08  0.02328     18.69  15.18  17.22  16.91  17.03  16.97
21   463.3  26.88  27.17  27.02  27.02  25.50    1036.1  6.04  0.143E+08  0.02434     18.64  15.35  16.93  16.87  16.97  16.92
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  26.55  26.84  26.69  26.69  25.11    1026.8  6.10  0.140E+08  0.02056     17.96  14.92  16.29  16.29  16.39  16.34
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                                                         XP090-09

INPUT ELECTRIC POWER =   750.0 W               HEAT RATE GAINED BY WATER =   714.6 W               HEAT BALANCE ERROR =  4.71%
MASS FLOW RATE = 28.6840 G/S           PRESSURE DROP = 0.7246 MM H2O          FRICTION FACTOR = 0.025228          FREM =  24.9733
REM =   989.9     GRM   = 0.50087E+07     UPSTREAM BULK TEMPERATURE = 21.41 DEG C     DOWN STREAM BULK TEMPERATURE = 27.38 DEG C
PRM =   6.217     RAM   = 0.31141E+08     INLET BULK TEMPERATURE     = 21.42 DEG C     OUTLET BULK TEMPERATURE        = 27.38 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-    TB        RE      PR        RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-   (C)                                                  A      B      C    ----- AVERAGE -----
NO.                                AGE                                                                               T      H     T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.10  23.14  22.97  23.05  21.42     925.1  6.70  0.261E+08  0.00000     35.54  34.77  38.61  36.63  36.88  36.76
 1     1.5  23.42  23.47  23.30  23.39  21.44     925.5  6.70  0.261E+08  0.00008     30.16  29.39  32.04  30.69  30.91  30.80
 2     2.5  23.64  23.70  23.54  23.62  21.45     925.8  6.70  0.262E+08  0.00013     27.31  26.55  28.67  27.61  27.80  27.70
 3     5.5  24.30  24.39  24.23  24.31  21.49     926.7  6.69  0.262E+08  0.00029     21.28  20.59  21.79  21.21  21.22  21.21
 4    15.5  24.83  25.27  24.86  24.99  21.61     929.7  6.66  0.265E+08  0.00082     18.62  16.36  18.46  17.75  17.81  17.78
 5    25.5  25.23  25.62  25.39  25.41  21.74     932.6  6.64  0.267E+08  0.00135     17.13  15.41  16.40  16.28  16.31  16.30
 6    45.5  25.39  25.80  25.52  25.57  22.00     938.2  6.60  0.271E+08  0.00242     17.59  15.71  16.98  16.72  16.76  16.74
 7    75.5  25.58  26.14  25.67  25.80  22.38     946.0  6.54  0.277E+08  0.00402     18.66  15.87  18.12  17.47  17.55  17.51
 8   105.5  25.74  26.44  25.85  26.01  22.76     954.0  6.48  0.284E+08  0.00562     19.98  16.21  19.30  18.34  18.50  18.42
 9   135.5  26.18  26.74  26.41  26.44  23.14     962.1  6.42  0.290E+08  0.00722     19.59  16.56  18.26  18.05  18.14  18.09
10   165.2  26.42  27.02  26.81  26.75  23.52     970.3  6.36  0.296E+08  0.00881     20.55  17.02  18.12  18.45  18.56  18.50
11   205.2  26.70  27.43  27.05  27.06  24.03     981.5  6.28  0.305E+08  0.01096     22.25  17.49  19.67  19.61  19.81  19.71
12   245.2  27.11  27.86  27.48  27.48  24.54     993.0  6.20  0.314E+08  0.01311     23.12  17.89  20.15  20.17  20.39  20.28
13   275.2  27.46  28.21  27.86  27.84  24.92    1001.8  6.14  0.321E+08  0.01473     23.38  18.05  20.20  20.31  20.54  20.43
14   305.2  27.91  28.59  28.27  28.26  25.30    1010.8  6.08  0.327E+08  0.01635     22.70  17.99  19.98  20.04  20.22  20.13
15   333.3  28.36  29.09  28.81  28.75  25.66    1019.3  6.02  0.334E+08  0.01787     21.90  17.26  18.81  19.14  19.32  19.23
16   363.3  28.55  29.36  28.98  28.96  26.04    1028.6  5.96  0.341E+08  0.01950     23.56  17.81  20.13  20.23  20.50  20.37
17   383.3  28.87  29.52  29.19  29.19  26.29    1034.9  5.92  0.346E+08  0.02059     22.98  18.31  20.38  20.38  20.56  20.47
18   403.3  29.24  29.85  29.44  29.51  26.55    1041.2  5.88  0.351E+08  0.02168     21.96  17.90  20.40  19.94  20.08  20.01
19   423.3  29.43  30.11  29.83  29.79  26.80    1047.7  5.84  0.356E+08  0.02277     22.49  17.88  19.48  19.77  19.95  19.86
20   443.3  29.61  30.38  29.94  29.98  27.05    1053.3  5.80  0.360E+08  0.02385     23.15  17.74  20.48  20.22  20.46  20.34
21   463.3  29.88  30.65  30.30  30.28  27.31    1058.7  5.77  0.364E+08  0.02494     22.93  17.67  19.73  19.88  20.11  19.99
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  29.01  29.72  29.37  29.36  26.40    1037.5  5.90  0.348E+08  0.02104     22.67  17.82  19.95  19.95  20.15  20.05
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                                                          XP090-10

INPUT ELECTRIC POWER = 1290.0 W               HEAT RATE GAINED BY WATER = 1245.7 W              HEAT BALANCE ERROR =  3.44%
MASS FLOW RATE = 50.5610 G/S         PRESSURE DROP = 0.0000 MM H2O        FRICTION FACTOR = 0.000000         FREM =   0.0000
REM = 1516.8     GRM   = 0.50753E+07   UPSTREAM BULK TEMPERATURE = 15.46 DEG C   DOWN STREAM BULK TEMPERATURE = 21.36 DEG C
PRM =  7.266     RAM   = 0.36879E+08   INLET BULK TEMPERATURE    = 15.47 DEG C   OUTLET BULK TEMPERATURE      = 21.36 DEG C
_____________________________________________________________________________________________________________________________
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A      B       C    AVER-  (C)                                               A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                            T      H      T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  18.16  18.21  18.02  18.11  15.47    1411.4  7.91  0.289E+08  0.00000     39.36  38.70  41.46  40.09  40.24  40.16
 1     1.5  18.66  18.72  18.54  18.63  15.49    1412.0  7.90  0.290E+08  0.00004     33.42  32.75  34.67  33.74  33.88  33.81
 2     2.5  19.00  19.08  18.90  18.98  15.50    1412.5  7.90  0.290E+08  0.00007     30.27  29.61  31.16  30.42  30.55  30.48
 3     5.5  20.03  20.14  19.97  20.05  15.54    1413.9  7.89  0.291E+08  0.00016     23.59  23.00  23.89  23.49  23.49  23.49
 4    15.5  21.12  21.56  21.07  21.25  15.66    1418.5  7.86  0.295E+08  0.00046     19.42  17.96  19.60  18.96  18.99  18.98
 5    25.5  21.77  22.35  22.17  22.10  15.79    1423.2  7.83  0.298E+08  0.00075     17.69  16.14  16.59  16.78  16.81  16.79
 6    45.5  21.63  22.41  21.84  21.96  16.04    1432.5  7.76  0.305E+08  0.00135     18.93  16.61  18.25  17.87  17.93  17.90
 7    75.5  21.98  22.70  22.05  22.24  16.42    1446.9  7.67  0.315E+08  0.00224     19.01  16.82  18.76  18.14  18.20  18.17
 8   105.5  22.07  23.09  22.29  22.49  16.79    1461.5  7.57  0.326E+08  0.00313     20.00  16.76  19.21  18.55  18.66  18.61
 9   135.5  22.52  23.41  22.91  22.94  17.17    1474.3  7.50  0.336E+08  0.00403     19.73  16.92  18.38  18.27  18.34  18.31
10   165.2  22.81  23.84  23.30  23.32  17.54    1486.8  7.43  0.346E+08  0.00492     20.01  16.73  18.31  18.25  18.35  18.30
11   205.2  22.81  23.98  23.32  23.37  18.05    1504.0  7.34  0.359E+08  0.00612     22.11  17.73  19.95  19.77  19.93  19.85
12   245.2  23.39  24.41  23.81  23.87  18.55    1521.6  7.24  0.372E+08  0.00732     21.69  17.94  19.99  19.76  19.88  19.82
13   275.2  23.57  24.64  24.13  24.11  18.92    1535.1  7.17  0.383E+08  0.00822     22.62  18.36  20.16  20.23  20.38  20.31
14   305.2  23.86  24.92  24.37  24.38  19.30    1548.8  7.10  0.393E+08  0.00913     23.04  18.66  20.71  20.65  20.80  20.73
15   333.3  24.37  25.62  25.06  25.01  19.65    1561.9  7.03  0.403E+08  0.00998     22.24  17.56  19.41  19.55  19.74  19.64
16   363.3  24.39  25.75  24.96  25.04  20.03    1576.1  6.96  0.414E+08  0.01089     24.00  18.31  21.24  20.92  21.18  21.05
17   383.3  24.65  25.89  25.20  25.25  20.28    1585.7  6.91  0.421E+08  0.01150     23.96  18.65  21.28  21.07  21.29  21.18
18   403.3  24.89  26.06  25.49  25.48  20.53    1595.5  6.87  0.429E+08  0.01211     24.01  18.94  21.08  21.14  21.34  21.24
19   423.3  25.16  26.32  25.76  25.75  20.79    1605.3  6.82  0.436E+08  0.01272     23.88  18.87  21.00  21.05  21.25  21.15
20   443.3  25.26  26.47  25.82  25.85  21.04    1615.3  6.77  0.444E+08  0.01333     24.72  19.23  21.82  21.69  21.92  21.81
21   463.3  25.88  26.67  26.46  26.34  21.29    1625.4  6.73  0.451E+08  0.01394     22.74  19.38  20.17  20.67  20.76  20.72
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  24.79  26.02  25.38  25.40  20.39    1590.0  6.89  0.425E+08  0.01175     23.80  18.59  20.97  20.91  21.12  21.01
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                                                          XP090-11

INPUT ELECTRIC POWER =  640.0 W               HEAT RATE GAINED BY WATER =  621.0 W              HEAT BALANCE ERROR =  2.97%
MASS FLOW RATE = 14.1000 G/S         PRESSURE DROP = 0.3461 MM H2O        FRICTION FACTOR = 0.049849         FREM =  25.4517
REM =  510.6     GRM   = 0.51412E+07   UPSTREAM BULK TEMPERATURE = 21.16 DEG C   DOWN STREAM BULK TEMPERATURE = 31.72 DEG C
PRM =  5.894     RAM   = 0.30303E+08   INLET BULK TEMPERATURE    = 21.18 DEG C   OUTLET BULK TEMPERATURE      = 31.71 DEG C
_____________________________________________________________________________________________________________________________
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A      B       C    AVER-  (C)                                               A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                            T      H      T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  23.10  23.21  23.11  23.14  21.18     452.0  6.75  0.223E+08  0.00001     27.02  25.65  26.87  26.51  26.60  26.55
 1     1.5  23.42  23.57  23.44  23.48  21.21     452.4  6.74  0.224E+08  0.00016     23.52  22.07  23.31  22.96  23.06  23.01
 2     2.5  23.64  23.81  23.67  23.71  21.23     452.6  6.74  0.224E+08  0.00027     21.59  20.14  21.36  21.02  21.12  21.07
 3     5.5  24.30  24.56  24.34  24.40  21.30     453.4  6.72  0.225E+08  0.00059     17.33  15.95  17.08  16.76  16.79  16.78
 4    15.5  24.88  25.33  24.97  25.06  21.52     455.9  6.68  0.229E+08  0.00167     15.47  13.67  15.10  14.70  14.75  14.73
 5    25.5  25.29  25.73  25.50  25.51  21.75     458.5  6.64  0.232E+08  0.00276     14.68  13.04  13.85  13.82  13.85  13.84
 6    45.5  25.39  25.86  25.57  25.61  22.20     463.2  6.57  0.238E+08  0.00492     16.24  14.19  15.38  15.22  15.27  15.25
 7    75.5  25.74  26.25  25.84  25.95  22.87     470.1  6.46  0.248E+08  0.00818     18.04  15.34  17.44  16.86  16.94  16.90
 8   105.5  26.19  26.77  26.41  26.46  23.55     477.3  6.35  0.258E+08  0.01145     19.56  16.04  18.10  17.79  17.91  17.85
 9   135.5  26.79  27.35  27.07  27.07  24.22     484.6  6.25  0.268E+08  0.01473     20.08  16.51  18.12  18.12  18.24  18.18
10   165.2  27.36  28.02  27.69  27.69  24.89     492.1  6.14  0.278E+08  0.01798     20.86  16.49  18.38  18.41  18.58  18.49
11   205.2  28.03  28.71  28.38  28.37  25.79     502.6  6.00  0.292E+08  0.02239     22.92  17.64  19.83  19.90  20.13  20.02
12   245.2  29.10  29.74  29.44  29.43  26.69     513.6  5.86  0.307E+08  0.02682     21.29  16.80  18.67  18.74  18.92  18.83
13   275.2  29.79  30.43  30.13  30.12  27.36     521.0  5.77  0.317E+08  0.03014     21.13  16.73  18.50  18.62  18.79  18.70
14   305.2  30.41  30.99  30.67  30.69  28.04     528.2  5.68  0.328E+08  0.03346     21.56  17.34  19.47  19.30  19.46  19.38
15   333.3  31.25  31.88  31.54  31.56  28.67     535.2  5.60  0.338E+08  0.03658     19.80  15.90  17.77  17.68  17.83  17.76
16   363.3  31.76  32.42  32.11  32.09  29.34     542.8  5.52  0.348E+08  0.03991     21.11  16.61  18.48  18.55  18.73  18.64
17   383.3  32.26  32.82  32.52  32.53  29.79     548.0  5.46  0.356E+08  0.04214     20.70  16.86  18.72  18.63  18.76  18.69
18   403.3  32.75  33.37  33.01  33.04  30.24     553.4  5.40  0.363E+08  0.04437     20.31  16.30  18.39  18.19  18.34  18.26
19   423.3  33.20  33.78  33.57  33.51  30.69     558.8  5.35  0.371E+08  0.04661     20.29  16.49  17.70  18.02  18.16  18.09
20   443.3  33.57  34.19  33.83  33.86  31.14     564.3  5.29  0.378E+08  0.04885     20.96  16.68  18.88  18.68  18.84  18.76
21   463.3  33.89  34.59  34.14  34.21  31.59     570.0  5.23  0.386E+08  0.05110     22.04  16.91  19.88  19.38  19.61  19.50
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  32.46  33.07  32.76  32.77  29.98     550.4  5.44  0.359E+08  0.04308     20.53  16.47  18.32  18.29  18.44  18.37
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                                                          XP090-12

INPUT ELECTRIC POWER = 1165.0 W               HEAT RATE GAINED BY WATER = 1109.9 W              HEAT BALANCE ERROR =  4.73%
MASS FLOW RATE = 32.8720 G/S         PRESSURE DROP = 0.0000 MM H2O        FRICTION FACTOR = 0.000000         FREM =   0.0000
REM = 1019.2     GRM   = 0.51860E+07   UPSTREAM BULK TEMPERATURE = 15.76 DEG C   DOWN STREAM BULK TEMPERATURE = 23.85 DEG C
PRM =  7.004     RAM   = 0.36323E+08   INLET BULK TEMPERATURE    = 15.77 DEG C   OUTLET BULK TEMPERATURE      = 23.84 DEG C
_____________________________________________________________________________________________________________________________
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM      A      B       C    AVER-  (C)                                               A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                            T      H      T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  18.57  18.57  18.39  18.49  15.77     924.9  7.83  0.265E+08  0.00000     33.74  33.68  36.01  34.68  34.86  34.77
 1     1.5  19.07  19.08  18.90  19.01  15.80     925.5  7.82  0.266E+08  0.00007     28.78  28.72  30.39  29.40  29.57  29.49
 2     2.5  19.42  19.43  19.25  19.36  15.81     925.9  7.82  0.266E+08  0.00011     26.13  26.08  27.44  26.61  26.77  26.69
 3     5.5  20.47  20.48  20.31  20.42  15.86     927.1  7.81  0.267E+08  0.00025     20.48  20.43  21.24  20.71  20.72  20.71
 4    15.5  21.34  21.84  21.35  21.51  16.04     931.3  7.76  0.272E+08  0.00071     17.79  16.25  17.75  17.23  17.26  17.25
 5    25.5  21.83  22.41  22.17  22.14  16.21     935.6  7.72  0.276E+08  0.00116     16.78  15.21  15.81  15.91  15.93  15.92
 6    45.5  21.74  22.36  21.95  22.01  16.55     944.1  7.63  0.284E+08  0.00208     18.16  16.23  17.45  17.24  17.28  17.26
 7    75.5  22.20  22.87  22.39  22.49  17.07     956.4  7.52  0.297E+08  0.00345     18.33  16.22  17.68  17.37  17.41  17.39
 8   105.5  22.29  23.37  22.51  22.73  17.59     967.6  7.42  0.309E+08  0.00483     19.95  16.23  19.07  18.27  18.42  18.35
 9   135.5  22.85  23.74  23.19  23.26  18.10     979.2  7.32  0.321E+08  0.00622     19.76  16.64  18.44  18.19  18.28  18.23
10   165.2  23.03  24.12  23.80  23.65  18.62     990.8  7.23  0.334E+08  0.00759     21.20  17.01  18.06  18.59  18.75  18.67
11   205.2  23.36  24.48  23.88  23.91  19.30    1007.0  7.10  0.351E+08  0.00944     23.04  18.05  20.44  20.31  20.51  20.41
12   245.2  24.17  25.19  24.53  24.63  19.99    1023.8  6.97  0.368E+08  0.01131     22.33  17.96  20.58  20.12  20.29  20.20
13   275.2  24.46  25.53  25.02  25.00  20.51    1036.7  6.87  0.381E+08  0.01271     23.61  18.55  20.65  20.73  20.94  20.83
14   305.2  24.74  25.70  25.21  25.22  21.03    1049.9  6.77  0.395E+08  0.01411     25.03  19.91  22.26  22.21  22.40  22.30
15   333.3  25.59  26.74  26.23  26.19  21.51    1062.6  6.68  0.408E+08  0.01544     22.78  17.77  19.68  19.87  20.08  19.97
16   363.3  25.83  27.08  26.53  26.48  22.03    1075.9  6.59  0.422E+08  0.01685     24.38  18.35  20.62  20.83  21.12  20.98
17   383.3  26.32  27.23  26.76  26.77  22.37    1084.0  6.54  0.430E+08  0.01779     23.50  19.07  21.15  21.09  21.24  21.17
18   403.3  26.67  27.67  27.22  27.19  22.72    1092.2  6.48  0.439E+08  0.01873     23.42  18.70  20.59  20.72  20.90  20.81
19   423.3  27.04  28.10  27.61  27.58  23.06    1100.6  6.43  0.448E+08  0.01968     23.24  18.37  20.37  20.47  20.66  20.56
20   443.3  27.21  28.37  27.83  27.80  23.40    1109.1  6.37  0.457E+08  0.02063     24.30  18.64  20.92  21.04  21.29  21.16
21   463.3  27.83  28.72  28.36  28.30  23.75    1117.8  6.32  0.466E+08  0.02157     22.66  18.61  20.07  20.31  20.45  20.38
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  26.44  27.53  27.03  27.00  22.51    1087.4  6.52  0.434E+08  0.01819     23.61  18.49  20.55  20.67  20.88  20.78
_____________________________________________________________________________________________________________________________
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                                                 XP090-13

INPUT ELECTRIC POWER =  905.0 W               HEAT RATE GAINED BY WATER =  859.6 W              HEAT BALANCE ERROR =  5.01%
MASS FLOW RATE = 15.5440 G/S          PRESSURE DROP = 0.0000 MM H2O          FRICTION FACTOR = 0.000000          FREM =   0.0000
REM =  512.8      GRM   = 0.51082E+07     UPSTREAM BULK TEMPERATURE = 15.76 DEG C    DOWN STREAM BULK TEMPERATURE = 29.02 DEG C
PRM =  6.534      RAM   = 0.33379E+08     INLET BULK TEMPERATURE    = 15.78 DEG C    OUTLET BULK TEMPERATURE      = 29.01 DEG C
----------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA         Z       ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                            A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                        T      H     T+H
----------------------------------------------------------------------------------------------------------------------------
 0    0.1  18.52  18.61  18.35  18.47  15.78     437.4  7.83  0.206E+08  0.00000    26.71  25.84  28.44  27.20  27.36  27.28
 1    1.5  18.93  19.06  18.80  18.91  15.82     437.9  7.82  0.206E+08  0.00014    23.48  22.54  24.56  23.63  23.79  23.71
 2    2.5  19.22  19.38  19.10  19.22  15.85     438.2  7.81  0.207E+08  0.00024    21.67  20.72  22.45  21.67  21.82  21.75
 3    5.5  20.08  20.32  20.03  20.14  15.93     439.2  7.79  0.208E+08  0.00053    17.60  16.67  17.84  17.35  17.37  17.36
 4   15.5  20.67  21.22  20.73  20.88  16.22     442.5  7.72  0.214E+08  0.00149    16.38  14.58  16.16  15.66  15.71  15.68
 5   25.5  21.16  21.79  21.51  21.49  16.50     445.8  7.65  0.219E+08  0.00246    15.66  13.77  14.55  14.62  14.66  14.64
 6   45.5  21.29  21.97  21.56  21.61  17.06     452.2  7.52  0.230E+08  0.00440    17.21  14.85  16.19  16.02  16.08  16.05
 7   75.5  21.76  22.42  21.94  22.04  17.91     460.9  7.36  0.245E+08  0.00732    18.89  16.10  18.03  17.59  17.67  17.63
 8  105.5  22.18  23.09  22.40  22.56  18.75     470.1  7.20  0.261E+08  0.01025    21.15  16.71  19.89  19.06  19.25  19.15
 9  135.5  23.02  23.85  23.46  23.44  19.60     479.6  7.04  0.277E+08  0.01320    21.18  17.03  18.74  18.83  18.98  18.91
10  165.2  23.76  24.62  24.24  24.21  20.44     489.4  6.89  0.294E+08  0.01613    21.77  17.26  18.97  19.16  19.33  19.24
11  205.2  24.64  25.54  25.05  25.08  21.57     503.2  6.67  0.317E+08  0.02010    23.44  18.12  20.67  20.52  20.74  20.63
12  245.2  25.89  26.74  26.26  26.30  22.70     516.3  6.49  0.340E+08  0.02409    22.48  17.73  20.14  19.93  20.12  20.02
13  275.2  26.62  27.48  27.08  27.06  23.54     526.1  6.35  0.357E+08  0.02709    23.26  18.21  20.27  20.37  20.58  20.48
14  305.2  27.30  28.15  27.66  27.70  24.39     536.3  6.22  0.374E+08  0.03010    24.57  19.01  21.89  21.59  21.82  21.70
15  333.3  28.42  29.31  28.92  28.88  25.18     546.3  6.09  0.391E+08  0.03294    22.07  17.29  19.11  19.29  19.49  19.39
16  363.3  29.11  30.03  29.59  29.58  26.03     557.3  5.96  0.410E+08  0.03598    23.15  17.81  19.98  20.08  20.31  20.20
17  383.3  29.70  30.47  30.08  30.08  26.59     564.9  5.87  0.423E+08  0.03802    22.90  18.34  20.42  20.38  20.55  20.47
18  403.3  30.24  31.08  30.67  30.66  27.16     572.0  5.79  0.435E+08  0.04005    23.06  18.12  20.21  20.27  20.46  20.37
19  423.3  30.93  31.72  31.39  31.35  27.72     578.6  5.72  0.447E+08  0.04207    22.13  17.76  19.32  19.58  19.74  19.66
20  443.3  31.33  32.17  31.78  31.76  28.29     585.3  5.65  0.459E+08  0.04410    23.26  18.24  20.30  20.39  20.60  20.49
21  463.3  32.00  32.72  32.42  32.38  28.85     592.3  5.58  0.471E+08  0.04613    22.47  18.28  19.85  20.05  20.20  20.13
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  29.95  30.80  30.41  30.39  26.83     567.4  5.85  0.428E+08  0.03886    22.76  17.93  19.89  20.00  20.19  20.10
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                                                 XP090-14

INPUT ELECTRIC POWER = 1415.0 W               HEAT RATE GAINED BY WATER = 1389.0 W              HEAT BALANCE ERROR =  1.84%
MASS FLOW RATE = 42.9800 G/S          PRESSURE DROP = 1.0827 MM H2O          FRICTION FACTOR = 0.016788          FREM =  25.2531
REM = 1504.3      GRM   = 0.10230E+08     UPSTREAM BULK TEMPERATURE = 21.13 DEG C    DOWN STREAM BULK TEMPERATURE = 28.88 DEG C
PRM =  6.121      RAM   = 0.62624E+08     INLET BULK TEMPERATURE    = 21.14 DEG C    OUTLET BULK TEMPERATURE      = 28.87 DEG C
----------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA         Z       ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                            A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                        T      H     T+H
----------------------------------------------------------------------------------------------------------------------------
 0    0.1  23.74  23.80  23.58  23.69  21.14    1376.7  6.75  0.498E+08  0.00000    44.85  43.74  47.71  45.69  46.00  45.85
 1    1.5  24.27  24.36  24.12  24.24  21.17    1377.5  6.75  0.499E+08  0.00005    37.50  36.41  39.36  37.88  38.15  38.02
 2    2.5  24.64  24.75  24.50  24.62  21.18    1378.0  6.75  0.500E+08  0.00009    33.69  32.64  35.12  33.88  34.14  34.01
 3    5.5  25.74  25.91  25.62  25.75  21.23    1379.7  6.74  0.501E+08  0.00019    25.82  24.90  26.54  25.73  25.75  25.74
 4   15.5  26.43  27.19  26.58  26.73  21.40    1385.4  6.71  0.507E+08  0.00055    23.09  20.08  22.45  21.80  21.88  21.84
 5   25.5  27.13  27.73  27.44  27.44  21.56    1391.1  6.67  0.512E+08  0.00090    20.87  18.84  19.78  19.80  19.83  19.81
 6   45.5  27.33  28.08  27.63  27.68  21.89    1402.5  6.61  0.524E+08  0.00161    21.35  18.78  20.23  20.06  20.12  20.09
 7   75.5  27.73  28.52  27.79  28.02  22.39    1417.8  6.54  0.539E+08  0.00268    21.70  18.91  21.46  20.61  20.69  20.65
 8  105.5  27.97  28.89  28.19  28.35  22.88    1433.3  6.46  0.555E+08  0.00375    22.79  19.29  21.84  21.20  21.31  21.25
 9  135.5  28.52  29.41  28.84  28.92  23.38    1449.2  6.38  0.571E+08  0.00482    22.52  19.20  21.17  20.87  20.96  20.92
10  165.2  28.69  29.96  29.42  29.36  23.87    1465.3  6.30  0.587E+08  0.00589    23.98  18.97  20.81  21.06  21.25  21.16
11  205.2  29.09  30.43  29.67  29.73  24.52    1487.6  6.20  0.610E+08  0.00732    25.30  19.56  22.46  22.19  22.44  22.32
12  245.2  29.66  30.97  30.27  30.30  25.18    1510.5  6.09  0.632E+08  0.00876    25.79  19.94  22.66  22.55  22.80  22.67
13  275.2  30.07  31.37  30.69  30.71  25.68    1528.2  6.01  0.650E+08  0.00985    26.25  20.23  22.99  22.90  23.16  23.03
14  305.2  30.47  31.77  31.06  31.10  26.17    1546.3  5.94  0.668E+08  0.01094    26.80  20.57  23.57  23.37  23.65  23.51
15  333.3  30.97  32.39  31.82  31.73  26.64    1563.6  5.86  0.685E+08  0.01196    26.51  19.98  22.17  22.58  22.89  22.73
16  363.3  31.32  32.81  32.11  32.08  27.13    1580.7  5.79  0.702E+08  0.01305    27.40  20.23  23.08  23.21  23.57  23.39
17  383.3  31.76  33.04  32.41  32.40  27.46    1591.3  5.75  0.713E+08  0.01377    26.72  20.55  23.18  23.21  23.48  23.35
18  403.3  32.13  33.48  32.79  32.80  27.79    1602.1  5.71  0.725E+08  0.01450    26.40  20.16  22.94  22.89  23.17  23.03
19  423.3  32.53  33.83  33.29  33.22  28.12    1613.0  5.67  0.736E+08  0.01523    25.96  20.05  22.17  22.47  22.73  22.60
20  443.3  32.67  34.07  33.33  33.36  28.45    1624.1  5.63  0.747E+08  0.01595    27.12  20.36  23.44  23.32  23.64  23.48
21  463.3  33.12  34.37  33.81  33.77  28.78    1635.3  5.59  0.759E+08  0.01668    26.38  20.46  22.74  22.94  23.19  23.07
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  31.90  33.27  32.63  32.60  27.60    1595.8  5.74  0.718E+08  0.01408    26.68  20.22  22.83  22.95  23.24  23.10
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                                                 XP090-15

INPUT ELECTRIC POWER = 1255.0 W               HEAT RATE GAINED BY WATER = 1212.7 W              HEAT BALANCE ERROR =  3.37%
MASS FLOW RATE = 27.8180 G/S          PRESSURE DROP = 0.7280 MM H2O          FRICTION FACTOR = 0.026940          FREM =  26.8890
REM =  998.1      GRM   = 0.97318E+07     UPSTREAM BULK TEMPERATURE = 20.83 DEG C    DOWN STREAM BULK TEMPERATURE = 31.28 DEG C
PRM =  5.955      RAM   = 0.57951E+08     INLET BULK TEMPERATURE    = 20.84 DEG C    OUTLET BULK TEMPERATURE      = 31.28 DEG C
----------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR      RA         Z       ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                            A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                        T      H     T+H
----------------------------------------------------------------------------------------------------------------------------
 0    0.1  23.58  23.71  23.46  23.56  20.85     884.5  6.81  0.426E+08  0.00000    37.17  35.47  38.93  37.46  37.62  37.54
 1    1.5  24.10  24.28  24.02  24.12  20.88     885.2  6.80  0.427E+08  0.00008    31.60  29.88  32.39  31.42  31.56  31.49
 2    2.5  24.45  24.67  24.40  24.50  20.90     885.7  6.80  0.428E+08  0.00014    28.64  26.95  29.03  28.28  28.41  28.34
 3    5.5  25.52  25.85  25.56  25.64  20.97     887.2  6.79  0.430E+08  0.00030    22.35  20.82  22.13  21.75  21.77  21.76
 4   15.5  26.38  27.13  26.41  26.64  21.19     892.1  6.74  0.436E+08  0.00085    19.59  17.10  19.46  18.64  18.72  18.68
 5   25.5  26.97  27.68  27.27  27.31  21.41     897.0  6.70  0.443E+08  0.00140    18.28  16.21  17.33  17.23  17.27  17.25
 6   45.5  27.06  27.97  27.47  27.50  21.86     907.1  6.62  0.456E+08  0.00249    19.51  16.60  18.08  17.99  18.07  18.03
 7   75.5  27.35  28.24  27.57  27.72  22.52     920.4  6.51  0.475E+08  0.00414    20.99  17.71  20.07  19.49  19.59  19.54
 8  105.5  27.63  28.89  27.86  28.13  23.19     934.1  6.41  0.493E+08  0.00580    22.77  17.75  21.69  20.50  20.74  20.62
 9  135.5  28.24  29.29  28.73  28.76  23.86     948.3  6.30  0.513E+08  0.00746    23.06  18.58  20.72  20.62  20.78  20.70
10  165.2  28.69  29.91  29.42  29.34  24.52     962.7  6.20  0.532E+08  0.00911    24.19  18.72  20.57  20.92  21.16  21.04
11  205.2  29.26  30.54  29.89  29.89  25.41     982.9  6.06  0.559E+08  0.01134    26.17  19.62  22.47  22.44  22.75  22.59
12  245.2  30.21  31.41  30.77  30.80  26.30    1003.9  5.92  0.587E+08  0.01358    25.68  19.65  22.45  22.32  22.59  22.46
13  275.2  30.84  32.04  31.47  31.45  26.97    1019.7  5.82  0.608E+08  0.01527    25.86  19.75  22.29  22.36  22.63  22.50
14  305.2  31.57  32.77  32.12  32.15  27.64    1033.6  5.73  0.628E+08  0.01695    25.43  19.49  22.34  22.16  22.42  22.29
15  333.3  32.31  33.62  33.00  32.97  28.26    1047.0  5.65  0.647E+08  0.01853    24.71  18.66  21.09  21.21  21.49  21.35
16  363.3  32.82  34.08  33.44  33.45  28.93    1061.7  5.57  0.667E+08  0.02022    25.67  19.36  22.13  22.09  22.39  22.24
17  383.3  33.31  34.38  33.79  33.83  29.37    1071.7  5.51  0.681E+08  0.02134    25.32  19.90  22.55  22.37  22.59  22.48
18  403.3  33.75  34.82  34.29  34.29  29.82    1081.9  5.46  0.695E+08  0.02248    25.33  19.93  22.28  22.30  22.51  22.41
19  423.3  34.26  35.44  34.91  34.87  30.26    1092.3  5.40  0.710E+08  0.02361    24.92  19.21  21.43  21.61  21.85  21.73
20  443.3  34.51  35.75  35.12  35.13  30.71    1102.9  5.34  0.724E+08  0.02474    26.14  19.72  22.55  22.50  22.80  22.65
21  463.3  35.01  36.22  35.59  35.61  31.15    1113.7  5.29  0.739E+08  0.02588    25.74  19.59  22.36  22.29  22.56  22.43
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  33.49  34.68  34.09  34.09  29.56    1076.2  5.49  0.687E+08  0.02182    25.35  19.46  22.01  22.01  22.27  22.14
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                                                XP090-16

INPUT ELECTRIC POWER = 2100.0 W              HEAT RATE GAINED BY WATER = 2016.6 W              HEAT BALANCE ERROR =  3.97%
MASS FLOW RATE = 47.3120 G/S           PRESSURE DROP = 0.0000 MM H2O       FRICTION FACTOR = 0.000000         FREM =   0.0000
REM = 1511.4     GRM   = 0.10603E+08     UPSTREAM BULK TEMPERATURE = 15.93 DEG C    DOWN STREAM BULK TEMPERATURE = 26.14 DEG C
PRM =   6.773    RAM   = 0.71814E+08     INLET BULK TEMPERATURE     = 15.94 DEG C    OUTLET BULK TEMPERATURE      = 26.13 DEG C
------------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR      RA         Z         ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                          A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                       T      H      T+H
------------------------------------------------------------------------------------------------------------------------------
 0     0.1  20.00  20.12  19.79  19.93  15.94   1337.0  7.79  0.489E+08  0.00000    42.21  40.97  44.56  42.90  43.07  42.99
 1     1.5  20.82  20.99  20.66  20.80  15.97   1338.1  7.78  0.491E+08  0.00005    35.35  34.13  36.54  35.50  35.64  35.57
 2     2.5  21.38  21.59  21.26  21.39  15.99   1338.9  7.77  0.492E+08  0.00008    31.79  30.61  32.51  31.73  31.85  31.79
 3     5.5  23.08  23.39  23.07  23.18  16.06   1341.2  7.76  0.495E+08  0.00017    24.40  23.37  24.42  24.05  24.07  24.06
 4    15.5  24.55  25.61  24.80  24.99  16.28   1348.9  7.70  0.504E+08  0.00049    20.69  18.34  20.08  19.65  19.71  19.68
 5    25.5  25.40  26.40  25.94  25.91  16.49   1356.7  7.65  0.514E+08  0.00081    19.21  17.27  18.10  18.16  18.20  18.18
 6    45.5  25.17  26.58  25.91  25.89  16.93   1372.1  7.55  0.534E+08  0.00145    20.73  17.71  19.04  19.08  19.16  19.12
 7    75.5  25.63  26.92  25.90  26.15  17.58   1392.5  7.42  0.561E+08  0.00240    21.19  18.27  20.51  19.91  19.99  19.95
 8   105.5  25.91  27.61  26.29  26.60  18.23   1413.5  7.30  0.589E+08  0.00336    22.18  18.17  21.13  20.35  20.49  20.42
 9   135.5  26.52  28.18  27.18  27.29  18.88   1435.1  7.18  0.618E+08  0.00433    22.28  18.28  20.49  20.22  20.35  20.28
10   165.2  26.92  28.63  27.53  27.69  19.53   1457.2  7.06  0.647E+08  0.00529    22.98  18.66  21.22  20.80  20.95  20.88
11   205.2  26.92  28.82  27.66  27.80  20.40   1488.1  6.89  0.688E+08  0.00658    25.96  20.12  23.32  22.88  23.14  23.01
12   245.2  27.88  29.69  28.71  28.76  21.27   1520.3  6.73  0.730E+08  0.00788    25.55  20.07  22.70  22.55  22.77  22.66
13   275.2  28.34  30.26  29.36  29.32  21.92   1544.9  6.61  0.762E+08  0.00887    26.26  20.23  22.69  22.80  23.06  22.93
14   305.2  29.02  30.93  29.88  29.95  22.57   1567.1  6.51  0.791E+08  0.00985    26.12  20.15  23.04  22.85  23.10  22.97
15   333.3  29.81  31.83  30.87  30.84  23.19   1588.5  6.41  0.820E+08  0.01077    25.40  19.46  21.88  21.98  22.25  22.12
16   363.3  29.99  32.08  31.10  31.06  23.84   1612.0  6.31  0.851E+08  0.01176    27.30  20.37  23.12  23.26  23.60  23.43
17   383.3  30.48  32.26  31.30  31.35  24.27   1628.1  6.24  0.873E+08  0.01242    27.03  21.00  23.87  23.72  23.97  23.84
18   403.3  30.86  32.75  31.78  31.80  24.71   1644.4  6.17  0.894E+08  0.01308    27.26  20.84  23.68  23.64  23.93  23.78
19   423.3  31.43  33.39  32.51  32.44  25.14   1661.1  6.10  0.916E+08  0.01374    26.64  20.30  22.72  22.93  23.22  23.08
20   443.3  31.56  33.63  32.56  32.58  25.58   1678.2  6.03  0.938E+08  0.01441    27.98  20.78  23.97  23.89  24.24  24.06
21   463.3  32.22  34.07  33.14  33.14  26.01   1695.6  5.96  0.961E+08  0.01507    26.91  20.74  23.43  23.43  23.69  23.56
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  30.69  32.66  31.69  31.68  24.45   1635.4  6.21  0.882E+08  0.01270    26.94  20.46  23.21  23.24  23.53  23.38
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                                                XP090-17

INPUT ELECTRIC POWER = 1800.0 W              HEAT RATE GAINED BY WATER = 1700.4 W              HEAT BALANCE ERROR =  5.53%
MASS FLOW RATE = 28.5400 G/S           PRESSURE DROP = 0.0000 MM H2O       FRICTION FACTOR = 0.000000         FREM =   0.0000
REM =  954.6     GRM   = 0.10638E+08     UPSTREAM BULK TEMPERATURE = 15.87 DEG C    DOWN STREAM BULK TEMPERATURE = 30.15 DEG C
PRM =   6.436    RAM   = 0.68464E+08     INLET BULK TEMPERATURE     = 15.89 DEG C    OUTLET BULK TEMPERATURE      = 30.14 DEG C
------------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR      RA         Z         ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                          A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                       T      H      T+H
------------------------------------------------------------------------------------------------------------------------------
 0     0.1  19.94  20.12  19.78  19.92  15.89    805.5  7.80  0.411E+08  0.00000    35.72  34.13  37.18  35.90  36.05  35.98
 1     1.5  20.68  20.95  20.58  20.72  15.93    806.4  7.79  0.412E+08  0.00008    30.43  28.82  31.10  30.22  30.36  30.29
 2     2.5  21.20  21.52  21.13  21.27  15.96    807.1  7.78  0.413E+08  0.00013    27.61  26.02  27.95  27.25  27.38  27.32
 3     5.5  22.74  23.22  22.79  22.92  16.06    809.0  7.76  0.417E+08  0.00029    21.60  20.16  21.44  21.04  21.06  21.05
 4    15.5  23.89  24.88  24.13  24.30  16.36    815.5  7.68  0.428E+08  0.00081    19.17  16.94  18.58  18.18  18.23  18.21
 5    25.5  24.62  25.73  25.22  25.19  16.66    822.1  7.61  0.440E+08  0.00134    18.12  15.90  16.85  16.91  16.96  16.93
 6    45.5  24.68  26.08  25.41  25.39  17.27    834.1  7.48  0.462E+08  0.00240    19.44  16.35  17.70  17.74  17.83  17.79
 7    75.5  25.19  26.42  25.45  25.69  18.18    851.7  7.31  0.495E+08  0.00399    20.50  17.45  19.77  19.15  19.24  19.19
 8   105.5  25.58  27.27  25.85  26.23  19.10    870.0  7.14  0.529E+08  0.00559    22.10  17.52  21.21  20.07  20.28  20.18
 9   135.5  26.41  27.91  27.07  27.13  20.01    889.2  6.97  0.564E+08  0.00720    22.34  18.10  20.23  20.07  20.22  20.15
10   165.2  26.86  28.63  27.81  27.76  20.91    908.9  6.80  0.600E+08  0.00880    23.96  18.48  20.68  20.80  21.04  20.92
11   205.2  27.48  29.21  28.22  28.30  22.13    936.1  6.58  0.650E+08  0.01096    26.56  20.08  23.34  23.03  23.33  23.18
12   245.2  28.77  30.47  29.61  29.61  23.34    961.6  6.38  0.698E+08  0.01314    26.11  19.90  22.63  22.60  22.88  22.74
13   275.2  29.57  31.32  30.58  30.49  24.25    981.7  6.24  0.735E+08  0.01478    26.63  20.03  22.37  22.70  23.01  22.85
14   305.2  30.47  32.10  31.28  31.28  25.17   1002.6  6.10  0.774E+08  0.01643    26.63  20.36  23.10  23.08  23.36  23.22
15   333.3  31.58  33.45  32.55  32.53  26.02   1023.0  5.96  0.811E+08  0.01798    25.33  18.96  21.58  21.65  21.96  21.80
16   363.3  32.26  34.14  33.22  33.21  26.93   1045.4  5.82  0.852E+08  0.01964    26.39  19.51  22.37  22.41  22.76  22.58
17   383.3  32.87  34.44  33.63  33.64  27.54   1058.4  5.74  0.877E+08  0.02074    26.36  20.35  23.06  23.00  23.26  23.13
18   403.3  33.42  35.04  34.23  34.23  28.15   1071.7  5.67  0.902E+08  0.02185    26.61  20.35  23.04  23.06  23.33  23.20
19   423.3  33.98  35.67  34.79  34.81  28.76   1085.3  5.59  0.928E+08  0.02295    26.82  20.26  23.19  23.12  23.42  23.27
20   443.3  34.62  36.20  35.34  35.39  29.36   1099.3  5.51  0.955E+08  0.02406    26.59  20.45  23.40  23.22  23.48  23.35
21   463.3  35.29  36.78  35.93  36.00  29.97   1113.6  5.44  0.982E+08  0.02517    26.26  20.50  23.45  23.16  23.40  23.28
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  33.12  34.82  33.96  33.97  27.79   1063.8  5.72  0.887E+08  0.02120    26.35  19.98  22.77  22.74  23.04  22.89
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                                                XP090-18

INPUT ELECTRIC POWER = 1300.0 W              HEAT RATE GAINED BY WATER = 1276.8 W              HEAT BALANCE ERROR =  1.78%
MASS FLOW RATE = 14.1000 G/S           PRESSURE DROP = 0.0000 MM H2O       FRICTION FACTOR = 0.000000         FREM =   0.0000
REM =  513.5     GRM   = 0.10774E+08     UPSTREAM BULK TEMPERATURE = 15.82 DEG C    DOWN STREAM BULK TEMPERATURE = 37.53 DEG C
PRM =   5.857    RAM   = 0.63103E+08     INLET BULK TEMPERATURE     = 15.84 DEG C    OUTLET BULK TEMPERATURE      = 37.51 DEG C
------------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR      RA         Z         ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                          A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                       T      H      T+H
------------------------------------------------------------------------------------------------------------------------------
 0     0.1  19.54  19.75  19.46  19.56  15.85    397.5  7.81  0.307E+08  0.00001    29.37  27.80  30.01  29.22  29.30  29.26
 1     1.5  20.13  20.42  20.11  20.20  15.91    398.2  7.79  0.309E+08  0.00016    25.75  24.07  25.83  25.29  25.37  25.33
 2     2.5  20.53  20.88  20.56  20.65  15.96    398.7  7.78  0.310E+08  0.00027    23.73  22.03  23.57  23.15  23.22  23.19
 3     5.5  21.74  22.27  21.91  21.98  16.10    400.1  7.75  0.314E+08  0.00058    19.21  17.56  18.66  18.45  18.48  18.46
 4    15.5  22.67  23.64  22.85  23.05  16.56    405.0  7.63  0.327E+08  0.00165    17.74  15.30  17.22  16.69  16.75  16.72
 5    25.5  23.44  24.40  23.95  23.93  17.02    409.8  7.53  0.340E+08  0.00272    16.85  14.66  15.62  15.66  15.71  15.68
 6    45.5  23.62  24.97  24.46  24.35  17.95    418.5  7.35  0.365E+08  0.00486    19.01  15.37  16.58  16.86  16.99  16.92
 7    75.5  24.36  25.47  24.67  24.83  19.33    432.2  7.09  0.404E+08  0.00810    21.41  17.51  20.14  19.55  19.69  19.62
 8   105.5  25.24  26.66  25.68  25.86  20.72    447.0  6.83  0.445E+08  0.01136    23.68  18.03  21.58  20.83  21.10  20.96
 9   135.5  26.74  27.91  27.35  27.33  22.11    462.3  6.58  0.487E+08  0.01465    23.04  18.41  20.36  20.43  20.60  20.52
10   165.2  27.86  29.24  28.64  28.58  23.48    476.5  6.36  0.528E+08  0.01792    24.31  18.47  20.60  20.86  21.13  21.00
11   205.2  29.31  30.65  29.89  29.95  25.33    497.2  6.07  0.586E+08  0.02236    26.60  19.91  23.23  22.92  23.25  23.09
12   245.2  31.32  32.63  32.00  31.98  27.18    519.0  5.79  0.647E+08  0.02684    25.49  19.34  21.88  21.95  22.23  22.09
13   275.2  32.62  33.93  33.36  33.31  28.56    534.0  5.61  0.691E+08  0.03019    25.91  19.59  21.92  22.18  22.47  22.33
14   305.2  34.02  35.22  34.51  34.58  29.95    549.9  5.44  0.736E+08  0.03356    25.78  19.89  22.99  22.63  22.89  22.76
15   333.3  35.47  36.92  36.30  36.23  31.25    565.7  5.28  0.781E+08  0.03674    24.79  18.44  20.70  21.00  21.31  21.15
16   363.3  36.58  37.97  37.34  37.30  32.64    582.1  5.11  0.828E+08  0.04019    26.39  19.52  22.13  22.34  22.68  22.51
17   383.3  37.42  38.63  38.06  38.04  33.56    592.8  5.00  0.857E+08  0.04253    26.95  20.51  23.09  23.23  23.52  23.37
18   403.3  38.32  39.56  38.97  38.95  34.48    603.9  4.89  0.888E+08  0.04488    27.02  20.45  23.13  23.23  23.53  23.38
19   423.3  39.36  40.62  40.03  40.00  35.41    615.4  4.79  0.919E+08  0.04726    26.21  19.84  22.37  22.51  22.81  22.66
20   443.3  40.03  41.35  40.73  40.70  36.33    627.4  4.68  0.951E+08  0.04966    27.94  20.57  23.46  23.61  23.99  23.80
21   463.3  40.91  42.24  41.55  41.57  37.26    639.1  4.58  0.984E+08  0.05204    28.19  20.65  23.99  23.89  24.28  24.08
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  37.86  39.17  38.57  38.54  33.95    597.9  4.96  0.871E+08  0.04354    26.55  19.89  22.48  22.65  22.97  22.81
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                                                          XP090-22

INPUT ELECTRIC POWER = 4310.0 W                HEAT RATE GAINED BY WATER = 4142.8 W              HEAT BALANCE ERROR =  3.88%
MASS FLOW RATE = 37.9260 G/S          PRESSURE DROP = 0.0000 MM H2O          FRICTION FACTOR = 0.000000          FREM =   0.0000
REM = 1549.4     GRM   = 0.50867E+08    UPSTREAM BULK TEMPERATURE = 19.00 DEG C    DOWN STREAM BULK TEMPERATURE = 45.18 DEG C
PRM =   5.171    RAM   = 0.26305E+09    INLET BULK TEMPERATURE    = 19.02 DEG C    OUTLET BULK TEMPERATURE      = 45.17 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                             A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                          T      H      T+H
--------------------------------------------------------------------------------------------------------------------------------
 0    0.1  26.65  27.17  26.41  26.68  19.03    1154.3  7.15  0.128E+09  0.00000     45.82  42.88  47.29  45.63  45.82  45.72
 1    1.5  28.12  28.86  28.04  28.29  19.11    1156.5  7.14  0.129E+09  0.00006     38.74  35.81  39.09  38.01  38.18  38.10
 2    2.5  29.13  30.02  29.16  29.40  19.16    1158.0  7.12  0.130E+09  0.00010     35.01  32.16  34.91  34.09  34.24  34.17
 3    5.5  32.18  33.51  32.53  32.74  19.33    1162.6  7.09  0.131E+09  0.00022     27.16  24.61  26.43  26.02  26.07  26.04
 4   15.5  33.42  36.14  34.04  34.53  19.89    1178.2  6.99  0.136E+09  0.00062     25.75  21.44  24.62  23.79  23.94  23.86
 5   25.5  34.90  37.39  36.09  36.13  20.45    1194.2  6.88  0.142E+09  0.00102     24.07  20.52  22.24  22.18  22.28  22.23
 6   45.5  34.54  37.47  35.99  36.00  21.56    1227.6  6.67  0.153E+09  0.00183     26.73  21.80  24.03  24.02  24.19  24.10
 7   75.5  35.38  38.34  36.27  36.66  23.24    1274.8  6.40  0.169E+09  0.00304     28.45  22.87  26.51  25.73  25.94  25.84
 8  105.5  36.20  39.86  36.98  37.68  24.91    1324.4  6.14  0.186E+09  0.00427     30.48  23.01  28.51  26.95  27.33  27.14
 9  135.5  37.35  41.02  38.72  39.03  26.58    1377.9  5.87  0.204E+09  0.00551     31.83  23.75  28.24  27.54  27.94  27.74
10  165.2  38.51  42.63  40.38  40.51  28.24    1426.7  5.66  0.221E+09  0.00674     33.26  23.72  28.12  27.83  28.37  28.10
11  205.2  39.53  43.59  40.90  41.34  30.47    1495.8  5.37  0.245E+09  0.00840     37.49  25.89  32.57  31.25  31.98  31.62
12  245.2  41.68  45.64  43.65  43.66  32.70    1567.6  5.10  0.269E+09  0.01009     37.62  26.12  30.87  30.84  31.54  31.19
13  275.2  43.12  47.23  45.31  45.22  34.37    1620.7  4.91  0.287E+09  0.01138     38.49  26.17  30.78  31.03  31.81  31.42
14  305.2  44.62  48.53  46.44  46.53  36.05    1677.5  4.71  0.305E+09  0.01270     39.10  26.85  32.24  31.97  32.73  32.35
15  333.3  46.01  50.73  48.32  48.35  37.61    1730.5  4.55  0.323E+09  0.01392     39.76  25.46  31.18  31.09  32.14  31.61
16  363.3  47.94  52.19  49.95  50.03  39.29    1786.3  4.40  0.343E+09  0.01522     38.47  25.80  31.21  30.99  31.83  31.41
17  383.3  48.86  52.65  50.54  50.68  40.40    1825.6  4.29  0.357E+09  0.01609     39.29  27.12  32.77  32.31  33.06  32.68
18  403.3  49.97  53.89  51.66  51.84  41.52    1866.6  4.19  0.371E+09  0.01696     39.20  26.78  32.67  32.10  32.88  32.49
19  423.3  51.39  55.37  53.25  53.34  42.63    1904.8  4.10  0.384E+09  0.01783     37.77  25.97  31.15  30.90  31.63  31.27
20  443.3  51.90  56.01  53.64  53.85  43.75    1942.3  4.01  0.398E+09  0.01871     40.49  26.93  33.37  32.68  33.59  33.14
21  463.3  53.44  57.06  55.03  55.18  44.86    1981.4  3.92  0.412E+09  0.01960     38.41  27.00  32.40  31.94  32.60  32.27
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  49.34  53.47  51.23  51.35  40.87    1842.7  4.26  0.363E+09  0.01646     39.16  26.34  32.06  31.68  32.52  32.10
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                                                          XP090-23

INPUT ELECTRIC POWER = 3100.0 W                HEAT RATE GAINED BY WATER = 2961.2 W              HEAT BALANCE ERROR =  4.48%
MASS FLOW RATE = 22.0420 G/S          PRESSURE DROP = 0.0000 MM H2O          FRICTION FACTOR = 0.000000          FREM =   0.0000
REM =   991.8    GRM   = 0.48697E+08    UPSTREAM BULK TEMPERATURE = 20.75 DEG C    DOWN STREAM BULK TEMPERATURE = 52.95 DEG C
PRM =   4.619    RAM   = 0.22493E+09    INLET BULK TEMPERATURE    = 20.78 DEG C    OUTLET BULK TEMPERATURE      = 52.94 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                             A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                          T      H      T+H
--------------------------------------------------------------------------------------------------------------------------------
 0    0.1  27.21  27.69  26.96  27.24  20.79     699.8  6.82  0.104E+09  0.00000     38.64  35.97  40.23  38.50  38.77  38.63
 1    1.5  28.33  29.00  28.18  28.46  20.89     701.6  6.80  0.104E+09  0.00010     33.37  30.60  34.05  32.76  33.02  32.89
 2    2.5  29.10  29.90  29.02  29.31  20.95     702.7  6.79  0.105E+09  0.00017     30.49  27.74  30.79  29.71  29.95  29.83
 3    5.5  31.40  32.61  31.54  31.85  21.16     706.3  6.75  0.106E+09  0.00038     24.23  21.67  23.91  23.21  23.27  23.24
 4   15.5  32.47  34.67  32.92  33.36  21.85     718.6  6.62  0.111E+09  0.00107     23.31  19.31  22.36  21.52  21.66  21.59
 5   25.5  33.67  35.84  34.70  34.74  22.53     729.4  6.51  0.116E+09  0.00177     22.20  18.59  20.32  20.26  20.37  20.32
 6   45.5  33.65  36.64  35.44  35.24  23.90     752.1  6.30  0.125E+09  0.00316     25.29  19.36  21.37  21.74  22.01  21.88
 7   75.5  34.82  37.45  35.71  35.99  25.96     789.0  5.97  0.141E+09  0.00527     27.69  21.36  25.18  24.46  24.74  24.60
 8  105.5  36.03  39.19  37.03  37.42  28.02     825.5  5.68  0.156E+09  0.00740     30.47  21.85  27.09  25.98  26.47  26.22
 9  135.5  37.68  40.68  39.22  39.20  30.08     862.0  5.42  0.172E+09  0.00953     31.96  22.92  26.58  26.65  27.15  26.90
10  165.2  39.73  43.03  41.49  41.42  32.11     900.8  5.17  0.188E+09  0.01167     31.78  22.17  25.79  26.01  26.58  26.29
11  205.2  41.70  44.93  43.13  43.25  34.86     951.2  4.85  0.209E+09  0.01463     35.11  23.86  29.05  28.62  29.34  28.98
12  245.2  44.51  47.53  45.99  46.01  37.60    1005.5  4.55  0.231E+09  0.01763     34.54  24.03  28.44  28.37  29.00  28.69
13  275.2  46.34  49.51  48.09  47.98  39.66    1045.7  4.36  0.248E+09  0.01985     35.59  24.13  28.20  28.57  29.31  28.94
14  305.2  47.67  50.64  49.17  49.16  41.72    1089.2  4.17  0.267E+09  0.02209     39.76  26.53  31.76  31.80  32.68  32.24
15  333.3  50.12  53.69  51.90  51.91  43.64    1126.8  4.02  0.283E+09  0.02420     36.42  23.48  28.58  28.56  29.49  29.03
16  363.3  52.15  55.41  53.63  53.73  45.70    1169.3  3.86  0.302E+09  0.02648     36.45  24.21  29.63  29.27  30.10  29.68
17  383.3  53.30  56.22  54.59  54.70  47.07    1198.9  3.75  0.315E+09  0.02801     37.65  25.63  31.20  30.73  31.49  31.11
18  403.3  54.77  57.74  56.12  56.21  48.44    1227.7  3.66  0.327E+09  0.02954     37.01  25.16  30.50  30.13  30.89  30.51
19  423.3  56.05  59.38  57.87  57.77  49.82    1257.8  3.56  0.341E+09  0.03108     37.45  24.42  28.98  29.37  30.28  29.82
20  443.3  57.14  60.31  58.59  58.68  51.19    1289.4  3.47  0.354E+09  0.03263     39.11  25.54  31.48  31.09  32.04  31.57
21  463.3  58.79  61.60  60.15  60.18  52.56    1319.1  3.38  0.368E+09  0.03417     37.32  25.72  30.63  30.51  31.22  30.87
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  53.92  57.13  55.45  55.50  47.64    1211.6  3.72  0.320E+09  0.02866     37.35  24.74  30.06  29.86  30.72  30.29
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                                                          XP090-24

INPUT ELECTRIC POWER = 3045.0 W                HEAT RATE GAINED BY WATER = 2941.9 W              HEAT BALANCE ERROR =  3.39%
MASS FLOW RATE = 22.0420 G/S          PRESSURE DROP = 0.7110 MM H2O          FRICTION FACTOR = 0.041721          FREM =  41.9280
REM = 1005.0     GRM   = 0.50328E+08    UPSTREAM BULK TEMPERATURE = 21.57 DEG C    DOWN STREAM BULK TEMPERATURE = 53.56 DEG C
PRM =   4.554    RAM   = 0.22917E+09    INLET BULK TEMPERATURE    = 21.60 DEG C    OUTLET BULK TEMPERATURE      = 53.54 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                             A      B      C     ----- AVERAGE -----
NO.                               AGE                                                                          T      H      T+H
--------------------------------------------------------------------------------------------------------------------------------
 0    0.1  31.04  31.52  27.45  29.39  21.60     714.2  6.67  0.109E+09  0.00000     26.08  24.83  42.13  31.61  33.79  32.70
 1    1.5  31.23  31.90  28.64  30.14  21.70     716.0  6.65  0.110E+09  0.00010     25.85  24.14  35.49  29.18  30.24  29.71
 2    2.5  31.35  32.16  29.46  30.65  21.77     717.2  6.64  0.110E+09  0.00017     25.68  23.69  32.01  27.70  28.35  28.03
 3    5.5  31.73  32.94  31.92  32.20  21.97     720.6  6.60  0.111E+09  0.00038     25.21  22.43  24.73  24.06  24.12  24.09
 4   15.5  32.86  35.07  33.26  33.73  22.66     731.4  6.49  0.116E+09  0.00107     24.07  19.79  23.16  22.18  22.34  22.26
 5   25.5  34.12  36.17  34.98  35.09  23.34     742.6  6.39  0.121E+09  0.00177     22.75  19.11  21.07  20.87  20.98  20.92
 6   45.5  34.04  36.81  35.61  35.48  24.70     766.0  6.17  0.130E+09  0.00317     26.18  20.20  22.42  22.67  22.93  22.80
 7   75.5  35.27  37.89  36.16  36.44  26.74     804.0  5.85  0.146E+09  0.00528     28.55  21.82  25.86  25.10  25.41  25.26
 8  105.5  36.53  39.81  37.53  37.96  28.79     838.8  5.59  0.161E+09  0.00741     31.27  21.98  27.70  26.42  26.98  26.70
 9  135.5  38.24  41.18  39.72  39.71  30.83     876.3  5.33  0.177E+09  0.00955     32.55  23.29  27.12  27.14  27.65  27.40
10  165.2  40.22  43.53  42.00  41.92  32.86     913.9  5.08  0.192E+09  0.01170     32.57  22.48  26.24  26.48  27.10  26.79
11  205.2  42.26  45.43  43.68  43.79  35.58     965.5  4.77  0.213E+09  0.01466     35.70  24.20  29.41  29.03  29.77  29.40
12  245.2  45.01  47.98  46.44  46.47  38.31    1019.0  4.49  0.235E+09  0.01765     35.36  24.49  29.12  29.00  29.66  29.33
13  275.2  46.56  49.73  48.31  48.20  40.35    1060.0  4.30  0.253E+09  0.01987     37.99  25.14  29.64  30.05  30.92  30.49
14  305.2  48.84  51.64  50.23  50.24  42.40    1102.5  4.12  0.271E+09  0.02212     36.47  25.41  30.00  29.97  30.63  30.30
15  333.3  51.07  54.42  52.68  52.72  44.31    1140.2  3.97  0.287E+09  0.02423     34.66  23.17  27.96  27.83  28.60  28.22
16  363.3  52.54  55.80  53.97  54.10  46.35    1183.4  3.81  0.306E+09  0.02651     37.72  24.69  30.64  30.11  31.02  30.56
17  383.3  53.80  56.67  55.14  55.20  47.72    1212.3  3.71  0.319E+09  0.02804     38.26  25.99  31.36  31.08  31.87  31.48
18  403.3  55.21  58.24  56.56  56.67  49.08    1241.4  3.61  0.331E+09  0.02957     37.88  25.34  31.04  30.59  31.42  31.00
19  423.3  56.66  59.77  58.27  58.23  50.44    1272.0  3.52  0.345E+09  0.03111     37.30  24.85  29.62  29.76  30.59  30.17
20  443.3  57.53  60.76  58.98  59.09  51.81    1304.2  3.42  0.359E+09  0.03266     40.37  25.82  32.24  31.74  32.81  32.28
21  463.3  59.18  62.02  60.71  60.64  53.17    1331.2  3.35  0.371E+09  0.03419     38.40  26.08  30.59  30.90  31.69  31.30
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  54.47  57.61  55.93  56.00  48.29    1225.6  3.67  0.324E+09  0.02869     37.70  24.98  30.48  30.19  31.05  30.62
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Appendix 3

Experimental Data for $\alpha = 135°$

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                                                        XP135-01

INPUT ELECTRIC POWER =  145.0 W               HEAT RATE GAINED BY WATER =  144.4 W               HEAT BALANCE ERROR =  0.43%
MASS FLOW RATE = 14.1000 G/S          PRESSURE DROP = 0.3069 MM H2O        FRICTION FACTOR = 0.044214        FREM =  21.8983
REM =  495.3    GRM   = 0.10770E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 26.39 DEG C
PRM =  6.097    RAM   = 0.65660E+07    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 26.39 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR     RA          Z         ------------ NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                             A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                          T      H     T+H
--------------------------------------------------------------------------------------------------------------------------------
 0     0.1 24.45  24.47  24.47  24.46  23.94    481.5  6.29  0.613E+07  0.00001    23.30  22.53  22.72  22.89  22.82  22.86
 1     1.5 24.53  24.55  24.55  24.54  23.94    481.6  6.29  0.613E+07  0.00016    20.56  19.73  19.79  20.05  19.97  20.01
 2     2.5 24.58  24.61  24.61  24.60  23.95    481.6  6.29  0.613E+07  0.00027    19.03  18.17  18.17  18.47  18.39  18.43
 3     5.5 24.74  24.78  24.79  24.77  23.97    481.8  6.29  0.614E+07  0.00060    15.54  14.69  14.60  14.93  14.94  14.94
 4    15.5 24.99  24.99  25.02  25.00  24.02    482.4  6.28  0.616E+07  0.00168    12.30  12.30  11.96  12.19  12.19  12.19
 5    25.5 25.07  25.12  25.17  25.12  24.07    483.0  6.27  0.618E+07  0.00277    12.06  11.42  10.96  11.46  11.48  11.47
 6    45.5 25.12  25.19  25.18  25.16  24.17    484.1  6.25  0.621E+07  0.00494    12.75  11.84  11.91  12.15  12.17  12.16
 7    75.5 25.02  25.14  25.12  25.09  24.33    485.9  6.23  0.627E+07  0.00821    17.38  14.87  15.29  15.77  15.85  15.81
 8   105.5 25.13  25.21  25.18  25.18  24.49    487.6  6.20  0.632E+07  0.01147    18.60  16.60  17.26  17.45  17.49  17.47
 9   135.5 25.24  25.35  25.52  25.37  24.64    489.4  6.18  0.638E+07  0.01474    20.20  17.02  13.76  16.58  16.99  16.79
10   165.2 25.47  25.57  25.69  25.58  24.80    491.1  6.15  0.644E+07  0.01798    17.85  15.65  13.41  15.42  15.63  15.53
11   205.2 25.64  25.76  25.77  25.72  25.01    493.5  6.12  0.651E+07  0.02235    19.04  15.94  15.71  16.77  16.90  16.83
12   245.2 25.89  26.02  26.03  25.98  25.22    495.9  6.09  0.659E+07  0.02672    17.87  14.90  14.70  15.70  15.82  15.76
13   275.2 26.07  26.14  26.19  26.13  25.37    497.8  6.06  0.664E+07  0.03000    17.32  15.57  14.72  15.79  15.87  15.83
14   305.2 26.19  26.31  26.32  26.27  25.53    499.6  6.04  0.670E+07  0.03328    18.22  15.36  15.25  16.17  16.28  16.22
15   333.3 26.42  26.57  26.57  26.52  25.68    501.3  6.02  0.676E+07  0.03636    16.10  13.39  13.48  14.22  14.32  14.27
16   363.3 26.56  26.69  26.75  26.67  25.84    503.2  5.99  0.681E+07  0.03965    16.61  13.93  13.08  14.39  14.54  14.47
17   383.3 26.70  26.78  26.81  26.76  25.94    504.5  5.97  0.685E+07  0.04184    15.74  14.18  13.73  14.50  14.55  14.53
18   403.3 26.78  26.84  26.88  26.84  26.04    505.7  5.96  0.689E+07  0.04404    16.19  15.05  14.26  15.12  15.16  15.14
19   423.3 26.88  26.99  26.99  26.95  26.15    507.0  5.94  0.693E+07  0.04623    16.40  14.24  14.24  14.89  14.96  14.92
20   443.3 26.93  26.97  27.05  26.98  26.25    508.2  5.92  0.697E+07  0.04843    17.58  16.76  15.01  16.38  16.45  16.41
21   463.3 27.04  27.03  27.24  27.11  26.36    509.5  5.91  0.701E+07  0.05063    17.41  17.69  13.57  15.99  16.22  16.10
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 26.71  26.81  26.84  26.79  25.98    505.0  5.97  0.687E+07  0.04276    16.44  14.59  13.97  14.92  15.00  14.96
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                                                        XP135-02

INPUT ELECTRIC POWER =  294.0 W               HEAT RATE GAINED BY WATER =  292.3 W               HEAT BALANCE ERROR =  0.56%
MASS FLOW RATE = 28.5400 G/S          PRESSURE DROP = 0.6581 MM H2O        FRICTION FACTOR = 0.023141        FREM =  23.1989
REM = 1002.5    GRM   = 0.21807E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 26.39 DEG C
PRM =  6.097    RAM   = 0.13295E+08    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 26.39 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR     RA          Z         ------------ NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                             A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                          T      H     T+H
--------------------------------------------------------------------------------------------------------------------------------
 0     0.1 24.70  24.69  24.66  24.68  23.94    974.6  6.29  0.124E+08  0.00000    32.05  32.14  33.41  32.57  32.75  32.66
 1     1.5 24.83  24.82  24.79  24.81  23.94    974.8  6.29  0.124E+08  0.00008    27.61  27.70  28.88  28.08  28.27  28.17
 2     2.5 24.91  24.91  24.87  24.90  23.95    974.9  6.29  0.124E+08  0.00013    25.20  25.30  26.41  25.64  25.83  25.74
 3     5.5 25.18  25.18  25.12  25.16  23.96    975.2  6.29  0.124E+08  0.00030    19.97  20.06  21.02  20.34  20.35  20.35
 4    15.5 25.49  25.56  25.52  25.52  24.02    976.4  6.28  0.125E+08  0.00083    16.47  15.82  16.17  16.15  16.15  16.15
 5    25.5 25.74  25.79  25.83  25.79  24.07    977.5  6.27  0.125E+08  0.00137    14.57  14.15  13.79  14.16  14.17  14.17
 6    45.5 25.78  25.86  25.91  25.85  24.17    979.9  6.25  0.126E+08  0.00244    15.11  14.46  14.05  14.53  14.54  14.53
 7    75.5 25.80  25.86  25.84  25.84  24.33    983.4  6.23  0.127E+08  0.00405    16.55  15.89  16.06  16.16  16.17  16.16
 8   105.5 25.74  25.88  25.91  25.84  24.49    986.9  6.20  0.128E+08  0.00567    19.34  17.48  17.14  17.94  17.99  17.96
 9   135.5 25.91  26.07  26.24  26.07  24.64    990.5  6.18  0.129E+08  0.00728    19.27  17.02  15.24  17.02  17.17  17.09
10   165.2 26.03  26.24  26.36  26.21  24.80    994.1  6.15  0.130E+08  0.00888    19.78  16.88  15.55  17.23  17.40  17.32
11   205.2 26.14  26.43  26.44  26.34  25.01    998.9  6.12  0.132E+08  0.01104    21.38  17.11  16.98  18.28  18.49  18.38
12   245.2 26.50  26.63  26.71  26.61  25.22   1003.8  6.09  0.133E+08  0.01320    18.93  17.14  16.31  17.39  17.46  17.43
13   275.2 26.62  26.81  26.91  26.78  25.37   1007.5  6.06  0.135E+08  0.01482    19.44  16.89  15.79  17.24  17.37  17.31
14   305.2 26.69  26.92  26.99  26.87  25.53   1011.2  6.04  0.136E+08  0.01644    20.95  17.44  16.64  18.16  18.34  18.25
15   333.3 27.03  27.30  27.41  27.24  25.68   1014.8  6.02  0.137E+08  0.01796    17.96  14.95  14.03  15.48  15.65  15.56
16   363.3 27.11  27.42  27.47  27.33  25.84   1018.5  5.99  0.138E+08  0.01959    18.99  15.32  14.80  16.17  16.37  16.27
17   383.3 27.31  27.51  27.58  27.47  25.94   1021.1  5.97  0.139E+08  0.02067    17.67  15.42  14.74  15.85  15.94  15.89
18   403.3 27.40  27.62  27.66  27.56  26.04   1023.6  5.96  0.140E+08  0.02176    17.87  15.40  14.98  15.99  16.08  16.04
19   423.3 27.54  27.77  27.83  27.71  26.15   1026.2  5.94  0.140E+08  0.02284    17.35  14.97  14.42  15.48  15.58  15.53
20   443.3 27.54  27.69  27.88  27.71  26.25   1028.7  5.92  0.141E+08  0.02393    18.75  16.80  14.85  16.65  16.80  16.73
21   463.3 27.71  27.73  28.02  27.82  26.36   1031.3  5.91  0.142E+08  0.02501    17.89  17.60  14.59  16.55  16.69  16.62
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 27.32  27.55  27.64  27.50  25.98   1022.1  5.97  0.139E+08  0.02112    18.10  15.48  14.64  15.94  16.07  16.00
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                                                        XP135-03

INPUT ELECTRIC POWER =  316.0 W               HEAT RATE GAINED BY WATER =  311.8 W               HEAT BALANCE ERROR =  1.31%
MASS FLOW RATE = 42.9800 G/S          PRESSURE DROP = 0.9616 MM H2O        FRICTION FACTOR = 0.014911        FREM =  22.2952
REM = 1495.2    GRM   = 0.22489E+07    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 25.62 DEG C
PRM =  6.162    RAM   = 0.13858E+08    INLET BULK TEMPERATURE    = 23.88 DEG C    OUTLET BULK TEMPERATURE      = 25.62 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR     RA          Z         ------------ NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                             A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                          T      H     T+H
--------------------------------------------------------------------------------------------------------------------------------
 0     0.1 24.62  24.62  24.59  24.61  23.88   1465.8  6.30  0.132E+08  0.00000    35.16  35.26  36.69  35.75  35.95  35.85
 1     1.5 24.74  24.74  24.70  24.72  23.88   1466.0  6.30  0.132E+08  0.00005    30.41  30.52  31.86  30.94  31.16  31.05
 2     2.5 24.82  24.82  24.78  24.81  23.89   1466.1  6.30  0.132E+08  0.00009    27.81  27.92  29.20  28.32  28.53  28.43
 3     5.5 25.07  25.07  25.01  25.05  23.90   1466.5  6.30  0.132E+08  0.00020    22.14  22.25  23.36  22.57  22.59  22.58
 4    15.5 25.27  25.33  25.24  25.28  23.94   1467.7  6.29  0.132E+08  0.00055    19.44  18.66  19.85  19.31  19.32  19.31
 5    25.5 25.46  25.46  25.50  25.47  23.97   1468.9  6.28  0.133E+08  0.00091    17.52  17.52  17.01  17.35  17.35  17.35
 6    45.5 25.56  25.58  25.63  25.59  24.05   1471.4  6.27  0.133E+08  0.00162    17.15  16.96  16.43  16.84  16.85  16.85
 7    75.5 25.69  25.69  25.67  25.69  24.16   1475.2  6.26  0.134E+08  0.00269    16.96  16.90  17.15  17.00  17.00  17.00
 8   105.5 25.63  25.88  25.79  25.77  24.27   1478.9  6.24  0.135E+08  0.00376    19.03  16.14  17.02  17.31  17.39  17.35
 9   135.5 25.79  25.85  26.07  25.91  24.38   1482.7  6.22  0.136E+08  0.00483    18.35  17.66  15.34  17.01  17.11  17.06
10   165.2 25.86  26.02  26.14  26.01  24.49   1486.4  6.20  0.137E+08  0.00589    18.93  17.00  15.74  17.12  17.22  17.17
11   205.2 25.98  26.15  26.22  26.11  24.64   1491.5  6.18  0.138E+08  0.00732    19.36  17.16  16.43  17.57  17.65  17.61
12   245.2 26.17  26.36  26.37  26.30  24.79   1496.6  6.16  0.139E+08  0.00875    18.78  16.52  16.35  17.15  17.22  17.18
13   275.2 26.23  26.48  26.58  26.43  24.90   1500.5  6.14  0.140E+08  0.00983    19.40  16.40  15.42  16.92  17.08  17.00
14   305.2 26.30  26.48  26.59  26.46  25.01   1504.4  6.12  0.141E+08  0.01090    20.07  17.64  16.34  17.89  18.02  17.95
15   333.3 26.59  26.79  26.96  26.78  25.11   1508.0  6.10  0.141E+08  0.01191    17.55  15.40  14.01  15.52  15.66  15.59
16   363.3 26.61  26.86  26.97  26.81  25.22   1511.9  6.09  0.142E+08  0.01299    18.67  15.82  14.81  16.28  16.43  16.36
17   383.3 26.76  26.96  27.03  26.91  25.30   1514.6  6.08  0.143E+08  0.01370    17.76  15.62  14.97  16.03  16.12  16.07
18   403.3 26.78  27.01  27.05  26.95  25.37   1517.2  6.06  0.143E+08  0.01442    18.34  15.85  15.43  16.44  16.54  16.49
19   423.3 26.88  27.10  27.21  27.06  25.45   1519.8  6.05  0.144E+08  0.01514    18.08  15.65  14.66  16.01  16.13  16.07
20   443.3 26.93  27.08  27.22  27.08  25.52   1522.5  6.04  0.145E+08  0.01586    18.31  16.56  15.25  16.61  16.71  16.66
21   463.3 26.99  27.12  27.24  27.11  25.59   1525.2  6.03  0.145E+08  0.01658    18.55  17.00  15.73  17.02  17.09  17.05
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 26.76  26.97  27.07  26.93  25.33   1515.7  6.07  0.143E+08  0.01400    18.12  15.82  14.86  16.15  16.26  16.21
--------------------------------------------------------------------------------------------------------------------------------
```

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                                                        XP135-04

INPUT ELECTRIC POWER =   268.0 W                HEAT RATE GAINED BY WATER =   264.6 W                 HEAT BALANCE ERROR =   1.28%
MASS FLOW RATE = 14.1000 G/S          PRESSURE DROP = 0.3274 MM H2O          FRICTION FACTOR = 0.047158          FREM =  23.8965
REM =   506.7     GRM   = 0.21350E+07    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 28.38 DEG C
PRM =   5.944     RAM   = 0.12690E+08    INLET BULK TEMPERATURE     = 23.88 DEG C    OUTLET BULK TEMPERATURE       = 28.37 DEG C
-------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR      RA          Z        ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                            T      H      T+H
-------------------------------------------------------------------------------------------------------------------------------
 0    0.1  24.83  24.83  24.86  24.84  23.88     480.9  6.30  0.112E+08  0.00001    23.33  23.38  22.55  23.11  22.95  23.03
 1    1.5  24.97  24.96  25.02  24.98  23.90     481.1  6.30  0.112E+08  0.00016    20.60  20.66  19.67  20.32  20.15  20.24
 2    2.5  25.06  25.06  25.13  25.08  23.91     481.2  6.29  0.112E+08  0.00027    19.07  19.13  18.08  18.76  18.59  18.67
 3    5.5  25.35  25.34  25.45  25.38  23.94     481.5  6.29  0.112E+08  0.00060    15.58  15.64  14.55  15.24  15.26  15.25
 4   15.5  25.66  25.78  25.74  25.73  24.03     482.5  6.28  0.113E+08  0.00168    13.52  12.62  12.86  12.99  13.00  12.99
 5   25.5  25.85  25.96  26.06  25.95  24.13     483.6  6.26  0.114E+08  0.00277    12.79  12.05  11.42  12.06  12.08  12.07
 6   45.5  25.84  26.02  26.07  25.98  24.32     485.7  6.23  0.115E+08  0.00495    14.48  12.92  12.56  13.27  13.32  13.30
 7   75.5  25.91  26.08  26.07  26.02  24.61     488.9  6.18  0.117E+08  0.00821    16.93  14.89  15.06  15.58  15.63  15.60
 8  105.5  26.02  26.27  26.18  26.16  24.89     492.2  6.14  0.119E+08  0.01149    19.48  16.01  17.05  17.40  17.51  17.46
 9  135.5  26.29  26.52  26.63  26.48  25.18     495.5  6.09  0.120E+08  0.01476    19.73  16.45  15.19  16.92  17.12  17.02
10  165.2  26.58  26.79  26.86  26.75  25.47     498.8  6.05  0.122E+08  0.01801    19.64  16.52  15.73  17.14  17.30  17.22
11  205.2  26.87  27.09  27.11  27.02  25.85     503.4  5.99  0.125E+08  0.02239    21.55  17.61  17.45  18.69  18.87  18.78
12  245.2  27.38  27.63  27.59  27.54  26.23     508.0  5.93  0.128E+08  0.02679    19.03  15.64  16.08  16.79  16.92  16.85
13  275.2  27.57  27.92  27.97  27.82  26.52     511.5  5.88  0.130E+08  0.03009    20.91  15.61  15.13  16.85  17.21  17.03
14  305.2  27.91  28.09  28.21  28.07  26.81     515.1  5.84  0.132E+08  0.03339    19.81  16.99  15.58  17.29  17.46  17.38
15  333.3  28.36  28.64  28.64  28.55  27.08     518.0  5.80  0.133E+08  0.03648    17.01  13.94  13.99  14.85  14.98  14.92
16  363.3  28.61  28.86  28.87  28.78  27.36     521.0  5.77  0.135E+08  0.03979    17.59  14.59  14.53  15.45  15.57  15.51
17  383.3  28.81  29.02  29.08  28.97  27.55     523.0  5.74  0.136E+08  0.04199    17.38  14.88  14.29  15.41  15.52  15.46
18  403.3  29.02  29.18  29.22  29.14  27.75     525.1  5.72  0.138E+08  0.04419    17.19  15.19  14.79  15.66  15.72  15.69
19  423.3  29.21  29.44  29.44  29.36  27.94     527.2  5.69  0.139E+08  0.04640    17.14  14.54  14.48  15.29  15.39  15.34
20  443.3  29.33  29.43  29.61  29.46  28.13     529.2  5.67  0.140E+08  0.04860    18.20  16.73  14.78  16.45  16.57  16.51
21  463.3  29.49  29.56  29.74  29.60  28.32     531.3  5.64  0.141E+08  0.05081    18.58  17.66  15.32  17.07  17.18  17.13
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  28.89  29.10  29.14  29.04  27.63     523.9  5.73  0.137E+08  0.04291    17.42  14.98  14.48  15.52  15.62  15.57
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                                                        XP135-05

INPUT ELECTRIC POWER =   665.0 W                HEAT RATE GAINED BY WATER =   657.2 W                 HEAT BALANCE ERROR =   1.17%
MASS FLOW RATE = 42.2580 G/S          PRESSURE DROP = 0.9991 MM H2O          FRICTION FACTOR = 0.016023          FREM =  24.1423
REM = 1506.7      GRM   = 0.51628E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 27.66 DEG C
PRM =   5.996     RAM   = 0.30958E+08    INLET BULK TEMPERATURE     = 23.94 DEG C    OUTLET BULK TEMPERATURE       = 27.66 DEG C
-------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR      RA          Z        ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                            T      H      T+H
-------------------------------------------------------------------------------------------------------------------------------
 0    0.1  25.25  25.22  25.16  25.20  23.94    1443.1  6.29  0.279E+08  0.00000    41.79  42.51  44.83  43.23  43.49  43.36
 1    1.5  25.51  25.48  25.41  25.46  23.95    1443.5  6.29  0.279E+08  0.00005    35.04  35.74  37.37  36.14  36.38  36.26
 2    2.5  25.69  25.66  25.59  25.64  23.96    1443.7  6.29  0.279E+08  0.00009    31.52  32.21  33.52  32.47  32.69  32.58
 3    5.5  26.24  26.18  26.12  26.18  23.98    1444.5  6.28  0.280E+08  0.00020    24.23  24.84  25.61  24.88  24.89  24.88
 4   15.5  26.60  26.79  26.69  26.69  24.06    1447.1  6.27  0.281E+08  0.00056    21.53  20.00  20.81  20.76  20.78  20.77
 5   25.5  26.97  27.12  27.16  27.08  24.14    1449.7  6.26  0.282E+08  0.00092    19.34  18.33  18.10  18.58  18.59  18.58
 6   45.5  27.11  27.19  27.41  27.24  24.30    1455.0  6.23  0.285E+08  0.00165    19.43  18.91  17.56  18.60  18.64  18.62
 7   75.5  27.29  27.47  27.52  27.43  24.54    1463.0  6.20  0.289E+08  0.00274    19.81  18.61  18.33  18.90  18.92  18.91
 8  105.5  27.36  27.77  27.74  27.62  24.77    1471.0  6.16  0.293E+08  0.00383    21.16  18.22  18.39  19.16  19.25  19.21
 9  135.5  27.74  28.07  28.29  28.03  25.01    1479.2  6.12  0.296E+08  0.00492    20.02  17.84  16.66  18.07  18.17  18.12
10  165.2  27.86  28.24  28.48  28.19  25.25    1487.4  6.08  0.300E+08  0.00601    20.92  18.24  16.89  18.54  18.68  18.61
11  205.2  27.98  28.43  28.56  28.32  25.57    1498.5  6.03  0.306E+08  0.00747    22.60  19.05  18.23  19.79  19.96  19.87
12  245.2  28.38  28.80  28.99  28.72  25.88    1509.8  5.98  0.311E+08  0.00893    21.79  18.68  17.54  19.17  19.33  19.25
13  275.2  28.57  29.09  29.30  28.99  26.12    1518.4  5.95  0.315E+08  0.01003    22.26  18.31  17.13  19.00  19.23  19.12
14  305.2  28.63  29.09  29.33  29.02  26.36    1527.1  5.91  0.319E+08  0.01113    23.93  19.90  18.33  20.46  20.72  20.59
15  333.3  29.25  29.76  29.98  29.66  26.58    1535.3  5.87  0.323E+08  0.01216    20.39  17.11  16.02  17.65  17.84  17.75
16  363.3  29.27  29.86  30.04  29.72  26.82    1544.2  5.83  0.327E+08  0.01326    22.17  17.88  16.89  18.72  18.98  18.85
17  383.3  29.48  30.03  30.19  29.90  26.98    1549.4  5.81  0.330E+08  0.01400    21.75  17.82  16.93  18.62  18.83  18.73
18  403.3  29.68  30.13  30.34  30.05  27.14    1554.3  5.79  0.332E+08  0.01473    21.34  18.17  16.97  18.65  18.83  18.74
19  423.3  29.87  30.38  30.56  30.27  27.30    1559.3  5.77  0.335E+08  0.01547    21.08  17.59  16.66  18.26  18.45  18.35
20  443.3  29.94  30.38  30.67  30.33  27.46    1564.4  5.75  0.337E+08  0.01620    21.86  18.54  16.90  18.89  19.10  18.99
21  463.3  30.17  30.51  30.86  30.51  27.61    1569.5  5.73  0.340E+08  0.01694    21.26  18.73  16.71  18.72  18.90  18.81
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  29.58  30.09  30.29  29.99  27.05    1551.2  5.81  0.331E+08  0.01430    21.43  17.85  16.73  18.47  18.67  18.57
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                                                        XP135-06

INPUT ELECTRIC POWER =   625.0 W                HEAT RATE GAINED BY WATER =   612.4 W                 HEAT BALANCE ERROR =   2.02%
MASS FLOW RATE = 27.8180 G/S          PRESSURE DROP = 0.6564 MM H2O          FRICTION FACTOR = 0.024288          FREM =  24.5424
REM = 1010.5      GRM   = 0.51233E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 29.21 DEG C
PRM =   5.874     RAM   = 0.30093E+08    INLET BULK TEMPERATURE     = 23.94 DEG C    OUTLET BULK TEMPERATURE       = 29.21 DEG C
-------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR      RA          Z        ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                            T      H      T+H
-------------------------------------------------------------------------------------------------------------------------------
 0    0.1  25.35  25.35  25.32  25.33  23.94     950.0  6.29  0.260E+08  0.00000    36.26  36.26  36.86  36.63  36.56  36.60
 1    1.5  25.63  25.63  25.62  25.62  23.96     950.4  6.29  0.260E+08  0.00008    30.50  30.50  30.59  30.62  30.54  30.58
 2    2.5  25.82  25.82  25.83  25.82  23.97     950.6  6.29  0.260E+08  0.00014    27.48  27.48  27.37  27.50  27.43  27.47
 3    5.5  26.41  26.41  26.45  26.42  24.00     951.3  6.28  0.261E+08  0.00030    21.20  21.20  20.81  21.07  21.07  21.07
 4   15.5  26.88  27.08  27.08  27.01  24.11     953.8  6.26  0.263E+08  0.00085    18.43  17.19  17.19  17.59  17.61  17.60
 5   25.5  27.24  27.40  27.66  27.44  24.23     956.2  6.24  0.264E+08  0.00140    16.88  16.05  14.83  15.87  15.92  15.90
 6   45.5  27.33  27.52  27.74  27.53  24.45     961.2  6.21  0.268E+08  0.00251    17.66  16.58  15.46  16.52  16.57  16.54
 7   75.5  27.41  27.69  27.74  27.61  24.79     968.7  6.16  0.273E+08  0.00416    19.44  17.50  17.24  18.01  18.06  18.03
 8  105.5  27.52  27.99  27.97  27.83  25.12     976.3  6.10  0.278E+08  0.00582    21.21  17.72  17.89  18.81  18.94  18.87
 9  135.5  27.85  28.24  28.51  28.20  25.46     984.0  6.05  0.283E+08  0.00749    21.27  18.29  16.66  18.55  18.74  18.65
10  165.2  28.08  28.52  28.76  28.45  25.80     991.8  6.00  0.288E+08  0.00914    22.24  18.65  17.15  19.12  19.35  19.24
11  205.2  28.31  28.87  28.94  28.71  26.24    1002.5  5.93  0.296E+08  0.01136    24.54  19.30  18.79  20.58  20.88  20.73
12  245.2  28.88  29.41  29.55  29.28  26.69    1013.4  5.85  0.303E+08  0.01359    23.14  18.65  17.74  19.58  19.84  19.71
13  275.2  29.18  29.71  29.97  29.62  27.03    1021.0  5.81  0.308E+08  0.01527    23.58  18.93  17.25  19.58  19.92  19.75
14  305.2  29.47  29.93  30.17  29.86  27.37    1028.0  5.76  0.313E+08  0.01694    24.11  19.72  18.08  20.34  20.64  20.49
15  333.3  30.14  30.66  30.87  30.56  27.68    1034.6  5.72  0.318E+08  0.01851    20.59  17.01  15.85  17.60  17.82  17.71
16  363.3  30.27  30.92  31.10  30.76  28.02    1041.8  5.68  0.323E+08  0.02019    22.49  17.44  16.41  18.43  18.78  18.61
17  383.3  30.64  31.14  31.30  31.03  28.25    1046.7  5.65  0.326E+08  0.02131    21.05  17.42  16.53  18.14  18.33  18.23
18  403.3  30.86  31.36  31.23  31.15  28.47    1051.6  5.63  0.330E+08  0.02243    21.16  17.49  18.30  18.86  18.98  18.92
19  423.3  31.15  31.66  31.84  31.55  28.70    1056.5  5.60  0.333E+08  0.02355    20.55  17.00  16.04  17.67  17.86  17.77
20  443.3  31.22  31.61  31.94  31.59  28.92    1061.5  5.57  0.337E+08  0.02467    21.90  18.73  16.67  18.86  19.10  18.98
21  463.3  31.56  31.74  32.19  31.83  29.14    1066.5  5.54  0.340E+08  0.02579    20.90  19.42  16.52  18.76  18.95  18.86
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  30.71  31.22  31.38  31.11  28.34    1048.8  5.64  0.328E+08  0.02177    21.29  17.52  16.63  18.26  18.48  18.37
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XP135-07

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INPUT ELECTRIC POWER =  535.0 W             HEAT RATE GAINED BY WATER =  525.6 W              HEAT BALANCE ERROR =  1.75%
MASS FLOW RATE = 13.3780 G/S         PRESSURE DROP = 0.3035 MM H2O        FRICTION FACTOR = 0.048520          FREM =  24.6270
REM =  507.6     GRM  = 0.50936E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 33.36 DEG C
PRM =  5.604     RAM  = 0.28542E+08    INLET BULK TEMPERATURE     = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 33.35 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C     AVER-  (C)                                                A      B      C     ----- AVERAGE -----
NO.                                 AGE                                                                           T      H      T+H
--------------------------------------------------------------------------------------------------------------------------------
 0     0.1  25.52  25.57  25.51  25.52  23.95     456.9  6.29  0.223E+08  0.00001    27.74  26.99  28.00  27.79  27.68  27.73
 1     1.5  25.79  25.85  25.82  25.81  23.98     457.2  6.28  0.224E+08  0.00017    24.14  23.35  23.76  23.86  23.75  23.81
 2     2.5  25.97  26.04  26.03  26.01  24.00     457.5  6.28  0.224E+08  0.00029    22.16  21.36  21.51  21.74  21.64  21.69
 3     5.5  26.52  26.63  26.67  26.60  24.06     458.1  6.27  0.225E+08  0.00063    17.78  17.01  16.76  17.17  17.18  17.18
 4    15.5  26.93  27.19  27.19  27.11  24.26     460.2  6.24  0.227E+08  0.00178    16.34  14.91  14.88  15.35  15.38  15.36
 5    25.5  27.19  27.51  27.66  27.45  24.46     462.3  6.21  0.230E+08  0.00292    16.00  14.31  13.64  14.59  14.65  14.62
 6    45.5  27.39  27.63  27.80  27.61  24.86     466.6  6.14  0.235E+08  0.00522    17.26  15.74  14.84  15.88  15.95  15.91
 7    75.5  27.62  27.97  27.96  27.85  25.46     473.2  6.05  0.243E+08  0.00868    20.17  17.36  17.44  18.23  18.32  18.28
 8   105.5  27.97  28.50  28.47  28.31  26.06     480.0  5.95  0.251E+08  0.01214    22.86  17.86  18.11  19.36  19.61  19.48
 9   135.5  28.63  29.07  29.29  29.00  26.66     487.0  5.86  0.260E+08  0.01562    22.14  18.05  16.56  18.64  18.92  18.78
10   165.2  29.24  29.68  29.81  29.58  27.26     493.3  5.78  0.267E+08  0.01906    21.87  17.91  17.02  18.71  18.94  18.83
11   205.2  29.87  30.32  30.39  30.19  28.06     501.4  5.68  0.278E+08  0.02371    24.01  19.22  18.62  20.36  20.62  20.49
12   245.2  30.77  31.19  31.33  31.10  28.86     509.9  5.58  0.288E+08  0.02837    22.74  18.61  17.52  19.38  19.62  19.50
13   275.2  31.73  31.76  31.97  31.82  29.47     516.4  5.50  0.296E+08  0.03187    19.05  18.82  17.28  18.35  18.38  18.37
14   305.2  31.85  32.27  32.45  32.19  30.07     523.1  5.42  0.305E+08  0.03538    24.20  19.57  18.11  20.32  20.63  20.47
15   333.3  32.69  33.17  33.33  33.07  30.63     529.5  5.35  0.313E+08  0.03868    20.88  16.96  15.95  17.69  17.93  17.81
16   363.3  33.21  33.69  33.83  33.58  31.23     536.5  5.28  0.321E+08  0.04220    21.81  17.48  16.55  18.35  18.61  18.48
17   383.3  33.64  33.99  34.18  33.94  31.63     541.3  5.23  0.327E+08  0.04456    21.38  18.21  16.86  18.64  18.82  18.73
18   403.3  34.03  34.48  34.57  34.36  32.03     545.9  5.18  0.333E+08  0.04693    21.49  17.58  16.97  18.48  18.68  18.58
19   423.3  34.48  34.89  35.02  34.79  32.44     550.1  5.13  0.338E+08  0.04932    21.02  17.49  16.63  18.19  18.38  18.29
20   443.3  34.79  34.91  35.39  35.03  32.84     554.5  5.09  0.343E+08  0.05172    21.96  20.67  16.76  19.53  19.80  19.67
21   463.3  35.23  35.13  35.76  35.37  33.24     558.9  5.04  0.349E+08  0.05412    21.46  22.66  16.97  20.05  20.37  20.21
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  33.81  34.19  34.39  34.13  31.80     543.0  5.21  0.329E+08  0.04557    21.43  18.07  16.62  18.48  18.70  18.59
--------------------------------------------------------------------------------------------------------------------------------
```

XP135-08

```
INPUT ELECTRIC POWER = 1170.0 W             HEAT RATE GAINED BY WATER = 1152.2 W              HEAT BALANCE ERROR =  1.52%
MASS FLOW RATE = 40.8140 G/S         PRESSURE DROP = 1.0128 MM H2O        FRICTION FACTOR = 0.017406          FREM =  26.1953
REM = 1505.0     GRM  = 0.10145E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 30.64 DEG C
PRM =  5.778     RAM  = 0.58619E+08    INLET BULK TEMPERATURE     = 23.88 DEG C    OUTLET BULK TEMPERATURE      = 30.64 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C     AVER-  (C)                                                A      B      C     ----- AVERAGE -----
NO.                                 AGE                                                                           T      H      T+H
--------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.00  26.02  25.96  25.98  23.88    1392.1  6.30  0.488E+08  0.00000    45.44  44.88  46.25  45.78  45.70  45.74
 1     1.5  26.43  26.47  26.43  26.43  23.91    1392.8  6.30  0.488E+08  0.00006    38.00  37.45  38.03  37.96  37.88  37.92
 2     2.5  26.73  26.77  26.75  26.75  23.92    1393.2  6.29  0.489E+08  0.00009    34.15  33.61  33.88  33.96  33.88  33.92
 3     5.5  27.63  27.69  27.72  27.68  23.96    1394.6  6.29  0.490E+08  0.00021    26.18  25.71  25.52  25.80  25.80  25.80
 4    15.5  28.21  28.59  28.53  28.44  24.11    1399.2  6.26  0.494E+08  0.00058    23.40  21.37  21.69  22.12  22.15  22.14
 5    25.5  28.76  29.07  29.32  29.05  24.25    1403.8  6.24  0.498E+08  0.00096    21.28  19.91  18.90  19.98  20.03  20.01
 6    45.5  28.83  29.13  29.42  29.13  24.54    1413.1  6.20  0.506E+08  0.00171    22.31  20.85  19.64  20.88  20.94  20.91
 7    75.5  29.12  29.52  29.74  29.46  24.97    1427.3  6.13  0.519E+08  0.00284    23.06  21.03  20.05  21.31  21.38  21.35
 8   105.5  29.31  30.06  30.02  29.79  25.40    1441.8  6.06  0.531E+08  0.00397    24.51  20.55  20.70  21.78  21.92  21.85
 9   135.5  29.96  30.52  30.90  30.46  25.84    1456.6  5.99  0.544E+08  0.00511    23.16  20.41  18.86  20.66  20.81  20.74
10   165.2  30.08  30.91  31.20  30.73  26.26    1471.6  5.92  0.557E+08  0.00624    25.02  20.56  19.33  21.38  21.64  21.51
11   205.2  30.37  31.15  31.33  30.95  26.84    1492.2  5.83  0.575E+08  0.00776    27.03  22.11  21.21  23.19  23.45  23.32
12   245.2  30.88  31.69  32.06  31.54  27.42    1509.8  5.76  0.591E+08  0.00928    27.50  22.28  20.52  23.08  23.43  23.26
13   275.2  31.29  32.16  32.52  31.99  27.85    1523.2  5.70  0.603E+08  0.01042    27.65  22.08  20.35  22.97  23.36  23.16
14   305.2  31.46  32.33  32.67  32.15  28.28    1536.8  5.65  0.615E+08  0.01156    29.88  23.48  21.63  24.53  25.00  24.76
15   333.3  32.36  33.39  33.73  33.16  28.69    1549.8  5.60  0.627E+08  0.01264    25.83  20.16  18.82  21.21  21.60  21.41
16   363.3  32.54  33.58  33.89  33.34  29.12    1563.9  5.54  0.640E+08  0.01378    27.72  21.24  19.88  22.48  22.95  22.71
17   383.3  32.92  33.77  34.07  33.59  29.41    1573.5  5.51  0.648E+08  0.01455    26.96  21.73  20.31  22.67  23.00  22.83
18   403.3  33.31  34.14  34.46  33.97  29.70    1583.2  5.47  0.657E+08  0.01532    26.23  21.28  19.89  22.16  22.47  22.31
19   423.3  33.59  34.50  34.79  34.29  29.98    1593.0  5.44  0.666E+08  0.01608    26.25  20.95  19.67  21.95  22.29  22.12
20   443.3  33.68  34.41  34.89  34.33  30.27    1602.9  5.40  0.674E+08  0.01685    27.76  22.84  20.46  23.31  23.69  23.50
21   463.3  34.17  34.54  35.37  34.70  30.56    1612.9  5.36  0.683E+08  0.01762    26.16  23.72  19.64  22.85  23.17  23.01
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  33.07  33.97  34.31  33.78  29.53    1577.7  5.49  0.652E+08  0.01487    26.79  21.37  19.84  22.30  22.67  22.48
--------------------------------------------------------------------------------------------------------------------------------
```

XP135-09

```
INPUT ELECTRIC POWER = 1115.0 W             HEAT RATE GAINED BY WATER = 1081.9 W              HEAT BALANCE ERROR =  2.97%
MASS FLOW RATE = 32.1500 G/S         PRESSURE DROP = 0.8133 MM H2O        FRICTION FACTOR = 0.022519          FREM =  27.0845
REM = 1202.7     GRM  = 0.10003E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 32.00 DEG C
PRM =  5.689     RAM  = 0.56907E+08    INLET BULK TEMPERATURE     = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 31.99 DEG C
--------------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C     AVER-  (C)                                                A      B      C     ----- AVERAGE -----
NO.                                 AGE                                                                           T      H      T+H
--------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.18  26.21  26.13  26.16  23.94    1098.0  6.29  0.459E+08  0.00000    40.17  39.70  41.10  40.64  40.52  40.58
 1     1.5  26.63  26.66  26.63  26.63  23.97    1098.6  6.29  0.460E+08  0.00007    33.85  33.39  33.84  33.86  33.73  33.79
 2     2.5  26.93  26.98  26.97  26.95  23.98    1099.1  6.28  0.461E+08  0.00012    30.54  30.09  30.16  30.36  30.24  30.30
 3     5.5  27.85  27.92  27.99  27.92  24.04    1100.4  6.27  0.462E+08  0.00026    23.61  23.20  22.75  23.18  23.19  23.19
 4    15.5  28.43  28.93  28.86  28.74  24.21    1104.7  6.25  0.466E+08  0.00074    21.33  19.05  19.34  19.86  19.91  19.88
 5    25.5  28.98  29.34  29.66  29.33  24.38    1109.0  6.22  0.471E+08  0.00122    19.57  18.12  17.05  18.19  18.25  18.22
 6    45.5  29.06  29.36  29.69  29.37  24.72    1117.9  6.17  0.480E+08  0.00217    20.75  19.41  18.09  19.35  19.42  19.38
 7    75.5  29.29  29.74  29.97  29.67  25.24    1131.3  6.08  0.494E+08  0.00361    22.17  19.93  18.99  20.28  20.36  20.32
 8   105.5  29.42  30.33  30.30  30.02  25.75    1145.2  6.00  0.508E+08  0.00505    24.49  19.59  19.73  21.04  21.27  21.15
 9   135.5  30.02  30.63  31.12  30.59  26.27    1159.3  5.92  0.523E+08  0.00649    23.91  20.55  18.46  20.74  20.97  20.86
10   165.2  30.30  31.13  31.48  30.97  26.78    1173.7  5.84  0.538E+08  0.00793    25.42  20.58  19.05  21.36  21.68  21.52
11   205.2  30.76  31.59  31.78  31.38  27.47    1190.5  5.75  0.556E+08  0.00986    27.16  21.64  20.72  22.85  23.18  23.01
12   245.2  31.59  32.41  32.67  32.23  28.15    1207.4  5.67  0.574E+08  0.01179    25.92  20.95  19.74  21.90  22.21  22.06
13   275.2  32.01  32.93  33.31  32.75  28.67    1220.3  5.60  0.588E+08  0.01324    26.66  20.89  19.22  21.83  22.26  22.04
14   305.2  32.35  33.22  33.51  33.03  29.18    1233.6  5.54  0.602E+08  0.01470    28.11  22.07  20.57  23.17  23.58  23.37
15   333.3  33.36  34.29  34.57  34.07  29.67    1246.3  5.48  0.616E+08  0.01607    24.10  19.23  18.14  20.19  20.49  20.34
16   363.3  33.59  34.53  34.83  34.32  30.18    1260.2  5.41  0.631E+08  0.01753    26.06  20.43  19.09  21.48  21.86  21.67
17   383.3  33.98  34.83  35.07  34.63  30.53    1269.6  5.37  0.641E+08  0.01851    25.70  20.62  19.51  21.64  21.95  21.79
18   403.3  34.37  35.26  35.52  35.05  30.87    1279.1  5.32  0.651E+08  0.01948    25.35  20.19  19.08  21.22  21.54  21.38
19   423.3  34.81  35.67  36.02  35.50  31.21    1288.8  5.28  0.661E+08  0.02046    24.62  19.89  18.42  20.66  20.98  20.82
20   443.3  34.96  35.64  36.17  35.59  31.56    1298.6  5.24  0.671E+08  0.02144    26.04  21.68  19.18  21.95  22.30  22.13
21   463.3  35.46  35.83  36.59  35.96  31.90    1308.4  5.19  0.682E+08  0.02242    24.88  22.49  18.84  21.78  22.07  21.92
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  34.18  35.04  35.36  34.86  30.67    1273.8  5.35  0.645E+08  0.01891    25.31  20.34  18.90  21.19  21.52  21.35
--------------------------------------------------------------------------------------------------------------------------------
```

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                                                           XP135-10

INPUT ELECTRIC POWER = 1065.0 W                 HEAT RATE GAINED BY WATER = 1033.5 W              HEAT BALANCE ERROR =  2.95%
MASS FLOW RATE = 26.3740 G/S          PRESSURE DROP = 0.6053 MM H2O         FRICTION FACTOR = 0.024898          FREM =  24.8921
REM =  999.8     GRM  = 0.99859E+07    UPSTREAM BULK TEMPERATURE = 23.91 DEG C    DOWN STREAM BULK TEMPERATURE = 33.30 DEG C
PRM =  5.609     RAM  = 0.56010E+08    INLET BULK TEMPERATURE    = 23.92 DEG C    OUTLET BULK TEMPERATURE      = 33.29 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB      RE      PR     RA           Z        ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                             A       B      C     ----- AVERAGE -----
NO.                               AGE                 '                                                        T       H       T+H
---------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.16   26.19   26.17   26.16  23.92     900.2  6.29  0.438E+08  0.00000    38.31  37.86  38.22  38.34  38.16  38.25
 1     1.5  26.60   26.63   26.65   26.62  23.95     900.8  6.29  0.439E+08  0.00009    32.45  32.01  31.77  32.18  32.00  32.09
 2     2.5  26.90   26.94   26.99   26.94  23.97     901.2  6.29  0.439E+08  0.00015    29.36  28.92  28.46  28.97  28.80  28.89
 3     5.5  27.79   27.86   27.99   27.88  24.03     902.5  6.28  0.441E+08  0.00032    22.83  22.43  21.68  22.30  22.31  22.30
 4    15.5  28.43   28.82   28.75   28.67  24.23     906.6  6.24  0.446E+08  0.00090    20.46  18.71  19.01  19.36  19.39  19.38
 5    25.5  28.87   29.23   29.60   29.23  24.43     910.8  6.21  0.451E+08  0.00148    19.35  17.88  16.61  17.88  17.95  17.91
 6    45.5  28.94   29.36   29.64   29.31  24.83     919.2  6.15  0.461E+08  0.00265    20.85  18.96  17.84  19.14  19.22  19.18
 7    75.5  29.18   29.74   29.86   29.59  25.43     932.2  6.06  0.477E+08  0.00440    22.86  19.86  19.36  20.58  20.69  20.63
 8   105.5  29.36   30.22   30.24   29.94  26.03     945.5  5.96  0.493E+08  0.00616    25.68  20.41  20.30  21.86  22.13  22.00
 9   135.5  30.13   30.74   31.12   30.66  26.63     959.2  5.87  0.509E+08  0.00792    24.42  20.79  19.02  21.18  21.41  21.30
10   165.2  30.52   31.41   31.71   31.21  27.22     971.7  5.78  0.525E+08  0.00967    25.86  20.40  19.04  21.40  21.77  21.58
11   205.2  31.09   31.98   32.11   31.73  28.02     987.7  5.68  0.545E+08  0.01203    27.78  21.51  20.84  22.99  23.38  23.18
12   245.2  31.98   32.80   33.06   32.61  28.82    1004.3  5.58  0.566E+08  0.01439    26.90  21.38  20.07  22.43  22.78  22.60
13   275.2  32.57   33.38   33.69   33.21  29.42    1017.1  5.51  0.582E+08  0.01617    27.01  21.47  19.88  22.41  22.79  22.60
14   305.2  33.18   33.99   34.23   33.80  30.02    1030.2  5.43  0.598E+08  0.01795    26.83  21.36  20.14  22.43  22.78  22.60
15   333.3  33.69   34.57   34.90   34.39  30.58    1042.8  5.36  0.614E+06  0.01962    27.29  21.27  19.63  22.29  22.73  22.51
16   363.3  34.26   35.19   35.45   34.97  31.18    1056.6  5.28  0.631E+08  0.02141    27.55  21.10  19.84  22.37  22.83  22.60
17   383.3  34.70   35.50   35.73   35.31  31.58    1066.0  5.23  0.642E+08  0.02260    27.13  21.59  20.37  22.68  23.03  22.86
18   403.3  35.14   35.93   36.13   35.74  31.98    1075.1  5.18  0.653E+08  0.02380    26.72  21.39  20.38  22.52  22.83  22.67
19   423.3  35.58   36.34   36.69   36.20  32.38    1083.5  5.14  0.664E+08  0.02501    26.37  21.34  19.60  22.09  22.44  22.26
20   443.3  35.79   36.31   36.89   36.33  32.78    1091.9  5.09  0.674E+08  0.02623    28.00  23.90  20.51  23.75  24.13  23.94
21   463.3  36.34   36.51   37.49   36.78  33.18    1100.6  5.05  0.684E+08  0.02745    26.64  25.35  19.56  23.42  23.85  23.64
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  34.86   35.64   35.97   35.49  31.75    1069.3  5.22  0.646E+08  0.02311    27.18  21'.76  20.06  22.62  23.00  22.81
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                                                           XP135-11

INPUT ELECTRIC POWER =  995.0 W                 HEAT RATE GAINED BY WATER =  961.2 W              HEAT BALANCE ERROR =  3.39%
MASS FLOW RATE = 20.5980 G/S          PRESSURE DROP = 0.4808 MM H2O         FRICTION FACTOR = 0.032412          FREM =  25.8054
REM =  796.2     GRM  = 0.99011E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 35.12 DEG C
PRM =  5.492     RAM  = 0.54380E+08    INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 35.11 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB      RE      PR     RA           Z        ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                             A       B      C     ----- AVERAGE -----
NO.                               AGE                                                                          T       H       T+H
---------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.20   26.24   26.22   26.21  23.95     703.6  6.29  0.408E+08  0.00000    35.58  34.83  35.16  35.38  35.18  35.28
 1     1.5  26.62   26.69   26.71   26.66  23.98     704.1  6.28  0.409E+08  0.00011    30.31  29.55  29.34  29.83  29.64  29.73
 2     2.5  26.91   27.00   27.04   26.98  24.01     704.5  6.28  0.410E+08  0.00019    27.50  26.75  26.33  26.92  26.73  26.82
 3     5.5  27.79   27.92   28.05   27.92  24.08     705.6  6.27  0.411E+08  0.00041    21.52  20.84  20.14  20.82  20.83  20.82
 4    15.5  28.32   28.82   28.81   28.65  24.32     709.5  6.23  0.417E+08  0.00115    19.98  17.74  17.81  18.45  18.51  18.48
 5    25.5  28.87   29.18   29.49   29.18  24.55     713.4  6.19  0.423E+08  0.00190    18.53  17.28  16.19  17.28  17.33  17.31
 6    45.5  28.89   29.36   29.64   29.29  25.03     721.3  6.12  0.434E+08  0.00339    20.69  18.45  17.32  18.72  18.82  18.77
 7    75.5  29.12   29.69   29.91   29.57  25.74     733.5  6.00  0.451E+08  0.00564    23.60  20.21  19.13  20.81  20.98  20.89
 8   105.5  29.53   30.33   30.36   30.07  26.46     746.2  5.89  0.469E+08  0.00789    25.93  20.54  20.42  22.02  22.30  22.16
 9   135.5  30.35   31.07   31.46   30.96  27.17     758.2  5.79  0.487E+08  0.01015    25.01  20.38  18.55  20.99  21.31  21.15
10   165.2  31.02   31.79   32.15   31.65  27.88     769.2  5.70  0.504E+08  0.01239    25.30  20.27  18.58  21.03  21.38  21.20
11   205.2  31.70   32.59   32.73   32.34  28.83     784.6  5.58  0.527E+08  0.01542    27.62  21.05  20.33  22.57  23.00  22.78
12   245.2  32.82   33.58   33.84   33.41  29.79     800.6  5.46  0.550E+08  0.01845    26.07  20.83  19.49  21.79  22.13  21.96
13   275.2  33.40   34.27   34.58   34.08  30.50     813.0  5.37  0.569E+08  0.02074    27.21  20.94  19.32  22.01  22.49  22.25
14   305.2  34.02   34.78   35.07   34.62  31.22     825.8  5.28  0.587E+08  0.02303    28.11  22.10  20.45  23.13  23.55  23.34
15   333.3  35.02   35.86   36.13   35.67  31.89     838.1  5.20  0.605E+08  0.02518    25.06  19.80  18.53  20.78  21.13  20.95
16   363.3  35.58   36.42   36.62   36.21  32.60     849.8  5.11  0.622E+08  0.02751    26.30  20.56  19.51  21.75  22.12  21.94
17   383.3  36.03   36.73   37.07   36.61  33.08     857.7  5.06  0.634E+08  0.02906    26.51  21.46  19.64  22.18  22.54  22.36
18   403.3  36.54   37.33   37.52   37.13  33.55     865.9  5.00  0.645E+08  0.03063    26.22  20.74  19.75  21.90  22.23  22.06
19   423.3  37.08   37.89   38.14   37.71  34.03     874.2  4.95  0.657E+08  0.03220    25.60  20.23  19.02  21.27  21.62  21.44
20   443.3  37.36   37.88   38.45   37.89  34.51     882.6  4.89  0.669E+08  0.03377    27.40  23.16  19.80  23.04  23.45  23.25
21   463.3  38.02   38.16   39.04   38.41  34.98     891.2  4.84  0.681E+08  0.03536    25.70  24.58  19.20  22.78  23.16  22.97
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  36.27   37.02   37.32   36.87  33.28     861.4  5.03  0.639E+08  0.02972    26.18  20.99  19.37  21.82  22.18  22.00
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                                                           XP135-12

INPUT ELECTRIC POWER =  850.0 W                 HEAT RATE GAINED BY WATER =  816.1 W              HEAT BALANCE ERROR =  3.99%
MASS FLOW RATE = 12.2950 G/S          PRESSURE DROP = 0.2779 MM H2O         FRICTION FACTOR = 0.052531          FREM =  26.2546
REM =  499.8     GRM  = 0.98638E+07    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 39.79 DEG C
PRM =  5.201     RAM  = 0.51303E+08    INLET BULK TEMPERATURE    = 23.90 DEG C    OUTLET BULK TEMPERATURE      = 39.78 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z    -WALL TEMPERATURE (DEG C)-   TB      RE      PR     RA           Z        ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                             A       B      C     ----- AVERAGE -----
NO.                               AGE                                                                          T       H       T+H
---------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.05   26.15   26.15   26.11  23.90     419.5  6.30  0.346E+08  0.00001    31.54  30.25  30.19  30.67  30.55  30.61
 1     1.5  26.44   26.57   26.58   26.53  23.95     420.0  6.29  0.347E+08  0.00019    27.24  25.89  25.79  26.30  26.18  26.24
 2     2.5  26.71   26.87   26.88   26.82  23.98     420.3  6.28  0.347E+08  0.00031    24.89  23.55  23.43  23.95  23.83  23.89
 3     5.5  27.52   27.75   27.78   27.68  24.08     421.3  6.27  0.349E+08  0.00069    19.78  18.53  18.39  18.88  18.90  18.89
 4    15.5  28.09   28.54   28.53   28.39  24.42     424.5  6.21  0.356E+08  0.00193    18.48  16.49  16.53  17.12  17.17  17.14
 5    25.5  28.59   29.01   29.32   28.97  24.76     427.9  6.16  0.363E+08  0.00318    17.72  15.96  14.87  16.10  16.18  16.14
 6    45.5  28.72   29.19   29.53   29.15  25.44     434.7  6.05  0.377E+08  0.00569    20.62  18.06  16.56  18.26  18.41  18.34
 7    75.5  29.34   29.97   30.02   29.78  26.46     445.3  5.89  0.398E+08  0.00946    23.39  19.24  18.94  20.33  20.52  20.43
 8   105.5  30.08   30.95   30.91   30.65  27.47     455.3  5.75  0.419E+08  0.01325    25.81  19.38  19.60  21.22  21.60  21.41
 9   135.5  31.18   31.96   32.23   31.79  28.49     464.9  5.62  0.440E+08  0.01705    24.96  19.37  17.96  20.35  20.76  20.56
10   165.2  32.18   32.96   33.21   32.78  29.50     474.9  5.50  0.461E+08  0.02082    24.96  19.36  18.08  20.40  20.80  20.60
11   205.2  33.31   34.09   34.17   33.86  30.85     489.0  5.33  0.491E+08  0.02592    27.19  20.62  20.14  22.23  22.65  22.44
12   245.2  34.81   35.52   35.68   35.34  32.21     503.4  5.16  0.520E+08  0.03106    25.60  20.11  19.20  21.30  21.64  21.47
13   275.2  35.73   36.44   36.69   36.29  33.22     513.5  5.04  0.541E+08  0.03498    26.55  20.68  19.15  21.70  22.13  21.91
14   305.2  36.63   37.28   37.58   37.16  34.24     524.0  4.92  0.562E+08  0.03892    27.77  21.79  19.87  22.69  23.14  22.91
15   333.3  37.86   38.65   38.93   38.48  35.19     534.3  4.81  0.583E+08  0.04264    24.84  19.13  17.71  20.13  20.56  20.35
16   363.3  38.74   39.53   39.74   39.34  36.21     545.7  4.69  0.605E+08  0.04665    26.02  19.88  18.66  21.08  21.52  21.30
17   383.3  39.42   40.08   40.39   39.96  36.89     553.5  4.62  0.620E+08  0.04934    26.03  20.64  18.78  21.41  21.82  21.61
18   403.3  40.16   40.84   40.97   40.66  37.56     560.5  4.55  0.636E+08  0.05197    25.33  20.09  19.30  21.27  21.57  21.42
19   423.3  40.80   41.62   41.82   41.41  38.24     567.7  4.49  0.651E+08  0.05461    25.68  19.44  18.38  20.72  21.17  20.94
20   443.3  41.37   41.63   42.34   41.78  38.92     575.0  4.43  0.667E+08  0.05725    26.81  24.23  19.16  22.94  23.40  23.17
21   463.3  42.03   42.02   43.00   42.35  39.60     582.6  4.37  0.683E+08  0.05990    26.96  27.03  19.26  23.81  24.42  24.11
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  39.72   40.39   40.70   40.27  37.17     556.1  4.60  0.627E+08  0.05041    25.79  20.57  18.66  21.26  21.67  21.47
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                                                  XP135-13

INPUT ELECTRIC POWER = 1950.0 W                HEAT RATE GAINED BY WATER = 1875.8 W               HEAT BALANCE ERROR =  3.80%
MASS FLOW RATE = 38.6480 G/S           PRESSURE DROP = 0.9514 MM H2O           FRICTION FACTOR = 0.018217          FREM =  27.3095
REM = 1499.2     GRM   = 0.19544E+08     UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 35.51 DEG C
PRM =   5.471    RAM   = 0.10694E+09     INLET BULK TEMPERATURE     = 23.89 DEG C    OUTLET BULK TEMPERATURE        = 35.50 DEG C
-----------------------------------------------------------------------------------------------------------------------------
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA          Z          ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C     AVER-   (C)                                                A       B       C      ----- AVERAGE -----
NO.                                   AGE                                                                          T       H       T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.22   27.23   27.16   27.18   23.89    1318.4  6.30   0.794E+08   0.00000      46.92   46.76   47.81   47.50   47.33   47.41
 1     1.5  27.90   27.92   27.91   27.89   23.93    1319.4  6.29   0.796E+08   0.00006      39.27   39.12   39.20   39.36   39.19   39.28
 2     2.5  28.37   28.39   28.43   28.39   23.95    1320.2  6.29   0.797E+08   0.00010      35.30   35.15   34.86   35.21   35.04   35.13
 3     5.5  29.79   29.82   29.99   29.86   24.02    1322.4  6.28   0.800E+08   0.00022      27.09   26.96   26.18   26.73   26.74   26.74
 4    15.5  30.48   31.18   31.09   30.92   24.27    1329.9  6.24   0.812E+08   0.00061      25.15   22.58   22.89   23.49   23.54   23.51
 5    25.5  31.27   31.73   32.37   31.79   24.52    1337.5  6.20   0.823E+08   0.00101      23.12   21.64   19.86   21.46   21.54   21.50
 6    45.5  31.32   31.86   32.54   31.91   25.02    1352.9  6.12   0.846E+08   0.00181      24.70   22.78   20.71   22.61   22.73   22.67
 7    75.5  31.89   32.63   32.98   32.50   25.76    1376.8  6.00   0.882E+08   0.00301      25.37   22.64   21.54   23.08   23.18   23.13
 8   105.5  32.08   33.40   33.53   33.00   26.50    1401.5  5.88   0.918E+08   0.00421      27.82   22.51   22.10   23.88   24.14   24.01
 9   135.5  33.07   34.02   34.73   33.94   27.25    1424.7  5.78   0.954E+08   0.00541      26.60   22.89   20.71   23.16   23.40   23.28
10   165.2  33.41   34.74   35.32   34.49   27.98    1446.2  5.69   0.987E+08   0.00661      28.53   22.88   21.08   23.77   24.16   23.97
11   205.2  33.87   35.26   35.67   34.93   28.97    1476.4  5.56   0.103E+09   0.00822      31.54   24.55   23.04   25.90   26.38   26.14
12   245.2  34.87   36.19   36.79   35.95   29.96    1507.8  5.44   0.108E+09   0.00984      31.42   24.72   22.55   25.72   26.23   25.98
13   275.2  35.56   36.99   37.64   36.73   30.71    1532.2  5.34   0.112E+09   0.01106      31.68   24.46   22.18   25.53   26.11   25.82
14   305.2  35.91   37.34   37.86   37.03   31.45    1557.5  5.25   0.116E+09   0.01228      34.46   26.07   23.97   27.50   28.17   27.83
15   333.3  37.24   38.82   39.37   38.48   32.15    1580.4  5.17   0.119E+09   0.01343      30.06   22.98   21.21   24.21   24.75   24.48
16   363.3  37.58   39.19   39.74   38.84   32.89    1603.5  5.08   0.123E+09   0.01467      32.63   24.26   22.32   25.71   26.40   26.06
17   383.3  38.19   39.52   40.12   39.28   33.39    1619.2  5.02   0.125E+09   0.01551      31.77   24.89   22.70   25.93   26.45   26.19
18   403.3  38.77   40.17   40.64   39.86   33.88    1635.3  4.96   0.127E+09   0.01634      31.23   24.25   22.58   25.52   26.02   25.77
19   423.3  39.30   40.84   41.48   40.54   34.38    1651.7  4.91   0.130E+09   0.01718      30.95   23.56   21.44   24.71   25.32   25.02
20   443.3  39.64   40.79   41.68   40.70   34.87    1668.4  4.85   0.132E+09   0.01802      31.93   25.72   22.36   26.11   26.67   26.39
21   463.3  40.41   41.09   42.39   41.30   35.37    1685.5  4.79   0.135E+09   0.01887      30.14   26.54   21.65   25.63   26.11   25.87
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  38.45   39.89   40.51   39.62   33.59    1626.4  5.00   0.126E+09   0.01586      31.43   24.28   22.10   25.37   25.94   25.65
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                                                  XP135-14

INPUT ELECTRIC POWER = 1810.0 W                HEAT RATE GAINED BY WATER = 1738.6 W               HEAT BALANCE ERROR =  3.94%
MASS FLOW RATE = 29.9840 G/S           PRESSURE DROP = 0.7519 MM H2O           FRICTION FACTOR = 0.023908          FREM =  28.4965
REM = 1191.9     GRM   = 0.19594E+08     UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 37.78 DEG C
PRM =   5.328    RAM   = 0.10440E+09     INLET BULK TEMPERATURE     = 23.89 DEG C    OUTLET BULK TEMPERATURE        = 37.77 DEG C
-----------------------------------------------------------------------------------------------------------------------------
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA          Z          ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C     AVER-   (C)                                                A       B       C      ----- AVERAGE -----
NO.                                   AGE                                                                          T       H       T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.29   27.36   27.31   27.30   23.89    1022.9  6.30   0.736E+08   0.00000      42.67   41.72   42.35   42.53   42.27   42.40
 1     1.5  27.95   28.06   28.08   28.01   23.94    1023.9  6.29   0.738E+08   0.00008      36.04   35.10   34.91   35.49   35.24   35.36
 2     2.5  28.41   28.54   28.61   28.51   23.97    1024.6  6.29   0.739E+08   0.00013      32.56   31.63   31.13   31.85   31.61   31.73
 3     5.5  29.79   29.98   30.21   29.99   24.05    1026.7  6.27   0.743E+08   0.00028      25.23   24.41   23.50   24.36   24.38   24.37
 4    15.5  30.53   31.29   31.31   31.05   24.35    1033.6  6.22   0.756E+08   0.00079      23.39   20.82   20.77   21.60   21.66   21.63
 5    25.5  31.33   31.84   32.48   31.88   24.65    1040.7  6.18   0.768E+08   0.00130      21.63   20.09   18.44   19.97   20.05   20.01
 6    45.5  31.32   31.91   32.54   31.92   25.24    1055.1  6.08   0.794E+08   0.00233      23.72   21.63   19.77   21.59   21.71   21.65
 7    75.5  31.78   32.74   33.14   32.55   26.13    1077.5  5.94   0.834E+08   0.00388      25.48   21.78   20.52   22.41   22.60   22.50
 8   105.5  32.25   33.62   33.69   33.19   27.01    1100.1  5.81   0.874E+08   0.00543      27.45   21.75   21.52   23.28   23.57   23.43
 9   135.5  33.29   34.35   35.06   34.24   27.90    1120.2  5.70   0.912E+08   0.00698      26.60   22.25   20.04   22.65   22.96   22.81
10   165.2  33.85   35.13   35.66   34.88   28.78    1140.8  5.59   0.950E+08   0.00853      28.25   22.54   20.83   23.48   23.87   23.67
11   205.2  34.48   35.93   36.17   35.53   29.97    1169.8  5.44   0.100E+09   0.01061      31.64   23.95   23.00   25.68   26.20   25.94
12   245.2  35.81   37.14   37.63   36.86   31.15    1200.3  5.29   0.106E+09   0.01271      30.58   23.78   21.96   24.94   25.44   25.19
13   275.2  36.51   37.94   38.53   37.66   32.04    1223.5  5.18   0.110E+09   0.01429      31.81   24.08   21.90   25.29   25.93   25.61
14   305.2  37.18   38.51   39.03   38.24   32.93    1244.9  5.08   0.114E+09   0.01589      33.30   25.41   23.23   26.69   27.32   27.00
15   333.3  38.41   39.99   40.55   39.65   33.76    1265.6  4.98   0.118E+09   0.01740      30.40   22.68   20.83   24.00   24.64   24.32
16   363.3  38.97   40.53   41.03   40.17   34.65    1288.4  4.88   0.122E+09   0.01902      32.67   24.00   22.12   25.53   26.26   25.90
17   383.3  39.69   40.92   41.50   40.70   35.24    1304.2  4.81   0.124E+09   0.02011      31.63   24.82   22.51   25.79   26.32   26.05
18   403.3  40.38   41.73   42.08   41.40   35.83    1320.2  4.74   0.127E+09   0.02121      30.91   23.84   22.50   25.26   25.75   25.51
19   423.3  40.97   42.52   43.04   42.18   36.42    1336.7  4.67   0.130E+09   0.02231      30.92   23.06   21.22   24.42   25.06   24.74
20   443.3  41.37   42.41   43.41   42.39   37.01    1353.0  4.60   0.133E+09   0.02340      32.24   26.00   21.95   26.08   26.73   26.40
21   463.3  42.25   42.75   44.23   43.08   37.61    1368.0  4.55   0.136E+09   0.02448      30.18   27.25   21.17   25.62   26.20   25.91
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  39.96   41.35   41.94   41.08   35.49    1311.4  4.78   0.126E+09   0.02058      31.46   24.07   21.85   25.18   25.79   25.49
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                                                  XP135-15

INPUT ELECTRIC POWER = 1695.0 W                HEAT RATE GAINED BY WATER = 1619.7 W               HEAT BALANCE ERROR =  4.44%
MASS FLOW RATE = 24.5690 G/S           PRESSURE DROP = 0.5746 MM H2O           FRICTION FACTOR = 0.027200          FREM =  27.1804
REM =  999.3     GRM   = 0.19612E+08     UPSTREAM BULK TEMPERATURE = 23.96 DEG C    DOWN STREAM BULK TEMPERATURE = 39.77 DEG C
PRM =   5.198    RAM   = 0.10194E+09     INLET BULK TEMPERATURE     = 23.98 DEG C    OUTLET BULK TEMPERATURE        = 39.76 DEG C
-----------------------------------------------------------------------------------------------------------------------------
STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA          Z          ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C     AVER-   (C)                                                A       B       C      ----- AVERAGE -----
NO.                                   AGE                                                                          T       H       T+H
-----------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.49   27.56   27.59   27.53   23.98     839.8  6.28   0.689E+08   0.00000      38.45   37.63   37.38   38.00   37.71   37.86
 1     1.5  28.14   28.25   28.36   28.24   24.03     840.7  6.28   0.691E+08   0.00009      32.76   31.93   31.14   32.03   31.74   31.89
 2     2.5  28.60   28.73   28.89   28.73   24.06     841.4  6.27   0.693E+08   0.00016      29.73   28.90   27.93   28.90   28.62   28.76
 3     5.5  29.96   30.15   30.48   30.20   24.16     843.3  6.25   0.697E+08   0.00034      23.27   22.51   21.32   22.34   22.37   22.35
 4    15.5  30.70   31.47   31.42   31.20   24.50     849.9  6.20   0.710E+08   0.00097      21.72   19.33   19.45   20.11   20.17   20.14
 5    25.5  31.38   31.95   32.59   31.98   24.84     856.5  6.15   0.723E+08   0.00159      20.55   18.92   17.34   18.85   18.94   18.89
 6    45.5  31.38   32.08   32.59   32.02   25.51     870.1  6.04   0.751E+08   0.00285      22.90   20.46   18.96   20.65   20.77   20.71
 7    75.5  31.72   32.63   32.98   32.44   26.52     891.3  5.88   0.794E+08   0.00474      25.76   21.94   20.75   22.63   22.82   22.73
 8   105.5  32.19   33.57   33.69   33.15   27.53     910.9  5.74   0.835E+08   0.00663      28.67   22.15   21.69   23.78   24.17   23.98
 9   135.5  33.41   34.52   35.12   34.35   28.54     930.1  5.62   0.875E+08   0.00853      27.42   22.32   20.28   22.98   23.34   23.16
10   165.2  34.18   35.52   35.93   35.21   29.54     949.8  5.49   0.917E+08   0.01042      28.70   22.25   20.82   23.47   23.92   23.69
11   205.2  35.09   36.48   36.67   36.08   30.88     977.8  5.32   0.975E+08   0.01297      31.57   23.71   22.93   25.54   26.07   25.80
12   245.2  36.58   37.92   38.36   37.62   32.23    1006.3  5.16   0.103E+09   0.01555      30.40   23.27   21.60   24.56   25.09   24.82
13   275.2  37.45   38.83   39.36   38.55   33.24    1026.4  5.04   0.107E+09   0.01750      31.35   23.62   21.56   24.87   25.51   25.19
14   305.2  38.23   39.56   40.14   39.31   34.25    1047.3  4.92   0.112E+09   0.01948      33.05   24.78   22.35   26.01   26.73   26.37
15   333.3  39.57   41.00   41.61   40.73   35.20    1067.7  4.81   0.116E+09   0.02134      30.01   22.62   20.47   23.74   24.37   24.05
16   363.3  40.41   41.75   42.31   41.49   36.21    1090.4  4.69   0.120E+09   0.02335      31.19   23.62   21.45   24.79   25.42   25.11
17   383.3  41.14   42.37   42.89   42.13   36.88    1105.9  4.62   0.123E+09   0.02469      30.69   23.80   21.76   24.88   25.42   25.15
18   403.3  41.83   43.18   43.48   42.83   37.55    1119.8  4.56   0.126E+09   0.02601      30.50   23.19   22.04   24.73   25.24   24.99
19   423.3  42.52   44.02   44.49   43.68   38.23    1134.0  4.49   0.129E+09   0.02733      30.39   22.52   20.80   23.93   24.57   24.25
20   443.3  43.04   44.03   44.91   43.99   38.90    1148.6  4.43   0.132E+09   0.02865      31.46   25.37   21.68   25.57   26.17   25.87
21   463.3  43.92   44.46   45.78   44.72   39.57    1163.6  4.37   0.135E+09   0.02997      29.94   26.63   20.94   25.27   25.84   25.56
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  41.42   42.73   43.28   42.48   37.16    1111.1  4.60   0.124E+09   0.02523      30.71   23.52   21.37   24.61   25.20   24.90
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                                               XP135-16

INPUT ELECTRIC POWER = 1550.0 W               HEAT RATE GAINED BY WATER = 1503.3 W              HEAT BALANCE ERROR =  3.01%
MASS FLOW RATE = 19.1540 G/S          PRESSURE DROP = 0.4399 MM H2O          FRICTION FACTOR = 0.034242           FREM =  27.4572
REM =  801.9     GRM  = 0.19919E+08     UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 42.75 DEG C
PRM =  5.026     RAM  = 0.10012E+09     INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 42.74 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T      H       T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.35  27.52  27.51  27.45  23.96     654.4  6.29  0.639E+08  0.00000     36.81  35.12  35.18  35.81  35.57  35.69
 1     1.5  27.96  28.19  28.23  28.12  24.01     655.2  6.28  0.641E+08  0.00012     31.72  29.96  29.67  30.49  30.26  30.37
 2     2.5  28.37  28.65  28.73  28.58  24.05     655.8  6.27  0.642E+08  0.00020     28.96  27.21  26.78  27.66  27.43  27.54
 3     5.5  29.62  30.04  30.21  29.96  24.17     657.6  6.25  0.647E+08  0.00044     22.96  21.33  20.72  21.63  21.67  21.65
 4    15.5  30.37  31.18  31.20  30.92  24.57     663.7  6.19  0.662E+08  0.00124     21.58  18.91  18.86  19.70  19.78  19.74
 5    25.5  31.10  31.73  32.26  31.70  24.98     669.9  6.13  0.677E+08  0.00204     20.38  18.49  17.14  18.58  18.67  18.62
 6    45.5  31.16  31.86  32.37  31.80  25.78     682.6  6.00  0.707E+08  0.00365     23.15  20.50  18.90  20.70  20.85  20.77
 7    75.5  31.61  32.57  32.92  32.37  26.98     702.3  5.81  0.755E+08  0.00608     26.83  22.22  20.91  23.06  23.32  23.19
 8   105.5  32.42  33.84  33.86  33.37  28.18     719.7  5.66  0.799E+08  0.00852     29.26  21.88  21.82  23.87  24.32  24.09
 9   135.5  33.85  35.07  35.51  34.81  29.38     738.0  5.51  0.845E+08  0.01096     27.67  21.73  20.19  22.78  23.20  22.99
10   165.2  34.79  36.08  36.49  35.79  30.57     757.1  5.36  0.892E+08  0.01339     29.24  22.39  20.84  23.65  24.16  23.90
11   205.2  36.03  37.32  37.57  36.97  32.18     783.7  5.16  0.957E+08  0.01669     31.84  23.89  22.78  25.61  26.17  25.89
12   245.2  37.86  39.08  39.42  38.79  33.78     808.8  4.98  0.102E+09  0.02004     29.96  23.06  21.69  24.42  24.90  24.66
13   275.2  38.89  40.22  40.69  39.94  34.98     828.7  4.84  0.106E+09  0.02258     31.16  23.26  21.34  24.60  25.25  24.93
14   305.2  39.90  41.07  41.53  40.83  36.18     849.6  4.70  0.111E+09  0.02516     32.71  24.89  22.72  26.14  26.77  26.46
15   333.3  41.35  42.62  43.23  42.40  37.31     869.0  4.58  0.116E+09  0.02756     30.01  22.82  20.47  23.81  24.43  24.12
16   363.3  42.29  43.69  44.15  43.38  38.51     888.9  4.47  0.121E+09  0.03010     32.02  23.34  21.45  24.86  25.61  25.23
17   383.3  43.25  44.44  44.88  44.19  39.31     902.6  4.39  0.125E+09  0.03179     30.68  23.56  21.68  24.76  25.31  25.03
18   403.3  44.07  45.30  45.59  44.99  40.11     916.8  4.32  0.128E+09  0.03350     30.51  23.26  22.01  24.75  25.26  25.00
19   423.3  44.96  46.24  46.72  45.97  40.92     931.4  4.25  0.132E+09  0.03521     29.81  22.60  20.74  23.81  24.38  24.09
20   443.3  45.55  46.38  47.29  46.41  41.72     946.5  4.17  0.135E+09  0.03692     31.37  25.77  21.56  25.62  26.23  25.93
21   463.3  46.48  46.92  48.18  47.19  42.52     960.1  4.11  0.139E+09  0.03864     30.28  27.26  21.21  25.67  26.25  25.96
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  43.58  44.78  45.31  44.56  39.65     909.2  4.36  0.126E+09  0.03251     30.73  23.56  21.32  24.60  25.20  24.90


                                               XP135-17

INPUT ELECTRIC POWER = 1240.0 W               HEAT RATE GAINED BY WATER = 1210.9 W              HEAT BALANCE ERROR =  2.35%
MASS FLOW RATE = 11.2120 G/S          PRESSURE DROP = 0.2626 MM H2O          FRICTION FACTOR = 0.059571           FREM =  30.0536
REM =  504.5     GRM  = 0.19914E+08     UPSTREAM BULK TEMPERATURE = 23.91 DEG C    DOWN STREAM BULK TEMPERATURE = 49.80 DEG C
PRM =  4.619     RAM  = 0.91983E+08     INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 49.79 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T      H       T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.99  27.13  27.22  27.11  23.94     382.9  6.29  0.514E+08  0.00001     33.03  31.58  30.76  31.77  31.53  31.65
 1     1.5  27.51  27.71  27.84  27.69  24.02     383.6  6.28  0.516E+08  0.00020     28.84  27.30  26.40  27.48  27.24  27.36
 2     2.5  27.87  28.11  28.26  28.08  24.07     384.1  6.27  0.518E+08  0.00034     26.52  24.96  24.06  25.14  24.90  25.02
 3     5.5  28.96  29.31  29.54  29.27  24.24     385.5  6.24  0.523E+08  0.00075     21.36  19.86  18.99  20.02  20.07  20.05
 4    15.5  29.71  30.39  30.53  30.21  24.79     390.4  6.16  0.539E+08  0.00212     20.47  17.95  17.52  18.56  18.65  18.60
 5    25.5  30.43  31.12  31.66  31.07  25.34     395.5  6.07  0.556E+08  0.00350     19.74  17.38  15.92  17.54  17.68  17.61
 6    45.5  30.72  31.41  31.93  31.35  26.44     406.0  5.89  0.591E+08  0.00625     23.46  20.18  18.28  20.43  20.64  20.53
 7    75.5  31.83  32.85  33.09  32.59  28.10     420.6  5.67  0.641E+08  0.01041     26.74  21.02  20.01  22.23  22.59  22.41
 8   105.5  33.31  34.57  34.53  34.14  29.75     435.4  5.46  0.692E+08  0.01459     27.96  20.67  20.83  22.70  23.15  22.93
 9   135.5  35.07  36.13  36.51  35.90  31.41     451.4  5.26  0.746E+08  0.01879     27.04  21.00  19.44  22.05  22.49  22.27
10   165.2  36.51  37.69  37.93  37.38  33.05     466.6  5.06  0.797E+08  0.02301     28.48  21.25  20.19  22.78  23.31  23.04
11   205.2  38.26  39.43  39.57  39.08  35.25     487.8  4.81  0.866E+08  0.02880     32.66  23.50  22.74  25.61  26.30  25.95
12   245.2  40.63  41.75  41.98  41.45  37.46     510.1  4.56  0.939E+08  0.03464     30.78  22.74  21.59  24.43  25.04  24.74
13   275.2  42.17  43.34  43.75  43.09  39.11     526.3  4.41  0.996E+08  0.03898     31.79  23.02  20.98  24.47  25.26  24.87
14   305.2  43.62  44.63  45.10  44.45  40.76     543.6  4.26  0.106E+09  0.04336     33.95  25.08  22.38  26.31  27.14  26.72
15   333.3  45.57  46.76  47.32  46.55  42.31     560.0  4.12  0.111E+09  0.04748     29.74  21.75  19.34  22.85  23.61  23.23
16   363.3  46.99  48.30  48.61  47.97  43.97     576.5  3.99  0.117E+09  0.05190     31.87  22.26  20.77  24.11  24.97  24.54
17   383.3  48.13  49.24  49.71  49.03  45.07     588.0  3.91  0.121E+09  0.05486     31.42  23.09  20.76  24.33  25.09  24.71
18   403.3  49.19  50.32  50.55  50.02  46.17     600.0  3.82  0.125E+09  0.05784     31.79  23.15  21.94  24.95  25.63  25.29
19   423.3  50.28  51.53  51.86  51.22  47.28     612.0  3.74  0.129E+09  0.06083     31.88  22.55  20.93  24.29  25.12  24.71
20   443.3  51.18  51.64  52.75  51.86  48.38     623.8  3.66  0.134E+09  0.06382     34.19  29.36  21.89  27.53  28.48  28.00
21   463.3  52.33  52.30  53.75  52.79  49.48     636.0  3.59  0.138E+09  0.06683     33.57  33.90  22.38  28.85  29.95  29.40
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  48.56  49.63  50.13  49.44  45.53     593.4  3.88  0.123E+09  0.05612     31.82  23.69  20.94  24.68  25.48  25.08


                                               XP135-18

INPUT ELECTRIC POWER = 3380.0 W               HEAT RATE GAINED BY WATER = 3248.4 W              HEAT BALANCE ERROR =  3.89%
MASS FLOW RATE = 34.3160 G/S          PRESSURE DROP = 0.9719 MM H2O          FRICTION FACTOR = 0.023551           FREM =  35.1835
REM = 1493.9     GRM  = 0.48463E+08     UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 46.62 DEG C
PRM =  4.802     RAM  = 0.23271E+09     INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 46.61 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE     PR       RA          Z         ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T      H       T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.47  29.62  29.64  29.54  23.96    1172.4  6.29  0.138E+09  0.00000     49.06  47.73  47.58  48.41  47.99  48.20
 1     1.5  30.57  30.79  30.95  30.75  24.03    1174.2  6.28  0.139E+09  0.00007     41.30  39.98  39.03  40.24  39.84  40.04
 2     2.5  31.33  31.59  31.86  31.58  24.07    1175.5  6.27  0.139E+09  0.00011     37.24  35.96  34.73  36.04  35.66  35.85
 3     5.5  33.62  34.01  34.58  34.07  24.22    1179.4  6.25  0.140E+09  0.00025     28.76  27.62  26.09  27.45  27.49  27.47
 4    15.5  34.41  35.86  35.93  35.40  24.70    1192.6  6.17  0.144E+09  0.00069     27.81  24.21  24.05  25.24  25.35  25.30
 5    25.5  35.68  36.78  37.92  36.79  25.19    1206.1  6.09  0.148E+09  0.00114     25.69  23.25  21.18  23.23  23.37  23.30
 6    45.5  35.64  36.75  37.89  36.76  26.15    1234.0  5.94  0.156E+09  0.00204     28.35  25.39  22.93  25.36  25.55  25.46
 7    75.5  36.27  37.89  38.61  37.59  27.60    1274.2  5.74  0.168E+09  0.00340     30.95  26.06  24.37  26.85  27.13  26.99
 8   105.5  36.87  39.25  39.48  38.53  29.05    1313.1  5.55  0.180E+09  0.00476     34.21  26.21  25.64  28.20  28.69  28.44
 9   135.5  38.41  40.41  41.66  40.16  30.50    1354.4  5.37  0.192E+09  0.00613     33.71  26.90  23.87  27.59  28.16  27.88
10   165.2  39.23  41.74  42.83  41.27  31.94    1397.6  5.19  0.205E+09  0.00749     36.43  27.08  24.37  28.46  29.29  28.88
11   205.2  40.59  42.98  43.68  42.42  33.87    1451.7  4.97  0.221E+09  0.00936     39.33  29.00  26.93  30.91  31.75  31.33
12   245.2  42.73  45.25  46.22  44.73  35.80    1510.2  4.74  0.237E+09  0.01126     37.94  27.83  25.25  29.45  30.34  29.89
13   275.2  44.01  46.84  47.92  46.26  37.25    1555.4  4.58  0.250E+09  0.01270     38.81  27.32  24.56  29.10  30.23  29.67
14   305.2  45.12  47.64  48.56  47.10  38.70    1598.4  4.45  0.263E+09  0.01412     40.75  29.24  26.52  31.11  32.17  31.64
15   333.3  46.96  49.72  51.06  49.25  40.06    1640.9  4.32  0.276E+09  0.01545     37.81  26.98  23.70  28.38  29.49  28.94
16   363.3  47.94  50.63  51.73  50.10  41.51    1688.8  4.19  0.291E+09  0.01688     40.44  28.49  25.43  30.26  31.45  30.86
17   383.3  48.97  51.14  52.37  50.82  42.48    1718.9  4.11  0.300E+09  0.01784     39.99  29.96  26.24  31.09  32.06  31.57
18   403.3  49.81  52.22  53.06  51.69  43.45    1748.1  4.04  0.309E+09  0.01881     40.72  29.52  26.95  31.40  32.39  31.90
19   423.3  50.83  53.42  54.64  52.96  44.41    1778.4  3.96  0.318E+09  0.01977     40.25  28.69  25.27  30.22  31.41  30.81
20   443.3  51.62  53.77  55.14  53.51  45.38    1809.7  3.88  0.328E+09  0.02074     41.32  30.76  26.44  31.73  32.84  32.29
21   463.3  53.22  54.54  56.76  54.84  46.35    1842.1  3.81  0.338E+09  0.02172     37.48  31.43  24.74  30.33  31.22  30.77
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  49.35  51.82  53.00  51.39  42.88    1730.8  4.08  0.304E+09  0.01825     40.09  29.07  25.67  30.51  31.61  31.06
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                                                XP135-19

INPUT ELECTRIC POWER = 3045.0 W              HEAT RATE GAINED BY WATER = 2910.4 W              HEAT BALANCE ERROR =  4.42%
MASS FLOW RATE = 26.3740 G/S         PRESSURE DROP = 0.7485 MM H2O          FRICTION FACTOR = 0.030683          FREM =  36.5987
REM = 1192.8     GRM  = 0.48601E+08    UPSTREAM BULK TEMPERATURE = 23.91 DEG C    DOWN STREAM BULK TEMPERATURE = 50.36 DEG C
PRM =  4.594     RAM  = 0.22325E+09    INLET BULK TEMPERATURE    = 23.93 DEG C    OUTLET BULK TEMPERATURE      = 50.34 DEG C
_______________________________________________________________________________________________________________________________
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE      PR        RA          Z        ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C     AVER-  (C)                                              A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                            T       H      T+H
-------------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.34   29.56   29.59   29.48   23.93     900.6   6.29   0.124E+09   0.00000    44.84   43.09   42.84   43.71   43.40   43.56
 1     1.5  30.39   30.70   30.81   30.62   24.02     902.2   6.28   0.124E+09   0.00009    38.02   36.26   35.63   36.68   36.38   36.53
 2     2.5  31.11   31.48   31.66   31.41   24.07     903.4   6.27   0.125E+09   0.00015    34.41   32.69   31.92   33.02   32.73   32.88
 3     5.5  33.28   33.84   34.19   33.77   24.24     906.9   6.24   0.126E+09   0.00032    26.78   25.23   24.32   25.40   25.44   25.42
 4    15.5  34.02   35.57   35.59   35.06   24.80     918.7   6.15   0.130E+09   0.00090    26.23   22.46   22.41   23.57   23.70   23.63
 5    25.5  35.24   36.34   37.47   36.35   25.37     930.9   6.06   0.134E+09   0.00149    24.46   22.01   19.95   21.99   22.14   22.07
 6    45.5  35.15   36.42   37.50   36.36   26.49     956.2   5.89   0.142E+09   0.00266    27.83   24.28   21.89   24.43   24.66   24.54
 7    75.5  35.93   37.56   38.22   37.24   28.18     991.1   5.66   0.155E+09   0.00443    30.96   25.59   23.92   26.51   26.82   26.66
 8   105.5  36.87   39.25   39.48   38.53   29.87    1026.9   5.45   0.167E+09   0.00620    34.18   25.49   24.89   27.61   28.19   27.90
 9   135.5  38.74   40.79   41.88   40.47   31.56    1065.5   5.24   0.181E+09   0.00799    33.19   25.80   23.08   26.73   27.35   27.04
10   165.2  39.95   42.36   43.28   41.86   33.24    1101.8   5.04   0.193E+09   0.00979    35.33   26.01   23.62   27.50   28.32   27.91
11   205.2  41.64   44.04   44.52   43.40   35.49    1153.1   4.78   0.210E+09   0.01225    38.31   27.58   26.12   29.81   30.67   30.24
12   245.2  44.01   46.53   47.28   45.94   37.75    1206.4   4.54   0.228E+09   0.01473    37.43   26.69   24.60   28.62   29.57   29.09
13   275.2  45.56   48.12   49.03   47.57   39.44    1245.8   4.38   0.242E+09   0.01658    38.16   26.91   24.36   28.73   29.81   29.27
14   305.2  46.84   49.19   50.06   48.70   41.13    1287.9   4.23   0.257E+09   0.01844    40.79   28.88   26.08   30.77   31.91   31.34
15   333.3  48.79   51.34   52.63   50.92   42.71    1326.3   4.09   0.271E+09   0.02020    38.21   26.90   23.42   28.29   29.51   28.90
16   363.3  50.10   52.63   53.63   52.12   44.40    1366.5   3.96   0.285E+09   0.02208    40.62   28.12   25.08   29.98   31.27   30.63
17   383.3  51.41   53.49   54.53   53.14   45.53    1394.6   3.87   0.295E+09   0.02334    39.26   29.02   25.66   30.33   31.31   30.82
18   403.3  52.32   54.56   55.51   54.13   46.65    1423.9   3.79   0.306E+09   0.02461    40.71   29.16   26.05   30.85   31.97   31.41
19   423.3  53.61   56.04   57.15   55.60   47.78    1452.1   3.70   0.316E+09   0.02588    39.51   27.87   24.56   29.44   30.65   30.04
20   443.3  54.63   56.39   57.92   56.32   48.91    1480.9   3.63   0.326E+09   0.02716    40.12   30.68   25.49   31.01   32.10   31.55
21   463.3  56.28   57.32   59.59   57.73   50.03    1510.8   3.55   0.337E+09   0.02844    36.70   31.49   23.99   29.79   30.73   30.26
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  51.81   54.08   55.23   53.70   45.99    1407.4   3.84   0.300E+09   0.02388    39.74   26.63   25.04   29.98   31.14   30.56
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                                                XP135-20

INPUT ELECTRIC POWER = 2750.0 W              HEAT RATE GAINED BY WATER = 2637.9 W              HEAT BALANCE ERROR =  4.08%
MASS FLOW RATE = 21.3200 G/S         PRESSURE DROP = 0.5951 MM H2O          FRICTION FACTOR = 0.037307          FREM =  37.0926
REM =  994.3     GRM  = 0.48239E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 53.59 DEG C
PRM =  4.444     RAM  = 0.21435E+09    INLET BULK TEMPERATURE    = 23.96 DEG C    OUTLET BULK TEMPERATURE      = 53.57 DEG C
_______________________________________________________________________________________________________________________________
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE      PR        RA          Z        ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C     AVER-  (C)                                              A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                            T       H      T+H
-------------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.12   29.38   29.41   29.29   23.97     728.5   6.29   0.112E+09   0.00000    42.62   40.55   40.31   41.27   40.94   41.11
 1     1.5  30.08   30.45   30.57   30.35   24.06     730.0   6.27   0.113E+09   0.00011    36.46   34.35   33.72   34.88   34.56   34.72
 2     2.5  30.74   31.19   31.36   31.09   24.12     731.1   6.26   0.113E+09   0.00018    33.16   31.07   30.31   31.51   31.21   31.36
 3     5.5  32.73   33.39   33.75   33.29   24.31     734.3   6.23   0.114E+09   0.00040    26.07   24.15   23.24   24.43   24.49   24.46
 4    15.5  33.58   34.96   34.98   34.51   24.94     745.1   6.13   0.119E+09   0.00112    25.35   21.88   21.82   22.90   23.02   22.96
 5    25.5  34.68   35.84   36.81   35.77   25.57     756.2   6.03   0.123E+09   0.00184    24.03   21.31   19.48   21.45   21.61   21.53
 6    45.5  34.71   35.97   36.99   35.89   26.84     779.4   5.83   0.131E+09   0.00329    27.72   23.88   21.48   24.09   24.36   24.23
 7    75.5  35.60   37.23   37.94   36.92   28.73     810.3   5.59   0.144E+09   0.00548    31.62   25.55   23.59   26.51   26.92   26.72
 8   105.5  36.87   39.19   39.42   38.49   30.63     843.7   5.35   0.157E+09   0.00768    34.66   25.24   24.59   27.49   28.16   27.82
 9   135.5  39.07   41.18   42.05   40.77   32.52     878.2   5.12   0.170E+09   0.00991    32.87   24.86   22.60   26.11   26.77   26.44
10   165.2  40.50   42.86   43.61   42.32   34.40     911.5   4.90   0.183E+09   0.01216    35.11   25.32   23.25   27.03   27.89   27.46
11   205.2  42.42   44.71   45.18   44.10   36.92     960.4   4.61   0.201E+09   0.01523    38.72   27.36   25.78   29.65   30.62   30.13
12   245.2  45.17   47.42   48.11   46.90   39.45    1007.4   4.38   0.220E+09   0.01828    37.03   26.58   24.46   28.43   29.36   28.89
13   275.2  46.95   49.29   50.14   48.79   41.35    1045.7   4.21   0.235E+09   0.02058    37.67   26.58   23.99   28.34   29.41   28.88
14   305.2  48.45   50.59   51.34   50.13   43.24    1082.2   4.05   0.249E+09   0.02290    40.38   28.62   25.96   30.54   31.65   31.10
15   333.3  50.68   52.97   54.08   52.58   45.01    1116.9   3.91   0.263E+09   0.02509    37.02   26.37   23.12   27.73   28.84   28.28
16   363.3  52.15   54.58   55.47   54.07   46.91    1156.5   3.77   0.279E+09   0.02744    39.87   27.25   24.40   29.19   30.50   29.85
17   383.3  53.63   55.72   56.58   55.31   48.17    1181.8   3.68   0.289E+09   0.02901    38.19   27.62   24.79   29.20   30.20   29.70
18   403.3  54.66   56.74   57.62   56.34   49.44    1208.4   3.59   0.300E+09   0.03059    39.87   28.50   25.42   30.15   31.26   30.71
19   423.3  56.05   58.37   59.32   57.91   50.70    1236.1   3.50   0.311E+09   0.03218    38.82   27.07   24.09   28.78   29.99   29.39
20   443.3  57.14   58.92   60.26   58.77   51.96    1264.6   3.41   0.323E+09   0.03378    40.00   29.81   25.00   30.44   31.60   31.02
21   463.3  58.73   60.00   61.82   60.19   53.23    1288.7   3.35   0.333E+09   0.03535    37.56   30.54   24.07   29.73   30.72   30.23
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  54.05   56.22   57.22   55.83   48.70    1194.0   3.64   0.294E+09   0.02968    38.96   27.77   24.47   29.25   30.40   29.82
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                                                XP135-21

INPUT ELECTRIC POWER = 2435.0 W              HEAT RATE GAINED BY WATER = 2333.2 W              HEAT BALANCE ERROR =  4.18%
MASS FLOW RATE = 16.2660 G/S         PRESSURE DROP = 0.4058 MM H2O          FRICTION FACTOR = 0.043664          FREM =  34.6481
REM =  793.5     GRM  = 0.48589E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 58.26 DEG C
PRM =  4.231     RAM  = 0.20559E+09    INLET BULK TEMPERATURE    = 23.91 DEG C    OUTLET BULK TEMPERATURE      = 58.24 DEG C
_______________________________________________________________________________________________________________________________
STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE      PR        RA          Z        ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C     AVER-  (C)                                              A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                            T       H      T+H
-------------------------------------------------------------------------------------------------------------------------------
 0     0.1  28.76   29.01   29.08   28.94   23.92     555.2   6.29   0.989E+08   0.00000    40.14   38.10   37.60   38.68   38.36   38.52
 1     1.5  29.64   30.00   30.15   29.92   24.02     556.6   6.28   0.995E+08   0.00014    34.59   32.48   31.71   32.93   32.62   32.78
 2     2.5  30.24   30.68   30.88   30.60   24.10     557.5   6.27   0.100E+09   0.00024    31.58   29.49   28.62   29.87   29.57   29.72
 3     5.5  32.07   32.72   33.08   32.62   24.32     560.3   6.23   0.101E+09   0.00052    25.04   23.09   22.14   23.36   23.42   23.39
 4    15.5  32.92   34.34   34.48   33.91   25.05     569.8   6.11   0.105E+09   0.00146    24.62   20.85   20.53   21.86   22.00   21.93
 5    25.5  34.06   35.28   36.14   35.16   25.78     579.7   6.00   0.110E+09   0.00241    23.36   20.35   18.66   20.61   20.79   20.70
 6    45.5  34.09   35.97   36.33   35.46   27.24     599.6   5.78   0.119E+09   0.00432    28.14   22.09   21.22   23.45   23.82   23.63
 7    75.5  35.49   37.28   37.72   36.83   29.44     627.5   5.50   0.131E+09   0.00719    31.72   24.46   23.18   25.96   26.45   26.21
 8   105.5  37.26   39.64   39.70   38.87   31.64     658.2   5.23   0.145E+09   0.01009    33.94   23.85   23.67   26.40   27.16   26.78
 9   135.5  39.74   41.85   42.55   41.38   33.83     687.6   4.97   0.158E+09   0.01304    32.14   23.68   21.78   25.15   25.87   25.51
10   165.2  41.56   43.75   44.44   43.25   36.01     718.9   4.72   0.172E+09   0.01602    34.03   24.38   22.37   26.07   26.93   26.50
11   205.2  43.93   46.09   46.41   45.48   38.94     761.0   4.43   0.191E+09   0.02003    37.59   26.21   25.10   28.68   29.63   29.16
12   245.2  47.06   49.14   49.73   48.64   41.87     806.2   4.16   0.211E+09   0.02406    35.95   25.63   23.73   27.53   28.44   27.98
13   275.2  49.17   51.35   52.09   50.87   44.06     837.7   3.99   0.226E+09   0.02710    36.40   25.49   23.15   27.30   28.35   27.82
14   305.2  51.01   52.87   53.63   52.50   46.26     871.8   3.82   0.242E+09   0.03018    38.98   27.98   25.11   29.64   30.69   30.16
15   333.3  53.45   55.65   56.71   55.27   48.32     903.9   3.67   0.257E+09   0.03307    35.92   25.14   21.97   26.52   27.68   27.10
16   363.3  55.36   57.63   58.32   57.10   50.51     939.9   3.51   0.274E+09   0.03619    37.91   25.81   23.55   27.88   29.09   28.49
17   383.3  56.96   58.91   59.74   58.54   51.98     965.0   3.41   0.286E+09   0.03828    36.79   26.46   23.61   27.95   28.95   28.45
18   403.3  58.11   60.08   60.91   59.70   53.44     986.4   3.33   0.296E+09   0.04034    39.18   27.54   24.51   29.23   30.41   29.82
19   423.3  59.76   61.99   62.78   61.51   54.91    1008.8   3.25   0.307E+09   0.04241    37.60   25.77   23.17   27.63   28.85   28.24
20   443.3  61.04   62.27   64.04   62.45   56.37    1032.2   3.18   0.319E+09   0.04449    38.96   30.86   23.75   29.95   31.19   30.57
21   463.3  62.79   63.37   65.67   63.94   57.84    1055.4   3.10   0.330E+09   0.04663    36.63   32.84   23.19   29.74   30.89   30.31
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  57.45   59.42   60.42   59.10   52.59     972.7   3.39   0.290E+09   0.03913    37.73   26.93   23.42   28.19   29.36   28.78
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Appendix 4

Experimental Data for $\alpha = 180°$

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                                                  XP180-01

INPUT ELECTRIC POWER =  155.0 W             HEAT RATE GAINED BY WATER =  154.1 W             HEAT BALANCE ERROR =  0.56%
MASS FLOW RATE = 14.1000 G/S        PRESSURE DROP = 0.2847 MM H2O        FRICTION FACTOR = 0.041015          FREM =  20.3534
REM =  496.2    GRM  = 0.11576E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 26.56 DEG C
PRM =  6.084    RAM  = 0.70422E+07    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 26.55 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-  TB       RE     PR      RA+         Z+      ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-  (C)                                            A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                       T      H      T+H
---------------------------------------------------------------------------------------------------------------------------
 0     0.1  24.47  24.47  24.49  24.48  23.94    481.5  6.29  0.654E+07  0.00001    23.87  24.07  23.31  23.63  23.64  23.63
 1     1.5  24.56  24.55  24.58  24.57  23.95    481.6  6.29  0.655E+07  0.00016    20.88  21.09  20.13  20.55  20.56  20.55
 2     2.5  24.62  24.61  24.65  24.63  23.95    481.7  6.29  0.655E+07  0.00027    19.22  19.44  18.40  18.85  18.87  18.86
 3     5.5  24.79  24.78  24.84  24.82  23.97    481.8  6.29  0.656E+07  0.00060    15.52  15.73  14.63  15.11  15.13  15.12
 4    15.5  25.05  25.05  25.08  25.06  24.02    482.4  6.28  0.658E+07  0.00168    12.50  12.50  12.17  12.33  12.33  12.33
 5    25.5  25.18  25.23  25.33  25.27  24.08    483.1  6.27  0.660E+07  0.00277    11.68  11.12  10.23  10.78  10.81  10.80
 6    45.5  25.23  25.24  25.35  25.29  24.19    484.3  6.25  0.664E+07  0.00494    12.37  12.17  11.06  11.63  11.67  11.65
 7    75.5  25.19  25.14  25.23  25.20  24.36    486.2  6.22  0.670E+07  0.00821    15.43  16.42  14.74  15.30  15.33  15.32
 8   105.5  25.19  25.16  25.24  25.21  24.53    488.0  6.20  0.677E+07  0.01147    19.32  20.34  17.96  18.85  18.90  18.87
 9   135.5  25.41  25.41  25.68  25.54  24.69    489.9  6.17  0.683E+07  0.01474    17.98  17.98  12.93  15.04  15.45  15.25
10   165.2  25.69  25.62  25.86  25.76  24.86    491.8  6.14  0.689E+07  0.01798    15.32  16.77  12.77  14.21  14.41  14.31
11   205.2  25.75  25.82  25.99  25.89  25.08    494.4  6.11  0.698E+07  0.02235    19.15  17.42  14.02  15.86  16.15  16.01
12   245.2  26.11  26.08  26.26  26.18  25.30    496.9  6.07  0.707E+07  0.02672    15.87  16.55  13.38  14.66  14.79  14.72
13   275.2  26.23  26.26  26.41  26.33  25.47    498.9  6.05  0.713E+07  0.03000    16.80  16.33  13.62  14.95  15.09  15.02
14   305.2  26.36  26.42  26.54  26.46  25.64    500.9  6.02  0.720E+07  0.03329    17.86  16.33  14.21  15.51  15.65  15.58
15   333.3  26.59  26.63  26.84  26.73  25.80    502.7  6.00  0.726E+07  0.03637    16.12  15.37  12.19  13.74  13.97  13.86
16   363.3  26.78  26.75  26.97  26.87  25.96    504.7  5.97  0.733E+07  0.03966    15.69  16.25  12.67  14.13  14.32  14.22
17   383.3  26.92  26.90  27.03  26.97  26.08    506.1  5.95  0.737E+07  0.04186    15.08  15.49  13.41  14.28  14.35  14.31
18   403.3  27.01  27.01  27.11  27.06  26.19    507.4  5.93  0.742E+07  0.04405    15.60  15.60  13.90  14.70  14.75  14.72
19   423.3  27.16  27.10  27.27  27.20  26.30    508.8  5.92  0.746E+07  0.04625    14.89  15.93  13.18  14.20  14.30  14.25
20   443.3  27.21  27.25  27.38  27.31  26.41    510.2  5.90  0.751E+07  0.04845    15.93  15.19  13.11  14.23  14.34  14.28
21   463.3  27.32  27.37  27.57  27.46  26.52    511.5  5.88  0.755E+07  0.05065    15.94  15.00  12.14  13.60  13.81  13.70
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  26.94  26.94  27.10  27.02  26.12    506.7  5.95  0.739E+07  0.04277    15.55  15.64  13.08  14.21  14.34  14.27
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                                                  XP180-02

INPUT ELECTRIC POWER =  285.0 W             HEAT RATE GAINED BY WATER =  279.1 W             HEAT BALANCE ERROR =  2.08%
MASS FLOW RATE = 28.5400 G/S        PRESSURE DROP = 0.6257 MM H2O        FRICTION FACTOR = 0.022002          FREM =  22.0283
REM = 1001.2    GRM  = 0.20721E+07    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 26.28 DEG C
PRM =  6.106    RAM  = 0.12652E+08    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 26.28 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-  TB       RE     PR      RA+         Z+      ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-  (C)                                            A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                       T      H      T+H
---------------------------------------------------------------------------------------------------------------------------
 0     0.1  24.62  24.62  24.58  24.60  23.94    974.6  6.29  0.118E+08  0.00000    34.07  34.18  36.34  35.20  35.23  35.21
 1     1.5  24.74  24.74  24.71  24.72  23.94    974.8  6.29  0.119E+08  0.00008    29.20  29.32  30.46  29.85  29.86  29.85
 2     2.5  24.82  24.82  24.80  24.81  23.95    974.9  6.29  0.119E+08  0.00013    26.59  26.70  27.40  27.02  27.02  27.02
 3     5.5  25.07  25.07  25.07  25.07  23.96    975.2  6.29  0.119E+08  0.00030    20.95  21.06  21.06  21.03  21.03  21.03
 4    15.5  25.44  25.44  25.47  25.45  24.01    976.3  6.28  0.119E+08  0.00083    16.29  16.23  15.98  16.12  16.12  16.12
 5    25.5  25.63  25.62  25.72  25.67  24.06    977.4  6.27  0.119E+08  0.00137    14.84  14.90  14.00  14.42  14.43  14.43
 6    45.5  25.73  25.69  25.85  25.78  24.16    979.6  6.25  0.120E+08  0.00244    14.84  15.22  13.76  14.37  14.40  14.38
 7    75.5  25.74  25.69  25.79  25.75  24.31    983.0  6.23  0.121E+08  0.00405    16.21  16.80  15.72  16.10  16.11  16.11
 8   105.5  25.74  25.77  25.91  25.83  24.46    986.4  6.21  0.122E+08  0.00567    18.10  17.79  16.08  16.96  17.01  16.99
 9   135.5  25.96  25.91  26.24  26.09  24.61    989.8  6.18  0.123E+08  0.00728    17.19  17.93  14.26  15.74  15.91  15.82
10   165.2  26.14  26.18  26.47  26.32  24.76    993.2  6.16  0.124E+08  0.00888    16.82  16.29  13.54  14.90  15.05  14.97
11   205.2  26.26  26.32  26.55  26.42  24.96    997.8  6.13  0.125E+08  0.01104    17.89  17.08  14.58  15.89  16.03  15.96
12   245.2  26.44  26.41  26.71  26.57  25.16   1002.4  6.10  0.127E+08  0.01320    18.03  18.51  14.98  16.46  16.63  16.55
13   275.2  26.62  26.70  26.91  26.79  25.31   1006.0  6.07  0.128E+08  0.01482    17.64  16.65  14.46  15.68  15.80  15.74
14   305.2  26.69  26.70  26.99  26.84  25.46   1009.5  6.05  0.129E+08  0.01644    18.82  18.65  15.13  16.74  16.93  16.84
15   333.3  26.92  26.97  27.29  27.12  25.60   1012.9  6.03  0.130E+08  0.01796    17.57  16.92  13.65  15.24  15.45  15.34
16   363.3  27.06  27.03  27.36  27.20  25.75   1016.4  6.00  0.131E+08  0.01958    17.71  18.09  14.35  15.93  16.12  16.03
17   383.3  27.20  27.18  27.47  27.33  25.85   1018.9  5.99  0.132E+08  0.02067    17.12  17.40  14.25  15.61  15.75  15.68
18   403.3  27.34  27.23  27.55  27.42  25.95   1021.3  5.97  0.133E+08  0.02175    16.57  18.08  14.44  15.74  15.88  15.81
19   423.3  27.43  27.49  27.77  27.62  26.05   1023.7  5.96  0.133E+08  0.02283    16.69  16.05  13.41  14.74  14.89  14.82
20   443.3  27.54  27.58  27.83  27.70  26.15   1026.2  5.94  0.134E+08  0.02392    16.55  16.10  13.76  14.93  15.04  14.99
21   463.3  27.77  27.76  28.02  27.89  26.25   1028.6  5.93  0.135E+08  0.02501    15.22  15.27  13.06  14.07  14.15  14.11
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  27.25  27.25  27.55  27.40  25.89   1019.9  5.98  0.132E+08  0.02112    17.03  17.11  13.98  15.36  15.52  15.44
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                                                  XP180-03

INPUT ELECTRIC POWER =  295.0 W             HEAT RATE GAINED BY WATER =  301.9 W             HEAT BALANCE ERROR = -2.34%
MASS FLOW RATE = 42.9800 G/S        PRESSURE DROP = 0.9395 MM H2O        FRICTION FACTOR = 0.014568          FREM =  21.7136
REM = 1490.4    GRM  = 0.21525E+07    UPSTREAM BULK TEMPERATURE = 23.77 DEG C    DOWN STREAM BULK TEMPERATURE = 25.45 DEG C
PRM =  6.184    RAM  = 0.13312E+08    INLET BULK TEMPERATURE    = 23.77 DEG C    OUTLET BULK TEMPERATURE      = 25.45 DEG C
---------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-  TB       RE     PR      RA+         Z+      ------------- NUSSELT NUMBER ------------
TION  CM      A      B      C    AVER-  (C)                                            A      B      C    ----- AVERAGE -----
NO.                               AGE                                                                       T      H      T+H
---------------------------------------------------------------------------------------------------------------------------
 0     0.1  24.35  24.35  24.29  24.32  23.77   1462.1  6.32  0.127E+08  0.00000    43.07  43.40  48.42  45.68  45.83  45.75
 1     1.5  24.45  24.45  24.39  24.42  23.77   1462.3  6.32  0.127E+08  0.00005    36.89  37.23  40.69  38.79  38.88  38.83
 2     2.5  24.53  24.52  24.46  24.49  23.78   1462.4  6.32  0.127E+08  0.00009    33.57  33.91  36.65  35.14  35.20  35.17
 3     5.5  24.74  24.73  24.68  24.71  23.79   1462.8  6.31  0.127E+08  0.00020    26.43  26.75  28.25  27.39  27.42  27.41
 4    15.5  24.99  24.99  24.91  24.95  23.82   1463.9  6.31  0.127E+08  0.00055    21.47  21.47  23.12  22.26  22.29  22.28
 5    25.5  25.12  25.18  25.17  25.16  23.86   1465.1  6.30  0.128E+08  0.00091    19.91  19.07  19.23  19.35  19.36  19.36
 6    45.5  25.23  25.24  25.29  25.27  23.93   1467.5  6.29  0.128E+08  0.00162    19.38  19.14  18.44  18.84  18.85  18.84
 7    75.5  25.41  25.31  25.45  25.40  24.04   1471.1  6.27  0.129E+08  0.00269    18.31  19.83  17.80  18.40  18.44  18.42
 8   105.5  25.47  25.49  25.63  25.55  24.15   1474.7  6.26  0.130E+08  0.00376    19.02  18.71  16.96  17.86  17.91  17.89
 9   135.5  25.63  25.63  25.91  25.77  24.25   1478.4  6.24  0.130E+08  0.00483    18.28  18.28  15.20  16.60  16.74  16.67
10   165.2  25.81  25.79  26.14  25.97  24.36   1482.0  6.22  0.131E+08  0.00589    17.37  17.57  14.12  15.62  15.79  15.71
11   205.2  25.87  25.87  26.16  26.02  24.50   1486.9  6.20  0.132E+08  0.00732    18.41  18.34  15.14  16.60  16.76  16.68
12   245.2  26.00  26.02  26.26  26.14  24.65   1491.8  6.18  0.133E+08  0.00875    18.55  18.25  15.55  16.85  16.97  16.91
13   275.2  26.12  26.14  26.41  26.27  24.75   1495.5  6.16  0.134E+08  0.00983    18.34  18.05  15.14  16.53  16.67  16.60
14   305.2  26.19  26.14  26.43  26.30  24.86   1499.2  6.14  0.135E+08  0.01090    18.90  19.56  16.02  17.48  17.62  17.55
15   333.3  26.42  26.46  26.73  26.59  24.96   1502.7  6.13  0.136E+08  0.01191    17.18  16.73  14.16  15.43  15.56  15.50
16   363.3  26.44  26.47  26.75  26.60  25.07   1506.5  6.11  0.137E+08  0.01298    18.24  17.88  14.92  16.34  16.49  16.42
17   383.3  26.59  26.56  26.87  26.72  25.14   1509.0  6.10  0.137E+08  0.01370    17.32  17.66  14.53  15.87  16.01  15.94
18   403.3  26.67  26.62  26.88  26.76  25.21   1511.6  6.09  0.138E+08  0.01442    17.18  17.86  15.01  16.17  16.27  16.22
19   423.3  26.71  26.77  26.99  26.86  25.29   1514.1  6.08  0.138E+08  0.01513    17.57  16.91  14.71  15.87  15.98  15.92
20   443.3  26.88  26.91  27.05  26.97  25.36   1516.6  6.07  0.139E+08  0.01585    16.47  16.12  14.80  15.51  15.55  15.53
21   463.3  27.04  27.06  27.29  27.17  25.43   1519.2  6.05  0.139E+08  0.01657    15.50  15.34  13.43  14.35  14.42  14.39
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  26.62  26.63  26.88  26.75  25.17   1510.1  6.10  0.137E+08  0.01400    17.33  17.20  14.69  15.87  15.98  15.92
---------------------------------------------------------------------------------------------------------------------------
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                                           XP180-04

INPUT ELECTRIC POWER =  265.0 W               HEAT RATE GAINED BY WATER =  258.0 W               HEAT BALANCE ERROR =  2.64%
MASS FLOW RATE = 14.1000 G/S          PRESSURE DROP = 0.2984 MM H2O        FRICTION FACTOR = 0.042981         FREM =  21.7798
REM =   506.7    GRM  = 0.20821E+07     UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 28.32 DEG C
PRM =   5.944    RAM  = 0.12376E+08     INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 28.32 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR      RA+        Z+      ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                           A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                        T      H     T+H
----------------------------------------------------------------------------------------------------------------------------
 0     0.1 24.79  24.77  24.78  24.78  23.94     481.5  6.29  0.110E+08  0.00001    25.12  25.85  25.45  25.47  25.47  25.47
 1     1.5 24.94  24.91  24.93  24.93  23.95     481.7  6.29  0.110E+08  0.00016    21.71  22.49  21.96  22.03  22.03  22.03
 2     2.5 25.04  25.00  25.03  25.03  23.96     481.8  6.29  0.110E+08  0.00027    19.86  20.63  20.06  20.15  20.15  20.15
 3     5.5 25.35  25.29  25.34  25.33  23.99     482.1  6.28  0.110E+08  0.00060    15.80  16.55  15.93  16.05  16.05  16.05
 4    15.5 25.61  25.67  25.69  25.66  24.08     483.1  6.27  0.110E+08  0.00168    14.11  13.57  13.38  13.60  13.61  13.61
 5    25.5 25.74  25.79  25.94  25.85  24.18     484.1  6.25  0.111E+08  0.00277    13.75  13.32  12.15  12.80  12.84  12.82
 6    45.5 25.78  25.80  25.96  25.88  24.36     486.2  6.22  0.112E+08  0.00495    15.12  14.95  13.44  14.19  14.24  14.21
 7    75.5 25.74  25.64  25.84  25.77  24.64     489.4  6.18  0.114E+08  0.00821    19.50  21.57  17.87  19.09  19.20  19.15
 8   105.5 25.91  25.93  26.13  26.03  24.92     492.6  6.13  0.116E+08  0.01149    21.73  21.25  17.81  19.48  19.65  19.57
 9   135.5 26.35  26.35  26.74  26.54  25.20     495.8  6.09  0.118E+08  0.01476    18.70  18.70  13.96  15.99  16.33  16.16
10   165.2 26.69  26.68  27.08  26.89  25.48     499.0  6.05  0.119E+08  0.01801    17.66  17.82  13.37  15.25  15.55  15.40
11   205.2 27.03  27.09  27.44  27.25  25.86     503.4  5.99  0.122E+08  0.02239    18.16  17.27  13.51  15.33  15.61  15.47
12   245.2 27.49  27.47  27.71  27.59  26.23     508.0  5.93  0.124E+08  0.02679    16.89  17.27  14.48  15.67  15.78  15.72
13   275.2 27.62  27.64  27.97  27.80  26.51     511.4  5.88  0.126E+08  0.03009    19.19  18.82  14.66  16.55  16.83  16.69
14   305.2 27.91  27.93  28.21  28.07  26.79     514.9  5.84  0.128E+08  0.03339    19.03  18.75  15.02  16.73  16.95  16.84
15   333.3 28.36  28.31  28.64  28.49  27.05     517.7  5.80  0.130E+08  0.03648    16.30  17.02  13.44  14.88  15.05  14.96
16   363.3 28.49  28.53  28.87  28.69  27.33     520.7  5.77  0.132E+08  0.03978    18.34  17.83  13.89  15.71  15.99  15.85
17   383.3 28.81  28.79  29.03  28.92  27.52     522.7  5.75  0.133E+08  0.04199    16.49  16.71  14.12  15.26  15.36  15.31
18   403.3 28.96  28.96  29.22  29.09  27.71     524.7  5.72  0.134E+08  0.04419    16.97  17.04  14.05  15.39  15.53  15.46
19   423.3 29.16  29.16  29.44  29.30  27.89     526.7  5.70  0.135E+08  0.04639    16.86  16.79  13.72  15.11  15.27  15.19
20   443.3 29.33  29.37  29.61  29.48  28.08     528.7  5.68  0.136E+08  0.04860    17.05  16.46  13.94  15.22  15.35  15.28
21   463.3 29.61  29.58  29.97  29.78  28.27     530.7  5.65  0.138E+08  0.05081    15.88  16.15  12.51  14.05  14.26  14.16
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 28.85  28.85  29.13  28.99  27.60     523.5  5.74  0.133E+08  0.04291    17.00  16.98  13.86  15.26  15.43  15.34
```

```
                                           XP180-05

INPUT ELECTRIC POWER =  665.0 W               HEAT RATE GAINED BY WATER =  647.4 W               HEAT BALANCE ERROR =  2.64%
MASS FLOW RATE = 42.2580 G/S          PRESSURE DROP = 0.9088 MM H2O        FRICTION FACTOR = 0.014575         FREM =  21.9459
REM =  1505.8    GRM  = 0.50745E+07     UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 27.61 DEG C
PRM =   6.001    RAM  = 0.30451E+08     INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 27.60 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR      RA+        Z+      ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                           A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                        T      H     T+H
----------------------------------------------------------------------------------------------------------------------------
 0     0.1 25.22  25.20  25.16  25.19  23.94    1443.1  6.29  0.275E+08  0.00000    41.87  42.59  44.16  43.17  43.19  43.18
 1     1.5 25.48  25.45  25.41  25.44  23.95    1443.4  6.29  0.275E+08  0.00005    35.20  35.93  36.80  36.17  36.18  36.18
 2     2.5 25.66  25.62  25.59  25.61  23.96    1443.7  6.29  0.275E+08  0.00009    31.72  32.43  33.01  32.53  32.54  32.54
 3     5.5 26.18  26.13  26.12  26.14  23.98    1444.5  6.28  0.276E+08  0.00020    24.46  25.09  25.22  24.99  25.00  25.00
 4    15.5 26.66  26.68  26.63  26.65  24.06    1447.0  6.27  0.277E+08  0.00056    20.74  20.52  20.92  20.78  20.78  20.78
 5    25.5 26.97  26.96  27.16  27.06  24.14    1449.6  6.26  0.278E+08  0.00092    19.03  19.11  17.81  18.42  18.44  18.43
 6    45.5 27.00  27.02  27.36  27.18  24.29    1454.8  6.23  0.280E+08  0.00165    19.89  19.73  17.58  18.63  18.70  18.66
 7    75.5 27.24  27.19  27.52  27.37  24.53    1462.7  6.20  0.284E+08  0.00274    19.85  20.18  18.01  18.96  19.01  18.98
 8   105.5 27.30  27.38  27.80  27.57  24.76    1470.6  6.16  0.288E+08  0.00383    21.19  20.52  17.71  19.15  19.28  19.22
 9   135.5 27.57  27.57  28.29  27.93  25.00    1478.6  6.12  0.292E+08  0.00492    20.87  20.87  16.33  18.32  18.60  18.46
10   165.2 27.80  27.85  28.59  28.21  25.23    1486.7  6.09  0.296E+08  0.00601    20.90  20.50  15.99  18.04  18.35  18.20
11   205.2 28.09  28.09  28.67  28.38  25.54    1497.6  6.04  0.301E+08  0.00747    21.08  21.03  17.18  18.92  19.12  19.02
12   245.2 28.38  28.41  29.04  28.72  25.85    1508.8  5.99  0.306E+08  0.00893    21.22  20.99  16.82  18.72  18.96  18.84
13   275.2 28.68  28.76  29.41  29.07  26.09    1517.2  5.95  0.310E+08  0.01003    20.72  20.07  16.14  18.02  18.27  18.14
14   305.2 28.80  28.76  29.44  29.11  26.32    1525.8  5.91  0.314E+08  0.01113    21.64  21.99  17.21  19.24  19.51  19.38
15   333.3 29.25  29.26  29.98  29.62  26.54    1533.9  5.88  0.318E+08  0.01216    19.79  19.75  15.60  17.44  17.69  17.56
16   363.3 29.33  29.36  30.04  29.69  26.78    1542.6  5.84  0.322E+08  0.01326    21.00  20.73  16.42  18.38  18.64  18.51
17   383.3 29.64  29.58  30.24  29.93  26.93    1547.9  5.82  0.324E+08  0.01400    19.75  20.25  16.17  17.88  18.09  17.98
18   403.3 29.74  29.68  30.34  30.03  27.09    1552.8  5.80  0.327E+08  0.01473    20.21  20.64  16.47  18.24  18.45  18.34
19   423.3 29.98  29.88  30.61  30.27  27.25    1557.8  5.78  0.329E+08  0.01546    19.55  20.29  15.90  17.68  17.91  17.80
20   443.3 29.99  30.04  30.67  30.34  27.40    1562.7  5.76  0.332E+08  0.01620    20.64  20.25  16.39  18.19  18.41  18.30
21   463.3 30.33  30.23  31.03  30.65  27.56    1567.7  5.74  0.334E+08  0.01693    19.27  20.03  15.41  17.27  17.53  17.40
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 29.66  29.63  30.31  29.98  27.00    1549.6  5.81  0.325E+08  0.01430    20.16  20.32  16.16  17.97  18.20  18.08
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```
                                           XP180-06

INPUT ELECTRIC POWER =  625.0 W               HEAT RATE GAINED BY WATER =  605.9 W               HEAT BALANCE ERROR =  3.05%
MASS FLOW RATE = 27.8180 G/S          PRESSURE DROP = 0.6223 MM H2O        FRICTION FACTOR = 0.023027         FREM =  23.2210
REM =  1008.4    GRM  = 0.50351E+07     UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 29.10 DEG C
PRM =   5.887    RAM  = 0.29641E+08     INLET BULK TEMPERATURE    = 23.88 DEG C    OUTLET BULK TEMPERATURE      = 29.10 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB       RE     PR      RA+        Z+      ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                           A      B      C    ----- AVERAGE -----
NO.                              AGE                                                                        T      H     T+H
----------------------------------------------------------------------------------------------------------------------------
 0     0.1 25.32  25.32  25.30  25.31  23.88     948.8  6.30  0.256E+08  0.00000    35.04  35.04  35.60  35.32  35.32  35.32
 1     1.5 25.60  25.60  25.59  25.59  23.90     949.2  6.30  0.257E+08  0.00008    29.73  29.73  29.82  29.78  29.78  29.78
 2     2.5 25.79  25.79  25.79  25.79  23.91     949.4  6.29  0.257E+08  0.00014    26.92  26.92  26.82  26.87  26.87  26.87
 3     5.5 26.35  26.35  26.39  26.37  23.94     950.1  6.29  0.257E+08  0.00030    20.97  20.97  20.59  20.78  20.78  20.78
 4    15.5 26.82  26.96  27.08  26.98  24.06     952.5  6.27  0.259E+08  0.00085    18.23  17.36  16.69  17.22  17.24  17.23
 5    25.5 27.19  27.23  27.61  27.41  24.17     954.9  6.25  0.261E+08  0.00140    16.68  16.44  14.66  15.55  15.61  15.58
 6    45.5 27.22  27.24  27.69  27.46  24.39     959.8  6.22  0.264E+08  0.00251    17.79  17.65  15.27  16.40  16.50  16.45
 7    75.5 27.35  27.31  27.74  27.53  24.72     967.2  6.17  0.269E+08  0.00416    19.17  19.50  16.70  17.92  18.01  17.97
 8   105.5 27.52  27.61  28.02  27.79  25.06     974.7  6.11  0.274E+08  0.00582    20.41  19.74  16.97  18.39  18.52  18.45
 9   135.5 27.96  27.91  28.62  28.28  25.39     982.4  6.06  0.279E+08  0.00749    19.55  19.99  15.55  17.41  17.66  17.54
10   165.2 28.24  28.24  29.03  28.64  25.72     990.1  6.01  0.284E+08  0.00913    19.90  19.95  15.16  17.22  17.54  17.38
11   205.2 28.53  28.59  29.22  28.89  26.16    1000.6  5.94  0.291E+08  0.01136    21.19  20.66  16.42  18.40  18.67  18.53
12   245.2 29.10  29.02  29.66  29.36  26.61    1011.4  5.87  0.298E+08  0.01359    20.13  20.78  16.43  18.22  18.44  18.33
13   275.2 29.29  29.32  30.08  29.69  26.94    1019.2  5.82  0.304E+08  0.01527    21.36  21.11  15.98  18.24  18.61  18.42
14   305.2 29.58  29.48  30.22  29.88  27.28    1026.1  5.78  0.308E+08  0.01694    21.75  22.69  16.99  19.26  19.61  19.43
15   333.3 30.08  30.09  30.82  30.45  27.59    1032.6  5.74  0.313E+08  0.01851    20.06  19.97  15.50  17.47  17.75  17.61
16   363.3 30.32  30.31  30.99  30.65  27.92    1039.7  5.69  0.318E+08  0.02018    20.83  20.98  16.30  18.32  18.60  18.46
17   383.3 30.53  30.58  31.30  30.93  28.14    1044.5  5.67  0.321E+08  0.02130    20.92  20.49  15.83  17.94  18.27  18.11
18   403.3 30.80  30.74  31.45  31.11  28.37    1049.3  5.64  0.325E+08  0.02242    20.53  21.01  16.20  18.20  18.48  18.34
19   423.3 31.15  31.16  31.84  31.50  28.59    1054.2  5.61  0.328E+08  0.02354    19.49  19.41  15.36  17.17  17.41  17.29
20   443.3 31.22  31.28  31.94  31.60  28.81    1059.1  5.58  0.332E+08  0.02466    20.70  20.23  15.93  17.91  18.19  18.05
21   463.3 31.50  31.54  32.19  31.86  29.03    1064.0  5.55  0.335E+08  0.02579    20.22  19.86  15.78  17.66  17.91  17.78
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6 30.69  30.69  31.39  31.04  28.24    1046.6  5.66  0.323E+08  0.02177    20.42  20.35  15.85  17.83  18.12  17.98
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XP180-07

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INPUT ELECTRIC POWER =  535.0 W               HEAT RATE GAINED BY WATER =  522.5 W               HEAT BALANCE ERROR =  2.34%
MASS FLOW RATE = 13.3780 G/S         PRESSURE DROP = 0.2796 MM H2O         FRICTION FACTOR = 0.044697          FREM =  22.7263
REM =  508.4    GRM  = 0.50921E+07    UPSTREAM BULK TEMPERATURE = 24.04 DEG C    DOWN STREAM BULK TEMPERATURE = 33.41 DEG C
PRM =  5.593    RAM  = 0.28480E+08    INLET BULK TEMPERATURE    = 24.06 DEG C    OUTLET BULK TEMPERATURE      = 33.40 DEG C

STA-   Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+          Z+       ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C     AVER-  (C)                                             A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                           T       H      T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  25.55   25.55   25.60   25.57  24.06      458.1   6.27   0.223E+08   0.00001    29.22   29.22   28.22   28.71   28.72   28.72
 1     1.5  25.82   25.82   25.90   25.86  24.09      458.4   6.27   0.224E+08   0.00017    25.10   25.10   24.01   24.54   24.56   24.55
 2     2.5  26.01   26.01   26.10   26.06  24.11      458.6   6.26   0.224E+08   0.00029    22.88   22.88   21.77   22.31   22.32   22.32
 3     5.5  26.57   26.57   26.72   26.65  24.17      459.2   6.25   0.225E+08   0.00063    18.07   18.07   17.01   17.52   17.54   17.53
 4    15.5  26.99   27.13   27.31   27.18  24.37      461.3   6.22   0.227E+08   0.00178    16.57   15.70   14.78   15.42   15.46   15.44
 5    25.5  27.36   27.29   27.83   27.58  24.57      463.5   6.19   0.230E+08   0.00292    15.57   15.95   13.31   14.43   14.53   14.48
 6    45.5  27.39   27.36   27.86   27.61  24.96      467.8   6.13   0.235E+08   0.00522    17.89   18.14   15.01   16.38   16.51   16.44
 7    75.5  27.73   27.69   28.18   27.95  25.56      474.4   6.03   0.243E+08   0.00868    19.96   20.32   16.53   18.16   18.34   18.25
 8   105.5  28.24   28.33   28.74   28.52  26.16      481.1   5.94   0.251E+08   0.01214    20.76   19.96   16.75   18.38   18.55   18.46
 9   135.5  28.91   28.96   29.57   29.25  26.76      488.1   5.84   0.259E+08   0.01562    20.13   19.62   15.39   17.34   17.63   17.49
10   165.2  29.41   29.41   30.14   29.78  27.35      494.2   5.77   0.267E+08   0.01907    20.94   21.00   15.45   17.79   18.21   16.00
11   205.2  30.09   30.21   30.72   30.43  28.15      502.3   5.67   0.277E+08   0.02371    22.19   20.94   16.73   18.84   19.15   18.99
12   245.2  30.99   30.97   31.50   31.24  28.95      510.7   5.57   0.288E+08   0.02837    21.04   21.27   16.83   18.75   19.00   18.87
13   275.2  31.46   31.43   32.08   31.76  29.54      517.2   5.49   0.296E+08   0.03188    22.46   22.79   16.94   19.38   19.78   19.58
14   305.2  32.07   32.04   32.62   32.34  30.14      523.9   5.42   0.304E+08   0.03539    22.21   22.54   17.33   19.53   19.85   19.69
15   333.3  32.81   32.78   33.39   33.09  30.70      530.3   5.34   0.312E+08   0.03868    20.36   20.63   15.94   17.93   18.22   18.07
16   363.3  33.26   33.36   33.89   33.60  31.30      537.3   5.27   0.321E+08   0.04221    21.87   20.75   16.52   18.61   18.92   18.76
17   383.3  33.87   33.66   34.29   34.03  31.70      542.1   5.22   0.326E+08   0.04457    19.71   21.84   16.46   18.35   18.62   18.48
18   403.3  34.14   34.03   34.62   34.36  32.10      546.5   5.17   0.332E+08   0.04694    20.85   22.05   16.91   18.91   19.18   19.04
19   423.3  34.53   34.56   35.24   34.89  32.50      550.8   5.13   0.337E+08   0.04933    20.93   20.71   15.55   17.80   18.18   17.99
20   443.3  34.90   34.74   35.51   35.16  32.89      555.1   5.08   0.342E+08   0.05172    21.25   23.03   16.32   18.78   19.23   19.00
21   463.3  35.40   35.10   35.98   35.62  33.29      559.5   5.03   0.347E+08   0.05413    20.20   23.56   15.82   18.32   18.85   18.59
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  33.92   33.85   34.49   34.19  31.86      543.7   5.20   0.328E+08   0.04557    20.83   21.50   16.28   18.39   18.72   18.56
```

XP180-08

```
INPUT ELECTRIC POWER = 1175.0 W               HEAT RATE GAINED BY WATER = 1142.7 W               HEAT BALANCE ERROR =  2.75%
MASS FLOW RATE = 40.8140 G/S         PRESSURE DROP = 0.9548 MM H2O         FRICTION FACTOR = 0.016409          FREM =  24.7088
REM = 1505.8    GRM  = 0.10081E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 30.64 DEG C
PRM =  5.775    RAM  = 0.58211E+08    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 30.64 DEG C

STA-   Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+          Z+       ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C     AVER-  (C)                                             A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                           T       H      T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.07   26.01   25.98   26.01  23.94     1393.9   6.29   0.485E+08   0.00000    44.60   45.97   46.61   45.93   45.95   45.94
 1     1.5  26.52   26.43   26.46   26.47  23.96     1394.5   6.29   0.486E+08   0.00006    37.22   38.58   38.08   37.98   37.99   37.99
 2     2.5  26.82   26.71   26.79   26.78  23.98     1395.0   6.28   0.486E+08   0.00009    33.41   34.72   33.81   33.93   33.94   33.94
 3     5.5  27.74   27.58   27.78   27.72  24.02     1396.3   6.28   0.487E+08   0.00021    25.56   26.72   25.30   25.71   25.72   25.72
 4    15.5  28.32   28.48   28.69   28.55  24.16     1400.9   6.25   0.491E+08   0.00058    22.88   22.00   20.97   21.68   21.71   21.69
 5    25.5  28.81   28.84   29.49   29.16  24.30     1405.5   6.23   0.495E+08   0.00096    21.09   20.94   18.33   19.58   19.67   19.63
 6    45.5  28.83   28.86   29.53   29.19  24.59     1414.7   6.19   0.503E+08   0.00171    22.39   22.27   19.24   20.67   20.78   20.72
 7    75.5  29.12   29.13   29.91   29.52  25.02     1428.9   6.12   0.516E+08   0.00284    23.13   23.06   19.40   21.08   21.25   21.17
 8   105.5  29.36   29.44   30.24   29.82  25.45     1443.3   6.05   0.528E+08   0.00397    24.22   23.72   19.76   21.66   21.87   21.77
 9   135.5  29.91   29.96   31.12   30.53  25.88     1458.0   5.98   0.541E+08   0.00511    23.51   23.19   18.05   20.36   20.70   20.53
10   165.2  30.41   30.52   31.71   31.08  26.30     1472.8   5.92   0.553E+08   0.00624    23.02   22.44   17.51   19.78   20.12   19.95
11   205.2  30.76   30.87   31.83   31.32  26.87     1493.2   5.83   0.571E+08   0.00776    24.33   23.62   19.05   21.23   21.51   21.37
12   245.2  31.32   31.30   32.50   31.90  27.44     1510.6   5.76   0.586E+08   0.00928    24.37   24.47   18.67   21.16   21.54   21.35
13   275.2  31.79   31.82   33.08   32.44  27.87     1523.9   5.70   0.598E+08   0.01042    24.07   23.87   18.09   20.62   21.03   20.83
14   305.2  31.91   31.88   33.17   32.53  28.30     1537.4   5.65   0.611E+08   0.01156    26.13   26.34   19.34   22.26   22.79   22.53
15   333.3  32.81   32.83   34.01   33.41  28.70     1550.3   5.60   0.622E+08   0.01264    22.94   22.78   17.75   19.98   20.30   20.14
16   363.3  32.93   32.97   34.22   33.59  29.13     1564.3   5.54   0.635E+08   0.01378    24.77   24.48   18.47   21.11   21.55   21.33
17   383.3  33.37   33.38   34.46   33.92  29.42     1573.8   5.51   0.643E+08   0.01455    23.79   23.72   18.63   20.88   21.19   21.04
18   403.3  33.58   33.48   34.68   34.10  29.70     1583.4   5.47   0.652E+08   0.01532    24.20   24.88   18.87   21.34   21.71   21.52
19   423.3  33.98   34.00   35.13   34.56  29.99     1593.1   5.43   0.660E+08   0.01608    23.52   23.39   18.26   20.54   20.86   20.70
20   443.3  34.12   34.19   35.34   34.75  30.28     1603.0   5.40   0.669E+08   0.01685    24.37   23.96   18.52   20.97   21.34   21.15
21   463.3  34.67   34.54   35.82   35.21  30.56     1612.9   5.36   0.678E+08   0.01762    22.79   23.56   17.83   20.15   20.50   20.33
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  33.46   33.48   34.64   34.05  29.54     1578.0   5.49   0.647E+08   0.01487    23.93   23.87   18.42   20.80   21.16   20.98
```

XP180-09

```
INPUT ELECTRIC POWER = 1110.0 W               HEAT RATE GAINED BY WATER = 1085.6 W               HEAT BALANCE ERROR =  2.20%
MASS FLOW RATE = 32.1500 G/S         PRESSURE DROP = 0.7076 MM H2O         FRICTION FACTOR = 0.019593          FREM =  23.5446
REM = 1201.7    GRM  = 0.10008E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 31.97 DEG C
PRM =  5.694    RAM  = 0.56989E+08    INLET BULK TEMPERATURE    = 23.89 DEG C    OUTLET BULK TEMPERATURE      = 31.97 DEG C

STA-   Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+          Z+       ------------- NUSSELT NUMBER ------------
TION  CM      A       B       C     AVER-  (C)                                             A       B       C     ----- AVERAGE -----
NO.                                  AGE                                                                           T       H      T+H
----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  26.07   26.06   26.03   26.05  23.89     1096.6   6.30   0.460E+08   0.00000    41.33   41.67   42.08   41.79   41.79   41.79
 1     1.5  26.52   26.49   26.51   26.51  23.91     1097.3   6.29   0.460E+08   0.00007    34.70   35.03   34.76   34.81   34.81   34.81
 2     2.5  26.82   26.79   26.84   26.82  23.93     1097.7   6.29   0.461E+08   0.00012    31.24   31.56   31.04   31.22   31.22   31.22
 3     5.5  27.74   27.69   27.83   27.77  23.98     1099.0   6.28   0.462E+08   0.00026    24.05   24.33   23.49   23.83   23.84   23.84
 4    15.5  28.43   28.71   28.86   28.71  24.15     1103.3   6.26   0.467E+08   0.00074    21.13   19.84   19.19   19.81   19.84   19.82
 5    25.5  28.98   28.96   29.71   29.34  24.33     1107.7   6.23   0.471E+08   0.00122    19.41   19.50   16.77   18.01   18.11   18.06
 6    45.5  28.94   28.86   29.69   29.30  24.67     1116.5   6.17   0.480E+08   0.00217    21.11   21.56   17.96   19.50   19.65   19.57
 7    75.5  29.18   29.19   29.97   29.58  25.19     1130.0   6.09   0.494E+08   0.00361    22.58   22.52   18.86   20.54   20.70   20.62
 8   105.5  29.53   29.72   30.47   30.05  25.70     1143.8   6.01   0.509E+08   0.00505    23.54   22.40   18.90   20.73   20.94   20.83
 9   135.5  30.13   30.18   31.34   30.75  26.22     1158.0   5.93   0.523E+08   0.00649    23.01   22.69   17.55   19.85   20.20   20.03
10   165.2  30.58   30.52   31.87   31.21  26.73     1172.4   5.85   0.538E+08   0.00793    23.36   23.74   17.47   20.06   20.51   20.29
11   205.2  30.98   31.09   32.11   31.57  27.42     1189.4   5.76   0.557E+08   0.00986    25.22   24.42   19.12   21.60   21.97   21.79
12   245.2  31.76   31.80   32.89   32.34  28.11     1206.3   5.67   0.575E+08   0.01179    24.53   24.27   18.72   21.19   21.56   21.37
13   275.2  32.23   32.27   33.53   32.89  28.63     1219.3   5.61   0.589E+08   0.01324    24.81   24.58   18.25   20.99   21.47   21.23
14   305.2  32.63   32.61   33.79   33.20  29.15     1232.6   5.54   0.603E+08   0.01470    25.65   25.82   19.24   22.02   22.49   22.25
15   333.3  33.47   33.39   34.62   34.03  29.63     1245.4   5.48   0.617E+08   0.01607    23.26   23.70   17.87   20.29   20.68   20.49
16   363.3  33.87   33.86   35.01   34.43  30.15     1259.2   5.41   0.632E+08   0.01753    23.96   24.00   18.34   20.79   21.16   20.97
17   383.3  34.20   34.05   35.24   34.68  30.49     1268.7   5.37   0.642E+08   0.01850    24.01   25.03   18.76   21.25   21.64   21.45
18   403.3  34.53   34.48   35.52   35.01  30.84     1278.2   5.33   0.652E+08   0.01948    24.07   24.44   19.01   21.31   21.63   21.47
19   423.3  34.87   34.89   36.08   35.48  31.18     1287.9   5.28   0.662E+08   0.02046    24.13   23.98   18.16   20.69   21.11   20.90
20   443.3  35.13   35.19   36.23   35.69  31.53     1297.8   5.24   0.673E+08   0.02144    24.67   24.22   18.89   21.31   21.67   21.49
21   463.3  35.79   35.55   36.82   36.24  31.87     1307.7   5.20   0.683E+08   0.02242    22.66   24.13   17.95   20.30   20.67   20.49
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  34.34   34.31   35.45   34.89  30.64     1272.9   5.35   0.646E+08   0.01891    24.02   24.23   18.51   20.94   21.31   21.13
```

```
                                                     XP180-10

INPUT ELECTRIC POWER = 1065.0 W            HEAT RATE GAINED BY WATER = 1024.3 W            HEAT BALANCE ERROR =  3.83%
MASS FLOW RATE = 26.3740 G/S        PRESSURE DROP = 0.6138 MM H2O        FRICTION FACTOR = 0.025247         FREM =  25.2631
REM = 1000.6     GRM  = 0.99246E+07    UPSTREAM BULK TEMPERATURE = 23.99 DEG C    DOWN STREAM BULK TEMPERATURE = 33.30 DEG C
PRM =  5.604     RAM  = 0.55614E+08    INLET BULK TEMPERATURE    = 24.00 DEG C    OUTLET BULK TEMPERATURE      = 33.29 DEG C
------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA+         Z+     ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T      H     T+H
------------------------------------------------------------------------------------------------------------------------
 0    0.1  26.27  26.28  26.32  26.30  24.00     901.9  6.28  0.436E+08  0.00000    37.50  37.42  36.71  37.08  37.08  37.08
 1    1.5  26.71  26.71  26.83  26.77  24.03     902.5  6.28  0.437E+08  0.00009    31.82  31.75  30.47  31.11  31.13  31.12
 2    2.5  27.01  27.01  27.17  27.09  24.05     902.9  6.27  0.438E+08  0.00015    28.81  28.74  27.28  28.01  28.03  28.02
 3    5.5  27.91  27.92  28.22  28.06  24.11     904.2  6.26  0.439E+08  0.00032    22.45  22.38  20.75  21.55  21.58  21.56
 4   15.5  28.59  28.82  29.03  28.87  24.31     908.3  6.23  0.444E+08  0.00090    19.87  18.87  18.04  18.68  18.71  18.69
 5   25.5  29.09  29.07  29.88  29.48  24.50     912.4  6.20  0.449E+08  0.00148    18.58  18.67  15.85  17.12  17.24  17.18
 6   45.5  29.06  29.02  29.86  29.45  24.90     920.8  6.14  0.459E+08  0.00265    20.48  20.65  17.15  18.70  18.86  18.78
 7   75.5  29.34  29.36  30.13  29.74  25.50     933.7  6.04  0.475E+08  0.00440    22.08  22.01  18.32  20.01  20.18  20.10
 8  105.5  29.75  29.83  30.63  30.21  26.09     947.0  5.95  0.490E+08  0.00616    23.19  22.67  18.68  20.59  20.80  20.69
 9  135.5  30.46  30.52  31.62  31.06  26.69     960.6  5.86  0.506E+08  0.00792    22.44  22.12  17.16  19.39  19.72  19.56
10  165.2  30.96  31.02  32.26  31.63  27.27     972.8  5.78  0.521E+08  0.00967    22.95  22.61  16.97  19.45  19.87  19.66
11  205.2  31.59  31.54  32.56  32.06  28.07     988.7  5.68  0.541E+08  0.01203    23.98  24.33  18.82  21.16  21.49  21.32
12  245.2  32.32  32.36  33.45  32.89  28.86    1005.1  5.58  0.562E+08  0.01439    24.39  24.12  18.37  20.91  21.31  21.11
13  275.2  32.84  32.88  34.14  33.50  29.45    1017.8  5.50  0.577E+08  0.01617    24.84  24.60  17.98  20.82  21.35  21.08
14  305.2  33.46  33.38  34.51  33.97  30.05    1030.8  5.43  0.593E+08  0.01795    24.65  25.22  18.85  21.47  21.89  21.68
15  333.3  34.30  34.34  35.46  34.89  30.61    1043.3  5.36  0.609E+08  0.01962    22.74  22.47  17.30  19.60  19.95  19.78
16  363.3  34.64  34.75  35.89  35.30  31.20    1057.0  5.28  0.626E+08  0.02141    24.36  23.63  17.87  20.48  20.93  20.71
17  383.3  35.20  35.06  36.18  35.65  31.60    1066.3  5.23  0.637E+08  0.02260    23.26  24.23  18.30  20.67  21.02  20.84
18  403.3  35.59  35.54  36.46  36.01  31.99    1075.3  5.18  0.648E+08  0.02380    23.25  23.62  18.74  20.83  21.09  20.96
19  423.3  35.97  36.01  37.08  36.53  32.39    1083.6  5.14  0.658E+08  0.02501    23.35  23.14  17.84  20.19  20.54  20.37
20  443.3  36.18  36.26  37.34  36.78  32.79    1092.0  5.09  0.668E+08  0.02623    24.60  24.09  18.36  20.93  21.35  21.14
21  463.3  36.84  36.62  37.93  37.33  33.18    1100.6  5.05  0.678E+08  0.02745    22.80  24.31  17.57  20.12  20.56  20.34
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  35.32  35.33  36.40  35.86  31.76    1069.6  5.21  0.641E+08  0.02311    23.59  23.53  18.07  20.45  20.82  20.63
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                                                     XP180-11

INPUT ELECTRIC POWER =  990.0 W            HEAT RATE GAINED BY WATER =  965.9 W            HEAT BALANCE ERROR =  2.43%
MASS FLOW RATE = 20.5980 G/S        PRESSURE DROP = 0.4518 MM H2O        FRICTION FACTOR = 0.030456         FREM =  24.2909
REM =  797.6     GRM  = 0.10007E+08    UPSTREAM BULK TEMPERATURE = 23.99 DEG C    DOWN STREAM BULK TEMPERATURE = 35.23 DEG C
PRM =  5.482     RAM  = 0.54855E+08    INLET BULK TEMPERATURE    = 24.00 DEG C    OUTLET BULK TEMPERATURE      = 35.22 DEG C
------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA+         Z+     ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T      H     T+H
------------------------------------------------------------------------------------------------------------------------
 0    0.1  26.31  26.31  26.39  26.35  24.00     704.5  6.28  0.412E+08  0.00000    34.89  34.82  33.68  34.26  34.27  34.26
 1    1.5  26.73  26.74  26.88  26.81  24.04     705.0  6.27  0.412E+08  0.00011    29.83  29.76  28.33  29.04  29.06  29.05
 2    2.5  27.03  27.03  27.21  27.12  24.06     705.4  6.27  0.413E+08  0.00019    27.12  27.05  25.53  26.28  26.31  26.29
 3    5.5  27.91  27.92  28.22  28.06  24.13     706.6  6.26  0.415E+08  0.00041    21.31  21.25  19.68  20.45  20.48  20.47
 4   15.5  28.54  28.76  29.08  28.87  24.37     710.4  6.22  0.420E+08  0.00115    19.28  18.31  17.05  17.88  17.92  17.90
 5   25.5  28.98  28.96  29.82  29.39  24.61     714.4  6.18  0.426E+08  0.00190    18.39  18.49  15.41  16.79  16.92  16.86
 6   45.5  28.94  28.97  29.81  29.38  25.09     722.3  6.11  0.438E+08  0.00339    20.81  20.69  17.01  18.70  18.88  18.79
 7   75.5  29.34  29.36  30.19  29.77  25.81     734.6  5.99  0.455E+08  0.00564    22.65  22.58  18.28  20.22  20.45  20.33
 8  105.5  29.86  30.00  30.74  30.34  26.53     747.4  5.88  0.474E+08  0.00790    23.98  23.02  18.96  20.98  21.23  21.10
 9  135.5  30.74  30.74  31.84  31.29  27.25     759.3  5.78  0.491E+08  0.01016    22.85  22.85  17.35  19.72  20.10  19.91
10  165.2  31.35  31.57  32.65  32.06  27.96     770.4  5.69  0.508E+08  0.01240    23.48  22.04  16.98  19.44  19.87  19.65
11  205.2  32.09  32.15  33.17  32.65  28.91     785.9  5.57  0.531E+08  0.01542    25.04  24.57  18.67  21.31  21.74  21.52
12  245.2  33.15  33.13  34.18  33.66  29.87     802.0  5.45  0.555E+08  0.01846    24.20  24.32  18.42  20.94  21.34  21.14
13  275.2  33.84  33.82  34.92  34.38  30.59     814.5  5.36  0.574E+08  0.02074    24.34  24.50  18.31  20.93  21.36  21.14
14  305.2  34.46  34.44  35.46  34.96  31.31     827.5  5.27  0.593E+08  0.02303    25.08  25.26  19.04  21.68  22.10  21.89
15  333.3  35.47  35.46  36.47  35.97  31.98     839.6  5.18  0.611E+08  0.02519    22.65  22.69  17.60  19.81  20.13  19.97
16  363.3  36.03  36.08  37.01  36.53  32.70     851.4  5.10  0.628E+08  0.02751    23.67  23.29  18.28  20.55  20.88  20.72
17  383.3  36.47  36.34  37.40  36.90  33.18     859.4  5.05  0.639E+08  0.02907    23.89  24.90  18.64  21.13  21.52  21.32
18  403.3  36.93  36.88  37.80  37.35  33.66     867.7  4.99  0.651E+08  0.03064    24.03  24.40  18.97  21.28  21.60  21.44
19  423.3  37.42  37.45  38.47  37.95  34.14     876.0  4.93  0.663E+08  0.03221    23.93  23.69  18.10  20.57  20.96  20.76
20  443.3  37.74  37.82  38.84  38.31  34.61     884.5  4.88  0.675E+08  0.03379    25.05  24.44  18.56  21.21  21.66  21.43
21  463.3  38.46  38.29  39.43  38.91  35.09     893.2  4.82  0.687E+08  0.03537    23.25  24.46  18.05  20.54  20.95  20.75
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  36.68  36.67  37.66  37.17  33.38     863.1  5.02  0.644E+08  0.02973    23.87  23.90  18.36  20.76  21.12  20.94
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                                                     XP180-12

INPUT ELECTRIC POWER =  855.0 W            HEAT RATE GAINED BY WATER =  820.2 W            HEAT BALANCE ERROR =  4.07%
MASS FLOW RATE = 12.2950 G/S        PRESSURE DROP = 0.2677 MM H2O        FRICTION FACTOR = 0.050599         FREM =  25.3910
REM =  501.8     GRM  = 0.10041E+08    UPSTREAM BULK TEMPERATURE = 24.04 DEG C    DOWN STREAM BULK TEMPERATURE = 40.04 DEG C
PRM =  5.177     RAM  = 0.51980E+08    INLET BULK TEMPERATURE    = 24.06 DEG C    OUTLET BULK TEMPERATURE      = 40.03 DEG C
------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA+         Z+     ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C     AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                           T      H     T+H
------------------------------------------------------------------------------------------------------------------------
 0    0.1  26.24  26.25  26.38  26.31  24.07     421.1  6.27  0.351E+08  0.00001    31.38  31.32  29.51  30.40  30.43  30.42
 1    1.5  26.64  26.65  26.84  26.74  24.12     421.6  6.26  0.352E+08  0.00019    27.04  26.97  25.07  26.00  26.04  26.02
 2    2.5  26.91  26.92  27.16  27.04  24.15     421.9  6.26  0.352E+08  0.00031    24.68  24.62  22.71  23.64  23.68  23.66
 3    5.5  27.74  27.75  28.11  27.93  24.25     422.9  6.24  0.354E+08  0.00069    19.57  19.51  17.71  18.58  18.62  18.60
 4   15.5  28.32  28.48  28.86  28.63  24.59     426.2  6.19  0.361E+08  0.00193    18.31  17.52  15.97  16.89  16.94  16.91
 5   25.5  28.76  28.73  29.60  29.17  24.93     429.6  6.13  0.368E+08  0.00318    17.82  17.93  14.60  16.07  16.24  16.15
 6   45.5  28.94  28.86  29.75  29.33  25.61     436.5  6.03  0.382E+08  0.00569    20.43  20.99  16.45  18.33  18.58  18.45
 7   75.5  29.67  29.69  30.47  30.07  26.64     447.3  5.86  0.404E+08  0.00947    22.35  22.23  17.72  19.74  20.00  19.87
 8  105.5  30.53  30.67  31.36  30.98  27.66     457.0  5.73  0.425E+08  0.01326    23.59  22.46  18.31  20.39  20.67  20.53
 9  135.5  31.74  31.68  32.73  32.22  28.68     466.8  5.60  0.446E+08  0.01705    22.08  22.49  16.69  19.08  19.49  19.28
10  165.2  32.74  32.79  33.82  33.29  29.69     476.9  5.47  0.467E+08  0.02083    22.11  21.72  16.34  18.72  19.13  18.92
11  205.2  33.98  33.98  34.78  34.38  31.05     491.1  5.30  0.498E+08  0.02593    22.98  22.93  18.01  20.19  20.48  20.33
12  245.2  35.31  35.30  36.18  35.74  32.42     505.4  5.13  0.527E+08  0.03108    23.13  23.22  17.77  20.12  20.47  20.30
13  275.2  36.12  36.22  37.19  36.68  33.44     515.7  5.02  0.548E+08  0.03500    24.93  24.03  17.78  20.60  21.13  20.86
14  305.2  37.18  37.17  38.02  37.60  34.46     526.3  4.90  0.570E+08  0.03895    24.46  24.56  18.70  21.21  21.60  21.41
15  333.3  38.36  38.43  39.37  38.88  35.42     536.7  4.79  0.591E+08  0.04268    22.61  22.07  16.80  19.18  19.57  19.37
16  363.3  39.24  39.31  40.24  39.76  36.44     548.3  4.67  0.613E+08  0.04669    23.67  23.12  17.41  19.96  20.40  20.18
17  383.3  39.97  39.86  40.78  40.35  37.12     555.9  4.60  0.629E+08  0.04936    23.20  24.19  18.06  20.49  20.88  20.68
18  403.3  40.61  40.62  41.42  41.02  37.80     563.0  4.53  0.644E+08  0.05199    23.51  23.47  18.28  20.56  20.88  20.72
19  423.3  41.35  41.34  42.32  41.83  38.48     570.3  4.47  0.660E+08  0.05463    23.01  23.06  17.19  19.68  20.11  19.90
20  443.3  41.87  41.96  42.90  42.41  39.16     577.7  4.41  0.676E+08  0.05727    24.38  23.56  17.64  20.32  20.80  20.56
21  463.3  42.69  42.63  43.67  43.17  39.84     585.4  4.34  0.692E+08  0.05992    23.10  23.60  17.22  19.82  20.29  20.05
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
    391.6  40.23  40.25  41.17  40.71  37.40     558.7  4.58  0.635E+08  0.05044    23.40  23.24  17.56  20.03  20.44  20.24
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                                              XP180-13

INPUT ELECTRIC POWER = 1955.0 W                HEAT RATE GAINED BY WATER = 1866.7 W              HEAT BALANCE ERROR =  4.52%
MASS FLOW RATE = 38.6480 G/S          PRESSURE DROP = 0.9003 MM H2O        FRICTION FACTOR = 0.017238          FREM =  25.8576
REM = 1500.0     GRM  = 0.19487E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 35.51 DEG C
PRM =  5.468     RAM  = 0.10655E+09    INLET BULK TEMPERATURE    = 23.94 DEG C    OUTLET BULK TEMPERATURE      = 35.50 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                                A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                              T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.32  27.24  27.26  27.28  23.95     1320.0  6.29  0.793E+08  0.00000     46.08  47.15  46.64  46.62  46.63  46.62
 1     1.5  28.02  27.91  28.06  28.01  23.98     1321.1  6.28  0.794E+08  0.00006     38.48  39.53  38.12  38.55  38.56  38.56
 2     2.5  28.50  28.37  28.60  28.52  24.01     1321.9  6.28  0.796E+08  0.00010     34.55  35.57  33.85  34.44  34.45  34.45
 3     5.5  29.96  29.76  30.21  30.03  24.08     1324.1  6.27  0.799E+08  0.00022     26.44  27.34  25.34  26.09  26.11  26.10
 4    15.5  30.70  31.13  31.53  31.22  24.33     1331.6  6.23  0.810E+08  0.00061     24.36  22.83  21.54  22.51  22.57  22.54
 5    25.5  31.38  31.34  32.71  32.03  24.57     1339.1  6.19  0.821E+08  0.00101     22.79  22.92  19.08  20.80  20.97  20.88
 6    45.5  31.38  31.41  32.76  32.08  25.07     1354.5  6.11  0.844E+08  0.00181     24.56  24.43  20.14  22.11  22.32  22.21
 7    75.5  31.89  31.79  33.31  32.58  25.81     1378.3  5.99  0.880E+08  0.00301     25.44  25.84  20.62  22.85  23.13  22.99
 8   105.5  32.42  32.68  33.97  33.26  26.55     1402.9  5.88  0.916E+08  0.00421     26.31  25.19  20.80  23.01  23.28  23.14
 9   135.5  33.29  33.24  35.17  34.22  27.29     1425.8  5.78  0.951E+08  0.00541     25.66  25.90  19.55  22.24  22.67  22.45
10   165.2  33.96  33.96  36.04  35.00  28.02     1447.3  5.68  0.984E+08  0.00661     25.90  25.90  19.18  22.04  22.54  22.29
11   205.2  34.59  34.43  36.23  35.37  29.00     1477.3  5.56  0.103E+09  0.00822     27.50  28.32  21.26  24.14  24.59  24.36
12   245.2  35.42  35.36  37.41  36.40  29.99     1508.6  5.43  0.108E+09  0.00984     28.22  28.57  20.65  23.91  24.52  24.22
13   275.2  36.12  36.16  38.19  37.17  30.73     1533.0  5.34  0.112E+09  0.01106     28.41  28.17  20.50  23.77  24.39  24.08
14   305.2  36.46  36.44  38.41  37.43  31.47     1558.1  5.25  0.115E+09  0.01228     30.60  30.71  22.01  25.62  26.33  25.98
15   333.3  37.74  37.81  39.82  38.80  32.16     1580.9  5.16  0.119E+09  0.01343     27.32  27.00  19.91  22.98  23.53  23.26
16   363.3  38.30  38.36  40.36  39.34  32.90     1603.8  5.08  0.122E+09  0.01467     28.20  27.88  20.42  23.63  24.23  23.93
17   383.3  38.86  38.63  40.62  39.68  33.40     1619.5  5.02  0.125E+09  0.01551     27.81  29.05  21.05  24.19  24.74  24.46
18   403.3  39.38  39.28  41.08  40.21  33.89     1635.5  4.96  0.127E+09  0.01634     27.63  28.17  21.10  24.03  24.50  24.27
19   423.3  39.86  39.90  41.93  40.90  34.38     1651.9  4.91  0.129E+09  0.01718     27.70  27.48  20.09  23.25  23.84  23.55
20   443.3  40.20  40.28  42.23  41.24  34.87     1668.5  4.85  0.132E+09  0.01802     28.44  28.00  20.58  23.80  24.40  24.10
21   463.3  41.08  40.79  42.94  41.94  35.37     1685.5  4.79  0.134E+09  0.01887     26.49  27.90  19.96  23.02  23.58  23.30
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  39.06  39.04  41.01  40.03  33.60     1626.7  5.00  0.126E+09  0.01586     27.85  27.93  20.53  23.65  24.21  23.93
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                                              XP180-14

INPUT ELECTRIC POWER = 1810.0 W                HEAT RATE GAINED BY WATER = 1724.5 W              HEAT BALANCE ERROR =  4.72%
MASS FLOW RATE = 29.9840 G/S          PRESSURE DROP = 0.6922 MM H2O        FRICTION FACTOR = 0.022010          FREM =  26.2024
REM = 1190.5     GRM  = 0.19360E+08    UPSTREAM BULK TEMPERATURE = 23.88 DEG C    DOWN STREAM BULK TEMPERATURE = 37.67 DEG C
PRM =  5.335     RAM  = 0.10329E+09    INLET BULK TEMPERATURE    = 23.89 DEG C    OUTLET BULK TEMPERATURE      = 37.66 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                                A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                              T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.34  27.35  27.38  27.36  23.89     1022.9  6.30  0.730E+08  0.00000     41.64  41.51  41.22  41.40  41.40  41.40
 1     1.5  28.01  28.02  28.18  28.10  23.94     1023.9  6.29  0.732E+08  0.00008     35.26  35.13  33.87  34.52  34.53  34.52
 2     2.5  28.47  28.49  28.73  28.60  23.97     1024.6  6.29  0.733E+08  0.00013     31.89  31.76  30.16  30.97  30.99  30.98
 3     5.5  29.84  29.87  30.38  30.12  24.05     1026.6  6.27  0.737E+08  0.00028     24.78  24.67  22.69  23.67  23.71  23.69
 4    15.5  30.64  31.02  31.59  31.21  24.35     1033.5  6.23  0.749E+08  0.00079     22.78  21.51  19.81  20.90  20.97  20.94
 5    25.5  31.38  31.23  32.82  32.06  24.64     1040.6  6.18  0.762E+06  0.00130     21.26  21.74  17.53  19.31  19.52  19.41
 6    45.5  31.38  31.30  32.82  32.08  25.23     1054.9  6.09  0.787E+08  0.00233     23.28  23.57  18.86  20.90  21.14  21.02
 7    75.5  31.94  31.85  33.31  32.60  26.11     1077.1  5.95  0.826E+08  0.00388     24.48  24.88  19.83  21.99  22.26  22.13
 8   105.5  32.53  32.73  34.08  33.36  26.99     1099.6  5.81  0.866E+08  0.00543     25.74  24.82  20.10  22.39  22.69  22.54
 9   135.5  33.41  33.41  35.45  34.43  27.87     1119.5  5.70  0.903E+08  0.00698     25.71  25.71  18.77  21.70  22.24  21.97
10   165.2  34.23  34.29  36.27  35.27  28.74     1139.9  5.59  0.941E+08  0.00853     25.86  25.58  18.87  21.77  22.30  22.03
11   205.2  34.98  34.98  36.62  35.80  29.92     1168.6  5.44  0.993E+08  0.01061     27.99  27.95  21.14  24.08  24.55  24.32
12   245.2  36.25  36.19  38.13  37.18  31.09     1198.8  5.30  0.105E+09  0.01271     27.38  27.68  20.06  23.21  23.80  23.50
13   275.2  36.95  36.99  39.03  38.00  31.97     1222.0  5.19  0.109E+09  0.01429     28.32  28.07  19.98  23.39  24.09  23.74
14   305.2  37.68  37.51  39.42  38.50  32.85     1243.1  5.08  0.113E+09  0.01589     29.15  30.23  21.43  24.89  25.56  25.23
15   333.3  38.97  38.93  40.94  39.94  33.68     1263.6  4.99  0.116E+09  0.01740     26.54  26.74  19.33  22.40  22.98  22.69
16   363.3  39.63  39.75  41.53  40.61  34.56     1286.2  4.89  0.120E+09  0.01902     27.63  26.98  20.09  23.15  23.70  23.42
17   383.3  40.19  40.08  41.94  41.04  35.15     1301.7  4.82  0.123E+09  0.02011     27.70  28.35  20.57  23.72  24.30  24.01
18   403.3  40.89  40.84  42.53  41.70  35.73     1317.6  4.75  0.126E+09  0.02120     27.08  27.35  20.55  23.42  23.88  23.65
19   423.3  41.30  41.34  43.49  42.41  36.32     1333.9  4.68  0.128E+09  0.02230     28.00  27.75  19.45  22.91  23.66  23.29
20   443.3  41.81  41.91  43.79  42.83  36.91     1350.4  4.61  0.131E+09  0.02340     28.39  27.86  20.21  23.52  24.17  23.85
21   463.3  42.75  42.44  44.67  43.63  37.50     1365.1  4.56  0.134E+09  0.02448     26.46  28.13  19.37  22.65  23.33  22.99
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  40.46  40.47  42.37  41.42  35.39     1308.9  4.79  0.124E+09  0.02057     27.56  27.50  20.03  23.19  23.78  23.48
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                                              XP180-15

INPUT ELECTRIC POWER = 1690.0 W                HEAT RATE GAINED BY WATER = 1588.3 W              HEAT BALANCE ERROR =  6.02%
MASS FLOW RATE = 24.5690 G/S          PRESSURE DROP = 0.5627 MM H2O        FRICTION FACTOR = 0.026639          FREM =  26.5134
REM =  995.3     GRM  = 0.18993E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 39.43 DEG C
PRM =  5.221     RAM  = 0.99155E+08    INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 39.42 DEG C

STA-   Z    -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM     A      B      C    AVER-   (C)                                                A      B      C     ----- AVERAGE -----
NO.                                AGE                                                                              T      H     T+H
-----------------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.21  27.20  27.31  27.26  23.95      839.3  6.29  0.675E+08  0.00000     40.60  40.74  39.36  40.00  40.01  40.01
 1     1.5  27.87  27.85  28.08  27.97  24.00      840.2  6.28  0.677E+08  0.00009     34.20  34.33  32.38  33.30  33.32  33.31
 2     2.5  28.32  28.30  28.61  28.46  24.03      840.8  6.28  0.678E+08  0.00016     30.84  30.98  28.85  29.84  29.88  29.86
 3     5.5  29.68  29.65  30.21  29.94  24.13      842.7  6.26  0.682E+08  0.00034     23.83  23.95  21.74  22.76  22.81  22.79
 4    15.5  30.42  30.73  31.37  30.97  24.46      849.1  6.21  0.695E+08  0.00097     22.16  21.06  19.13  20.28  20.37  20.33
 5    25.5  31.10  31.07  32.54  31.81  24.79      855.6  6.16  0.708E+08  0.00159     20.92  21.03  17.03  18.80  19.00  18.90
 6    45.5  31.21  31.24  32.65  31.94  25.45      868.9  6.05  0.734E+08  0.00285     22.88  22.75  18.31  20.31  20.56  20.44
 7    75.5  31.89  31.74  33.26  32.53  26.44      889.6  5.89  0.775E+08  0.00474     24.14  24.82  19.29  21.58  21.89  21.73
 8   105.5  32.47  32.62  34.03  33.29  27.43      909.1  5.76  0.815E+08  0.00663     26.02  25.27  19.89  22.40  22.77  22.58
 9   135.5  33.68  33.63  35.51  34.58  28.42      927.8  5.63  0.853E+08  0.00853     24.88  25.14  18.48  21.25  21.74  21.50
10   165.2  34.57  34.58  36.66  35.61  29.40      947.1  5.51  0.893E+08  0.01042     25.29  25.23  18.00  21.02  21.63  21.33
11   205.2  35.64  35.65  37.29  36.47  30.72      974.4  5.34  0.949E+08  0.01297     26.45  26.42  19.83  22.66  23.13  22.90
12   245.2  36.86  36.86  38.63  37.75  32.04     1002.7  5.18  0.101E+09  0.01554     26.94  26.94  19.69  22.75  23.32  23.03
13   275.2  37.73  37.72  39.69  38.71  33.03     1022.2  5.06  0.105E+09  0.01749     27.58  27.64  19.43  22.81  23.52  23.17
14   305.2  38.57  38.51  40.31  39.42  34.02     1042.5  4.95  0.109E+09  0.01946     28.42  28.81  20.54  23.91  24.58  24.24
15   333.3  40.02  40.05  41.89  40.96  34.95     1062.3  4.84  0.112E+09  0.02132     25.43  25.26  18.57  21.43  21.96  21.70
16   363.3  40.79  40.81  42.64  41.72  35.94     1084.3  4.73  0.117E+09  0.02332     26.47  26.41  19.17  22.23  22.81  22.52
17   383.3  41.42  41.26  43.17  42.25  36.60     1099.5  4.65  0.119E+09  0.02467     26.64  27.56  19.54  22.70  23.32  23.01
18   403.3  42.17  42.07  43.76  42.94  37.26     1113.7  4.58  0.122E+09  0.02600     26.08  26.66  19.72  22.57  23.05  22.81
19   423.3  42.74  42.79  44.72  43.74  37.92     1127.5  4.52  0.125E+09  0.02731     26.56  26.25  18.83  21.98  22.62  22.30
20   443.3  43.37  43.47  45.24  44.33  38.58     1141.7  4.46  0.128E+09  0.02863     26.67  26.13  19.19  22.23  22.80  22.51
21   463.3  44.42  44.18  46.06  45.18  39.24     1156.2  4.40  0.131E+09  0.02996     24.63  25.85  18.71  21.49  21.98  21.73
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  41.75  41.74  43.57  42.66  36.88     1104.8  4.63  0.121E+09  0.02521     26.31  26.38  19.17  22.19  22.76  22.47
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                                                  XP180-16

INPUT ELECTRIC POWER = 1550.0 W              HEAT RATE GAINED BY WATER = 1472.4 W              HEAT BALANCE ERROR =  5.00%
MASS FLOW RATE = 19.1540 G/S        PRESSURE DROP = 0.4297 MM H2O        FRICTION FACTOR = 0.033450        FREM =  26.7208
REM =  798.8     GRM  = 0.19282E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 42.37 DEG C
PRM =  5.049     RAM  = 0.97349E+08    INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 42.35 DEG C
--------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                              A       B       C     ----- AVERAGE -----
NO.                                AGE                                                                           T       H      T+H
--------------------------------------------------------------------------------------------------------------------------
 0     0.1  27.16   27.15   27.33   27.25  23.96     654.4  6.29  0.626E+08  0.00000    38.20   38.33   36.28   37.25   37.27   37.26
 1     1.5  27.80   27.79   28.07   27.93  24.01     655.2  6.28  0.628E+08  0.00012    32.33   32.46   30.21   31.26   31.30   31.28
 2     2.5  28.24   28.23   28.58   28.41  24.05     655.8  6.27  0.629E+08  0.00020    29.23   29.36   27.08   28.14   28.19   28.17
 3     5.5  29.57   29.54   30.10   29.83  24.17     657.6  6.25  0.633E+08  0.00044    22.70   22.82   20.66   21.66   21.71   21.69
 4    15.5  30.26   30.57   31.20   30.81  24.56     663.5  6.19  0.648E+08  0.00124    21.50   20.39   18.44   19.61   19.69   19.65
 5    25.5  30.93   30.96   32.37   31.66  24.95     669.6  6.13  0.662E+08  0.00204    20.46   20.38   16.49   18.24   18.45   18.35
 6    45.5  31.05   30.97   32.48   31.75  25.74     682.0  6.01  0.691E+08  0.00365    22.99   23.36   18.10   20.33   20.64   20.48
 7    75.5  31.78   31.79   33.14   32.47  26.92     701.4  5.82  0.737E+08  0.00608    25.05   24.96   19.55   21.94   22.28   22.11
 8   105.5  32.69   32.90   34.19   33.50  28.09     718.4  5.67  0.779E+08  0.00851    26.40   25.27   19.91   22.48   22.87   22.68
 9   135.5  33.96   34.02   35.84   34.91  29.27     736.3  5.52  0.823E+08  0.01096    25.83   25.52   18.44   21.46   22.06   21.76
10   165.2  35.18   35.30   37.10   36.17  30.44     754.9  5.38  0.868E+08  0.01338    25.48   24.84   18.13   21.07   21.64   21.36
11   205.2  36.48   36.54   38.01   37.26  32.01     781.1  5.18  0.932E+08  0.01668    26.92   26.56   20.05   22.91   23.39   23.15
12   245.2  37.97   37.97   39.64   38.80  33.58     805.6  5.00  0.989E+08  0.02003    27.31   27.27   19.77   22.93   23.53   23.23
13   275.2  39.06   39.17   40.86   39.99  34.76     824.9  4.86  0.103E+09  0.02257    27.75   27.09   19.57   22.84   23.49   23.17
14   305.2  40.23   40.12   41.70   40.94  35.93     845.2  4.73  0.108E+09  0.02513    27.70   28.44   20.66   23.80   24.36   24.08
15   333.3  41.57   41.67   43.46   42.54  37.04     864.6  4.60  0.113E+09  0.02755    26.19   25.62   18.51   21.59   22.21   21.90
16   363.3  42.62   42.75   44.37   43.53  38.21     883.9  4.49  0.117E+09  0.03008    26.89   26.13   19.25   22.30   22.88   22.59
17   383.3  43.47   43.32   45.11   44.25  39.00     897.2  4.42  0.121E+09  0.03178    26.46   27.37   19.38   22.53   23.15   22.84
18   403.3  44.23   44.19   45.76   44.99  39.78     910.9  4.35  0.124E+09  0.03348    26.56   26.83   19.77   22.72   23.23   22.97
19   423.3  45.07   45.13   46.84   45.97  40.57     925.0  4.28  0.127E+09  0.03519    26.23   25.88   18.82   21.85   22.44   22.15
20   443.3  45.77   45.88   47.46   46.64  41.35     939.6  4.21  0.131E+09  0.03690    26.66   26.04   19.29   22.28   22.82   22.55
21   463.3  46.87   46.73   48.46   47.63  42.14     953.8  4.14  0.135E+09  0.03862    24.85   25.64   18.62   21.43   21.93   21.68
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  43.79   43.82   45.50   44.65  39.33     903.5  4.39  0.122E+09  0.03250    26.50   26.31   19.17   22.21   22.79   22.50
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                                                  XP180-17

INPUT ELECTRIC POWER = 3380.0 W              HEAT RATE GAINED BY WATER = 3240.2 W              HEAT BALANCE ERROR =  4.14%
MASS FLOW RATE = 34.3160 G/S        PRESSURE DROP = 0.8201 MM H2O        FRICTION FACTOR = 0.019873        FREM =  29.6713
REM = 1493.0     GRM  = 0.48256E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 46.57 DEG C
PRM =  4.805     RAM  = 0.23188E+09    INLET BULK TEMPERATURE    = 23.95 DEG C    OUTLET BULK TEMPERATURE      = 46.55 DEG C
--------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                              A       B       C     ----- AVERAGE -----
NO.                                AGE                                                                           T       H      T+H
--------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.48   29.46   29.79   29.63  23.96    1172.4  6.29  0.138E+09  0.00000    48.84   49.04   46.21   47.53   47.57   47.55
 1     1.5  30.61   30.58   31.13   30.86  24.03    1174.2  6.28  0.138E+09  0.00007    40.97   41.16   37.99   39.47   39.53   39.50
 2     2.5  31.39   31.35   32.04   31.71  24.07    1175.5  6.27  0.139E+09  0.00011    36.87   37.06   33.84   35.33   35.40   35.36
 3     5.5  33.73   33.67   34.80   34.25  24.22    1179.4  6.25  0.140E+09  0.00025    28.35   28.52   25.48   26.87   26.96   26.92
 4    15.5  34.63   35.12   36.32   35.60  24.70    1192.6  6.17  0.144E+09  0.00069    27.11   25.84   23.17   24.71   24.82   24.77
 5    25.5  35.63   35.62   38.31   36.96  25.18    1206.0  6.09  0.148E+09  0.00114    25.75   25.78   20.50   22.83   23.13   22.98
 6    45.5  35.59   35.53   38.22   36.89  26.15    1233.8  5.94  0.156E+09  0.00204    28.43   28.61   22.23   24.98   25.37   25.18
 7    75.5  36.71   36.46   39.33   37.95  27.59    1274.0  5.74  0.167E+09  0.00340    29.36   30.19   22.80   25.82   26.28   26.05
 8   105.5  37.65   38.08   40.31   39.09  29.04    1312.7  5.55  0.179E+09  0.00476    30.97   29.50   23.66   26.54   26.94   26.74
 9   135.5  38.96   38.96   42.49   40.73  30.49    1353.9  5.37  0.192E+09  0.00613    31.36   31.36   22.13   25.95   26.74   26.35
10   165.2  40.22   40.08   43.83   41.99  31.92    1397.1  5.19  0.204E+09  0.00749    31.90   32.46   22.23   26.29   27.21   26.75
11   205.2  41.14   41.21   44.46   42.82  33.85    1451.0  4.97  0.220E+09  0.00936    36.12   35.82   24.83   29.38   30.40   29.89
12   245.2  43.07   43.08   46.72   44.90  35.77    1509.2  4.74  0.236E+09  0.01126    35.97   35.89   23.97   28.75   29.95   29.35
13   275.2  44.56   44.51   48.31   46.42  37.22    1554.4  4.59  0.249E+09  0.01270    35.61   35.88   23.57   28.41   29.66   29.03
14   305.2  45.67   45.52   49.01   47.30  38.67    1597.2  4.45  0.262E+09  0.01412    37.21   38.02   25.21   30.19   31.41   30.80
15   333.3  47.79   47.82   51.57   49.69  40.02    1639.6  4.33  0.275E+09  0.01545    33.47   33.33   22.52   26.90   27.96   27.43
16   363.3  48.88   48.97   52.41   50.66  41.47    1687.3  4.20  0.289E+09  0.01688    34.99   34.58   23.70   28.19   29.24   28.72
17   383.3  49.91   49.58   53.14   51.44  42.43    1717.5  4.11  0.299E+09  0.01784    34.60   36.22   24.16   28.72   29.78   29.25
18   403.3  50.92   50.60   53.94   52.35  43.40    1746.6  4.04  0.308E+09  0.01880    34.32   35.86   24.49   28.84   29.79   29.32
19   423.3  51.72   51.69   55.42   53.57  44.36    1776.7  3.96  0.317E+09  0.01977    35.03   35.16   23.31   28.01   29.20   28.61
20   443.3  52.41   52.54   56.03   54.25  45.32    1807.9  3.89  0.327E+09  0.02074    36.35   35.68   24.05   28.84   30.03   29.43
21   463.3  54.00   53.51   57.37   55.56  46.29    1840.2  3.81  0.336E+09  0.02172    33.32   35.60   23.19   27.71   28.83   28.27
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  50.27   50.20   53.75   51.99  42.83    1729.3  4.09  0.302E+09  0.01825    34.79   35.14   23.71   28.25   29.34   28.79
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                                                  XP180-18

INPUT ELECTRIC POWER = 3045.0 W              HEAT RATE GAINED BY WATER = 2867.2 W              HEAT BALANCE ERROR =  5.84%
MASS FLOW RATE = 26.3740 G/S        PRESSURE DROP = 0.6343 MM H2O        FRICTION FACTOR = 0.026003        FREM =  30.9210
REM = 1189.1     GRM  = 0.47438E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 49.99 DEG C
PRM =  4.609     RAM  = 0.21864E+09    INLET BULK TEMPERATURE    = 23.96 DEG C    OUTLET BULK TEMPERATURE      = 49.98 DEG C
--------------------------------------------------------------------------------------------------------------------------
STA-  Z     -WALL TEMPERATURE (DEG C)-   TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM     A       B       C    AVER-  (C)                                              A       B       C     ----- AVERAGE -----
NO.                                AGE                                                                           T       H      T+H
--------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.30   29.30   29.64   29.47  23.96     901.1  6.29  0.122E+09  0.00000    44.68   44.70   42.03   43.32   43.36   43.34
 1     1.5  30.36   30.36   30.91   30.64  24.04     902.8  6.27  0.122E+09  0.00009    37.76   37.78   34.75   36.20   36.26   36.23
 2     2.5  31.09   31.09   31.79   31.44  24.10     903.9  6.26  0.123E+09  0.00015    34.11   34.13   31.04   32.51   32.58   32.54
 3     5.5  33.28   33.28   34.41   33.85  24.26     907.4  6.24  0.124E+09  0.00032    26.45   26.46   23.51   24.89   24.98   24.94
 4    15.5  34.02   34.62   35.93   35.12  24.82     919.1  6.15  0.128E+09  0.00090    25.88   24.31   21.44   23.12   23.27   23.19
 5    25.5  35.12   35.06   37.81   36.45  25.37     931.0  6.06  0.132E+09  0.00149    24.41   24.56   19.14   21.48   21.81   21.65
 6    45.5  35.21   35.03   37.78   36.45  26.48     956.0  5.89  0.140E+09  0.00266    27.21   27.78   21.01   23.82   24.25   24.04
 7    75.5  36.38   36.18   38.99   37.64  28.15     990.4  5.67  0.152E+09  0.00443    28.73   29.45   21.80   24.92   25.44   25.18
 8   105.5  37.48   37.80   40.09   38.87  29.81    1025.6  5.46  0.164E+09  0.00620    30.71   29.49   22.92   26.02   26.51   26.27
 9   135.5  39.02   39.18   42.44   40.77  31.48    1063.5  5.25  0.177E+09  0.00799    31.13   30.46   21.41   25.26   26.10   25.68
10   165.2  40.56   40.63   44.06   42.33  33.13    1099.4  5.05  0.189E+09  0.00978    31.46   31.13   21.38   25.41   26.34   25.87
11   205.2  42.14   42.32   45.13   43.68  35.35    1149.7  4.79  0.206E+09  0.01225    34.19   33.34   23.76   27.89   28.76   28.33
12   245.2  44.46   44.47   47.72   46.09  37.57    1202.4  4.55  0.223E+09  0.01473    33.56   33.48   22.76   27.11   28.14   27.63
13   275.2  46.01   46.06   49.48   47.76  39.23    1241.0  4.40  0.237E+09  0.01658    34.02   33.75   22.49   27.04   28.19   27.61
14   305.2  47.45   47.08   50.46   48.86  40.90    1282.1  4.25  0.251E+09  0.01844    35.06   37.14   24.03   28.85   30.07   29.46
15   333.3  49.68   49.89   53.02   51.40  42.46    1320.6  4.11  0.265E+09  0.02019    31.72   30.82   21.69   25.61   26.48   26.04
16   363.3  50.93   50.97   54.13   52.54  44.12    1359.8  3.98  0.278E+09  0.02207    33.55   33.36   22.81   27.12   28.13   27.63
17   383.3  52.19   51.70   55.08   53.51  45.23    1387.2  3.90  0.288E+09  0.02333    32.75   35.23   23.13   27.51   28.56   28.04
18   403.3  53.21   52.89   56.06   54.55  46.34    1415.7  3.81  0.298E+09  0.02460    33.13   34.73   23.39   27.69   28.66   28.18
19   423.3  54.33   54.37   57.65   56.00  47.45    1444.0  3.73  0.308E+09  0.02587    33.01   32.82   22.25   26.55   27.58   27.07
20   443.3  55.08   55.22   58.42   56.79  48.56    1472.0  3.65  0.318E+09  0.02714    34.77   34.02   22.98   27.55   28.69   28.12
21   463.3  56.73   56.39   59.87   58.22  49.67    1501.2  3.57  0.329E+09  0.02842    32.06   33.67   22.17   26.47   27.52   27.00
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  52.57   52.51   55.73   54.13  45.70    1399.9  3.86  0.293E+09  0.02387    33.16   33.50   22.71   27.01   28.02   27.51
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                                                    XP180-19

INPUT ELECTRIC POWER = 2750.0 W            HEAT RATE GAINED BY WATER = 2632.6 W               HEAT BALANCE ERROR =  4.27%
MASS FLOW RATE = 21.3200 G/S        PRESSURE DROP = 0.5081 MM H2O         FRICTION FACTOR = 0.031853           FREM =  31.6529
REM =   993.7      GRM   = 0.48066E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 53.53 DEG C
PRM =   4.446      RAM   = 0.21371E+09    INLET BULK TEMPERATURE    = 23.96 DEG C    OUTLET BULK TEMPERATURE      = 53.52 DEG C

STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C    AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                  AGE                                                                           T      H      T+H
------------------------------------------------------------------------------------------------------------------------------------
 0     0.1  29.07  29.03  29.42  29.24  23.97     728.5  6.29  0.112E+09  0.00000     42.92  43.31  40.16  41.58  41.63  41.61
 1     1.5  30.06  30.00  30.60  30.32  24.06     730.1  6.27  0.113E+09  0.00011     36.50  36.90  33.47  35.01  35.09  35.05
 2     2.5  30.74  30.66  31.42  31.06  24.12     731.1  6.26  0.113E+09  0.00018     33.09  33.49  30.02  31.57  31.65  31.61
 3     5.5  32.78  32.67  33.86  33.29  24.31     734.3  6.23  0.114E+09  0.00040     25.84  26.20  22.93  24.38  24.47  24.43
 4    15.5  33.42  34.00  35.37  34.54  24.94     745.0  6.13  0.118E+09  0.00112     25.80  24.14  20.96  22.78  22.96  22.87
 5    25.5  34.51  34.51  37.08  35.80  25.57     756.1  6.03  0.122E+09  0.00184     24.42  24.44  18.97  21.35  21.70  21.53
 6    45.5  34.76  34.69  37.17  35.95  26.83     779.3  5.83  0.131E+09  0.00329     27.46  27.69  21.07  23.88  24.32  24.10
 7    75.5  36.16  35.96  38.44  37.25  28.72     810.2  5.59  0.143E+09  0.00548     29.16  29.97  22.31  25.43  25.94  25.68
 8   105.5  37.43  37.74  39.92  38.75  30.61     843.5  5.36  0.157E+09  0.00768     31.68  30.27  23.19  26.52  27.08  26.80
 9   135.5  39.41  39.41  42.49  40.95  32.50     877.9  5.12  0.170E+09  0.00991     31.14  31.14  21.51  25.44  26.33  25.89
10   165.2  41.06  41.19  44.39  42.76  34.38     911.2  4.91  0.182E+09  0.01215     32.02  31.39  21.36  25.52  26.53  26.03
11   205.2  43.03  43.26  45.97  44.56  36.90     960.0  4.62  0.200E+09  0.01523     34.64  33.40  23.43  27.75  28.72  28.24
12   245.2  45.62  45.64  48.56  47.09  39.42    1006.8  4.38  0.219E+09  0.01828     34.13  34.01  23.13  27.56  28.60  28.08
13   275.2  47.45  47.57  50.59  49.05  41.31    1045.0  4.21  0.234E+09  0.02058     34.33  33.69  22.71  27.23  28.36  27.80
14   305.2  49.01  48.81  51.79  50.35  43.20    1081.4  4.05  0.249E+09  0.02290     36.18  37.47  24.45  29.39  30.64  30.01
15   333.3  51.39  51.46  54.58  53.00  44.97    1116.1  3.92  0.262E+09  0.02508     32.59  32.29  21.78  26.06  27.11  26.58
16   363.3  52.81  52.91  55.86  54.36  46.86    1155.6  3.77  0.278E+09  0.02744     35.07  34.49  23.18  27.82  28.98  28.40
17   383.3  54.19  53.88  56.97  55.50  48.13    1180.9  3.68  0.288E+09  0.02901     34.32  36.18  23.52  28.21  29.39  28.80
18   403.3  55.49  55.23  58.12  56.74  49.39    1207.3  3.59  0.299E+09  0.03059     34.01  35.52  23.78  28.23  29.27  28.75
19   423.3  56.66  56.71  59.77  58.23  50.65    1234.9  3.50  0.310E+09  0.03218     34.50  34.22  22.72  27.35  28.54  27.95
20   443.3  57.64  57.79  60.71  59.21  51.91    1263.6  3.42  0.322E+09  0.03377     36.07  35.15  23.52  28.32  29.56  28.94
21   463.3  59.57  59.08  62.43  60.88  53.17    1287.6  3.35  0.332E+09  0.03534     32.28  34.95  22.29  26.79  27.95  27.37
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  54.70  54.66  57.67  56.18  48.65    1193.1  3.65  0.293E+09  0.02968     34.43  34.64  23.08  27.67  28.81  28.24
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                                                    XP180-20

INPUT ELECTRIC POWER = 2430.0 W            HEAT RATE GAINED BY WATER = 2319.9 W               HEAT BALANCE ERROR =  4.53%
MASS FLOW RATE = 16.2660 G/S        PRESSURE DROP = 0.3836 MM H2O         FRICTION FACTOR = 0.041276           FREM =  32.7260
REM =   792.9      GRM   = 0.48198E+08    UPSTREAM BULK TEMPERATURE = 23.93 DEG C    DOWN STREAM BULK TEMPERATURE = 58.12 DEG C
PRM =   4.235      RAM   = 0.20412E+09    INLET BULK TEMPERATURE    = 23.97 DEG C    OUTLET BULK TEMPERATURE      = 58.10 DEG C

STA-   Z     -WALL TEMPERATURE (DEG C)-    TB        RE      PR       RA+         Z+       ------------- NUSSELT NUMBER ------------
TION  CM       A       B       C    AVER-   (C)                                               A      B      C     ----- AVERAGE -----
NO.                                  AGE                                                                           T      H      T+H
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 0     0.1  28.86  28.85  29.25  29.05  23.97     555.9  6.28  0.987E+08  0.00000     39.55  39.60  36.61  38.03  38.09  38.06
 1     1.5  29.75  29.75  30.36  30.05  24.08     557.3  6.27  0.993E+08  0.00014     34.02  34.07  30.75  32.31  32.40  32.35
 2     2.5  30.37  30.36  31.12  30.75  24.15     558.2  6.26  0.997E+08  0.00024     31.02  31.08  27.69  29.27  29.37  29.32
 3     5.5  32.23  32.22  33.42  32.82  24.37     561.0  6.22  0.101E+09  0.00052     24.54  24.59  21.33  22.83  22.94  22.89
 4    15.5  32.86  33.32  34.82  33.95  25.10     570.5  6.11  0.105E+09  0.00146     24.81  23.42  19.82  21.75  21.97  21.86
 5    25.5  34.12  34.17  36.47  35.31  25.83     580.4  5.99  0.109E+09  0.00241     23.19  23.04  18.06  20.28  20.59  20.43
 6    45.5  34.48  34.19  36.77  35.56  27.28     600.0  5.78  0.118E+09  0.00432     26.61  27.73  20.20  23.16  23.68  23.42
 7    75.5  36.04  36.07  38.44  37.25  29.47     627.9  5.50  0.131E+09  0.00719     28.99  28.89  21.25  24.51  25.10  24.80
 8   105.5  37.87  38.24  40.20  39.13  31.65     658.4  5.23  0.145E+09  0.01009     30.50  28.78  22.19  25.37  25.92  25.64
 9   135.5  40.07  40.24  42.99  41.58  33.83     687.6  4.97  0.157E+09  0.01304     30.25  29.46  20.60  24.38  25.23  24.80
10   165.2  42.17  42.24  45.12  43.66  36.00     718.7  4.72  0.171E+09  0.01602     30.41  30.04  20.58  24.48  25.40  24.94
11   205.2  44.65  44.71  47.13  45.91  38.91     760.6  4.43  0.189E+09  0.02003     32.49  32.18  22.68  26.66  27.50  27.08
12   245.2  47.61  47.59  50.29  48.94  41.82     805.5  4.16  0.210E+09  0.02405     32.03  32.16  21.90  26.04  27.00  26.52
13   275.2  49.56  49.62  52.53  51.06  44.00     836.8  3.99  0.224E+09  0.02710     33.28  32.88  21.66  26.18  27.37  26.78
14   305.2  51.67  51.48  54.19  52.88  46.19     870.6  3.82  0.240E+09  0.03017     33.58  34.78  23.00  27.49  28.59  28.04
15   333.3  54.23  54.19  57.16  55.68  48.23     902.6  3.67  0.255E+09  0.03307     30.59  30.76  20.55  24.61  25.61  25.11
16   363.3  55.92  56.08  58.76  57.38  50.42     938.3  3.52  0.272E+09  0.03618     33.23  32.29  21.90  26.25  27.33  26.79
17   383.3  57.63  57.23  60.24  58.84  51.87     963.6  3.42  0.283E+09  0.03828     31.69  34.06  21.78  26.19  27.33  26.76
18   403.3  59.01  58.80  61.41  60.15  53.33     984.8  3.34  0.294E+09  0.04033     32.05  33.26  22.53  26.66  27.59  27.12
19   423.3  60.37  60.54  63.28  61.87  54.79    1006.9  3.26  0.305E+09  0.04240     32.49  31.52  21.36  25.62  26.68  26.15
20   443.3  61.71  60.37  64.48  62.76  56.24    1030.1  3.18  0.316E+09  0.04448     33.11  43.91  21.97  27.78  30.24  29.01
21   463.3  63.52  61.15  66.28  64.31  57.70    1053.2  3.10  0.327E+09  0.04662     31.02  52.34  21.06  27.33  31.37  29.35
AVERAGE VALUES THROUGH STATIONS 15 TO 20:
     391.6  58.14  57.87  60.89  59.45  52.48     971.0  3.40  0.287E+09  0.03912     32.20  34.30  21.68  26.19  27.47  26.83
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Appendix 5

Fully Developed Nusselt Numbers, Eperimental Data

Appendix 5.1 Fully developed Nusselt numbers for $\alpha = 45°$.

$\alpha = 45°$			
Gr^+	Pr	Re	Nu/Nu_o
$2.684\text{x}10^6$	7.56	1541.0	3.28
$2.724\text{x}10^6$	7.22	512.6	3.52
$2.755\text{x}10^6$	7.44	1029.1	3.37
$2.864\text{x}10^6$	7.14	517.8	3.60
$5.197\text{x}10^6$	7.32	1560.0	3.68
$5.570\text{x}10^6$	7.12	1048.2	3.84
$6.050\text{x}10^6$	6.67	526.7	3.94
$1.412\text{x}10^7$	6.40	1056.8	4.51
$1.430\text{x}10^7$	6.82	1594.4	4.58
$1.477\text{x}10^7$	5.20	533.5	4.34
$1.623\text{x}10^7$	5.88	564.5	4.42
$2.717\text{x}10^7$	5.49	1578.0	5.08
$2.768\text{x}10^7$	5.24	1064.3	5.16
$2.809\text{x}10^7$	5.22	1068.6	5.01
$2.958\text{x}10^7$	5.02	863.1	5.08
$3.232\text{x}10^7$	4.58	558.4	4.77
$3.344\text{x}10^7$	4.95	567.6	4.96
$5.707\text{x}10^7$	5.01	1621.9	5.75
$5.938\text{x}10^7$	4.66	1115.6	5.84
$6.078\text{x}10^7$	4.78	1311.4	5.69
$6.089\text{x}10^7$	4.62	1106.9	5.53
$6.142\text{x}10^7$	4.43	897.0	5.46
$7.112\text{x}10^7$	4.96	1148.8	6.01
$7.172\text{x}10^7$	3.89	591.1	5.41
$1.686\text{x}10^8$	4.09	1726.9	6.93
$1.785\text{x}10^8$	3.85	1405.4	6.88
$1.827\text{x}10^8$	3.66	1190.2	6.68
$1.833\text{x}10^8$	3.66	1190.1	6.64
$1.972\text{x}10^8$	3.39	973.0	6.48
$2.135\text{x}10^8$	3.79	1230.6	6.99

Appendix 5.2 Fully developed Nusselt numbers for α = 90°.

α = 90°			
Gr^+	Pr	Re	Nu/Nu_o
2.508x10^6	6.37	1786.9	3.52
2.647x10^6	6.29	998.9	3.64
2.647x10^6	6.35	1406.7	3.51
2.764x10^6	7.40	757.5	3.67
2.870x10^6	6.38	1790.0	3.66
2.880x10^6	7.19	514.3	3.79
5.198x10^6	6.21	1434.4	3.95
5.292x10^6	6.10	1026.8	4.00
1.360x10^7	5.90	1037.5	4.90
1.422x10^7	6.89	1590.0	5.14
1.522x10^7	5.44	550.4	4.49
1.535x10^7	6.52	1087.4	5.08
1.687x10^7	5.85	567.4	4.92
2.884x10^7	5.74	1595.8	5.65
2.885x10^7	5.49	1076.2	5.42
3.275x10^7	6.21	1635.4	5.72
3.576x10^7	5.72	1063.8	5.60
4.049x10^7	4.96	597.9	5.58
1.195x10^8	4.34	1635.2	6.92
1.377x10^8	4.27	1592.7	7.24
1.870x10^8	4.13	1784.8	7.69
1.965x10^8	4.26	1842.7	7.85
1.983x10^8	3.72	1211.6	7.41
2.036x10^8	3.67	1225.6	7.49

Appendix 5.3 Fully developed Nusselt numbers for $\alpha = 135°$.

$\alpha = 135°$			
Gr^+	Pr	Re	Nu/Nu_o
$2.653\text{x}10^6$	5.97	505.0	3.66
$5.368\text{x}10^6$	5.97	1022.1	3.91
$5.432\text{x}10^6$	6.07	1515.7	3.97
$5.513\text{x}10^6$	5.73	523.9	3.81
$1.314\text{x}10^7$	5.81	1551.2	4.54
$1.341\text{x}10^7$	5.64	1048.8	4.49
$1.456\text{x}10^7$	5.21	543.0	4.55
$2.738\text{x}10^7$	5.49	1577.7	5.50
$2.780\text{x}10^7$	5.35	1273.8	5.22
$2.853\text{x}10^7$	5.22	1069.3	5.53
$2.929\text{x}10^7$	5.03	861.4	5.38
$3.143\text{x}10^7$	4.60	556.1	5.25
$5.810\text{x}10^7$	5.00	1626.4	6.27
$6.078\text{x}10^7$	4.78	1311.4	6.24
$6.215\text{x}10^7$	4.60	1111.1	6.09
$6.663\text{x}10^7$	4.36	909.2	6.09
$7.309\text{x}10^7$	3.88	593.4	6.14
$1.718\text{x}10^8$	4.08	1730.8	7.60
$1.801\text{x}10^8$	3.84	1407.4	7.48
$1.862\text{x}10^8$	3.64	1194.0	7.29
$1.972\text{x}10^8$	3.39	972.7	7.04

Appendix 5.4 Fully developed Nusselt numbers for α = 180°.

$\alpha = 180°$			
Gr^+	Pr	Re	Nu/Nu_o
2.864×10^6	5.95	506.7	3.49
5.090×10^6	5.98	1019.9	3.78
5.178×10^6	6.10	1510.1	3.89
5.343×10^6	5.74	523.5	3.75
1.290×10^7	5.81	1549.6	4.42
1.316×10^7	5.66	1046.6	4.40
1.454×10^7	5.20	543.7	4.54
2.717×10^7	5.49	1578.0	5.13
2.784×10^7	5.35	1272.9	5.17
2.837×10^7	5.21	1069.6	5.05
2.958×10^7	5.02	863.1	5.12
3.197×10^7	4.58	558.7	4.95
5.810×10^7	5.00	1626.7	5.85
5.969×10^7	4.79	1308.9	5.74
6.026×10^7	4.63	1104.8	5.50
6.408×10^7	4.39	903.5	5.50
1.703×10^8	4.09	1729.3	7.04
1.750×10^8	3.86	1399.9	6.73
1.851×10^8	3.65	1193.1	6.91
1.946×10^8	3.40	971.0	6.56