LAMINAR MIXED CONVECTION IN INCLINED SEMICIRCULAR DUCTS UNDER BUOYANCY ASSISTED AND OPPOSED CONDITIONS

by

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ABDULKARIM A. BUSEDRA

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

of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Laminar mixed convection in inclined semicircular ducts (with the flat surface in the vertical position) is investigated theoretically in the fully-developed region, and experimentally in the developing and fully-developed regions, under buoyancy assisted and buoyancy opposed conditions. The investigation started with the numerical analysis of laminar, fully-developed flow and heat transfer. This analysis used a control-volume-based finite-difference approach in solving the governing equations. Results were obtained for the two limiting thermal boundary conditions; uniform heat input axially with uniform peripheral wall temperature (H1) and uniform heat input axially with uniform wall heat flux circumferentially (H2). These theoretical results include the axial velocity and temperature distributions, the secondary flow pattern, a map for the onset of flow reversal and data for the friction factor and Nusselt number. Using a single value of $Pr = 7$ and a range of Reynolds number, the tube inclination and Grashof number were found to have a strong effect on the distortion of the axial velocity and temperature distributions for upward and downward inclinations in both thermal boundary conditions. The thermal stratification in the H2 condition was found to reduce the enhancement in Nu. Further, Nu_{H1} was found to be larger than Nu_{H2} for upward inclination at low Gr, while at high Gr both values of Nu_{H1} and Nu_{H2} increase with α up to a maximum and decrease with further increase in α. However, for downward inclination both Nu_{H1} and Nu_{H2} were always lower than that of the horizontal orientation.

Next, a series of experiments for laminar water flow in the entrance region of a semicircular duct with upward and downward inclinations within ±20° were performed using the thermal boundary condition of uniform heat input axially. The experiment was designed for determining the effect of inclination (particularly the downward) on the wall temperature, the local and fully-developed Nusselt numbers,

and the overall pressure drop across the test section at three Reynolds numbers (500, 1000, and 1500) and a wide range of Grashof numbers. The circumferential variation of wall temperature was found to increase with Gr for all angles of inclinations. However, in the upward inclinations the experimental data showed less circumferential variation in wall temperature than that for the horizontal orientation, while for downward inclinations the circumferential variation of wall temperature was much larger than that for the upward inclinations. For the upward inclinations, the experimental values of Nusselt number were found to increase with Grashof number and the inclination angle (up to 20°), while the effect of Reynolds number was found to be small. For the downward inclinations, however, Reynolds number has a strong effect on Nusselt number and the manner by which it varies with Grashof number. For low Re_m ($Re_m = 500$) and large downward inclination ($\alpha = -20°$), the local values of Nusselt number were found to decrease continuously with Gr_m, while for higher Re_m, Nu_Z was found to increase and then decrease with Gr_m. Further, at low Re_m and high Gr_m it was not possible to achieve fully-developed temperature profile within the heated section. The fully-developed values of Nusselt number agreed in magnitude and trend with the predicted results for upward inclinations. The value of fRe was found to increase as α and/or Gr increase in both the theory and the experiment for the upward inclinations. For the downward inclinations, the predicted fRe was lower than its value at the horizontal orientation. Similar trend was observed for the measured fRe up to a critical value of Gr_m which could be close to the onset of flow reversal. Beyond that a sharp increase was observed for the measured fRe.

Two recent publications summarizing the major results of this investigation have been prepared by Busedra and Soliman [1, 2]

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NOMENCLATURE

A_{fl}	cross-sectional area defined by equation(5.1), $[m^2]$
B_1, B_2, B_3	dimensionless parameters defined by equation (3.16)
c_p	specific heat $[Jkg^{-1}K^{-1}]$
D_h	hydraulic diameter, $D_h = 2\pi r_o/(2+\pi)$ $[m]$
f	friction factor defined by equation (3.20)
g_r, g_θ, g_z	radial, angular and axial components of the gravitational acceleration $[ms^{-2}]$
Gr	Grashof number defined by equation (3.15)
h	circumferential-average heat transfer coefficient $[Wm^{-2}K^{-1}]$
k	thermal conductivity $[Wm^{-1}K^{-1}]$
L	distance between pressure taps $[m]$
$\dot{m}$	mass flow rate $[kg\ s^{-1}]$
Nu	circumferential-average Nusselt number
p	pressure $[Nm^{-2}]$
p_1	cross-sectional average pressure $[Nm^{-2}]$
p_2	cross-sectional excess pressure $[Nm^{-2}]$
P_1	dimensionless cross-sectional average pressure defined by equation (3.15)
P_2	dimensionless cross-sectional excess pressure defined by equation (3.15)
Pr	Prandtl number defined by equation (3.15)
q'	rate of heat input per unit length $[Wm^{-1}]$
r	radial coordinate $[m]$
r_o	radius of circular wall $[m]$
R	dimensionless radial coordinate defined by equation (3.15)

Re	Reynolds number defined by equation (3.15)
s	distance along the duct circumference $[m]$
t	temperature $[K]$
T	dimensionless temperature defined by equation (3.15)
u	radial velocity $[ms^{-1}]$
U	dimensionless radial velocity defined by equation (3.15)
v	angular velocity $[ms^{-1}]$
V	dimensionless angular velocity defined by equation (3.15)
w	axial velocity $[ms^{-1}]$
W	dimensionless axial velocity defined by equation (3.15)
z	axial coordinate $[m]$
Z	dimensionless axial coordinate defined by equation (3.15)
Z^+	reciprocal of Graetz number $(= z/D_h\ Re\ Pr)$

Greek Letters

α	duct inclination angle
β	coefficient of thermal expansion $[K^{-1}]$
γ	Dimensionless parameter , $\gamma = B_2/B_1$
θ	angular coordinate $[radians]$
μ	dynamic viscosity $[N\ s\ m^{-2}]$
ν	kinematic viscosity $[m^2s^{-1}]$
ρ	density $[kgm^{-3}]$
τ	wall shear stress $[Nm^{-2}]$
ω	dimensionless parameter , $\omega = (B_1^2 + B_2^2)^{1/2}$

Subscripts

a, b, c	thermocouple positions at an axial station
$bulk$	bulk value
fd	fully-developed value
H1	corresponding to the H1 boundary condition
H2	corresponding to the H2 boundary condition
m	mean
o	corresponding to $Gr = 0$
w	at the wall
Z	axially local value

Superscript

$-$	average value

CHAPTER 1

INTRODUCTION

Due to the prominent importance of heat transfer in energy technology, several practical applications involving mixed convection in ducts of various cross-sections and orientations continue to command substantial attention. These applications include solar energy, cooling of electronic components, compact heat exchangers and the cooling core of nuclear reactors. Full understanding of the prevailing velocity and temperature fields, as well as the pressure drop and heat transfer characteristics is necessary for the proper design of such systems. The demand to produce more compact surfaces for heat exchangers by augmenting heat transfer, thereby conserving energy and reducing heat exchanger costs, have led to the use of a variety of noncircular passages. The semicircular duct is an example of a flow passage used in compact heat exchangers.

Heat transfer depends on whether the flow is laminar or turbulent, upflow or downflow, and on duct geometry as well as the thermal boundary condition. For the vertical orientation, the laminar, mixed-convection heat transfer in upward (buoyancy assisted) flow can be enhanced over pure forced convection, while in downward (buoyancy opposed) flow, the laminar mixed-convection heat transfer can be lower than that for pure forced flow. For the horizontal orientation, temperature variations in the fluid lead to the possibility of counter rotating secondary flow cells that are superimposed on the streamwise flow. This circulation of the secondary flow provides a strong mechanism for heat transfer enhancement. In the inclined orientation, the buoyancy force is no longer exclusively perpendicular to the main flow (as in the horizontal case), since another axial component exists in the streamwise direction. For buoyancy assisted flow, the main flow can be accelerated because of the axial component of the buoyancy force and therefore, the heat transfer can be enhanced for these situations. In buoyancy opposed flow, the axial component of the buoyancy force acts against the main flow which can have adverse effects on the heat transfer. To the author's best knowledge, no results (theoretical or experimental) currently exist for laminar mixed convection in inclined semicircular ducts, except for the limiting cases of the horizontal and vertical orientations.

The objective of the present investigation is to generate theoretical (fully-developed) and experimental (developing and fully-developed) results for laminar mixed convection in heated semicircular ducts with buoyancy assisted and buoyancy opposed flows. Two thermal boundary conditions will be used in the theoretical analysis: (*a*) uniform heat input axially with uniform wall temperature circumferentially (known as the H1 boundary condition [3]) and (*b*) uniform heat input axially with uniform wall heat flux circumferentially (the H2 condition). These boundary conditions simulate electric-resistance or nuclear heating for the limiting conditions of highly conductive wall material (H1) and very-low-conductivity wall material (H2). The emphasis in this study will be placed on the effects of duct inclination, free convection, and thermal boundary condition on the velocity and temperature profiles, as well as the friction factor and Nusselt number.

Depending on the flow parameters, flow reversal can occur in both buoyancy assisted and buoyancy opposed flows. This phenomenon can substantially influence the velocity distribution, the temperature distribution, wall friction, and heat transfer. As well, flow instability and the onset of turbulence can be promoted by flow reversal. Therefore, the conditions under which the onset of flow reversal was encountered are documented in this investigation. However, no computations were made in the region where flow reversal occurs because the solution method adopted here would not be applicable under these conditions.

The experimental investigation was performed to investigate the effects of buoyancy (aiding and opposed) on the pressure drop and heat transfer of laminar mixed convection in the thermal entrance and fully developed regions using water as the working fluid. These effects are to be examined over a range of the independent parameters α, Re and Gr. The experiments were carried out with electrical heat input applied at the outer surface of the duct. Test runs were carried out for different inclinations varying from $-20°$ to $20°$ and the measured parameters include the axial and circumferential variation of wall temperature, local mean Nusselt number, fully-developed Nusselt number, and the overall friction factor across the heated section. Values of Nu_{fd} are compared with the present numerical results.

CHAPTER 2

REVIEW OF LITERATURE

The importance of this topic (mixed convection in ducts) has motivated a large amount of research activity in the literature [4]. The present investigation deals with the laminar flow and heat-transfer characteristics of fluid flowing upward (buoyancy assisted) or downward (buoyancy opposed) in inclined heated semicircular ducts. Due to the limited amount of literature related to semicircular ducts, consideration was given in this review to ducts of various cross-sections. As well, this review was extended to include horizontal and vertical ducts since the number of studies dealing with inclined ducts is limited.

The size of the literature dealing analytically and experimentally with horizontal and vertical flows is huge. Only samples of these studies are included in this review. The emphasis in this review is placed on experimental and analytical studies of laminar mixed convection in inclined ducts.

2.1 Horizontal Ducts

Several investigations have dealt experimentally and theoretically with laminar mixed convection in horizontal ducts of various cross-sections (not reviewed here). Chinporncharoenpong [5] and Lei [6] presented a comprehensive review in their theses that cover most of the experimental and theoretical studies performed on combined free and forced convection during laminar flow in horizontal ducts of various cross-sections. Therefore, attention will be given in this section to mixed convection laminar flow in horizontal semicircular ducts only. In addition, most of the literature on mixed convection in inclined ducts of various cross-sections, presented later in this chapter, cover the horizontal orientation as well.

Laminar mixed convection in the entrance region of a horizontal semicircular duct was experimentally investigated by Lei and Trupp [7]. The experiments were conducted on a copper test section of $49.8 - mm$ i.d. with the flat side on top. They obtained results for the local and fully-developed Nusselt numbers for a wide range of flow parameters, and results for the pressure drop with and without heating. They also observed that for high heating rates, the experimental data showed large circumferential variations in wall temperatures. Numerical predictions of the fully-developed laminar mixed convection with the H1 thermal boundary condition in horizontal semicircular ducts with the flat wall on top have been reported by Lei and Trupp [8]. They noted that the dependence on Prandtl number can be removed by plotting Nusselt number versus Rayleigh number ($Gr\ Pr$) and the friction factor versus $Gr/Pr^{1.8}$. Their computations resulted in dual solutions for high Gr (e.g.,$Gr = 2 \times 10^8$) with several values of Pr.

Nandakumar et al. [9] solved the same problem considered in [8] using the H1 boundary condition but with the flat wall at the bottom. Their numerical model produced dual solutions with two and four vortices in the secondary flow pattern not only for the semicircular duct but also for rectangular and circular cross-sections. Chinporncharoenpong et al. [10] studied the fully-developed mixed convection with the H1 thermal boundary condition in a horizontal semicircular duct. They presented results for the effects of orientation of the flat surface of the semicircular duct (from 0° to 180° with an incremental angle of 45°) on the velocity and temperature profiles as well as the friction factor and Nusselt number. Chinporncharoenpong et al. [11] extended their study to horizontal circular sector ducts. They reported that the orientation effects are significant for the circular sector ducts only at high Grashof numbers. Further, a comparison of Nu for $Pr = 4$ among circular sector ducts having apex angles of 30°, 60°, 90°, 120°, and 180° with fixed orientation showed that Nu increased with increasing the apex angle.

2.2 Vertical Ducts

Considerable attention has been devoted to combined forced and free convection in vertical ducts. The problem of laminar mixed convection heat transfer in vertical ducts of various cross-sections has been studied analytically and experimentally.

2.2.1 Analytical Work

Hallman [12] presented an analytical prediction of the fully-developed and heat-transfer characteristics of laminar fluid flowing in a uniformly heated vertical tube under the conditions of combined forced and free convection, with and without internal heat generation. He solved for the velocity and temperature profiles, Nusselt number, and the pressure drop. The highest Gr/Re covered in his analysis was about 3×10^4. For this high Gr/Re, a fairly flat temperature profile covered most of the tube cross-section except near the tube wall where flow reversal and a high temperature gradient occurred. His exact solution was established in terms of Bessel functions. Tao [13] also treated the heat transfer problem of fully-developed laminar mixed convection in vertical tubes and circular sector ducts of constant wall temperature gradient with and without a heat source. He introduced a complex function, as illustrated in his paper [14] for the cases of flows between parallel plates and in rectangular channels, which gives the solution of the velocity and temperature fields simultaneously. The complex function had real and imaginary parts that are directly related to the velocity and temperature fields, respectively. The coupled momentum and energy equations of the problem were readily combinable into a single differential equation of second order. His analysis was limited to positive Gr/Re only. For the case of negative Gr/Re the definition of the complex function was no longer meaningful.

Morton [15] solved the problem of laminar mixed convection in uniformly heated vertical pipes when the upward or downward flow was heated or cooled for various values of Gr/Re. His analysis was basically similar to Hallman's analysis [12]. The general solutions for the velocity and temperature distributions were established in terms of Bessel functions. The exact solution showed that, when heating up-flow or cooling down-flow the velocity is increased near the pipe wall and decreased near the center. For sufficiently large Gr/Re, reversed flow was formed near the axis. In case of cooling up-flow or heating down-flow there is an increase in the velocity at the core and a decrease near the pipe wall for smaller values of Gr/Re. Increasing Gr/Re, the axial velocity became very large at the core and quite different from the one corresponding to pure forced flow.

Martin and Shadday [16] presented numerical solution of mixed convection through a vertical tube with high Grashof numbers and a Reynolds number of 100. The heated section of the tube had a constant wall temperature. They computed values of Nusselt number and the friction factor via a finite difference scheme for both the entrance and the fully developed regions. Their Grashof number ranged from 1×10^5 to 1×10^6. The results showed a significant effect of buoyancy on the fluid flow through vertical tubes in generating large scale vortices. This influence of buoyancy was to significantly raise the friction factor since the axial velocity was large near the tube wall.

Wang et al. [17] studied numerically the laminar mixed convection flow in vertical and horizontal pipes at low Peclet numbers in the thermal entrance region with uniform wall temperature. The Peclet number values were 71, 10 and 2.5. These low values have been analyzed in view of the simultaneous effects of free convection and axial conduction. They reported that for the vertical case, when heating in-upward flow the axial velocity profile is gradually distorted from the parabolic shape and became concave. The temperature field developed faster and heat transfer was enhanced with increasing Gr/Re. On the other hand, when cooling in-upward flow the velocity profile was distorted with an increase at the pipe center and the thermal field developed more slowly than that of pure forced convection and thus the heat transfer deteriorated. They have also investigated the existence of flow reversal at the pipe center for the heating case and near the wall for the cooling case at relatively high Gr/Re.

Other solutions for combined free and forced convection in vertical tubes with radial internal fins have been obtained analytically by Hu and Chang [18] and numerically by Prakash and Patankar [19] to determine the influence of the buoyancy forces. Their results are presented for a range of Gr/Re and for various values of the relative fin height and number of fins. Further, a numerical analysis of fully-developed mixed convection during laminar flow in a vertical semicircular duct with radial internal longitudinal fins has been reported by Dong and Ebadian [20]. They have presented results for the finless semicircular duct and compared with those of finned semicircular ducts. They have also concluded that the heat transfer of mixed convection in the semicircular duct is dramatically enhanced by using radial internal fins, especially the short ones.

Considering a vertical rectangular duct with one wall maintained at a high temperature and the other three walls at ambient temperature, Cheng and Weng [21] reported analytical solutions of the temperature and velocity fields of fully-developed mixed convection flow. They extended their study [22] to solve numerically the case of mixed convection flow in the developing region of vertical ducts under the same thermal conditions. Their results showed that the flow characteristics are significantly dependent on Gr/Re, aspect ratio of the cross-section, and the Prandtl number. Iqbal and Aggarwala [23] presented an exact theoretical solution of the problem of fully developed laminar combined free and forced convection through vertical rectangular channels with the broad sides at uniform temperature, while the short sides of the duct were maintained adiabatic. Aggarwala and Iqbal [24] presented also analytical solutions of combined free and forced convection through vertical triangular ducts of different shapes with H1 thermal boundary condition. Exact expressions, in the form of infinite series, have been presented for the velocity, temperature and Nusselt numbers. The three triangular ducts were equilateral, 30° - 60° - 90° triangular, and right-angled isosceles. Their results showed that the presence of free convection tended to diminish the difference in heat transfer rate between the three shapes considered.

Fully-developed laminar mixed convection heat transfer with the H1 boundary condition in vertical ducts of three shapes; right-angled triangular, isosceles triangular and rhombic ducts has been studied by Iqbal et al. [25]. Approximate solutions for the duct geometry which produced maximum value of Nusselt number, have been obtained by a finite-difference procedure. Their study also showed that for all the three ducts, a flow reversal occurs when Gr/Re is in the range of 3×10^4 and the duct geometry has only a minor effect on the onset of flow reversal. Buoyant instability in downward transient flow of nitrogen in a tall, partially heated vertical channel has been investigated numerically by Evans and Greif [26]. The vertical channel had three regions, the first region was upstream isothermal, the second region was the heated region and the final region of the channel was adiabatic. They obtained results for $Re = 219.7$, $Pr = 0.7$ and three values of the buoyancy term(Gr/Re^2) 1.83, 8.0 and 13.7. For the three values of the buoyancy term they reported that, when the upward buoyant flow near the walls reached the top of the heated region and encountered the cooler upper region, it turned toward the centerline and it incorporated into the rapidly moving downward flow in the central core of the channel. The velocity and temperature along the centerline were nonmonotonic and oscillatory. The average Nusselt number was periodic and increased with increasing Gr/Re^2. This investigation showed that, applying different thermal boundary conditions above the heated region were important since strong buoyancy caused the fluid flow to move upward along the heated surface.

Velusamy and Garg [27] studied numerically the fully-developed laminar mixed convection flow in vertical elliptic ducts with circumferentially uniform wall temperature and uniform axial heat input. They presented results for the velocity and temperature profiles, friction factor, Nusselt number and critical Gr/Re (at which flow reversal took place) for a wide range of duct aspect ratios and Gr/Re. They noted that the concentration of the velocity contours near the foci of the elliptic duct lead to increased wall shear at high values of Gr/Re. The fully-developed laminar mixed convection flow through a vertical annulus in the upward direction was investigated by Maitra and Raju [28]. Their results correspond to constant heat flux maintained at the inner wall while the outer wall was adiabatic. Their theoretical results indicated that, at high Gr/Re, a steep increase in Nusselt number occurred for all radius ratios (1.5, 2.65, 4, 5, and 10). Their experimental Nusselt-number results were found to be 45% higher than the theoretical analysis.

Theoretical investigations dealing with flow reversal in vertical parallel-plate channels were done by Aung and Worku [29] and Cheng et al. [30]. Aung and Worku [29] made their analysis for fully developed mixed convection flow. The forced flow entering between parallel-plate channels was in the vertical upward direction. The duct walls were maintained at uniform temperatures, but provision was made for asymmetric heating in that the two wall temperatures need not to be the same. They reported that for symmetric heating in which the walls were at an identical temperature, there was no flow reversal in the fully developed region. When the wall temperatures were unequal (asymmetric heating) flow reversal occurred at high value of Gr/Re. When Gr/Re was high enough, a situation arises in which the bulk temperature increased as the amount of flow reversal increased. Cheng et al. [30] solved analytically the same problem considered in [29] using different combinations of boundary conditions. Three combinations of thermal boundary conditions were considered; isoflux-isoflux, isoflux-isothermal and isothermal-isothermal, which covered all the symmetric or asymmetric thermal boundary conditions. They reported that the occurrence of flow reversal was strongly dependent on the value of Re/Gr and the thermal boundary condition. They noted that there were two possible patterns of reversed-flow velocity profiles for the isoflux-isoflux case, whereas only the single-peak pattern with negative velocity adjacent to the colder wall could be found for the isoflux-isothermal and isothermal-isothermal conditions. Cheng and Weng [21] also investigated the occurrence of reversed flow with buoyancy assisted flow in a vertical rectangular duct with isothermal walls of different temperature. The flow reversal was found to be significantly dependent on the value of Re/Gr and the aspect ratio. Cebeci et al. [31] presented numerical solutions (finite-difference method) for laminar mixed convection in the developing region of vertical ducts under thermal wall-boundary conditions leading to heating or cooling in up-flow. They obtained results for three values of Gr/Re^2 (0.001, 0.1, and 1.0) and three values of Prandtl numbers (0.1, 0.72, and 10). Their results showed the variation of the velocity, temperature, wall shear and pressure drop in the developing region. They also noted the existence of flow reversal near the wall for the cooling case at $Gr/Re^2 = 0.1$ and 1.

2.2.2 Experimental Work

An experimental investigation was conducted by Kemeny and Somers [32]. They used water and oil flowing upward in vertical $2.4-m$ long tubes of varying inside diameters from 12.7 mm to 38 mm with axially uniform heat input. Their work extended from low flow rate (to make the buoyancy effect significant) to turbulent flow. They obtained results of combined free and forced convection in vertical heated tubes for different values of Gr/Re and Z^+. Prandtl number varied from 3 to 8 for water and from 80 to 170 for oil. They presented experimental data for the local Nusselt number and pressure drop. For large values of Z^+, at which the fully-developed conditions were approached, their experimental results of the friction factor fell below the prediction of Hallman [12]. They have determined the friction factor from the frictional pressure drop, using the following definitions:

$$\Delta P_{meas} = \Delta P_f + (\rho_m - \rho_a)\ g\ L \tag{2.1}$$

$$f = \frac{\Delta P_f}{\rho_m w_m^2}\ \frac{D}{2\ L} \tag{2.2}$$

where ΔP_{meas} is the pressure difference measured by a manometer, ΔP_f is the frictional pressure drop, ρ_m is the average fluid density in the tube, ρ_a is the average fluid density in the manometer, and w_m is the mean velocity in the tube. The above expressions will be used in the present study to evaluate the experimental friction factor.

Hallman [33] confirmed experimentally the fully developed heat-transfer results predicted by his previous analysis [12] over a range of Gr/Re. The experiment was for combined forced and free convection in a vertical tube with uniform wall heat flux and no internal heat generation. The heated test section had a length to diameter ratio of 115, while the hydrodynamic developing length had a length to diameter ratio of 13. The axial spacing of the thermocouples was made small in order to allow an accurate determination of the wall temperature in the thermal entrance region for both up-flow and down flow. The experimental data of the local Nusselt number at very low Gr/Re agreed well with the pure forced-convection curve. However, the high Gr/Re runs agreed with the analytical curve of pure forced convection very near the entrance, but deviated later along the heated length. The fully developed Nusselt numbers in down flow were found to be lower than those for pure forced convection and most of the data fell above the analysis. Scheele and Hanratty [34] studied experimentally the effect of free convection when aiding and opposing the main flow in a vertical pipe of 762 diameters length with uniform heat input axially. One of the effects of free convection on the forced flow was the transition to turbulent flow at low Reynolds number. The transition was related to the distortion of the velocity profiles caused by the free convection. When the free convection and forced flow were in the same direction (heating up-flow) transition to turbulent occurred through a gradual growth of small disturbances. On the other hand, when the free convection was opposite to the direction of the forced flow (heating down flow), early transition to turbulence was caused by separation of the flow due to flow reversal.

Zhang and Dutta [35] presented experimental work for buoyancy assisted mixed convection in a vertical square channel with asymmetric heating conditions. The heated test section was placed between two identical unheated square channels. All three sections had the same square cross-section (5.715 cm × 5.715 cm) and were 122 cm long with the same hydraulic diameter. Two opposite sides of the test section were heated in four different heating models and the other two sides of the square channel were insulated. The experiment covered the range of Reynolds number from 200 to 11200 and the buoyancy term (Gr/Re^2) from 0.02 to 200. The heating conditions from model 1 to model 4 under comparable heat flux input showed that the local Nusselt number decreased significantly with an increase in Re for all four models. Further, they investigated the difference in heat transfer rate between the four models.

Flow reversal has been experimentally investigated at the tube centerline for vertical heated flow by Hanratty et al. [36]. They used water flowing upward and downward in a vertical 2 m long glass tube with 2.19 cm inside diameter at low Reynolds numbers. By injecting a thin stream of dye into the flowing water, they observed that the fluid in the tube center was decelerated to such an extent that the flow was reversed and the fluid near the surface was accelerated.

2.3 Inclined Ducts

The literature on mixed convection in inclined ducts of various cross-sections is very sparse in comparison with the horizontal and vertical orientations. Only recently has much attention been focused upon inclined ducts, especially, the experimental work, under combined free and forced laminar convection.

2.3.1 Analytical Work

Iqbal and Stachiewicz [37] reported a perturbation power-series solution for buoyancy-assisted, fully-developed flow in inclined circular tubes with uniform heat flux at the wall. They treated the density as being variable only in the buoyancy terms of the momentum equation, while keeping it constant in all other terms. They presented results for the velocity and temperature profiles and Nusselt number. They noted that Nusselt number reached a maximum at some inclination angle between the horizontal and vertical orientations. They also noted that the perturbation power-series is valid only for low Gr. Another approach for solving mixed convection in inclined tubes was reported by Iqbal and Stachiewicz [38]. In this case they treated the density as being variable in the radial and angular terms as well as the axial terms of the momentum equation. They reported that the friction factor, based on the wall shear stress, at 60^0 tube inclination increased from 30 to 50% over the isothermal value. They also reported that the velocity field became more distorted than the one in [37], while the temperature field and Nusselt number were essentially the same.

A numerical study using a combination of boundary vorticity and line iterative relaxation was presented by Cheng and Hong [39]. The numerical results for mixed convection using water at relatively low Reynolds numbers showed that the perturbation analysis of [37] in terms of power series of Grashof number is invalid and diverges quickly with the increase of Grashof number. Cheng and Hong [40] extended their work to investigate the effects of inclination angle, Gr and Re on the distortion of the velocity and temperature profiles. Furthermore, they reported a substantial difference between their values of Nusselt number and those in [37]. Later, Ou et al. [41] considered the geometry of rectangular ducts and solved the problem of laminar, fully-developed mixed convection for buoyancy assisted upwardly inclined flows with uniform heat input axially and uniform wall temperature circumferentially. They noted that the inclination angle greatly influenced the value of Nusselt number near the horizontal orientation.

Other results for laminar, fully-developed mixed convection were reported for inclined parallel plates under buoyancy-assisted [42] and buoyancy-opposed [43] conditions. The solutions in [42] and [43] was expressed in terms of two independent parameters (defined below) rather than the four fundamental parameters Re, Gr, Pr and the inclination angle.

$$P_1 = \left(\frac{Gr}{Re}\right) sin\alpha \quad , \qquad \text{and} \qquad P_2 = \left(\frac{Gr}{Pr\ Re^2}\right) cos\alpha$$

where P_1 and P_2 are dimensionless parameters and α is the inclination angle. The dependence of the velocity and temperature distributions, wall friction and heat transfer on the parameters P_1 and P_2 was determined. The occurrence of flow reversal was also reported for both buoyancy assisted and buoyancy opposed conditions.

Orfi et al. [44] investigated numerically the effect of buoyancy on the laminar fully-developed ascending flow of air in inclined, uniformly heated, circular tubes. The problem was solved using the SIMPLER algorithm and numerical results have been reported for $Pr = 0.7$, $Re = 305$, tube inclination ranging from $\alpha = 0^0$ to 90^0 and three values of Gr (5×10^3, 2×10^4, 5×10^4). Orfi et al. [45] solved the same problem considered in [44] using air ($Pr = 0.7$) and water ($Pr = 7$) and higher values of Gr. Their results showed that the effects of the buoyancy-induced secondary flow on the hydrodynamic and thermal fields are strongly dependent on Grashof number, Prandtl number and tube inclination. For fixed values of Re, Pr, and Gr, there exists an optimum tube inclination which maximizes Nusselt number and it was found that Nu for water is higher than the one for air. Furthermore, the average shear stress was found to be higher for air than for water and increases with tube inclination and with Grashof number. Orfi et al. [46] extended their study to show the effects of free convection in the entrance region of uniformly heated inclined circular tubes. They numerically investigated the behavior of the secondary flow and its effects on the velocity and temperature fields.

Laouadi et al. [47] solved the conjugate problem for laminar mixed convection in inclined circular tubes by applying the thermal boundary condition at the outer surface of the tube. They investigated the effect of wall conduction on mixed convection for the horizontal orientation and the inclination angle of 30° using different wall to fluid thermal conductivity ratios, different tube thicknesses and various values of Grashof number. Laouadi et al. [48] solved the same problem considered in [47] with larger inclination angles. They noted that for tubes inclined at 30°, the effect of wall conduction and thickness on Nu is very small, while for tubes inclined at 60° the effect is significant. For the horizontal orientation, Nu was found to be bounded by two curves. The upper curve corresponds to infinite wall thermal conductivity (reducing temperature stratification), while the lower curve corresponds to zero wall thermal conductivity (increasing temperature stratification). Laouadi et al. [49] extended their work to three Prandtl numbers (0.7, 7, 100) and inclination angle from 0° to 90° to illustrate the effects of these parameters as well as the thermal conductivity ratio and the thickness on Nusselt number and wall shear stress.

2.3.2 Experimental Work

Laminar mixed convection of water through inclined circular ducts having essentially uniform wall heat flux and circumferentially uniform wall temperature have been experimentally investigated by Barozzi et al. [50]. The test section was designed to reproduce the thermal effects of uniform solar irradiation on flat-plate collectors and therefore considered five, $1.5 - m$ long, parallel copper tubes of 10 mm $o.d.$ and 6 mm $i.d.$ connected by brazed copper fins. The experiment covered the range of Reynolds number from 200 to 2300 and Grashof number from 6×10^3 to 7×10^5 and inclination angles from $\alpha = 0°$ to 60°. They noted that the local Nusselt number first decreased along the heated length, reached a minimum, and then increased to the fully-developed value. The minimum value of Nu is due to a balance between entrance and free convection effects. Variation of Nusselt number with α from 0° to 60° was found to be very small, probably due to the small values of Gr used in the study.

An experimental study of laminar fully-developed mixed convection under uniform heat flux in inclined tubes was carried out by Iqbal [51]. The experimental work was done for tilt angles of 45° from the horizontal and for the vertical position ($\alpha = 90°$) in a single brass tube of a solar collector, 1.8 m long, 19 mm $o.d.$, and 15 mm $i.d.$. He noted that the experimental data for the heat transfer rate showed no appreciable difference between the two tube inclinations. This was probably due to the pressure fluctuation in the water line; the flow rate could not be held constant in the absence of a constant head tank and the heat input was varying. Sabbagh et al. [52] studied experimentally the problem of mixed convection of air in an inclined circular tube with uniform heat input axially and uniform peripheral wall temperature. The experiment was conducted in a copper tube of $3.175 - cm\ i.d.$ and tube length of $365.7\ cm$. Their experiments covered the range of tilt angles from 0° to 90° and three values of Reynolds number (740, 975 and 1204) in order to study the effect of these parameters on the velocity and temperature profiles and Nusselt number. At a location in the test section, where the fully-developed flow was established, they measured the temperature and axial velocity profiles across the tube diameter and compared them qualitatively with the available theoretical predictions. For the temperature measurement they used a thermocouple with tip size of about 2-mm mounted on a traversing mechanism. The axial velocity was measured by a pitot-static tube (2.5-mm tip) with micrometer traverse control. They also noted that no optimum angle was found for maximum heat transfer rate.

Morcos et al. [53] investigated experimentally the problem of combined forced and free convection during laminar flow in the entrance region of inclined rectangular channels. The experiments were performed with water and the test section was made of aluminum having outer dimensions of $20 \times 10\ mm$ with wall thickness of $2\ mm$ and a total length of $2.25\ m$. Their experimental data were obtained for the inclination angles of $\alpha = 0°, 15°, 30°$ and $45°$. Three values of Reynolds number (100, 250 and 500) and various values of Grashof number ranging from 1×10^5 to 3×10^6 were tested. Their investigation was mainly on the circumferential variation of wall temperature and the axial variation of Nusselt number in upward inclination. They reported that the upper wall temperatures were higher than the lower wall temperatures as a result of the secondary flow current. The axial variation of the local Nusselt number was similar to that reported in [50] and Nusselt number was found to increase with Gr and with the inclination angle up to a maximum near $\alpha = 30°$. They also observed that Nu was independent of Re for the horizontal orientation and the effect of Re became progressively more significant for higher inclination angles. A detailed experiment was reported by Maughan and Incropera [54] for laminar air flow between parallel plates (30.5 × 308 mm cross-section) heated uniformly from below. They used the horizontal and upward inclinations up to $\alpha = 30°$. Their reported variation of the local Nusselt number along the heated length was similar in trend to the ones reported in [50, 53]. Also, the data showed that the local Nusselt number increased with both Gr and α.

Very little experimental work has been done on buoyancy opposed mixed convection in inclined ducts. Lavine et al.[55] conducted a visual study on buoyancy opposed mixed convection flow in an inclined pipe. The test section was made of polycarbonate with inner diameter of 38.1 mm, outer diameter of 44.5 mm and a length of 3.66 m. The working fluid was water and the independent parameters were Reynolds number between 100 and 3500, Grashof number between 1×10^6 and 7×10^6 and inclination angle from 0° to −80°. They examined visually the influence of these parameters upon the temperature field, the occurrence of flow reversal, early transition to turbulence and the occurrence of periodic behavior. By injecting a thin stream of dye into the flowing water, it was observed that the flow reversal started from a region downstream of the heated section and extended to some upstream location that depended on α, Re and Gr. The flow reversal length was found to be an increasing function of Gr and α and a decreasing function of Re. Temperature measurements were made across the tube diameter at a location three diameters downstream from the thermal entrance region. A thermocouple probe was traversed from the lower to the upper tube wall through the symmetry plane. Unstable aiding and opposing mixed-convection flow has been investigated by Lin and Lin [56]. The experiment was performed for mixed convection of air in a bottom-heated inclined rectangular duct with the inclination angle ranging from $-20°$ to $26°$. The test section was constructed from $9-mm$ thick Plexiglass with a 30 mm height, 120 mm width and a total length of 800 mm. They observed that the onset of the secondary flow shifts upstream for increasing Gr and negative inclined angle, while increasing Re with positive angle moves the onset of the secondary flow downstream. They also reported that Nu values (defined in terms of the inlet temperature) for inclination angles of $\alpha = -10°$ and $-20°$ were higher than those for the horizontal orientation.

Leong et al. [57] performed experiments for laminar mixed convection in the thermal entrance region of a uniformly heated inclined circular tube with water flowing downward. The experimental set-up consisted of $1.83 - m$ long copper tube of $38.1 - mm$ $i.d.$ and $44.5 - mm$ $o.d.$ coupled to an acrylic tube of identical dimensions. They reported circumferential and axial variations of the local Nusselt number for low tilt angles $-20° \leq \alpha \leq 0°$, three values of Reynolds number(432, 864, and 1296), and two values of Grashof number 1.4×10^7 and 2.8×10^7. They noted that, the axial variation of the local Nusselt number is largest for $\alpha = 0°$ followed by values for $\alpha = -20°$ and $-15°$, while values of Nu_Z for $\alpha = -5°$ and $-10°$ were close to the pure forced convection. They also stated that, flow reversal starts downstream in the heated section and moves upstream along the unheated section to a point where it could not overcome the main flow.

Bohne and Obermeier [58] considered the geometry of a concentric annulus with the inner tube heated electrically. They reported data for the length-mean Nusselt number over the whole heated length in the horizontal, vertical (upward and downward flow) and inclined (upward and downward flow) orientations. Both laminar and turbulent flows were considered. Their results indicated that for upward and downward laminar flows, the average Nusselt number may increase or decrease with α depending on the values of Gr and Re. The effects of α, Re, and Gr on the wall temperature and the local Nusselt number were examined.

Based on the above review of the previous experimental and theoretical investigations on laminar mixed convection in horizontal, vertical and inclined ducts of various cross-sections, the following observations can be made:

1. For semicircular ducts, numerical results for fully-developed laminar mixed convection are available only for vertical buoyancy assisted flow and horizontal flow. No analysis is available for inclined semicircular ducts or buoyancy opposed conditions.

2. For upward inclinations, most of the numerical predictions of fully-developed laminar mixed convection through ducts of various cross-sections, except semicircular ducts, were performed for computing the velocity and temperature distribution as well as Nusselt number using a single value of Re and various values of Gr and α. No analysis is available in examining the behavior of the overall quantities of fRe and Nu for a wide range of Re for inclined (other than parallel plates by Lavine [42]) ducts.

3. No experimental results are available for the local and fully-developed Nusselt numbers and pressure drop as well as the axial and circumferential variation of wall temperature during laminar mixed convection in the thermal entrance and fully-developed regions of inclined semicircular ducts in upward or downward inclinations.

CHAPTER 3

ANALYSIS OF THE FULLY-DEVELOPED REGION

The appropriate forms of the Navier-Stokes equations and the energy equation in cylindrical coordinates involving the velocity, temperature and pressure fields are presented in this chapter. These equations are non dimensionalized and solved numerically in order to determine the effects of free convection and duct inclination, for the H1 and H2 thermal boundary conditions, on the axial velocity, secondary flow pattern and temperature profiles, as well as the friction factor and Nusselt number

3.1 Analytical Formulation of the Problem

The geometry under consideration, shown in figure 3.1, is that of a semicircular duct inclined at an angle α from the horizontal with the flat side always falling in a vertical plane. The fluid is incompressible and Newtonian and the flow is steady, laminar, and fully developed hydrodynamically and thermally. Viscous dissipation is assumed to be negligible. Fluid properties are assumed to be constant, except for the density in the buoyancy terms which varies with the temperature according to the Boussinesq approximation. Heat input is assumed to be uniform axially and two thermal boundary conditions, H1 and H2 (defined earlier), are considered in this study.

For this three-dimensional flow problem, we will follow a parabolized Navier-Stokes

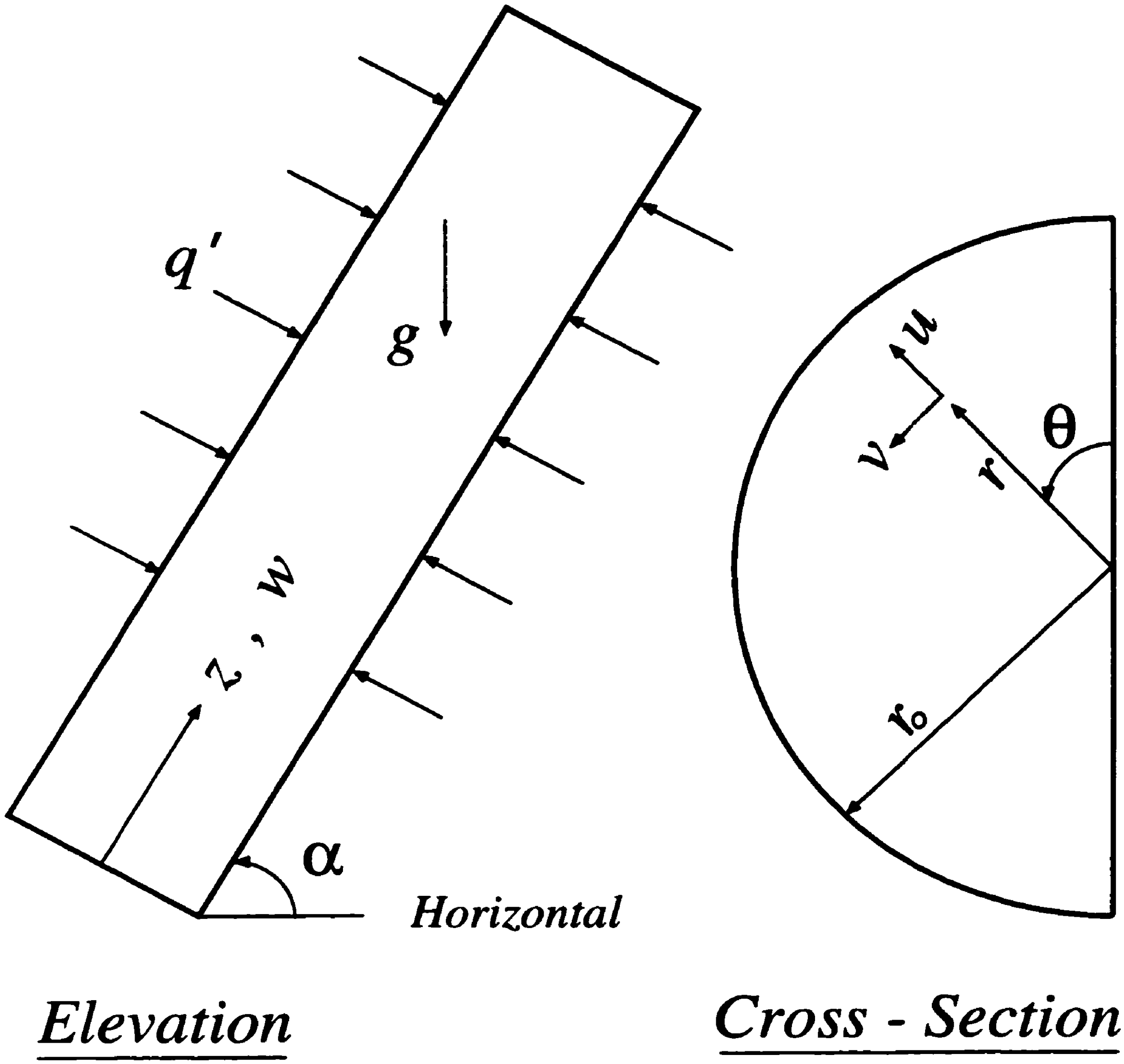


Figure 3.1: Geometry and coordinate system

procedure in which the pressure approximation quite widely used is given in [59]. It is assumed that the pressure at any point in the flow consists of two components. Thus, p is expressed as:

$$p(r, \theta, z) = p_1(z) + p_2(r, \theta) \tag{3.1}$$

where p_1 is the cross-sectional average pressure, which is assumed to vary linearly in the z-directions, while p_2 provides the driving force for the secondary flow within the cross-section.

With the above assumptions, the governing continuity, momentum, and energy equations in the cylindrical coordinate can be written as follows:

Continuity Equation

$$\frac{\partial (r\,u)}{\partial r} + \frac{\partial v}{\partial \theta} = 0 \tag{3.2}$$

Momentum Equations

r-direction:

$$\rho\left[u\,\frac{\partial u}{\partial r} + \frac{v}{r}\,\frac{\partial u}{\partial \theta} - \frac{v^2}{r}\right] = -\frac{\partial p_2}{\partial r} + \mu\left[(\nabla^2 u) - \frac{2}{r^2}\,\frac{\partial v}{\partial \theta} - \frac{u}{r^2}\right] + \rho\, g_r \tag{3.3}$$

θ-direction:

$$\rho\left[u\,\frac{\partial v}{\partial r} + \frac{v}{r}\,\frac{\partial v}{\partial \theta} + \frac{vu}{r}\right] = -\frac{1}{r}\frac{\partial p_2}{\partial \theta} + \mu\left[(\nabla^2 v) + \frac{2}{r^2}\,\frac{\partial u}{\partial \theta} - \frac{v}{r^2}\right] + \rho\, g_\theta \tag{3.4}$$

z-direction:

$$\rho\left[u\,\frac{\partial w}{\partial r}+\frac{v}{r}\,\frac{\partial w}{\partial \theta}\right]=-\frac{dp_1}{dz}+\mu\left(\nabla^2 w\right)+\rho\, g_z \tag{3.5}$$

Energy Equation

$$\rho\, c_p\left[u\,\frac{\partial t}{\partial r}+\frac{v}{r}\,\frac{\partial t}{\partial \theta}+w\,\frac{\partial t}{\partial z}\right]=k\,\left(\nabla^2 t\right) \tag{3.6}$$

The buoyancy terms in the momentum equations are approximated by the Boussinesq approximation in which the fluid density is expressed as

$$\rho=\rho_w\left[1-\beta(t-t_r)\right] \tag{3.7}$$

where ρ_w is the fluid density at the wall temperature and t_r is defined later. Considering the fully-developed conditions, the axial temperature gradient can be obtained as

$$\frac{\partial\, t_{bulk}}{\partial z}=\frac{\partial\, t}{\partial z}=\frac{2q'}{\rho\, c_p w_m\, \pi r_o^2} \tag{3.8}$$

and the axial pressure gradient is treated as a constant

$$\frac{dp_1}{dz}=constant \tag{3.9}$$

The governing equations for the fully-developed laminar flow were non-dimensionalized as follows:

Continuity Equation

$$\frac{\partial (R\,U)}{\partial R} + \frac{\partial V}{\partial \theta} = 0 \tag{3.10}$$

Momentum Equations

R-direction:

$$U\frac{\partial U}{\partial R} + \frac{V}{R}\frac{\partial U}{\partial \theta} = -\frac{\partial P_2}{\partial R} + \nabla^2 U - \frac{2}{R^2}\frac{\partial V}{\partial \theta} - \frac{U}{R^2} + \frac{V^2}{R} + Gr T cos\alpha \, cos\theta \tag{3.11}$$

θ-direction:

$$U\frac{\partial V}{\partial R} + \frac{V}{R}\frac{\partial V}{\partial \theta} = -\frac{1}{R}\frac{\partial P_2}{\partial \theta} + \nabla^2 V + \frac{2}{R^2}\frac{\partial U}{\partial \theta} - \frac{V}{R^2} - \frac{UV}{R} - Gr T cos\alpha \, sin\theta \tag{3.12}$$

Z-direction:

$$U\,\frac{\partial W}{\partial R} + \frac{V}{R}\,\frac{\partial W}{\partial \theta} = -\frac{dP_1}{dZ} + \nabla^2\, W + 2\left(\frac{\pi}{\pi+2}\right)\frac{Gr}{Re}\,T\,sin\alpha \tag{3.13}$$

Energy Equation

$$Pr\left[U\,\frac{\partial T}{\partial R} + \frac{V}{R}\,\frac{\partial T}{\partial \theta}\right] = \nabla^2\,T - \left(\frac{2}{\pi}\right)\,W \tag{3.14}$$

where the dimensionless parameters are defined as follows:

$$R = \frac{r}{r_o} \;, \quad Z = \frac{z}{r_o} \;, \quad U = \frac{u r_o}{\nu} \;, \quad V = \frac{v r_o}{\nu} \;, \quad W = \frac{w}{w_m} \;, \quad T = \frac{(t - t_r)}{q'/k}$$

$$P_1 = \frac{p_1^* r_o}{\rho \nu w_m} \;, \qquad p_1^* = p_1 + \rho_w \, g \, z \, sin\alpha \;,$$

$$P_2 = \frac{p_2^* r_o^2}{\rho \nu^2} \;, \qquad p_2^* = p_2 + \rho_w \, g \, r \, cos\alpha \, cos\theta \;,$$

$$Pr = \frac{\rho \, \nu \, c_p}{k} \;, \qquad Re = \frac{w_m \, D_h}{\nu} \;, \quad \text{and} \quad Gr = \frac{\beta \, g \, q' r_o^3}{k \, \nu^2} \qquad (3.15)$$

The parameter t_r used in equation(3.7) and in the definition of the dimensionless temperature was taken as t_w in the H1 condition and $\bar{t}_w$ in the H2 condition, while the term dP_1/dZ in equation (3.13) was treated as a constant (a consequence of the fully-developed condition).

The above mathematical formulation indicates that the velocity, pressure, and temperature distributions are functions of the following three independent parameters:

$$B_1 = Gr \; cos\alpha \;, \quad B_2 = \left(\frac{Gr}{Re}\right) sin\alpha \;, \quad \text{and} \quad B_3 = Pr \qquad (3.16)$$

For the horizontal orientation ($\alpha = 0°$), the independent parameters reduce to Gr and Pr, while for the vertical orientation ($\alpha = 90°$), the only independent parameter is Gr/Re (dependence on Pr disappears because the secondary velocity components U and V vanish and the left-hand side of equation (3.14) goes to zero). The overall quantities, such as the friction factor and Nusselt number, will follow the same form of dependence.

The applicable boundary conditions are:

$$U = V = W = 0 \qquad \text{on all walls} \tag{3.17a}$$

$$T = 0 \qquad \text{on all walls for the H1 condition} \tag{3.17b}$$

$$\frac{\partial T}{\partial R} = \frac{1}{\pi + 2} \qquad \text{at } R = 1 \text{ for the H2 conditon} \tag{3.17c}$$

$$\frac{\partial T}{\partial \theta} = -\frac{R}{\pi + 2} \qquad \text{at } \theta = 0 \text{ for the H2 conditon} \tag{3.17d}$$

$$\frac{\partial T}{\partial \theta} = \frac{R}{\pi + 2} \qquad \text{at } \theta = \pi \text{ for the H2 conditon} \tag{3.17e}$$

Two important parameters used in engineering design are the average Nusselt number, given by

$$Nu = \frac{\overline{h}\, D_h}{k} = -\frac{2\,\pi}{(\pi + 2)^2}\,\frac{1}{T_{bulk}} \tag{3.18}$$

where T_{bulk} is the dimensionless bulk temperature defined as

$$T_{bulk} = \frac{2}{\pi}\int_0^{\pi}\int_0^1 W\ T\ R\ dR\ d\theta \tag{3.19}$$

and the product fRe, where the Fanning friction factor f is defined as the average wall shear stress divided by the kinetic energy per unit volume

$$f = \frac{\overline{\tau}_w}{\frac{1}{2}\,\rho\, w_m^2} \tag{3.20}$$

Wall Shear Stress

The wall shear stresses were evaluated for the geometry of the semicircular duct which has a curved wall and a flat wall. At the curved wall, τ_{w1} was formulated as follows

$$\tau_{w1} = \frac{\mu\, w_m}{r_o}\left(-\frac{\partial W}{\partial R}\right)_{R=1}$$

Similarly, the formulations for τ_{w2} and τ_{w3} at the top and bottom portions of the flat wall, respectively, are

$$\tau_{w2} = \frac{\mu\, w_m}{r_o}\left(\frac{\partial W}{R\partial\theta}\right)_{\theta=0}$$

$$\tau_{w3} = \frac{\mu\, w_m}{r_o}\left(-\frac{\partial W}{R\partial\theta}\right)_{\theta=\pi}$$

The parameter $\overline{\tau}_w$, was then calculated by averaging the wall shear stresses around the circumference of the duct. Thus

$$\bar{\tau}_w = \frac{1}{(2+\pi)}\left[\int_0^{\pi} \tau_{w1} d\theta + \int_0^1 \tau_{w2} dR + \int_0^1 \tau_{w3} dR\right]$$

The product of the Fanning friction factor and Reynolds number, fRe, was determined from the average wall shear stress and expressed in dimensionless form as

$$fRe = \frac{4\ \pi}{(\pi+2)^2}\left[\int_0^1 \left(\frac{\partial W}{R\partial \theta}\right)_{\theta=0} dR - \int_0^1 \left(\frac{\partial W}{R\partial \theta}\right)_{\theta=\pi} dR - \int_0^{\pi} \left(\frac{\partial W}{\partial R}\right)_{R=1} d\theta\right] \quad (3.21)$$

3.2 Computational Procedure

Governing equations (3.10) - (3.14) were solved numerically using a control-volume-based finite difference method [60]. The differential equations were discretized and the power law scheme of Patankar [60] was used for the treatment of the convection and diffusion terms. The velocity-pressure coupling was handled using the SIMPLER algorithm. A staggered grid was used in the computations with uniform subdivisions in the R and θ directions. The control volumes adjacent to the flat and curved walls were subdivided into two control volumes in order to capture the steep gradients in the velocity and temperature.

For given values of the input parameters B_1, B_2, and B_3, computations started from an initial guess of the fields (U, V, W, T, and dP_1/dZ). Typically, the initial guess used was $U = V = W = T = 0$ at all mesh points and $dP_1/dZ = 20$ (which is close to the forced-convection value). The discretized equations were solved simultaneously for each radial line using TDMA (tridiagonal-matrix algorithm) and the domain was covered by sweeping line by line in the angular direction. At the end of each iteration, a correction procedure was applied to the values of W and dP_1/dZ, using the conservation of mass, equation(3.22), in order to insure that the mean value of the dimensionless axial velocity, W_m, is equal to 1. This correction procedure follows the method outlined by Patankar and Spalding [61]. Thus, the converged velocity profile must satisfy the following condition:

$$\int_0^{\pi} \int_0^1 W \; R \, dR \, d\theta = \frac{\pi}{2} \tag{3.22}$$

As well, for the H2 boundary condition, the average wall temperature given by equation(3.23) was calculated and this value was subtracted from the temperature at all nodes, thus, insuring an average wall temperature of zero.

$$\overline{T}_w = \frac{1}{(2+\pi)} \left[\int_0^{\pi} T_{w1} d\theta + \int_0^1 T_{w2} dR + \int_0^1 T_{w3} dR \right] \tag{3.23}$$

where T_{w1}, T_{w2} and T_{w3} are the wall temperatures at the curved, top and bottom flat walls, respectively.

Iteration continued until the three velocity components and the temperature at all grid points, as well as the value of dP_1/dZ satisfied the following convergence criterion:

$$\left| \frac{\phi_{new} - \phi_{old}}{\phi_{new}} \right| \leq 10^{-6} \tag{3.24}$$

where ϕ is a scalar function. The computer codes for both boundary conditions (H1 and H2) are listed in Appendix A.

Table 3.1: Effect of grid size on fRe and Nu for semicircular ducts ($Gr = 0$)

Mesh size	$(fRe)_o$	$(Nu_{H1})_o$	$(Nu_{H2})_o$
15×24	15.69	4.073	2.949
30×48	15.75	4.086	2.926
60×96	15.76	4.090	2.922
Exact value [62]	15.77	4.089	2.923

3.3 Numerical Accuracy

Numerical experimentation was conducted in order to determine the appropriate grid size. Three different grid sizes for pure forced convection were used and the results are presented in Table 3.1 for $(fRe)_o$, $(Nu_{H1})_o$, and $(Nu_{H2})_o$. Further, the numerical results of fRe and Nu for buoyancy-assisted and buoyancy-opposed mixed convection with different grid sizes are presented in Table 3.2 for $Re = 1500$, $Gr = 1 \times 10^5$, $Pr = 7$, and $\alpha = \pm 30°$. Examining the results in Table 3.2, it can be seen that the 30×48 ($R \times \theta$) grid is capable of producing Nu and fRe values that are within 1.3% and 0.12%, respectively, from the corresponding values produced by the 60×96 grid. In view of the large amount of computation required in this investigation, it was decided to use a (30×48) grid as a reasonable compromise between accuracy and computer time. Based on the results in Table 3.2 and the comparisons with

Table 3.2: Effect of grid size on fRe and Nu for $Gr = 1 \times 10^5$ and $Re = 1500$

α	*Mesh size*	H1		H2	
		Nu	fRe	Nu	fRe
30°	15 × 24	7.706	16.41	5.735	16.18
	30 × 48	7.390	16.42	5.485	16.24
	60 × 96	7.319	16.43	5.413	16.26
−30°	15 × 24	7.663	16.17	4.962	15.61
	30 × 48	7.347	16.14	4.771	15.63
	60 × 96	7.275	16.14	4.718	15.63

previous results (given in the following section), it can be stated that the numerical uncertainty in the present results is within $2 - 3\%$.

3.4 Comparison With Previous Results

For the forced-convection case (see Table 3.1), the present numerical grid of (30×48) produced $(fRe)_o = 15.75$, $(Nu_{H1})_o = 4.086$, and $(Nu_{H2})_o = 2.926$. These values are within 0.13%, 0.073%, and 0.1%, respectively from the exact solution

Table 3.3: Comparison between the present results and those of Dong and Ebadian [20]

Gr/Re	$-dP_1/dZ$		Nu_{H1}	
	Present	[20]	*Present*	[20]
0	21.09	21.11	4.086	4.088
128	29.97	30.00	4.313	4.314
1284	95.96	96.16	5.795	5.780
6440	296.4	297.9	8.831	8.772

reported in [62]. For buoyancy-assisted mixed convection in the vertical orientation, a comparison with the results in [20] is shown in Table 3.3. For the whole range of Gr/Re covered in [20], the two sets of results in Table 3.3 agree to within 0.5% in dP_1/dZ and to within 0.7% in Nu_{H1}. For the horizontal orientation, the results in [6, 9] correspond to the case where the flat wall of the duct is in a horizontal position and therefore, these could not be used for comparison. The results in [5] for the horizontal semicircular ducts with a vertical flat wall are practically identical to the present results for H1 because the present code is an extension of the code used in [5].

CHAPTER 4

NUMERICAL RESULTS

Solutions were obtained for buoyancy-assisted (upward) and buoyancy-opposed (downward) flows using the H1 and H2 thermal boundary conditions. A single value of Prandtl number, $Pr = 7$ (water) was used in all computations. However, wide ranges of B_1 and B_2 were covered providing results for the whole range of inclinations, $-\pi/2 \leq \alpha \leq \pi/2$, and wide ranges of Re and Gr. For each combination of α and Re (i.e., a fixed value of B_2/B_1), the solution was obtained for different values of Gr (by changing B_1 or B_2) until flow reversal was detected. It was decided not to advance the solution into the flow-reversal region because the parabolized flow behavior assumed in this study would not be applicable in this region.

In the following sections, detailed results for a representative sample of the velocity and temperature profiles are presented first, followed by an examination of the behavior of the overall quantities fRe and Nu.

4.1 Velocity and Temperature Distributions

A sample of the velocity and temperature results is presented in this section. It was decided to use α, Re, Pr, and Gr as independent parameters in these figures, rather than B_1, B_2, and B_3, in order to illustrate explicitly the effects of free convection and duct inclination for both thermal boundary conditions. All the results presented in this section correspond to $Re = 500$ and $Pr = 7$. The velocity and temperature contours were plotted at equal intervals between the indicated maximum and minimum values of the respective field.

4.1.1 Horizontal Orientation

For the horizontal orientation, figures 4.1 to 4.4 show that the maximum velocity and the minimum temperature shift to the lower part of the duct cross-section due to the secondary flow motion associated with free convection. It should be noted that the buoyancy force, which acts normal to the main flow, drives the secondary flow and causes this shift in the maximum velocity and the minimum temperature from the center ($\theta = \pi/2$).

The distortion in the velocity and temperature distributions increases with Gr for the H1 condition. At $Gr = 2 \times 10^6$, the maximum velocity and minimum temperature in figure 4.2 move significantly downward towards the lower part of the duct. In the H2 boundary condition, shown in figures 4.3 and 4.4, a strong variation in the wall temperature around the circumference (high at the top and low at the bottom) causes temperature stratification with layers of hot fluid occupying the upper part of the cross-section. As a result, the strength of the secondary flow is expected to be much lower for the H2 case than for the H1 case. Consequently, the enhancement in fRe and Nu due to free convection is expected to be much more pronounced for the H1 case than for the H2 case, as shown later.

4.1.2 Upward Inclination

The case of upward inclination is illustrated in this section for the H1 and H2 thermal boundary conditions with $\alpha = 30°$ and $60°$. Starting with $Gr = 1 \times 10^5$ for

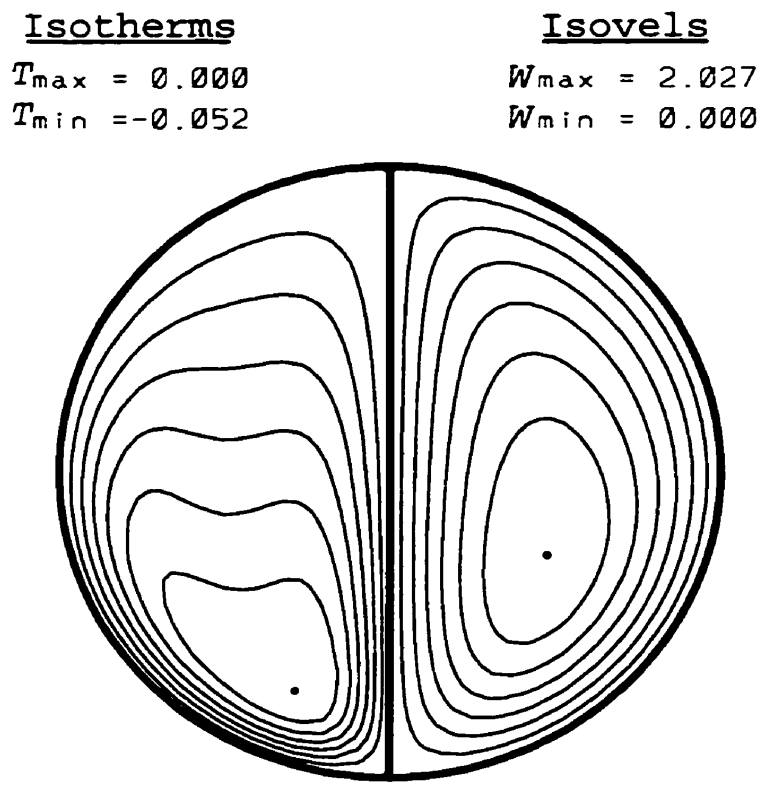


Figure 4.1: Velocity and temperature contours for H1, $\alpha = 0°$ and $Gr = 1 \times 10^5$

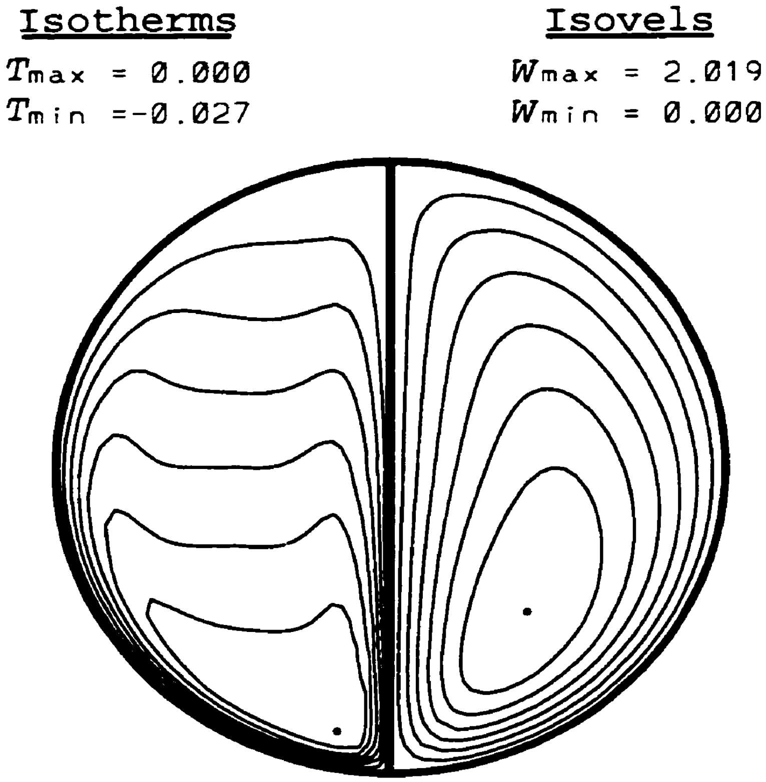


Figure 4.2: Velocity and temperature contours for H1, $\alpha = 0°$ and $Gr = 2 \times 10^6$

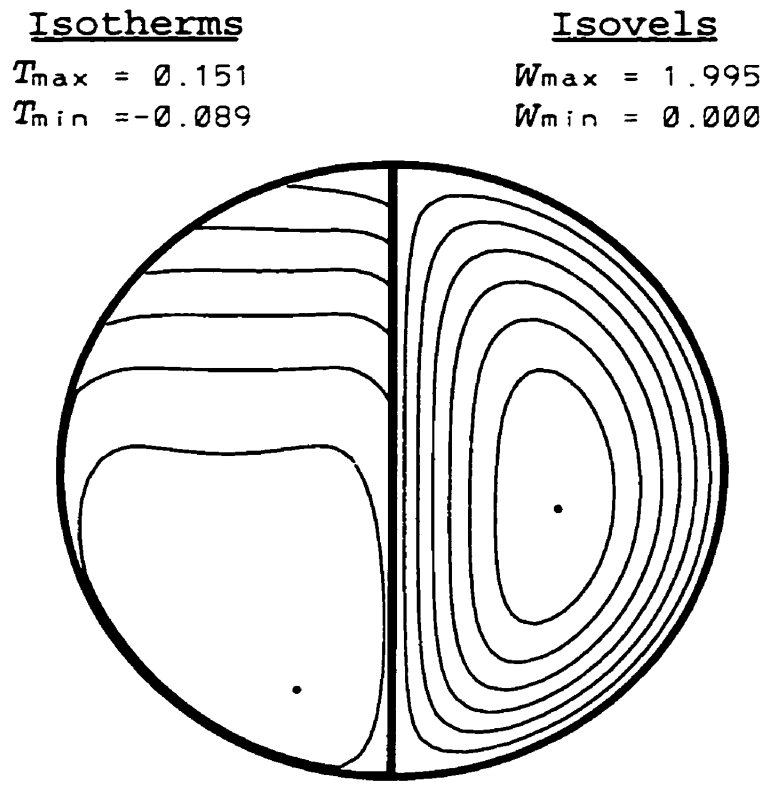


Figure 4.3: Velocity and temperature contours for H2, $\alpha = 0°$ and $Gr = 1 \times 10^5$

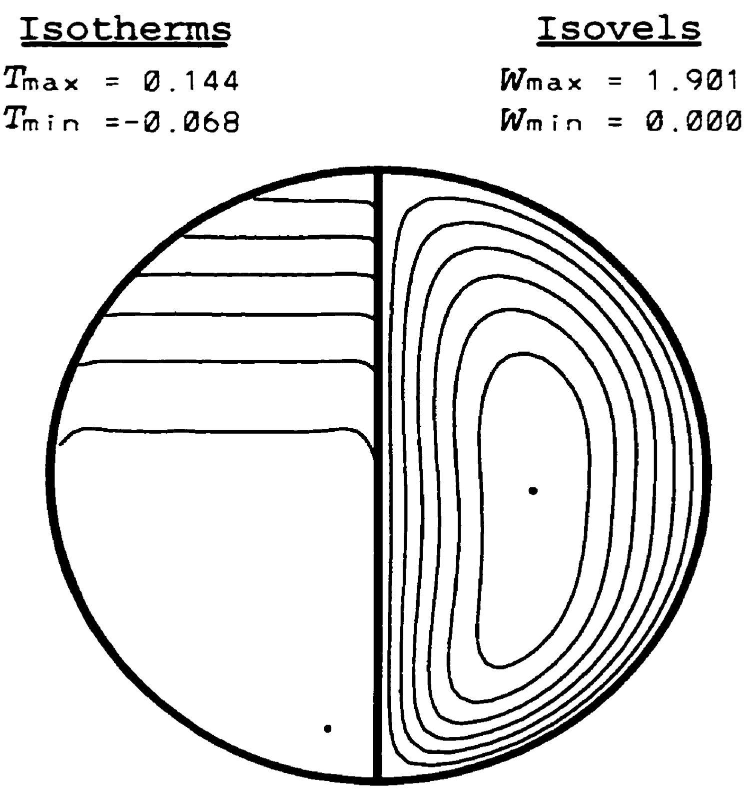


Figure 4.4: Velocity and temperature contours for H2, $\alpha = 0°$ and $Gr = 2 \times 10^6$

the H1 thermal boundary condition, figure 4.5 shows the isovels and isotherms for $\alpha = 30°$. Comparing with the velocity contours for $\alpha = 0°$ in figure 4.1, the maximum velocity in figure 4.5 is slightly shifted upwards towards the center ($\theta = \pi/2$), and the maximum velocity in figure 4.6 for $\alpha = 60°$ is moved further upwards towards $\theta = \pi/2$. However, the isotherms in figures 4.5 and 4.6 look similar to the ones in figure 4.1 for the horizontal case where the minimum temperature is confined to the lower part of the cross-section.

In upward inclinations, the net body force is no longer perpendicular to the main flow, since a component also exists in the flow direction. Thus only a component of the buoyancy force is driving the secondary flow due to inclination. As Gr increases, the velocity increases in the upper part of the cross-section and decreases in the lower part, as shown in figure 4.8 for $Gr = 2 \times 10^6$ and $\alpha = 60°$. The location of W_{max} within the cross-section appears to be dependent on Gr and α for upward inclinations.

Considering equation (3.13), we can see that as Gr increases and α increases from $\alpha = 0°$ to $90°$, the contribution of the terms $U\frac{\partial W}{\partial R}$ and $\frac{V}{R}\frac{\partial W}{\partial \theta}$ vary from maximum to minimum, whereas the contribution of the buoyancy term $\frac{Gr}{Re}Tsin\alpha$ varies from zero to maximum. For the horizontal orientation ($\alpha = 0°$), the contribution of the terms $U\frac{\partial W}{\partial R}$ and $\frac{V}{R}\frac{\partial W}{\partial \theta}$ is to shift the maximum velocity towards the lower part of the cross-section since the term $\frac{Gr}{Re}Tsin\alpha$ is zero. For the vertical case ($\alpha = 90°$), W_{max} depends only on the relative magnitude of $\frac{Gr}{Re}Tsin\alpha$ because the secondary velocity components U and V disappear. At $\alpha = 60°$ and $Gr = 2 \times 10^6$ (shown in figure 4.8), the maximum velocity is pushed towards the upper part of the cross-section because of the buoyancy term $\frac{Gr}{Re}Tsin\alpha$ dominates over the terms $U\frac{\partial W}{\partial R}$ and $\frac{V}{R}\frac{\partial W}{\partial \theta}$. In the meantime, cooler fluid shifts to the lower part of the tube, as noted in [40, 47].

The H2 thermal boundary condition is illustrated in figures 4.9 to 4.12. At lower Gr (e.g., $Gr = 1 \times 10^5$), temperature stratification still occupies a major part of

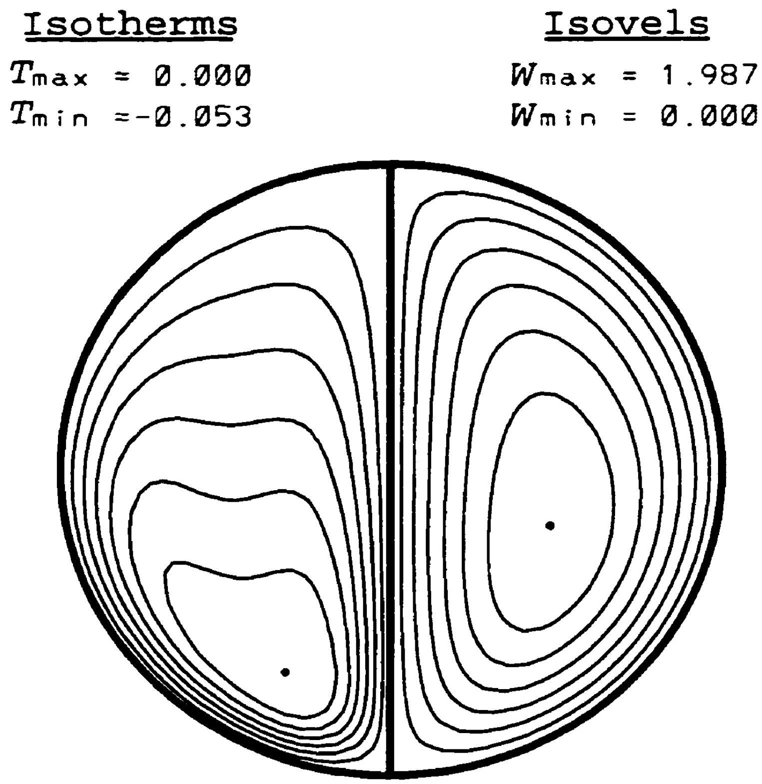


Figure 4.5: Velocity and temperature contours for H1, $\alpha = 30°$ and $Gr = 1 \times 10^5$

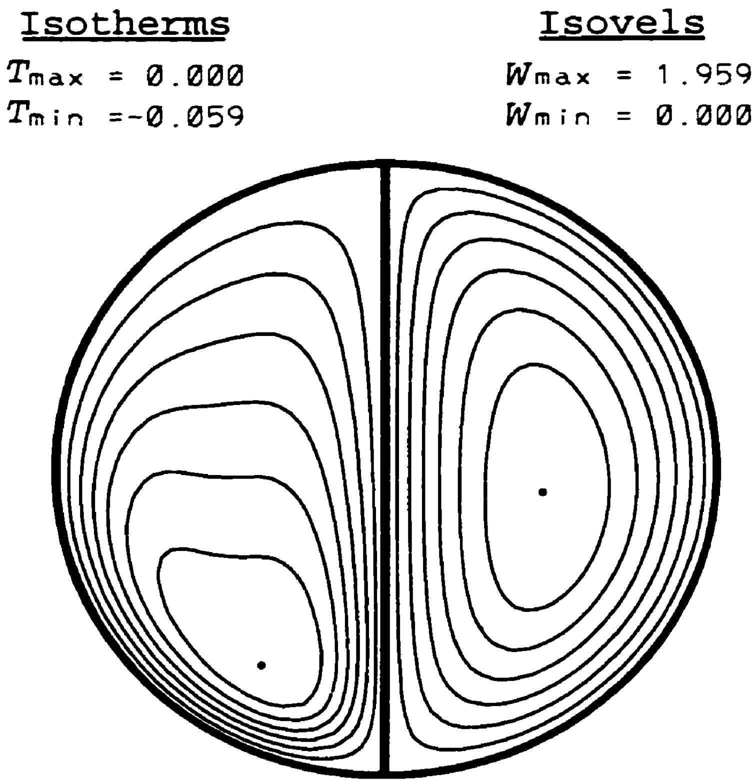


Figure 4.6: Velocity and temperature contours for H1, $\alpha = 60°$ and $Gr = 1 \times 10^5$

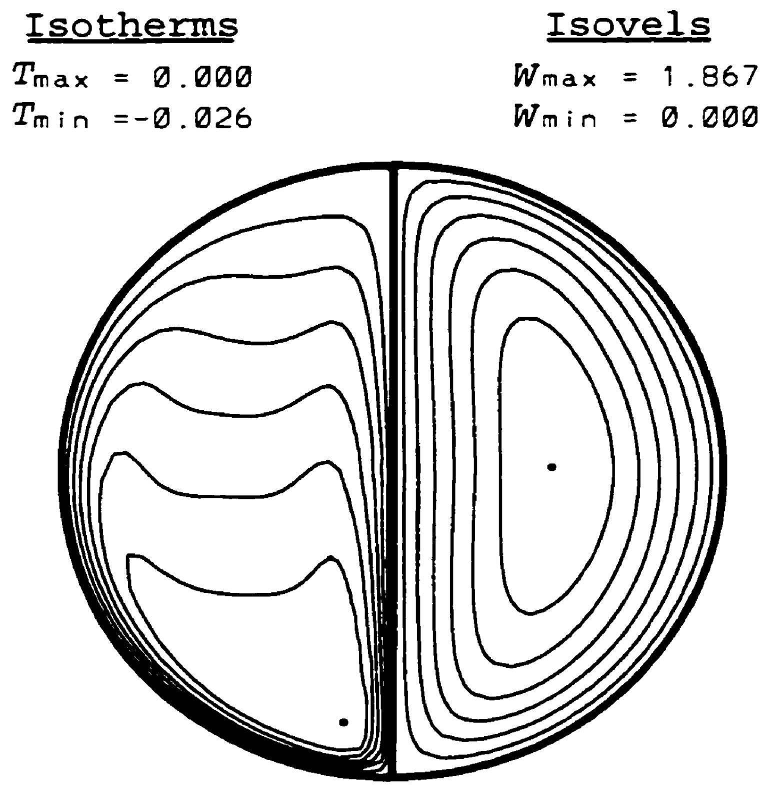


Figure 4.7: Velocity and temperature contours for H1, $\alpha = 30°$ and $Gr = 2 \times 10^6$

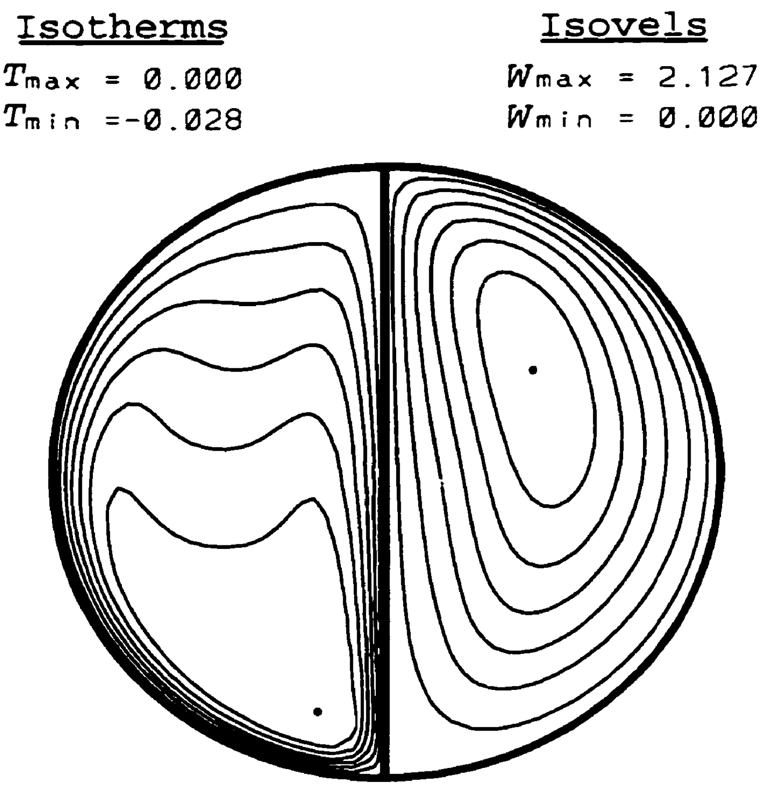


Figure 4.8: Velocity and temperature contours for H1, $\alpha = 60°$ and $Gr = 2 \times 10^6$

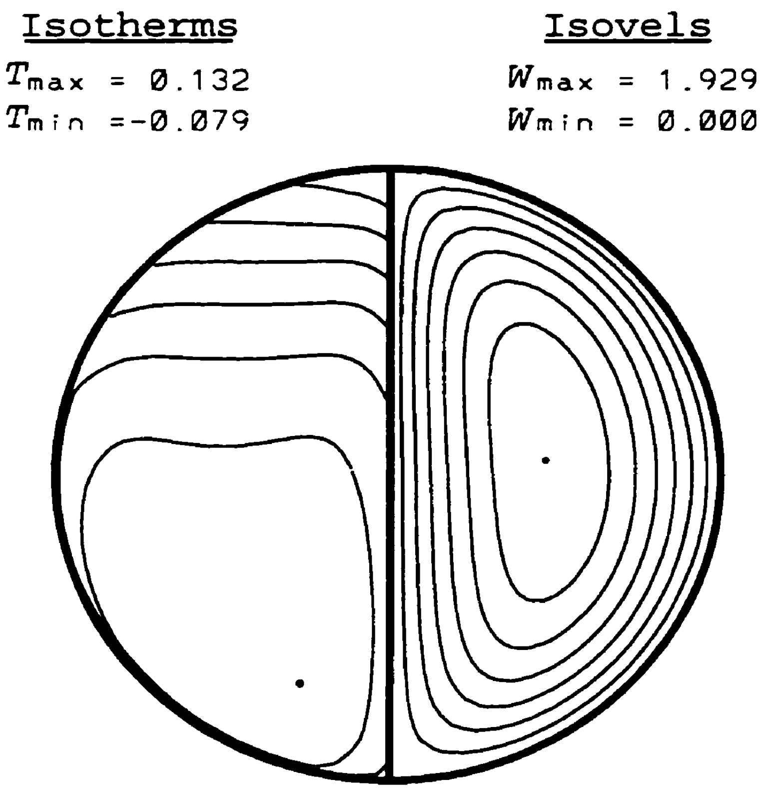


Figure 4.9: Velocity and temperature contours for H2, $\alpha = 30°$ and $Gr = 1 \times 10^5$

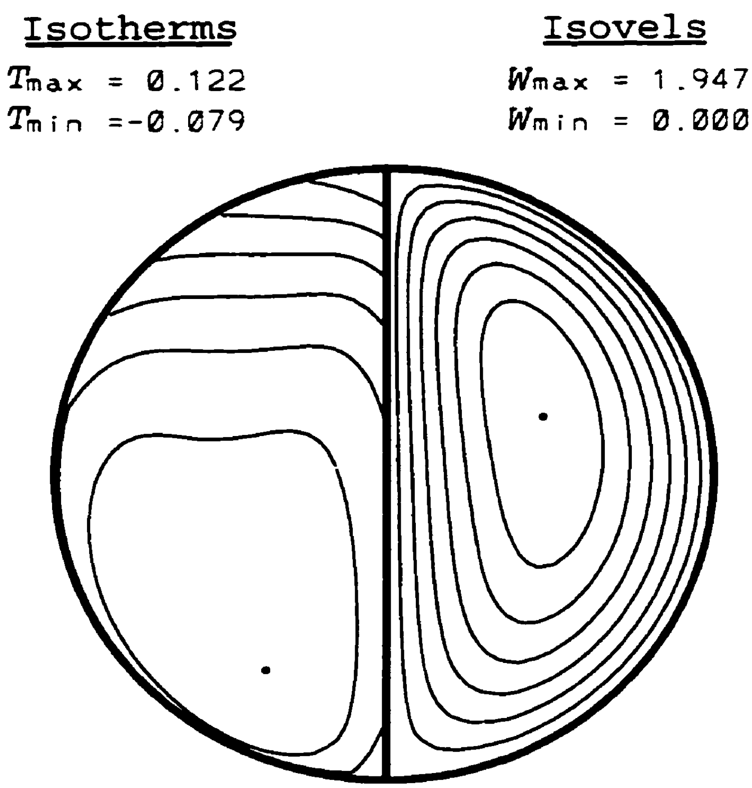


Figure 4.10: Velocity and temperature contours for H2, $\alpha = 60°$ and $Gr = 1 \times 10^5$

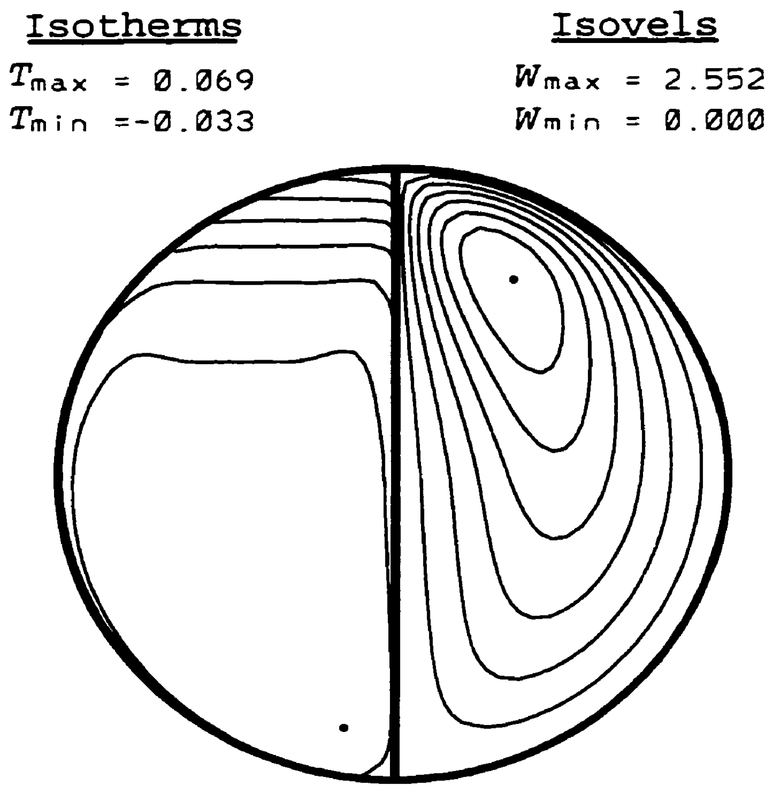


Figure 4.11: Velocity and temperature contours for H2, $\alpha = 30°$ and $Gr = 2 \times 10^6$

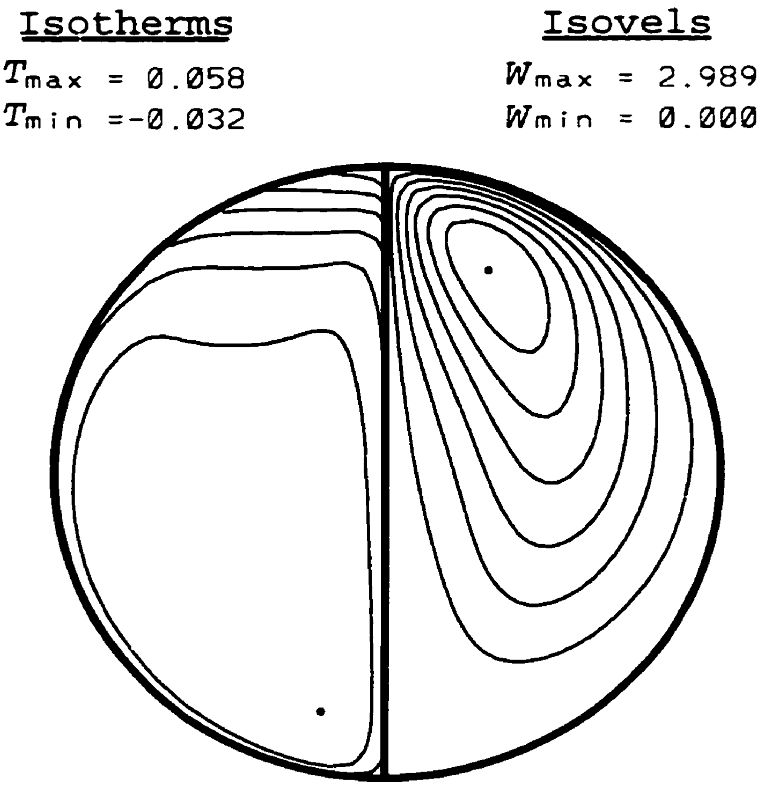


Figure 4.12: Velocity and temperature contours for H2, $\alpha = 60^\circ$ and $Gr = 2 \times 10^6$

the cross-section as shown in figures 4.9 and 4.10 for $\alpha = 30°$ and $60°$, respectively. Compared with the isovels shown in figure 4.3, the position of the maximum velocity in figure 4.9 has now moved slightly above $\theta = \pi/2$, while, the maximum velocity in figure 4.10 is shifted still further above $\theta = \pi/2$.

At a high enough Gr (e.g., $Gr = 2 \times 10^6$) the maximum velocity shifts considerably towards the upper part of the cross-section and temperature stratification largely disappears indicating much less circumferential variation in the wall temperature, as shown in figures 4.11 and 4.12 for $\alpha = 30°$ and $60°$, respectively. Consequently, the corresponding secondary flow is expected to be stronger than that for the horizontal case.

Due to temperature stratification in H2, Nu is expected to be lower for H2 than for H1 at low values of Gr. However, for high values of Gr, Nu_{H2} may exceed Nu_{H1} for some upward inclinations. Further, due to the axial component of the buoyancy force, the velocity in H2 increases more in the upper part of the cross-section with hotter fluid than H1. Thus, fRe is expected to be higher for H2 than for H1 at high values of Gr, as shown later.

4.1.3 Downward Inclination

For the downward inclination, the buoyancy force has two components, one normal to the main flow direction thus driving the secondary flow within the cross-section, and the other axial component acts against the streamwise direction thus retarding the main flow near the wall. For the H1 condition, the secondary flow shifts the locations of the maximum velocity and minimum temperature towards the lower part of the cross-section. This situation appears to be opposite to the case of upward inclination, where the contribution of the buoyancy term $\frac{Gr}{Re} T sin\alpha$ in the axial momentum equation is to move the maximum velocity towards the upper part of the cross-section.

For the H1 thermal boundary condition, at $Gr = 1 \times 10^5$ the isovels and isotherms in figures 4.13 and 4.14, for $\alpha = -30°$ and $-60°$, respectively, are very similar to the ones in figure 4.1 for the horizontal case. As Gr increases, the shift of the maximum velocity and the minimum temperature towards the lower part of the cross-section increases, as shown in figures 4.15 and 4.16.

For the H2 condition, at low Gr (e.g., $Gr = 1 \times 10^4$) temperature stratification occupies a major part of the cross-section, as shown in figures 4.17 and 4.18 for $\alpha = -30°$ and $-60°$, respectively, while the axial velocity contours are nearly the same as the ones for the forced convection ($Gr = 0$), with the maximum velocity very close to the center ($\theta = \pi/2$) of the duct.

As Gr increases to 5×10^4 for $\alpha = -30°$ in figure 4.19 and for $\alpha = -60°$ in figure 4.20, temperature stratification actually becomes more severe, which is consistent with the wall-temperature results shown later.

It can be seen that for the downward inclination, the isotherms in H2 show a drastic variation of the temperature. Stratification occupies a major part of the cross-section as compared with H1. Thus the intensity of the secondary flow is expected to be considerably less than that for H1.

4.1.4 Vertical Orientation

The case of vertical orientations in upward ($\alpha = 90°$) and downward ($\alpha = -90°$) flow is presented in this section. Under the effects of free convection the velocity and temperature distributions become different from the one corresponding to pure forced convection ($Gr = 0$). In general, for $\alpha = 90°$ the secondary flow is in the same direction as the main flow and therefore, the fluid near the duct wall accelerates

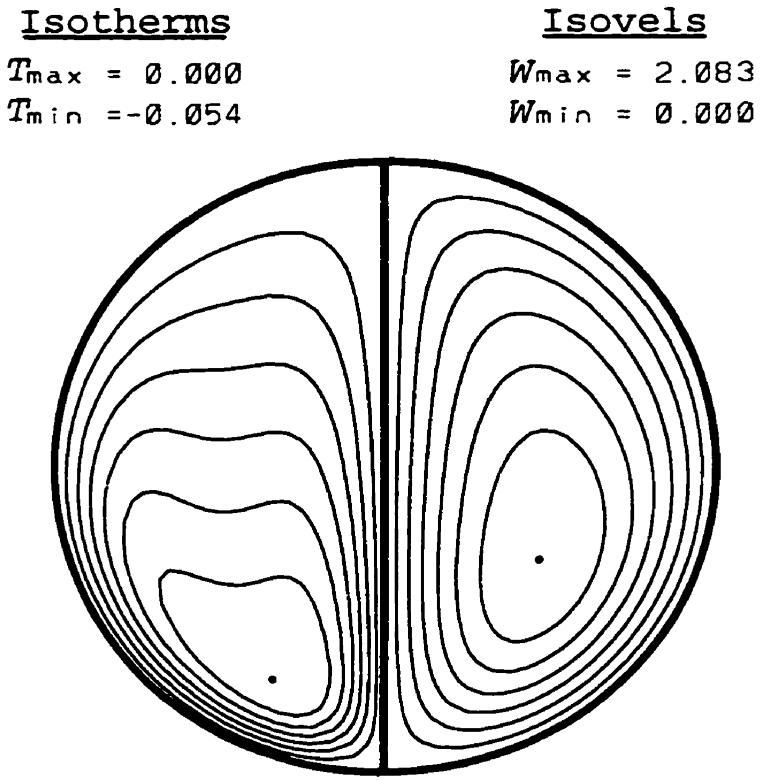


Figure 4.13: Velocity and temperature contours for H1, $\alpha = -30°$ and $Gr = 1 \times 10^5$

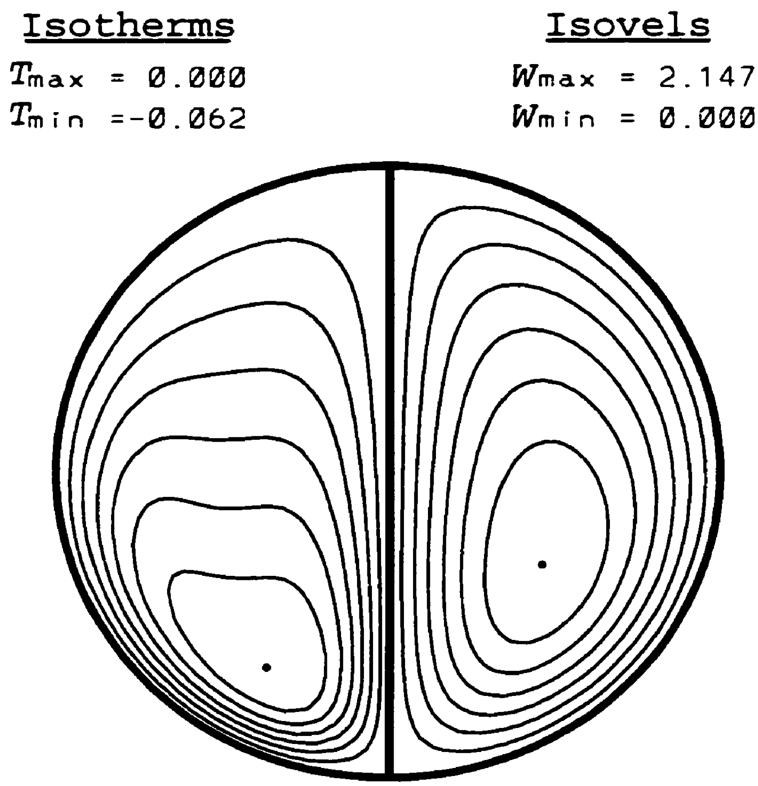


Figure 4.14: Velocity and temperature contours for H1, $\alpha = -60°$ and $Gr = 1 \times 10^5$

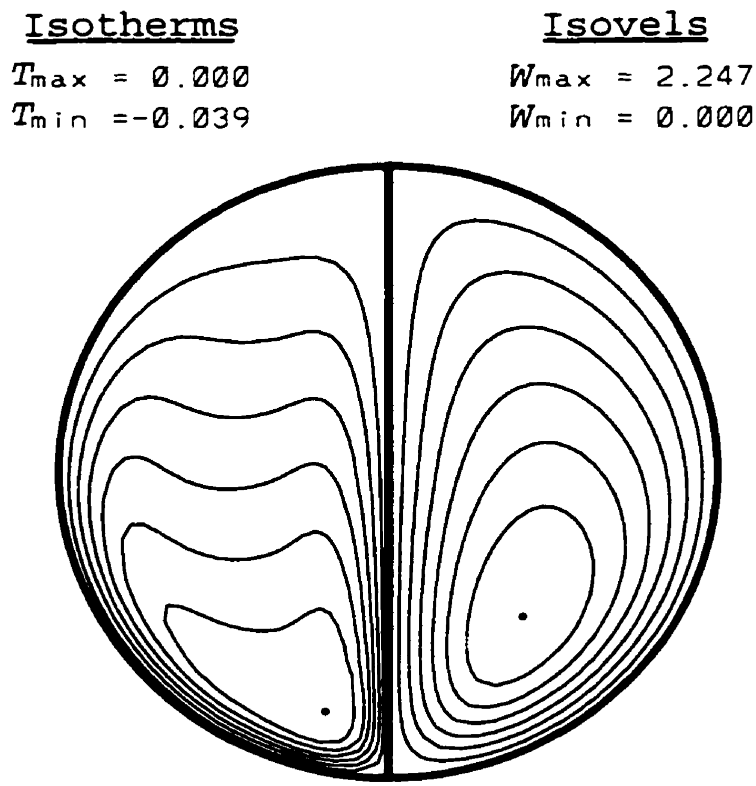


Figure 4.15: Velocity and temperature contours for H1, $\alpha = -30°$ and $Gr = 5 \times 10^5$

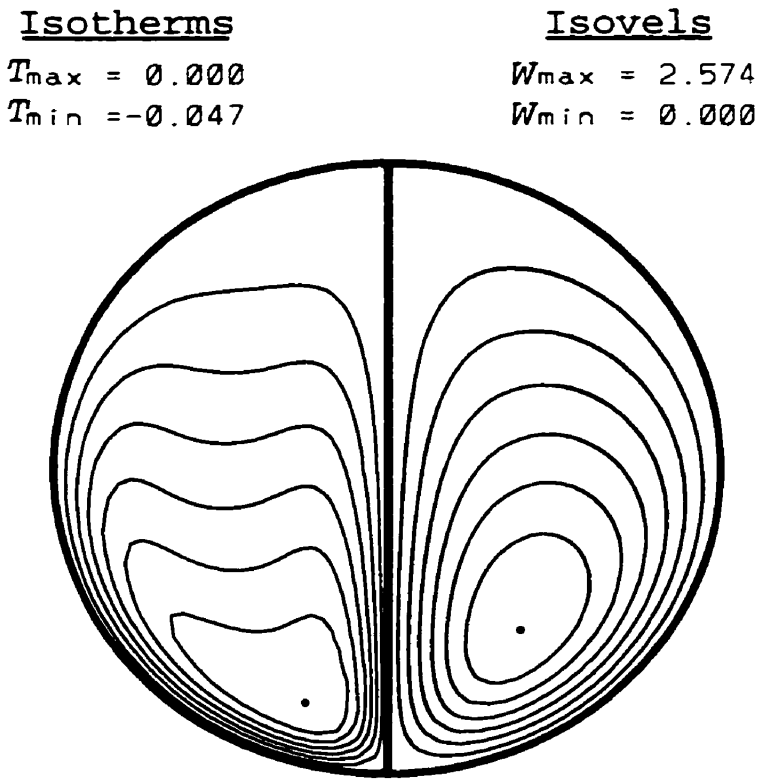


Figure 4.16: Velocity and temperature contours for H1, $\alpha = -60°$ and $Gr = 5 \times 10^5$

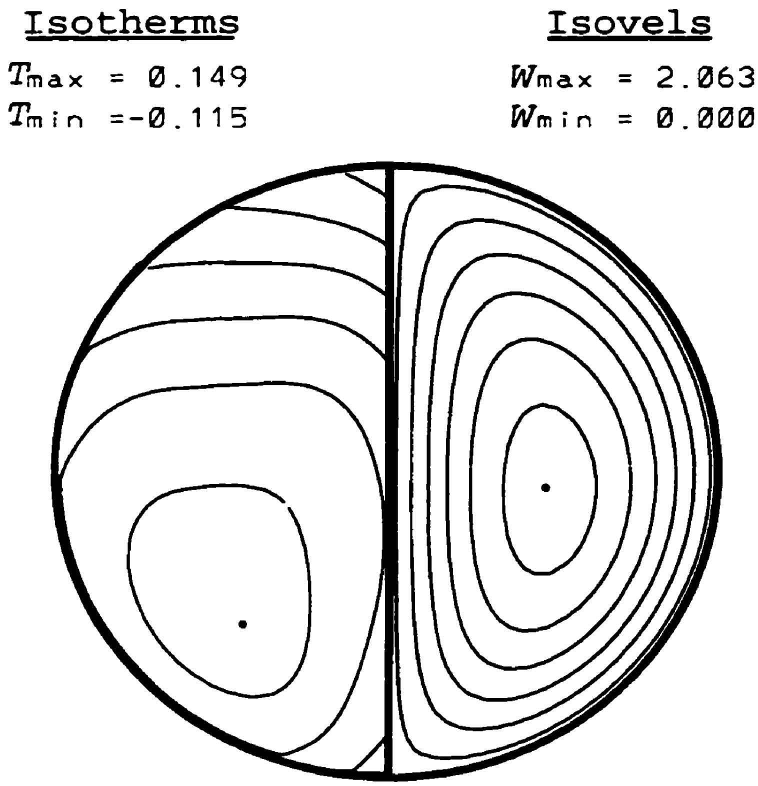


Figure 4.17: Velocity and temperature contours for H2, $\alpha = -30°$ and $Gr = 1 \times 10^4$

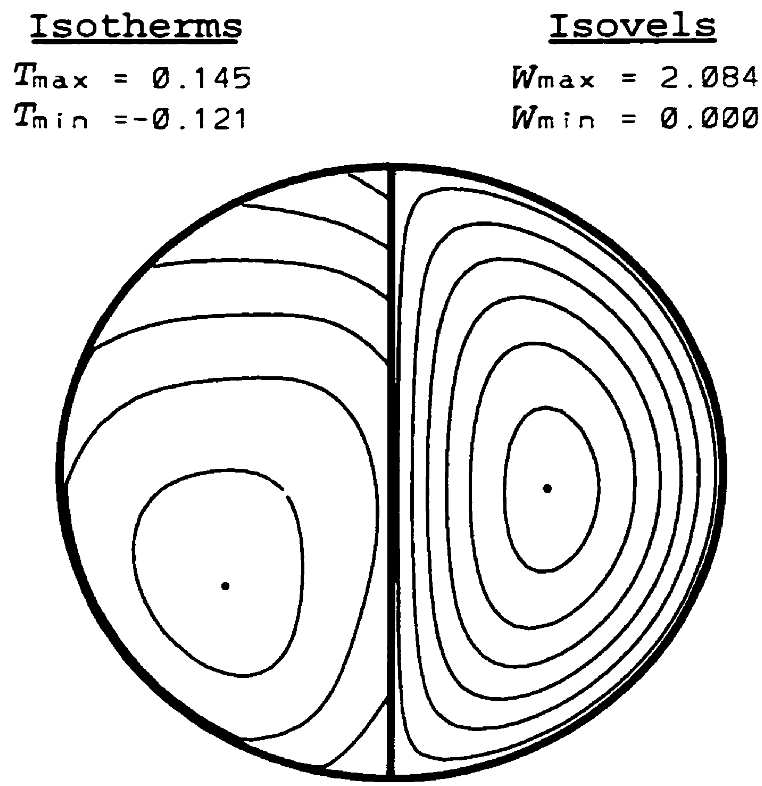


Figure 4.18: Velocity and temperature contours for H2, $\alpha = -60°$ and $Gr = 1 \times 10^4$

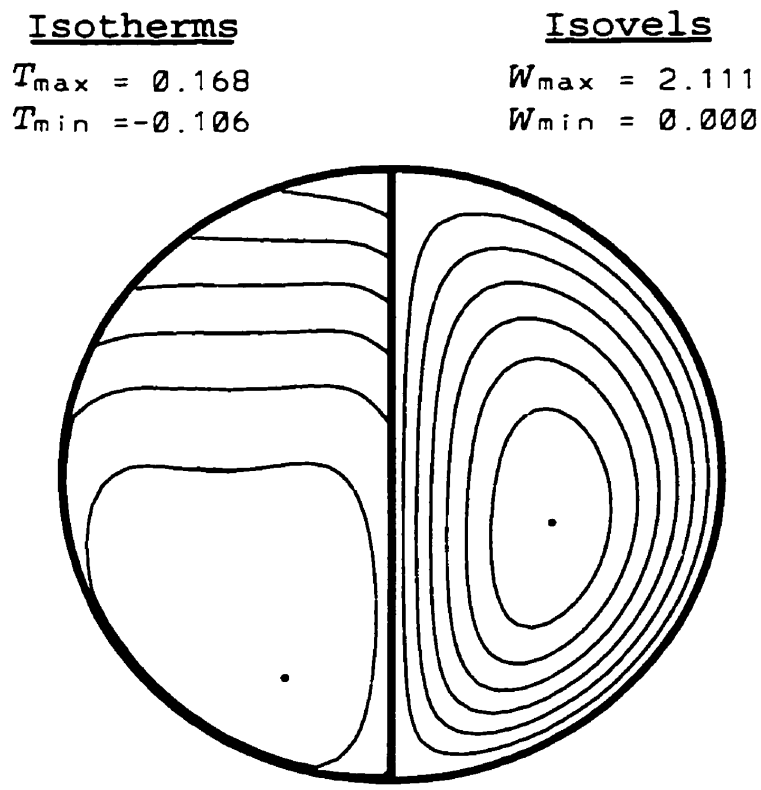


Figure 4.19: Velocity and temperature contours for H2, $\alpha = -30°$ and $Gr = 5 \times 10^4$

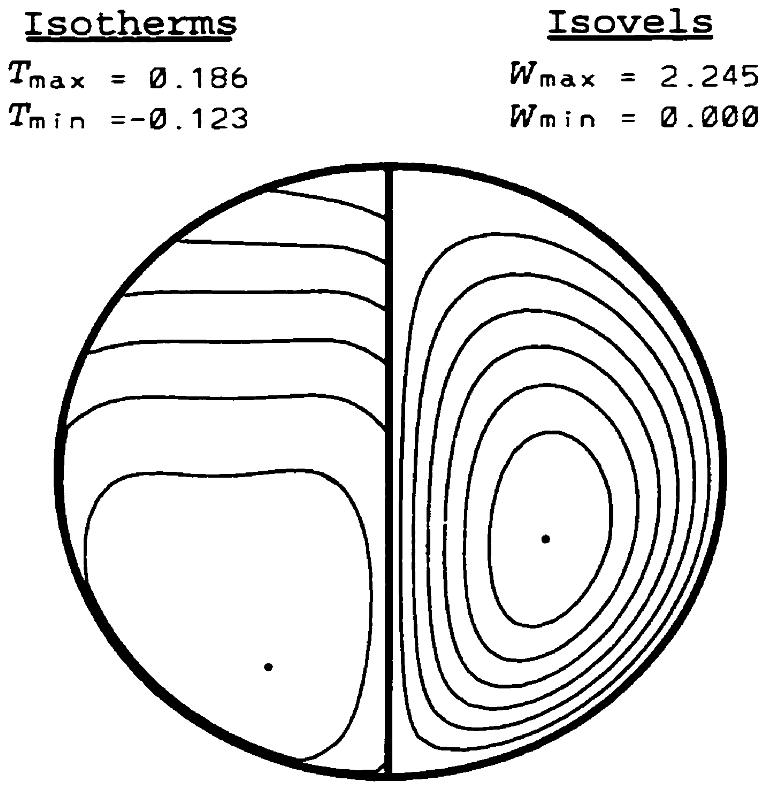


Figure 4.20: Velocity and temperature contours for H2, $\alpha = -60°$ and $Gr = 5 \times 10^4$

upwards forcing the fluid in the core to decelerate. For $\alpha = -90°$, however, the secondary flow is opposite to the main flow direction and thus resulting in an increase in the axial velocity in the core, and deceleration near the wall.

Figure 4.21a shows the isotherms and isovels at $Gr = 1 \times 10^5$ for the H1 case. The temperature and velocity contours are similar to the ones corresponding to pure forced flow, where the location of the maximum velocity and minimum temperature is confined to the horizontal radius ($\theta = \pi/2$). On the other hand, at the same Gr (shown in figure 4.22a), temperature stratification occupies the upper and lower parts of the cross-section in the H2 boundary condition and the isovels indicate high velocity gradients near the duct walls. However, the position of the maximum velocity and minimum temperature is still confined to the horizontal radius.

At high Gr (e.g., $Gr = 2 \times 10^6$) with $\alpha = 90°$, the isovels and isotherms for H1 and H2 get considerably distorted. The concentration of the isovel curves near the duct wall, for both thermal boundary conditions, leads to increased wall shear. These isovels increase in magnitude along the radial line up to a certain r. Beyond that the isovels start decreasing to minimum indicating a minimum velocity at the core. In the mean time, the high concentration of isotherms near the wall shows high temperature gradient. The area enclosed by the velocity contour at the top corner of the duct for H1 (figure 4.21b) and the smaller one for H2 (figure 4.22b) are high velocity contours. It can be seen that, the temperature stratification in H2 (figure 4.22b) is considerably reduced indicating much less circumferential variation in the wall temperature. The isovels for H2 are slightly more concentrated near the wall which resulted in a slight increase in the wall shear as compared with the H1. Further, the concentration of the isotherm contours near the duct v.all, for both H1 and H2, leads to increased heat transfer. These concentrations of the isovels and isotherms near the duct wall are consistent with [27].

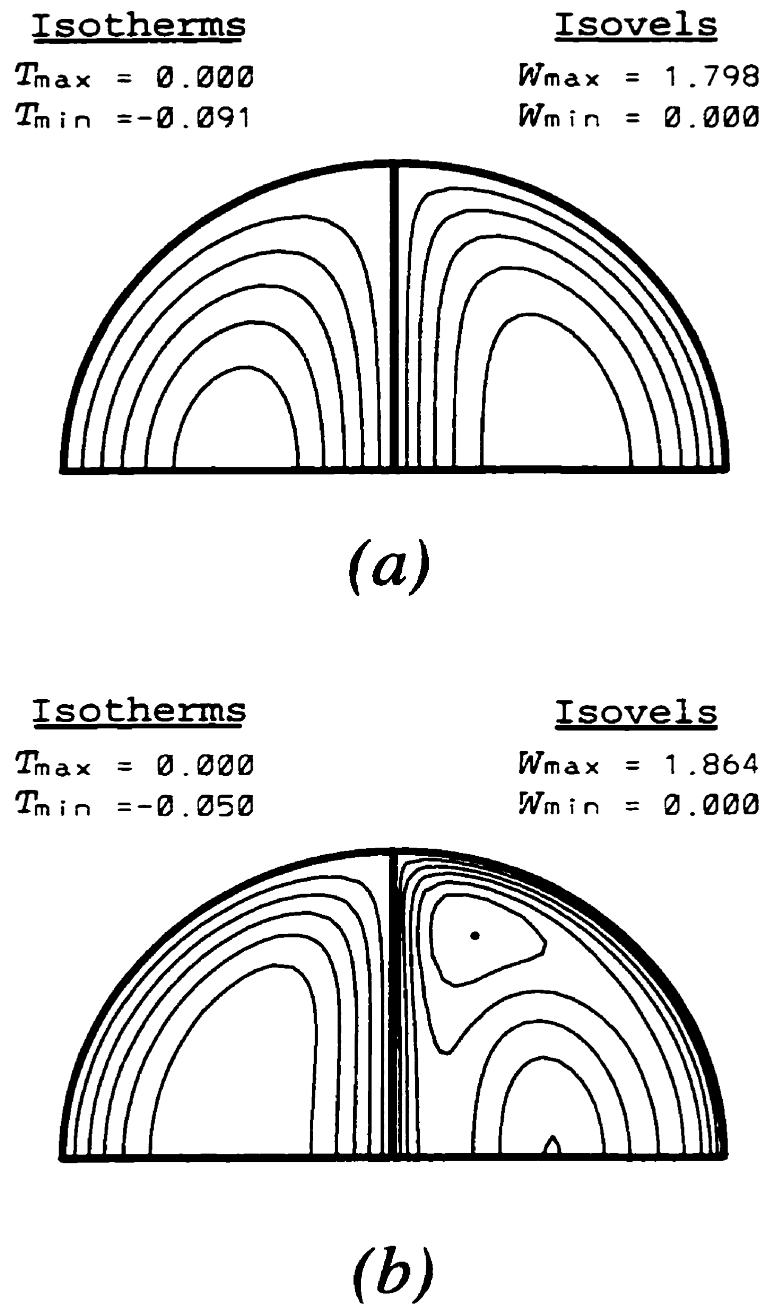


Figure 4.21: Velocity and temperature contours for H1, $\alpha = 90°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

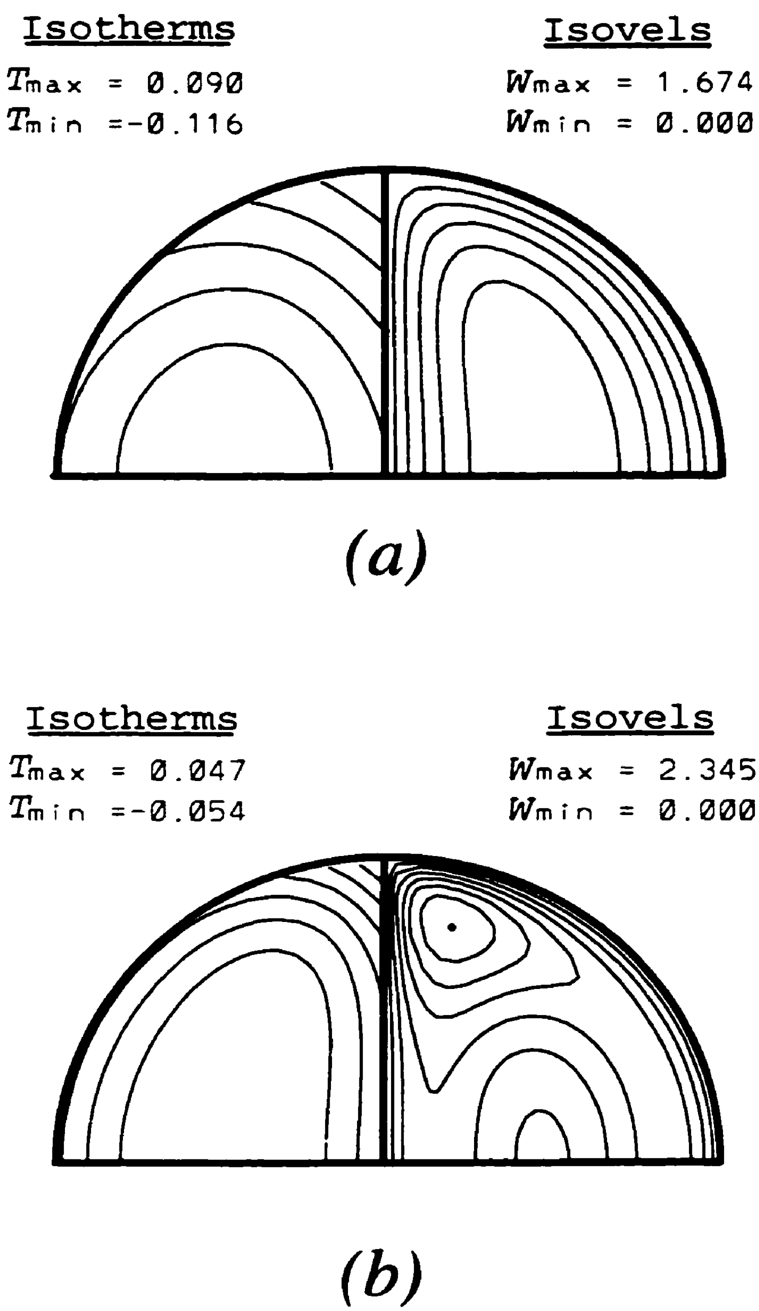


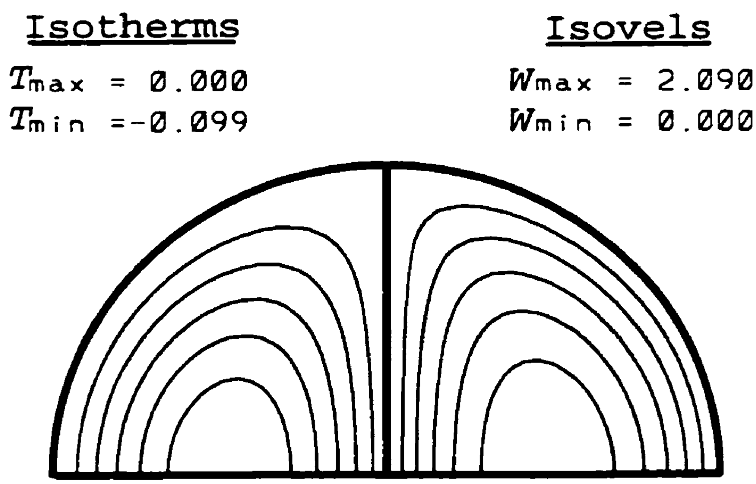
Figure 4.22: Velocity and temperature contours for H2, $\alpha = 90°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

With $\alpha = -90°$, the maximum velocity and minimum temperature are located at the horizontal radius ($\theta = \pi/2$) of the cross-section, as shown in figures 4.23 and 4.24. For the H2 thermal boundary condition, temperature stratification still occupies the upper and lower parts of the cross-section. Figures 4.23a and 4.24a for H1 and H2, respectively, show the velocity and temperature contours for $Gr = 1 \times 10^4$. The isovels and isotherms in these figures are nearly the same as the ones for the pure forced convection. With increasing Gr, it can be seen in both thermal boundary conditions that the maximum velocity increases in magnitude but is still confined to the center. The difference in temperature (between T_{max} and T_{min}) is also increased, as shown in figures 4.23b and 4.24b. Consequently, fRe and Nu for both thermal boundary conditions are expected to be lower than those for pure forced convection, as shown later.

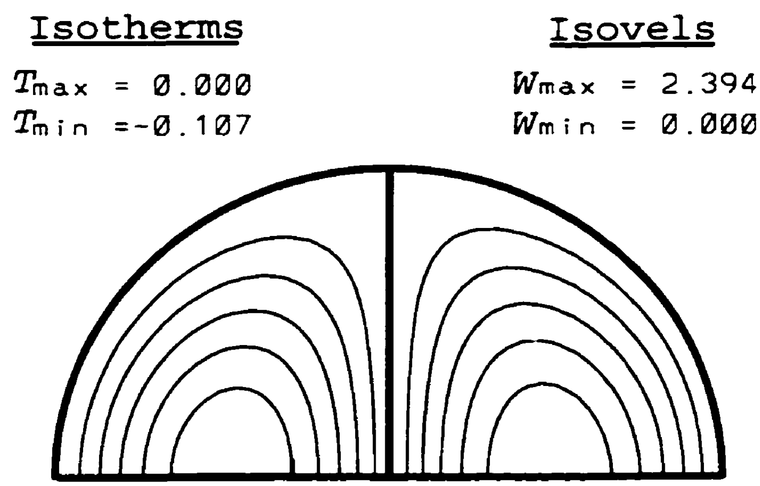
4.2 Secondary Flow Pattern

An examination of the secondary flow pattern is presented in this section. It is important to mention that the independent parameters used in presenting these results are α, Re, Pr and Gr rather than B_1, B_2 and B_3, in order to provide a complete understanding of the flow characteristics, by observing the secondary flow pattern for buoyancy aided and opposed flow with different inclinations and different thermal boundary conditions. The cross-stream velocity vectors are the resultant of the radial and angular velocity components U and V, respectively. All the results in this section correspond to $Re = 500$ and $Pr = 7$.

The case of horizontal orientation is illustrated in figures 4.25 and 4.26 for the H1 and H2 thermal boundary conditions, respectively. Figure 4.25a shows two counter rotating secondary flow cells, one large cell with upward flow along the heated flat

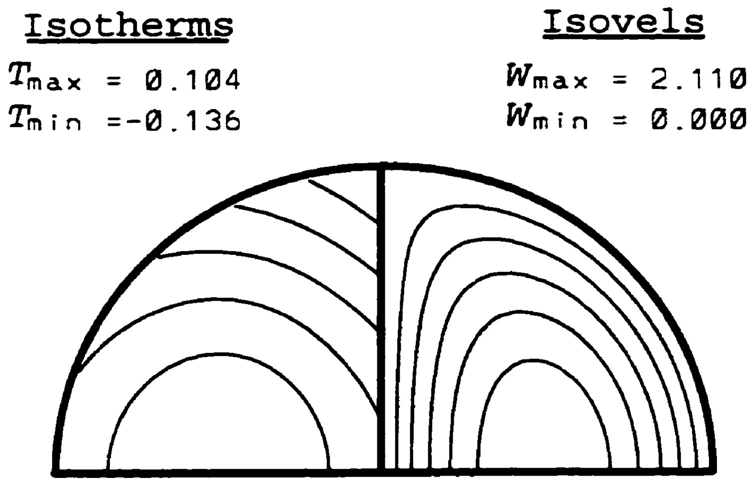


(a)

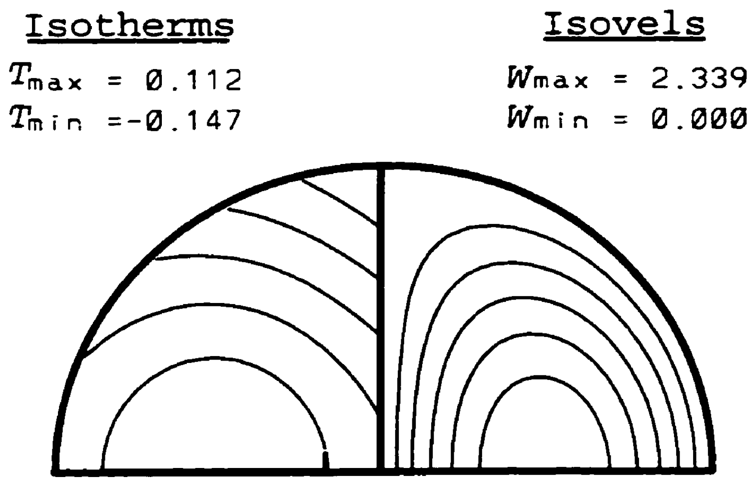


(b)

Figure 4.23: Velocity and temperature contours for H1, $\alpha = -90°$; (a) $Gr = 1 \times 10^4$ and (b) $Gr = 1 \times 10^5$



(a)



(b)

Figure 4.24: Velocity and temperature contours for H2, $\alpha = -90°$; (a) $Gr = 1 \times 10^4$ and (b) $Gr = 5 \times 10^4$

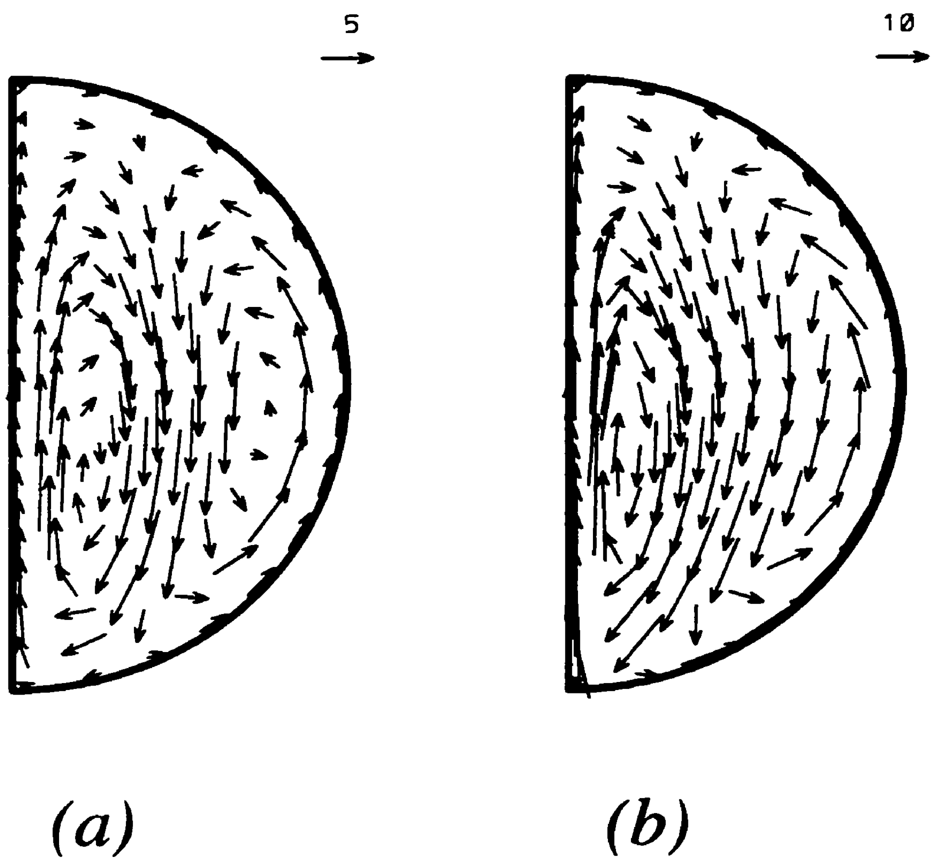


Figure 4.25: Secondary flow pattern for H1 with $\alpha = 0°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

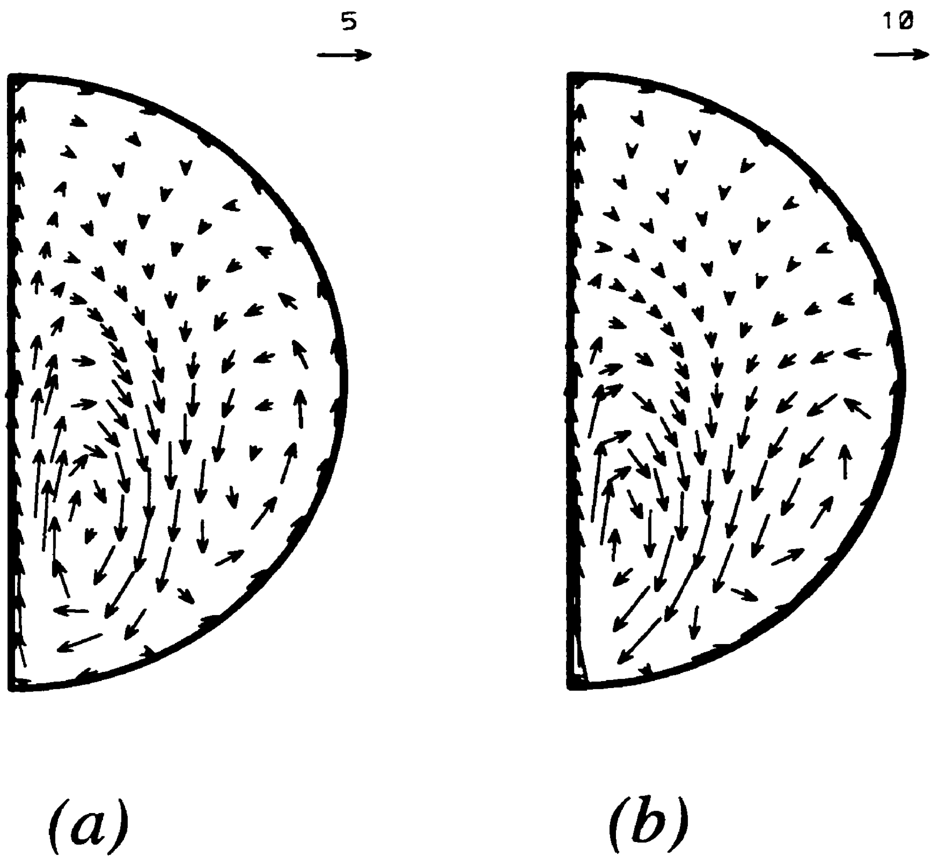


Figure 4.26: Secondary flow pattern for H2 with $\alpha = 0°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

wall and another smaller cell with upward flow along the heated curved wall. Both meet at the upper part of the semicircular duct, change their directions, and descend in the central portion as the fluid moves through the duct.

As Gr increases, the size of the large cell in H1 is enlarged with increased intensity of the secondary flow across the entire cross-section, as shown in figure 4.25b for $Gr = 2 \times 10^6$. The circulation in this cell indicates that the cooler fluid is being pushed upward to absorb more heat energy from the duct wall (which results in significant fluid mixing within the duct cross-section). This results in a drop of the wall-to-bulk temperature difference and thus provides a strong mechanism for heat transfer enhancement, as shown later.

For the H2 case with $Gr = 1 \times 10^5$, shown in figure 4.26a, the intensity of the secondary flow is low in the upper and central parts of the cross-section where the temperature gradients are quite low. However, the temperature gradient in the lower part is higher and consequently, the corresponding secondary flow is more intense. Figure 4.26b for $Gr = 2 \times 10^6$ shows also a higher secondary flow intensity in the lower part than in the upper part. It can also be seen clearly that, the strength of the secondary flow for the H2 boundary condition is much lower than H1, due to temperature stratification, as stated earlier.

The upward inclination is presented in figures 4.27 and 4.28 for the H1 case. At lower Gr (e.g.,$Gr = 1 \times 10^5$), two counter rotating secondary flow cells exist. The secondary flow pattern for $\alpha = 30°$ and $\alpha = 60°$ in figures 4.27a and 4.28a respectively, is similar to figure 4.25a for the horizontal orientation. However, the intensity of the secondary flow is slightly stronger for $\alpha = 0°$ than for both inclinations.

At high Gr (e.g.,$Gr = 2 \times 10^6$), figure 4.27b shows significant intensification in the secondary flow compared with figure 4.27a. Similarly, for $\alpha = 60°$ in figure 4.28b, the secondary flow intensifies in the two counter rotating cells. At high Gr, in the central

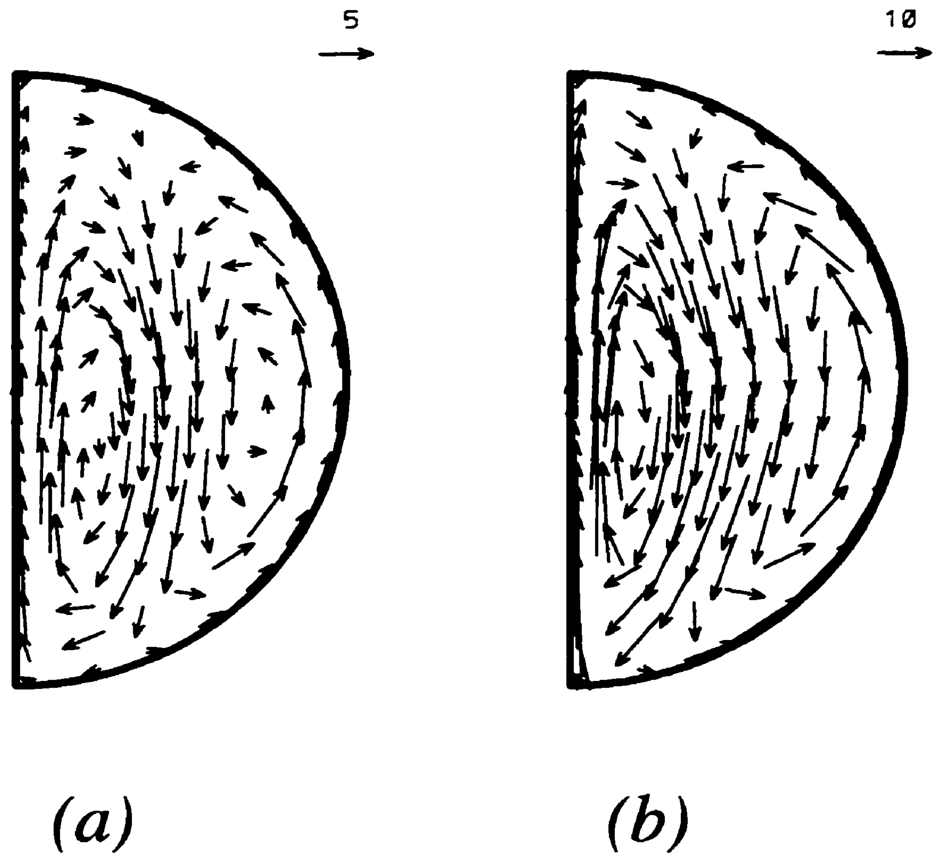


Figure 4.27: Secondary flow pattern for H1 with $\alpha = 30°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

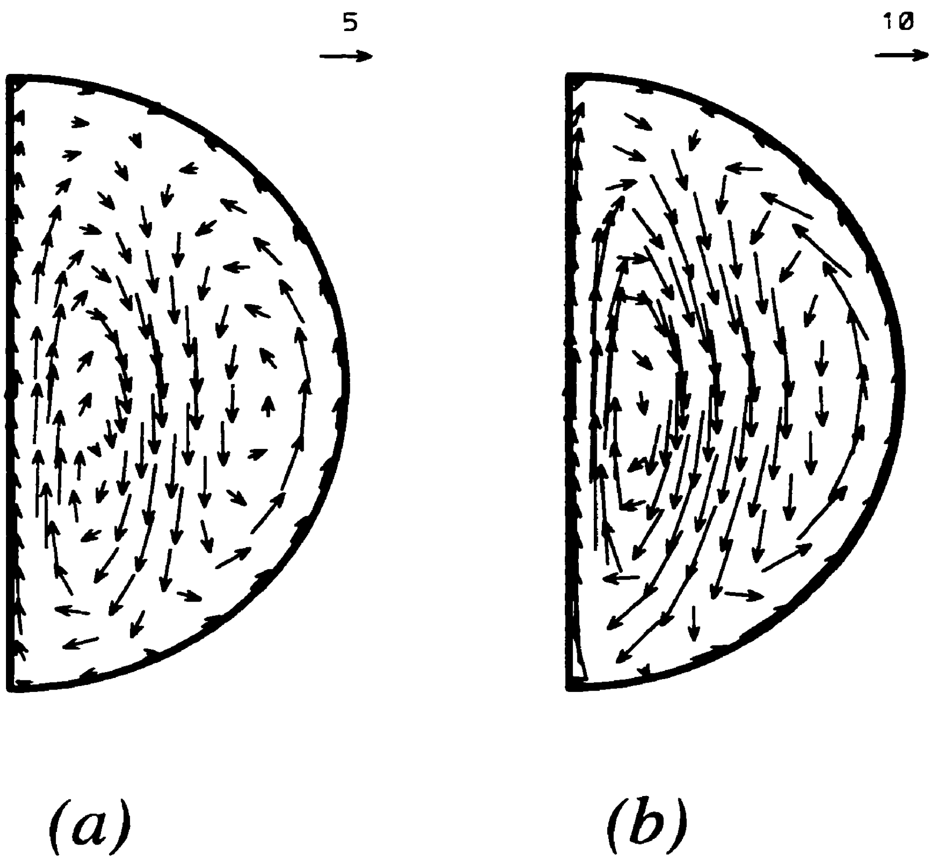


Figure 4.28: Secondary flow pattern for H1 with $\alpha = 60°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

part of the cross-section, particularly in the vicinity of the flat wall the intensity of the secondary flow for $\alpha = 30°$ is slightly higher than for $\alpha = 60°$.

The results corresponding to the upward inclinations for the H2 thermal boundary condition are shown in figures 4.29 and 4.30. At $Gr = 1 \times 10^5$ the secondary flow pattern in figures 4.29a and 4.30a for $\alpha = 30°$ and $60°$, respectively, is very similar to the one for the horizontal orientation in figure 4.26a with two counter rotating secondary flow cells. At high enough Gr (e.g., $Gr = 2 \times 10^6$) shown in figure 4.29b, the secondary flow intensifies across the entire cross-section due to the disappearance of thermal stratification, consistent with figure 4.11. The pattern of the buoyancy induced secondary flow for $\alpha = 60°$ in figure 4.30b is similar to the one for $\alpha = 30°$. It is clearly observed that, the strength of the secondary flow in both inclinations is much higher than that for $\alpha = 0°$ in figure 4.26b. Consequently, the enhancement in fRe and Nu is expected to be higher for $\alpha = 30°$ and $60°$ than that of $\alpha = 0°$, as shown later.

The downward inclination is presented in figures 4.31 and 4.32 for the H1 boundary condition. At low Gr (e.g., $Gr = 1 \times 10^5$) the pattern of the secondary flow for $\alpha = -30°$ and $-60°$ in figures 4.31a and 4.32a, respectively, is similar to the one for the horizontal orientation in figure 4.25a with two counter rotating cells.

Figure 4.31b for $Gr = 5 \times 10^5$ with $\alpha = -30°$ again shows two counter rotating secondary flow cells exist. It can be seen that, increasing Gr intensifies the secondary flow since figure 4.31b shows higher secondary flow intensity than that in figure 4.31a. Similarly, for $\alpha = -60°$ in figure 4.32b at $Gr = 5 \times 10^5$, the intensity of the secondary flow is higher than that in figure 4.32a. However, the strength of the secondary flow in figure 4.31 for $\alpha = -30°$ is stronger than that of $\alpha = -60°$ in figure 4.32. Consequently, the enhancement in fRe and Nu is expected to be higher for $\alpha = -30°$ than that for $\alpha = -60°$, as shown later.

The case of the H2 boundary condition in downward inclinations is shown in

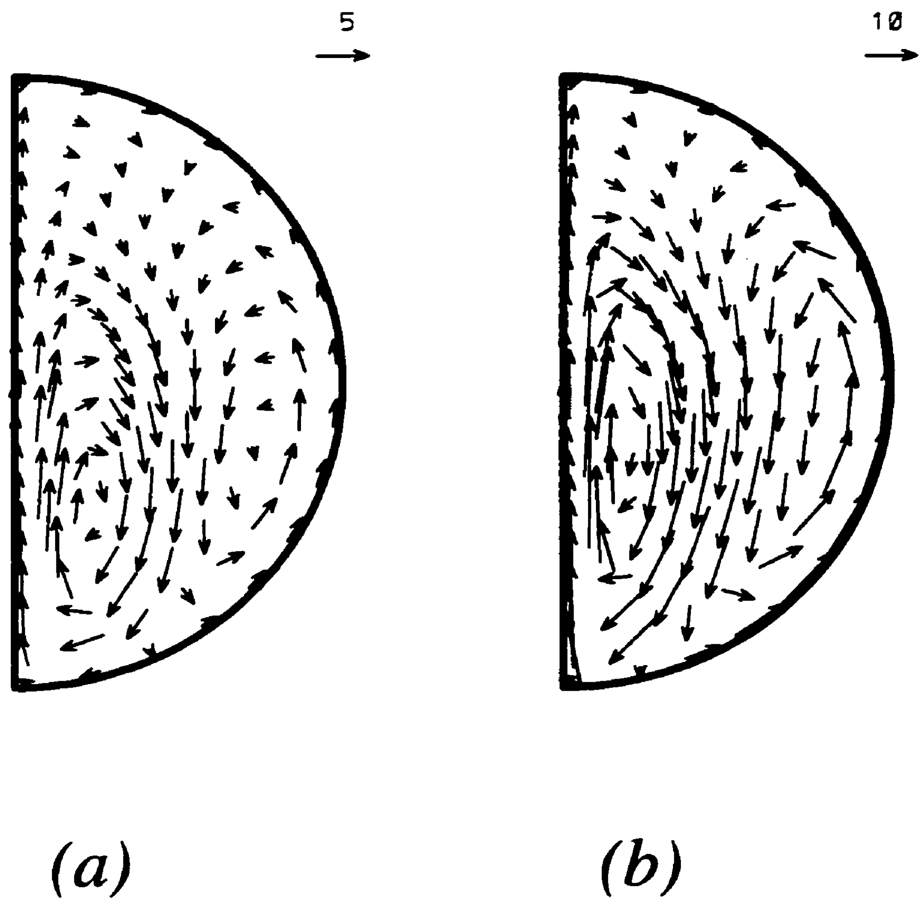


Figure 4.29: Secondary flow pattern for H2 with $\alpha = 30°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

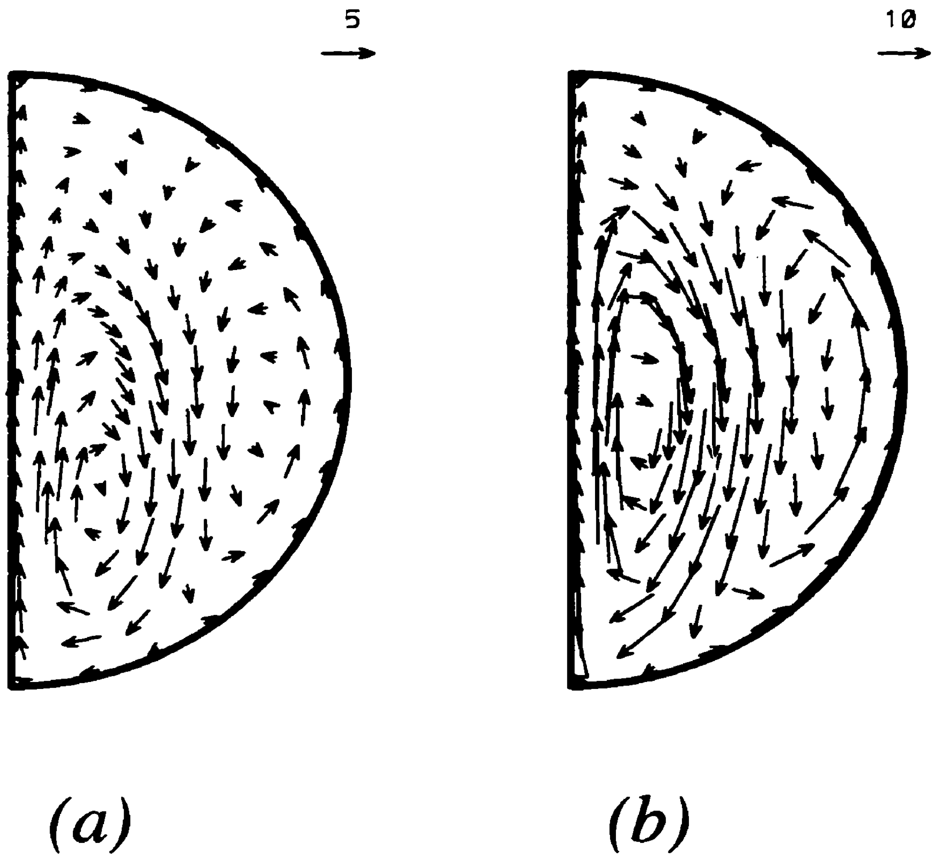


Figure 4.30: Secondary flow pattern for H2 with $\alpha = 60°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 2 \times 10^6$

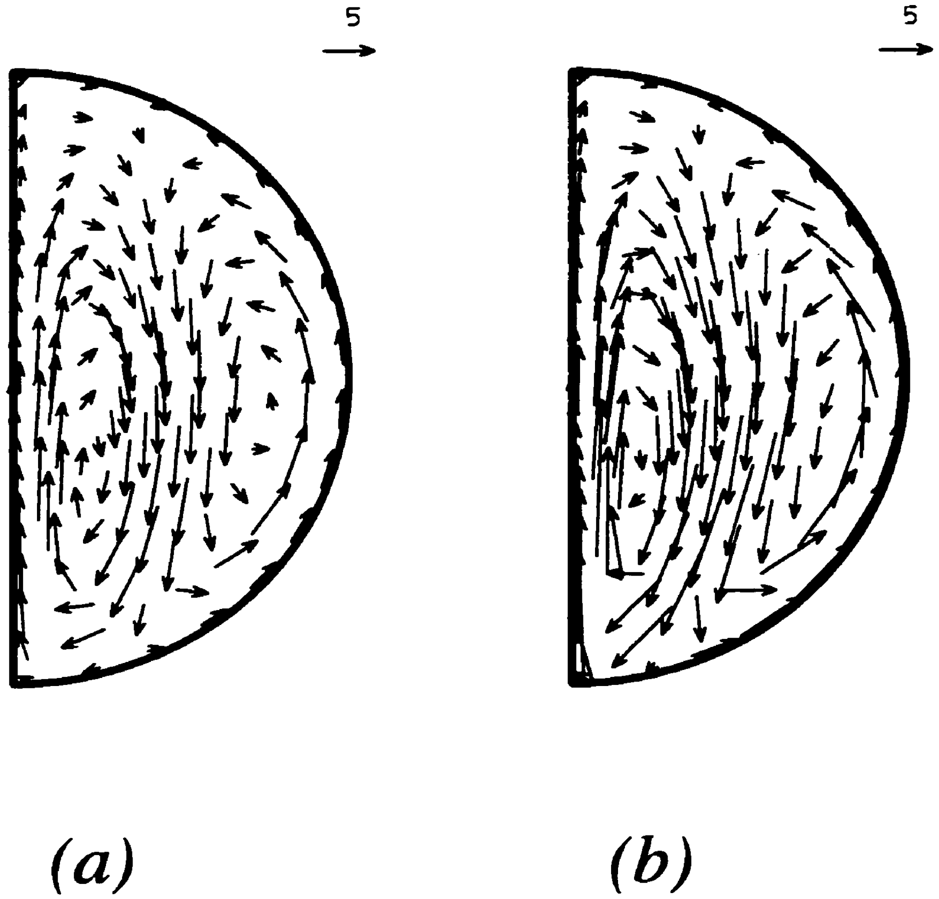


Figure 4.31: Secondary flow pattern for H1 with $\alpha = -30°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 5 \times 10^5$

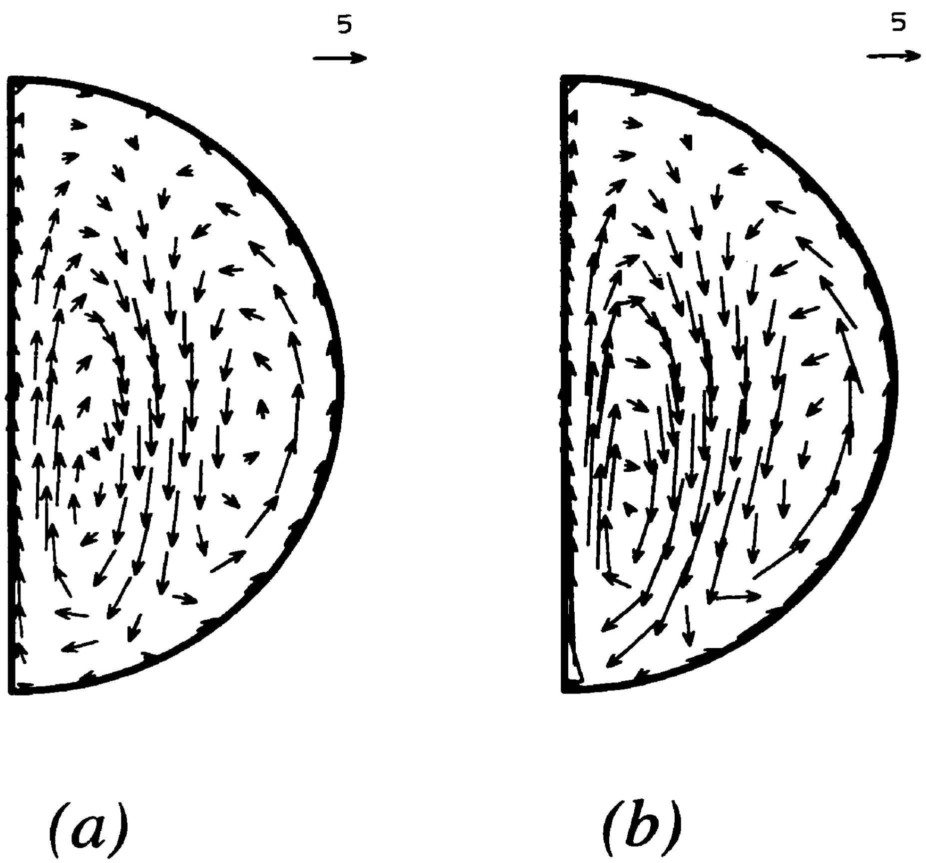


Figure 4.32: Secondary flow pattern for H1 with $\alpha = -60°$; (a) $Gr = 1 \times 10^5$ and (b) $Gr = 5 \times 10^5$

figures 4.33 and 4.34. Figures 4.33a and 4.34a for $\alpha = -30°$ and $-60°$, respectively, show that two counter rotating secondary flow cells exist. The secondary flow in both inclinations is very weak not only in the upper part of the cross-section but across the entire cross-section. At $Gr = 5 \times 10^4$ with $\alpha = -30°$, the secondary flow in figure 4.33b is slightly intensified compared with figure 4.33a. As the inclination angle increases to $\alpha = -60°$ with $Gr = 5 \times 10^4$, the intensity of the secondary flow becomes lower in most of the cross-section. Figure 4.33b shows higher secondary flow intensity in the lower part of the cross-section than that for $\alpha = -60°$ in figure 4.34b.

4.3 Wall Temperature

The circumferential variation of wall temperature for the H2 boundary condition is presented in this section for typical cases of horizontal, upward and downward inclinations. The forced-convection case calculated at $Gr = 0$ is presented as a reference in all figures in order to observe the effect of free convection.

4.3.1 Horizontal Orientation

For mixed convection in the horizontal orientation, the wall temperature varies considerably around the circumference with high temperature in the upper part and low temperature in the lower part of the semicircular duct. The difference between the maximum (at the upper part) and minimum (at the lower part) wall temperatures remains nearly constant for the three values of Gr. Figure 4.35 shows that, increasing Gr has no observable effect on the disappearance of the thermal stratification due to the strong variation in the wall temperature around the circumference. This is

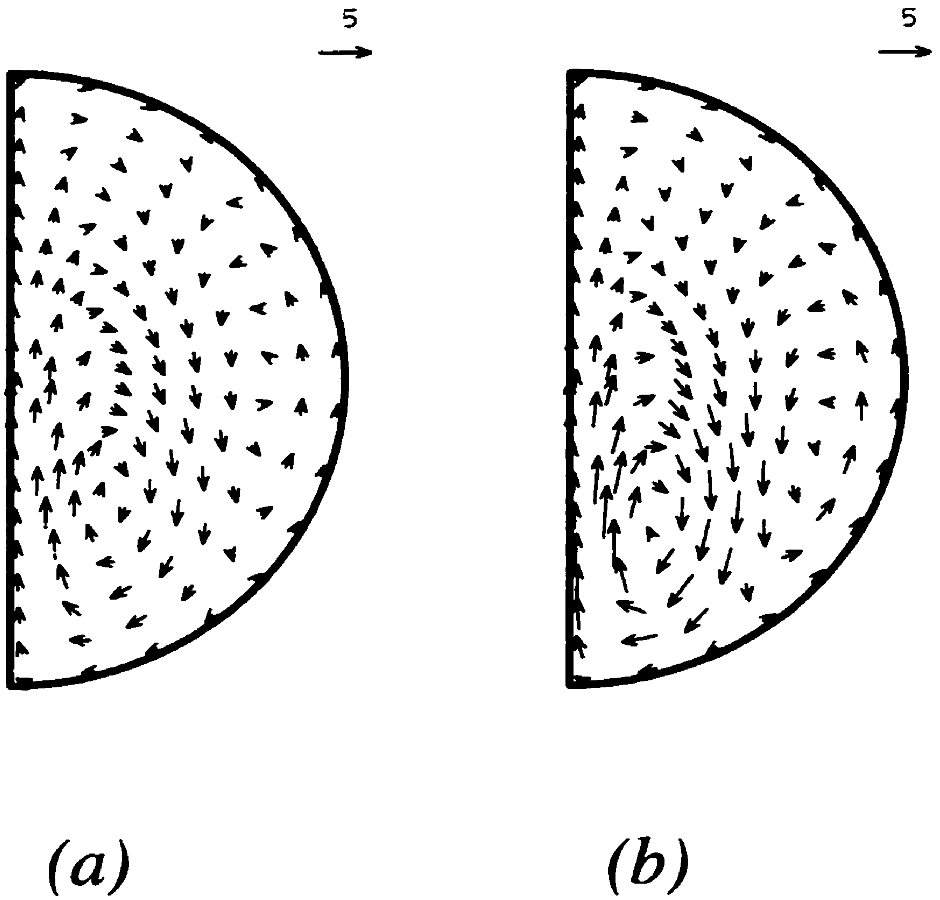


Figure 4.33: Secondary flow pattern for H2 with $\alpha = -30°$; (a) $Gr = 1 \times 10^4$ and (b) $Gr = 5 \times 10^4$

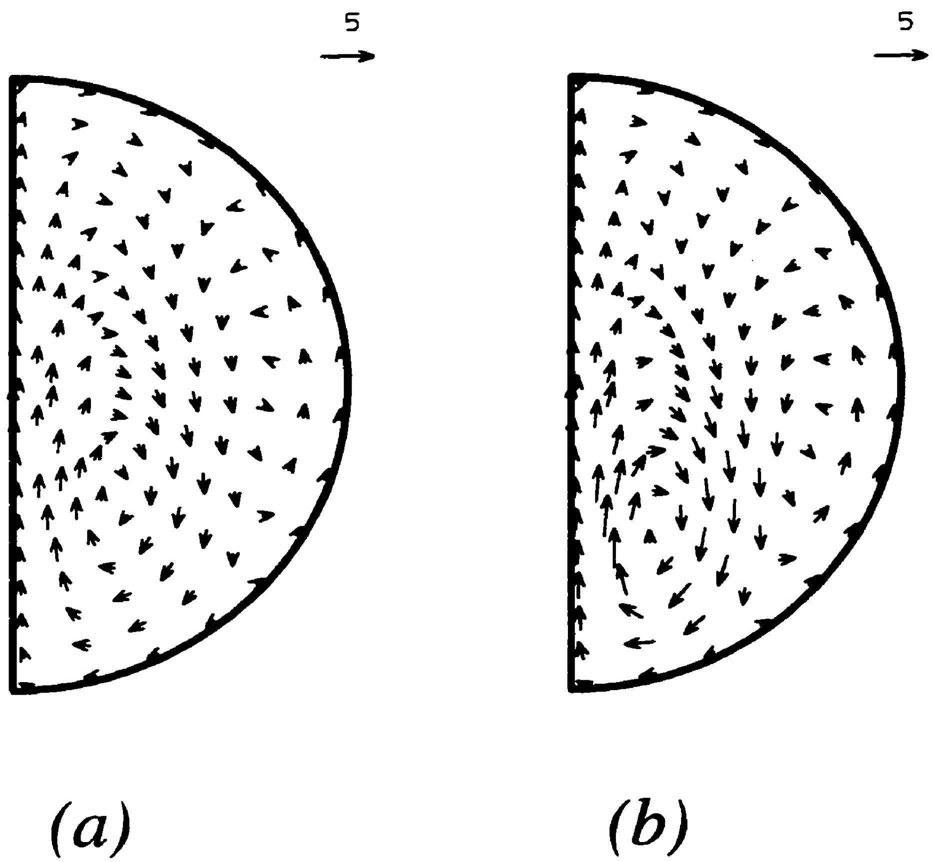


Figure 4.34: Secondary flow pattern for H2 with $\alpha = -60°$; (a) $Gr = 1 \times 10^4$ and (b) $Gr = 5 \times 10^4$

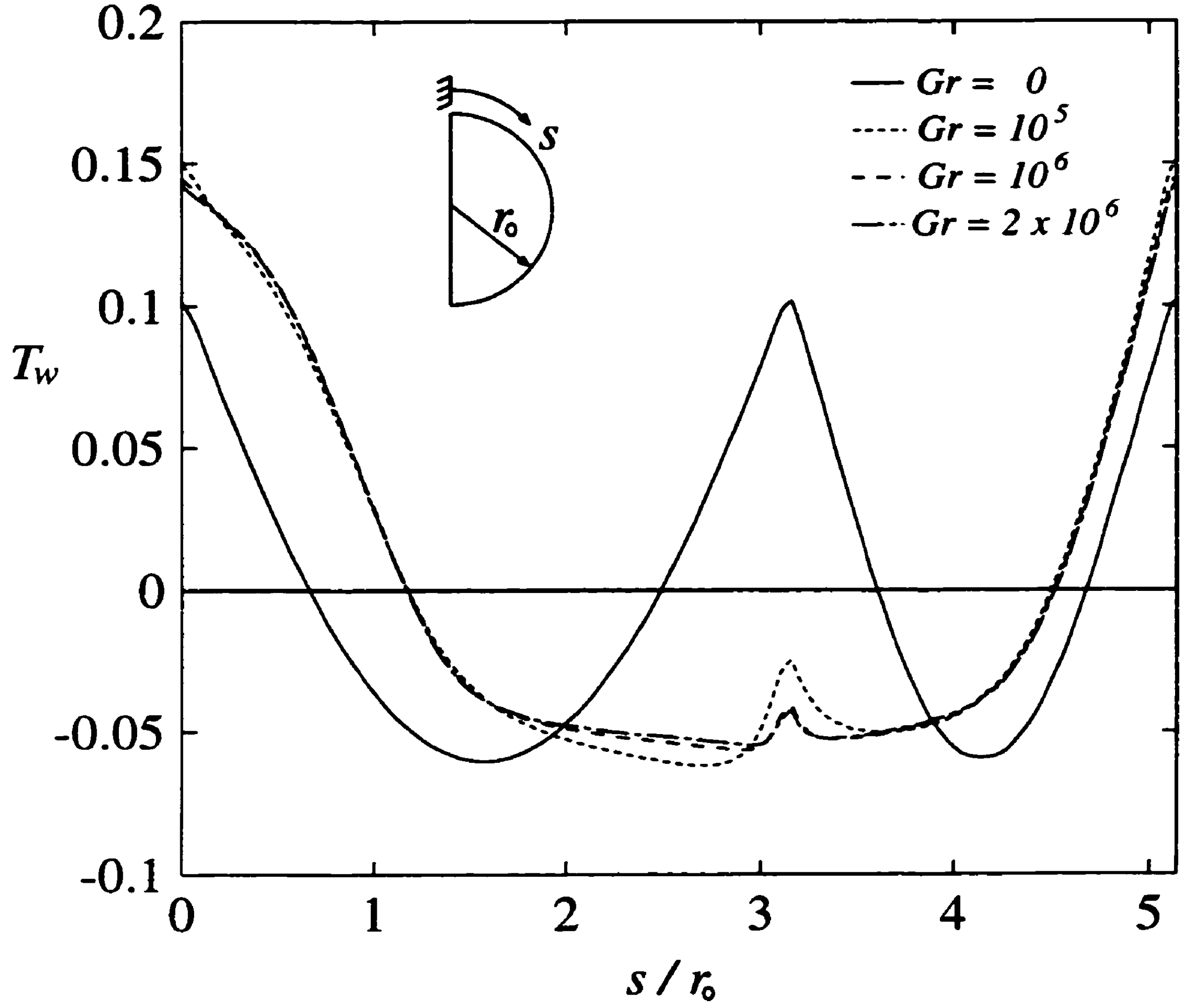


Figure 4.35: Circumferential variation of wall temperature for the H2 condition with $\alpha = 0°$

consistent with the temperature distribution shown earlier in figure 4.4 for the H2 boundary condition, where the isotherms show temperature stratification for the high value of Grashof number used ($Gr = 2 \times 10^6$).

4.3.2 Upward Inclination

For upward inclination, the difference between high and low wall temperatures is affected by the value of Gr. As can be seen for the upward inclinations (figures 4.36 and 4.37), the difference between these extreme wall temperatures decreases as the value of Gr and α increase. Therefore, the general trend is that an increase in Gr tends to move the results towards a uniform wall temperature for upward inclinations.

At high Gr (i.e., $Gr = 2 \times 10^6$) with $\alpha = 30^\circ$ and 60° in figures 4.36 and 4.37, respectively, the uniformity appearance of T_w may lead to increased heat transfer which may exceed the values for the H1 condition for both upward inclinations. This trend is consistent with the gradual disappearance of thermal stratification with increasing Gr for upward inclinations, as noted earlier in figures 4.11 and 4.12 for the H2 thermal boundary condition. Consequently, the corresponding secondary flow is shown to intensify in the upper part of the cross-section as well as in the lower part.

4.3.3 Downward Inclination

Figures 4.38 and 4.39 show the circumferential variation of wall temperature for downward inclinations. The difference between high and low wall temperatures is also affected by the value of Gr. However, for downward inclination (figures 4.38 and 4.39) this difference increases as Gr and α increase.

The general trend is that an increase in Gr tends to increase the circumferential variation of wall temperature for downward inclinations. At low Gr (e.g., $Gr =$

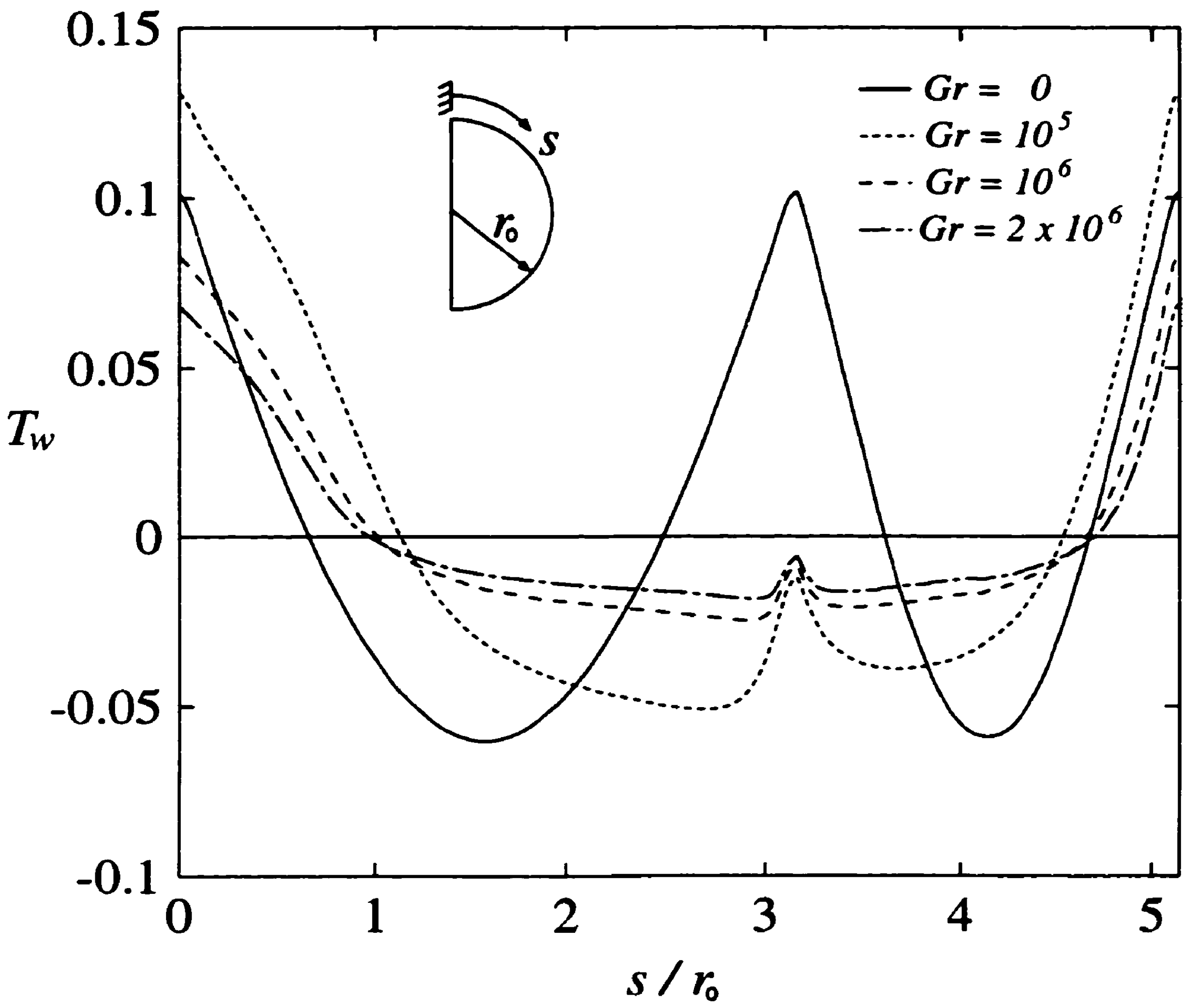


Figure 4.36: Circumferential variation of wall temperature for the H2 condition with $\alpha = 30°$

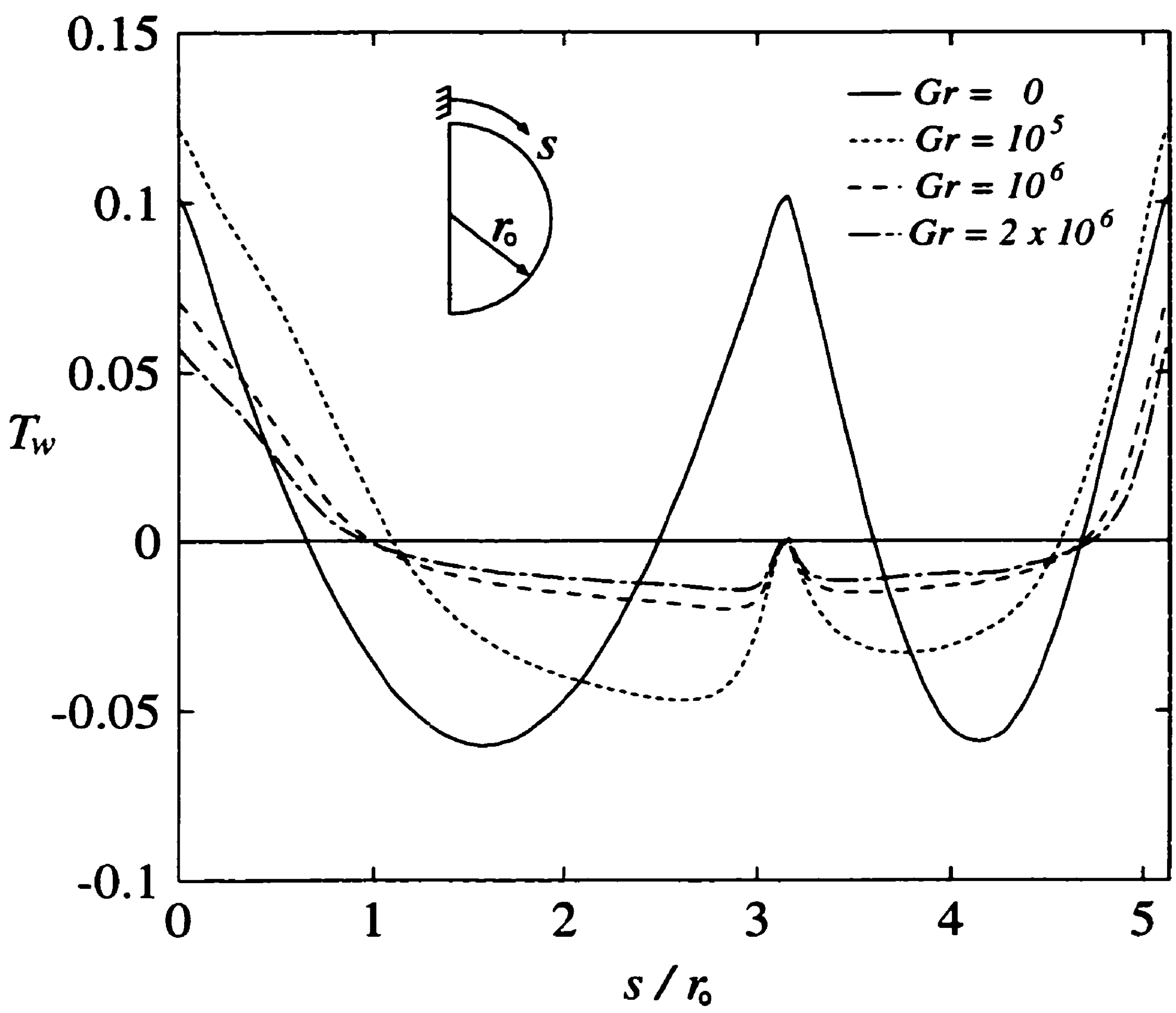


Figure 4.37: Circumferential variation of wall temperature for the H2 condition with $\alpha = 60°$

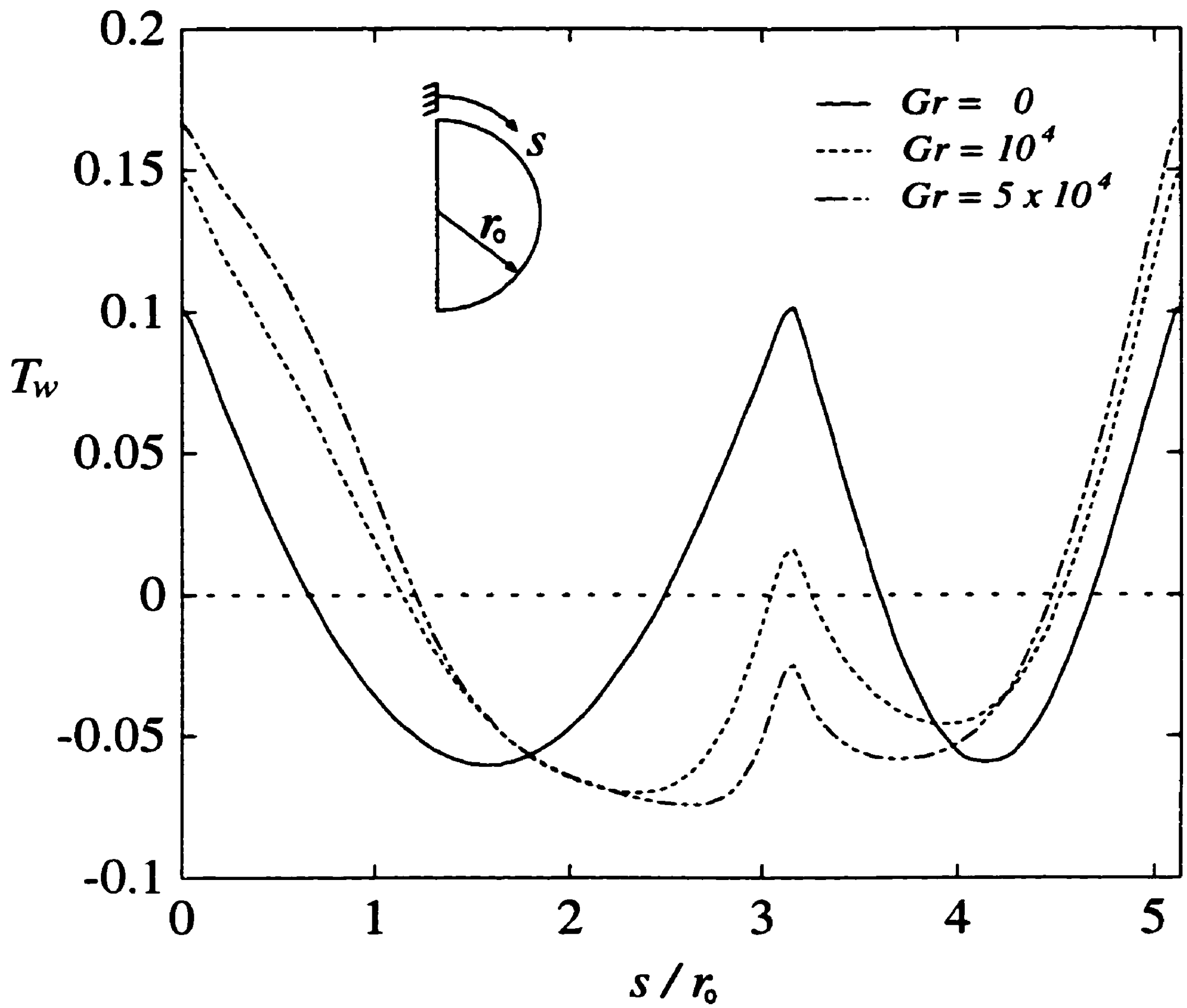


Figure 4.38: Circumferential variation of wall temperature for the H2 condition with $\alpha = -30°$

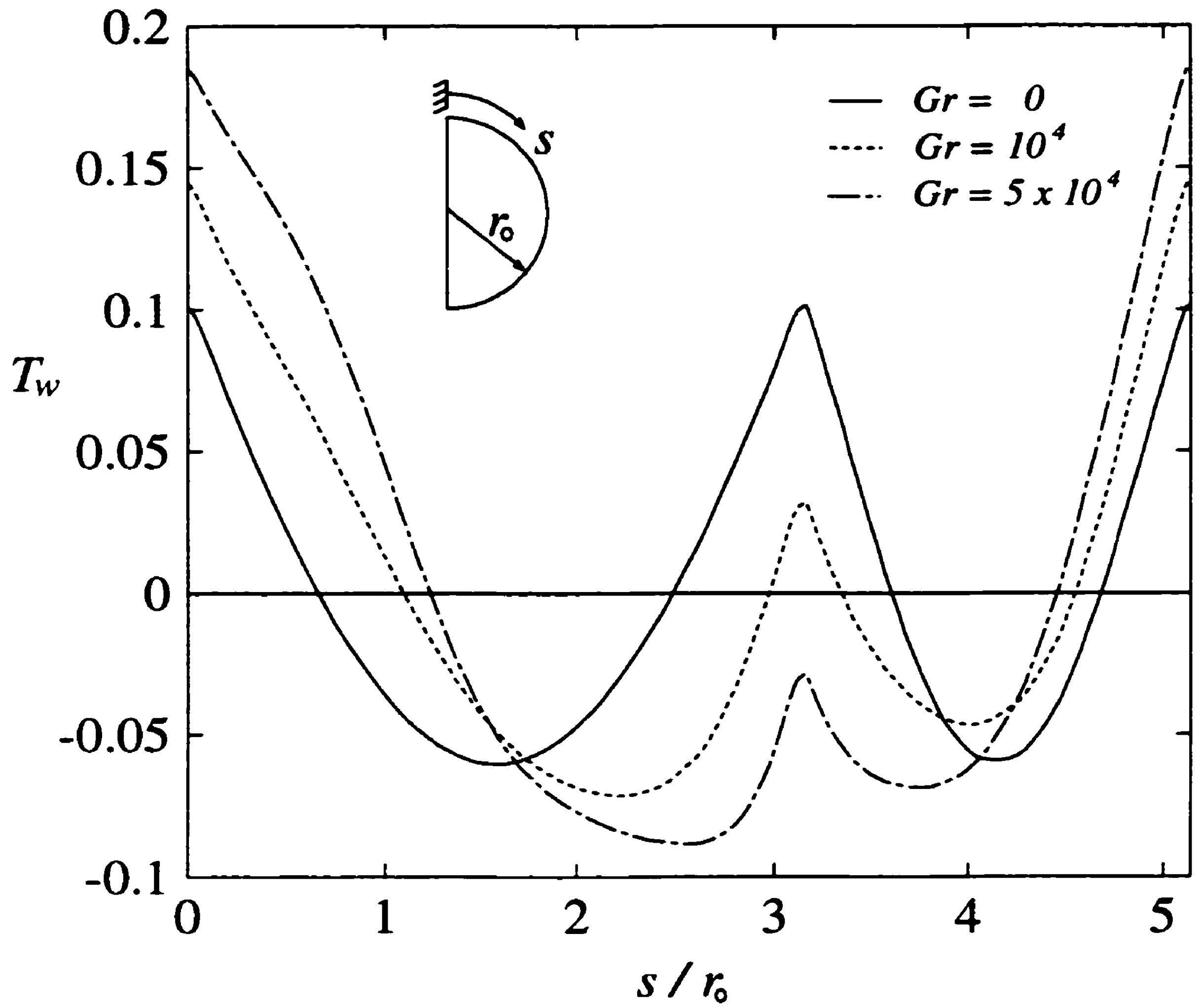


Figure 4.39: Circumferential variation of wall temperature for the H2 condition with $\alpha = -60°$

1×10^4), there is a strong variation in the wall temperature around the circumference. This circumferential variation of T_w remains relatively unchanged for $\alpha = -30°$ and $\alpha = -60°$, as shown in figures 4.38 and 4.39. However, at higher Gr, a stronger variation in the wall temperature around the circumference was noted. The difference between high and low temperatures is large and becomes slightly larger for $\alpha = -60°$ than that for $\alpha = -30°$. This trend is also consistent with the gradual intensification of thermal stratification with Gr for downward inclinations, where the secondary flow is very weak, not only in the upper part but in most of the duct cross-section, as shown earlier in figures 4.33 and 4.34.

4.3.4 Vertical Orientation

Symmetry around $\theta = \pi/2$ is expected in all these results. Figure 4.40 shows the circumferential variation of T_w for $\alpha = 90°$. At low Gr (e.g., $Gr = 1 \times 10^5$) due to symmetry, the circumferential variation of T_w is similar to the one for pure forced convection ($Gr = 0$). However, increasing Gr tends to reduce the circumferential variation of T_w. For $Gr = 1 \times 10^6$, T_w becomes nearly uniform from $\theta = 45°$ to $\theta = 130°$ along the curved wall. Similarly for $Gr = 2 \times 10^6$, T_w becomes uniform from $\theta = 35°$ to $\theta = 145°$ along the curved wall. Due to symmetry, the maximum wall temperature appears to be the same at the top ($\theta = 0°$) and bottom corners ($\theta = \pi$) of the cross-section.

Figure 4.41 shows the circumferential variation of wall temperature for $\alpha = -90°$. At low Gr (i.e. $Gr = 1 \times 10^4$), the circumferential variation of wall temperature is nearly the same as the one for pure forced convection, while at higher Gr , the wall temperature becomes slightly hotter at the top and bottom corners of the cross-section and somewhat lower at $\theta = \pi/2$ than that for the pure forced convection. The difference between high and low wall temperatures increases with Gr, which is

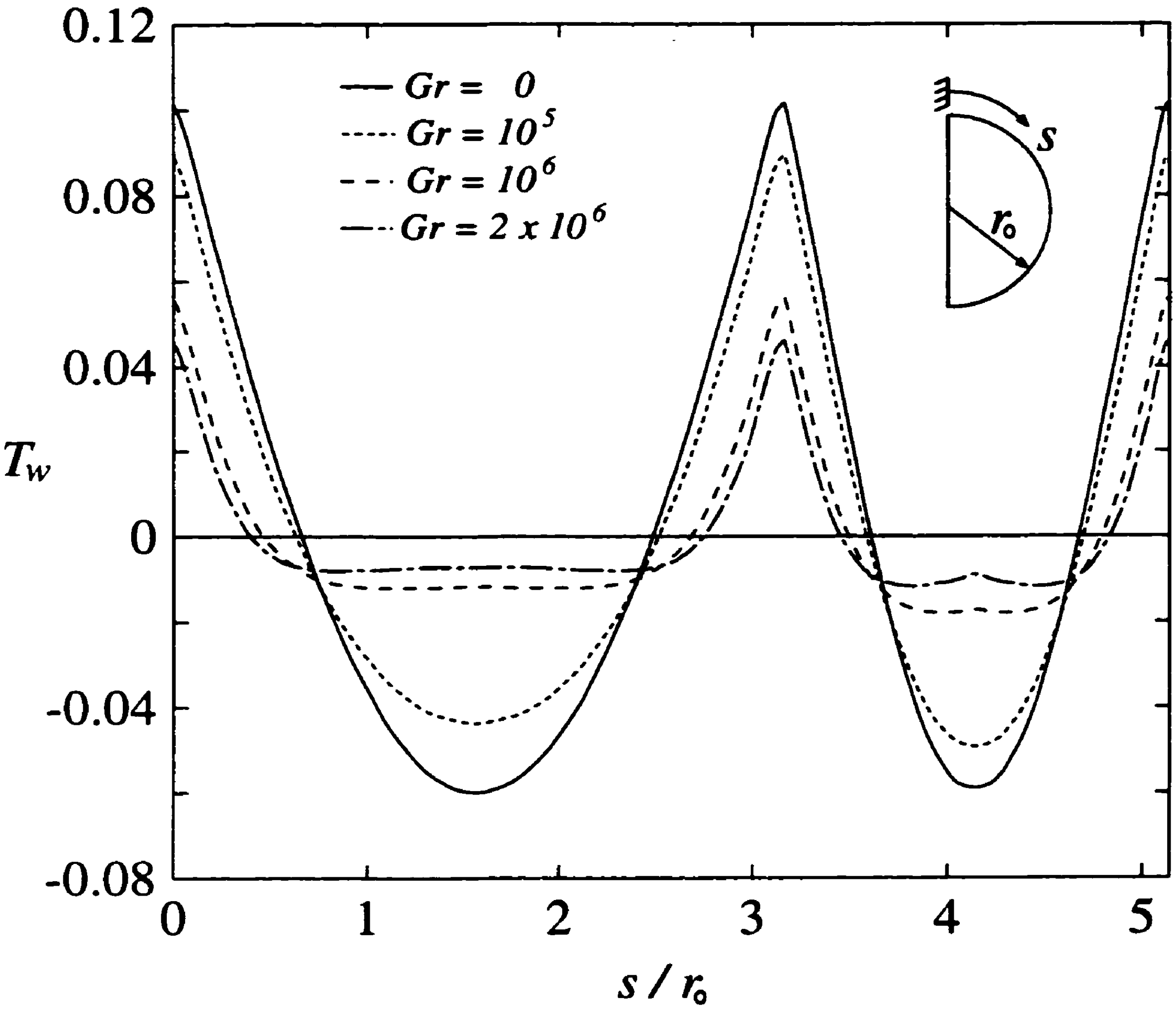


Figure 4.40: Circumferential variation of wall temperature for the H2 condition with $\alpha = 90°$

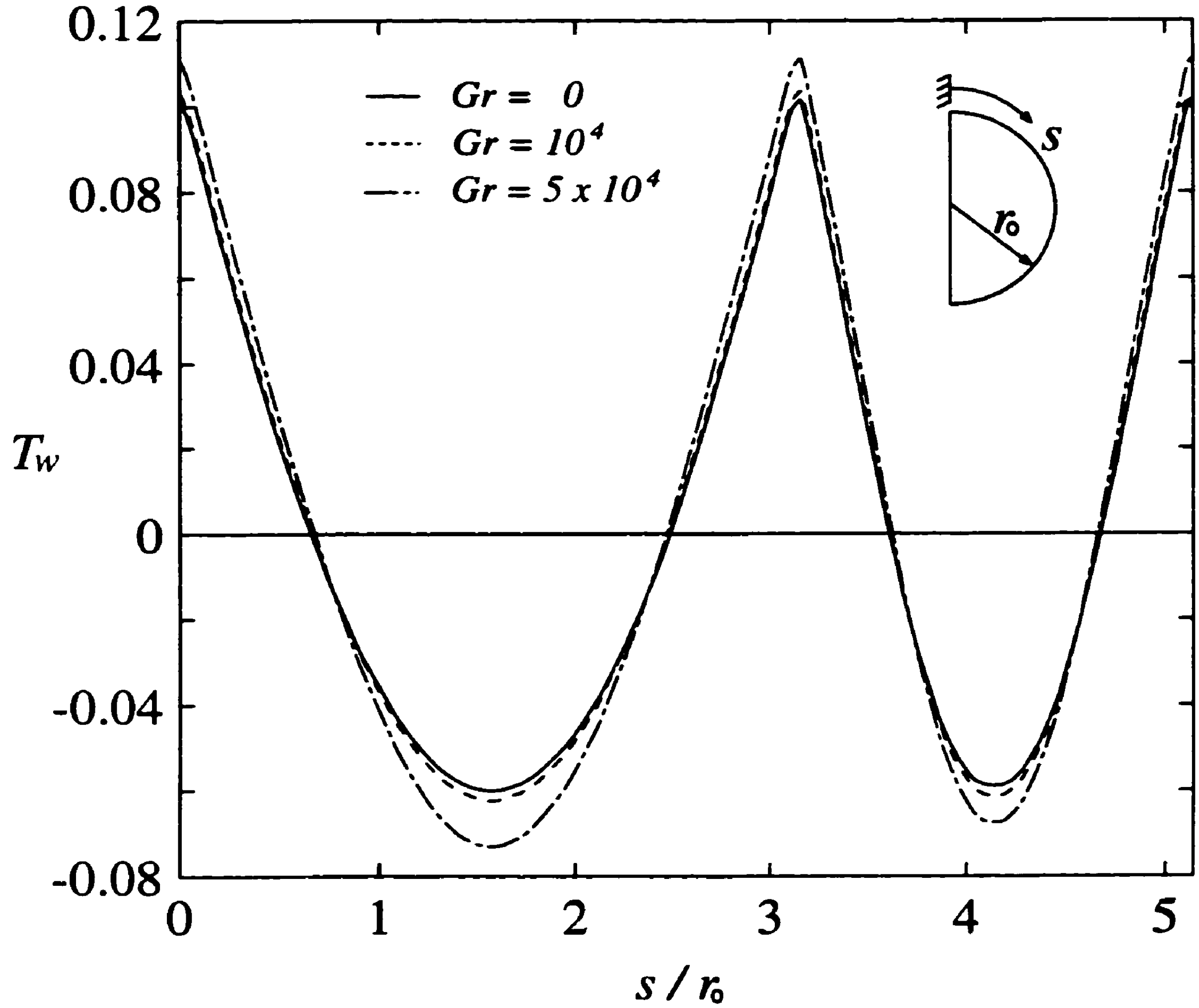


Figure 4.41: Circumferential variation of wall temperature for the H2 condition with $\alpha = -90°$

consistent with the increased difference between T_{max} and T_{min}, as shown earlier in figure 4.24b. As a result, Nu_{H2} is expected to be lower than that for the pure forced flow, as shown later.

4.4 Flow Reversal

The phenomenon of flow reversal, which can be encountered in both upward and downward inclinations, is very important because of its effect on the velocity and temperature distributions, as well as its possible impact on the steadiness and stability of the flow. Figure 4.42 shows a map with boundaries corresponding to the conditions where the onset of flow reversal was detected in the present study. In order to make this map applicable to wide ranges of Re and α, it was decided to use γ and ω as coordinates, where

$$\gamma = B_2/B_1 = \frac{tan\ \alpha}{Re}, \tag{4.1}$$

and

$$\omega = \sqrt{B_1^2 + B_2^2} = Gr\left[1 - sin^2\alpha\left(1 - \frac{1}{Re^2}\right)\right]^{1/2} \tag{4.2}$$

For $\alpha = 0°$, $\gamma = 0$ and $\omega = Gr$, while for $\alpha = \pm 90°$, $\gamma = \pm \infty$ and $\omega = Gr/Re$. Any combination of α and Re would give a certain value for γ and the corresponding ω from figure 4.42 would be indicative of the value of Gr of which flow reversal initiates. Using $[tan^{-1}\gamma]^{1/3}$ in the vertical axis of figure 4.42 made it possible to cover all inclinations from $-90°$ to $+90°$.

For both upward and downward inclinations, figure 4.42 shows that the critical

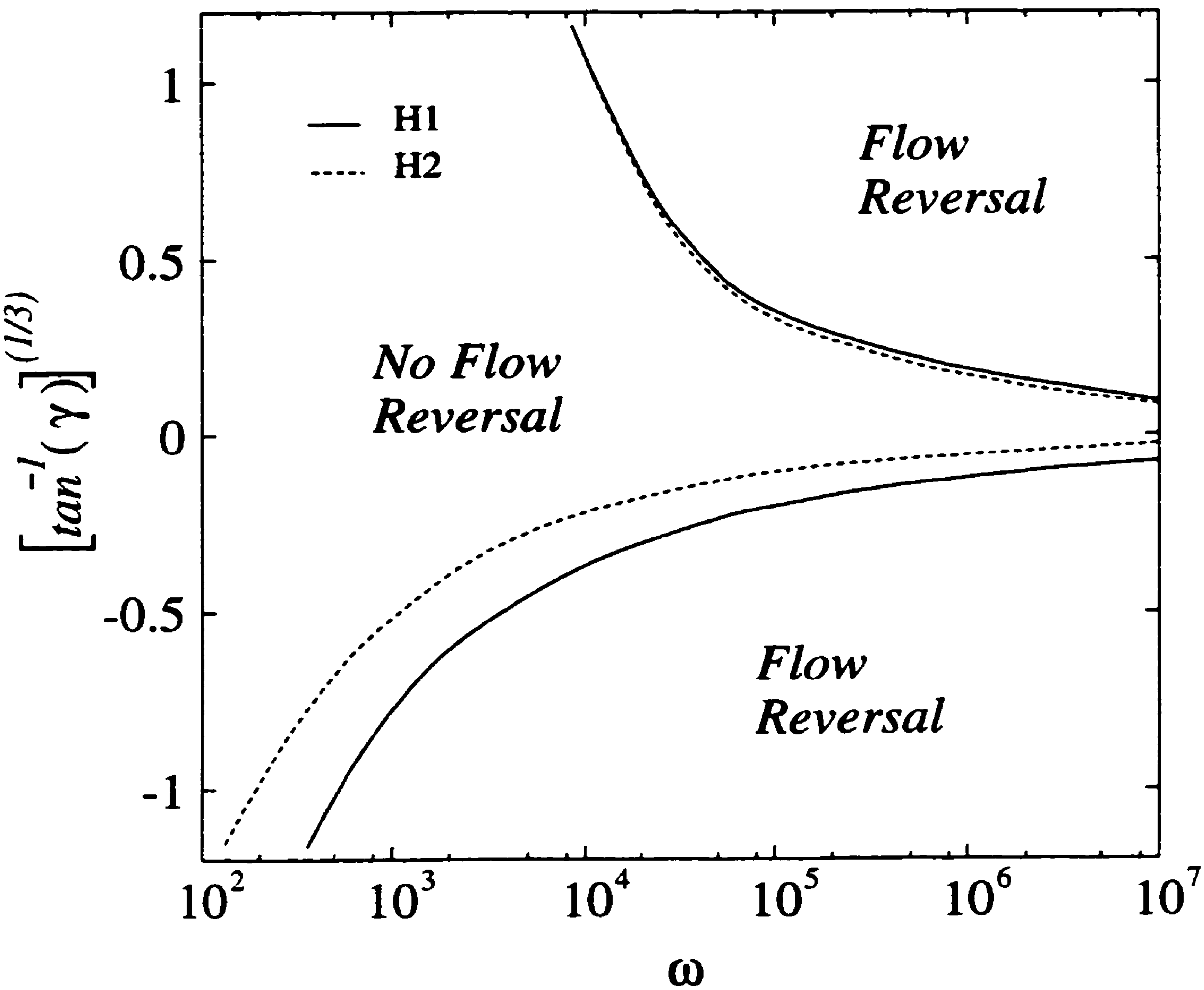


Figure 4.42: Flow reversal map

value of ω decreases as the absolute value of γ increases (larger inclination or lower Re). For the same $|\gamma|$, ω at the onset of flow reversal is much higher for upward flow than for downward flow. No flow reversal is expected in the horizontal orientation and therefore, $\omega \to \infty$ at $\gamma = 0$. Flow reversal occurs at lower Gr for the H2 condition, particularly in the downward inclinations.

4.5 Friction Factor and Nusselt Number

Due to the free-convection effect, the friction factor and Nusselt number for buoyancy assisted mixed convection laminar flow are found to be substantially higher than those of pure forced convection ($Gr = 0$), while for buoyancy opposed flow, the friction factor and Nusselt number showed some interesting results, as discussed later.

4.5.1 Friction Factor for Upward Inclination

Figure 4.43 shows the friction-factor results for upward inclinations using ω and γ as independent parameters. The lines for $\gamma = 0$ and $\gamma = \infty$ correspond to the horizontal and vertical orientations, respectively. The general trend in these results is that $fRe/(fRe)_o$ increases with ω for any given value of γ, i.e., $fRe/(fRe)_o$ increases with Gr for fixed α and Re. The magnitude of this increase becomes larger as γ increases (which may be due to an increase in α or a decrease in Re). The critical value of ω at which $fRe/(fRe)_o$ starts deviating from 1 decreases as γ increases.

The effect of the thermal boundary condition is significant at low values of γ (small inclinations). At the horizontal orientation, $(fRe)_{H1}$ exceeds $(fRe)_{H2}$ due to the thermal stratification in H2 discussed earlier. As this stratification disappears with upward inclinations, particularly at high Gr, we can see that the trend in the

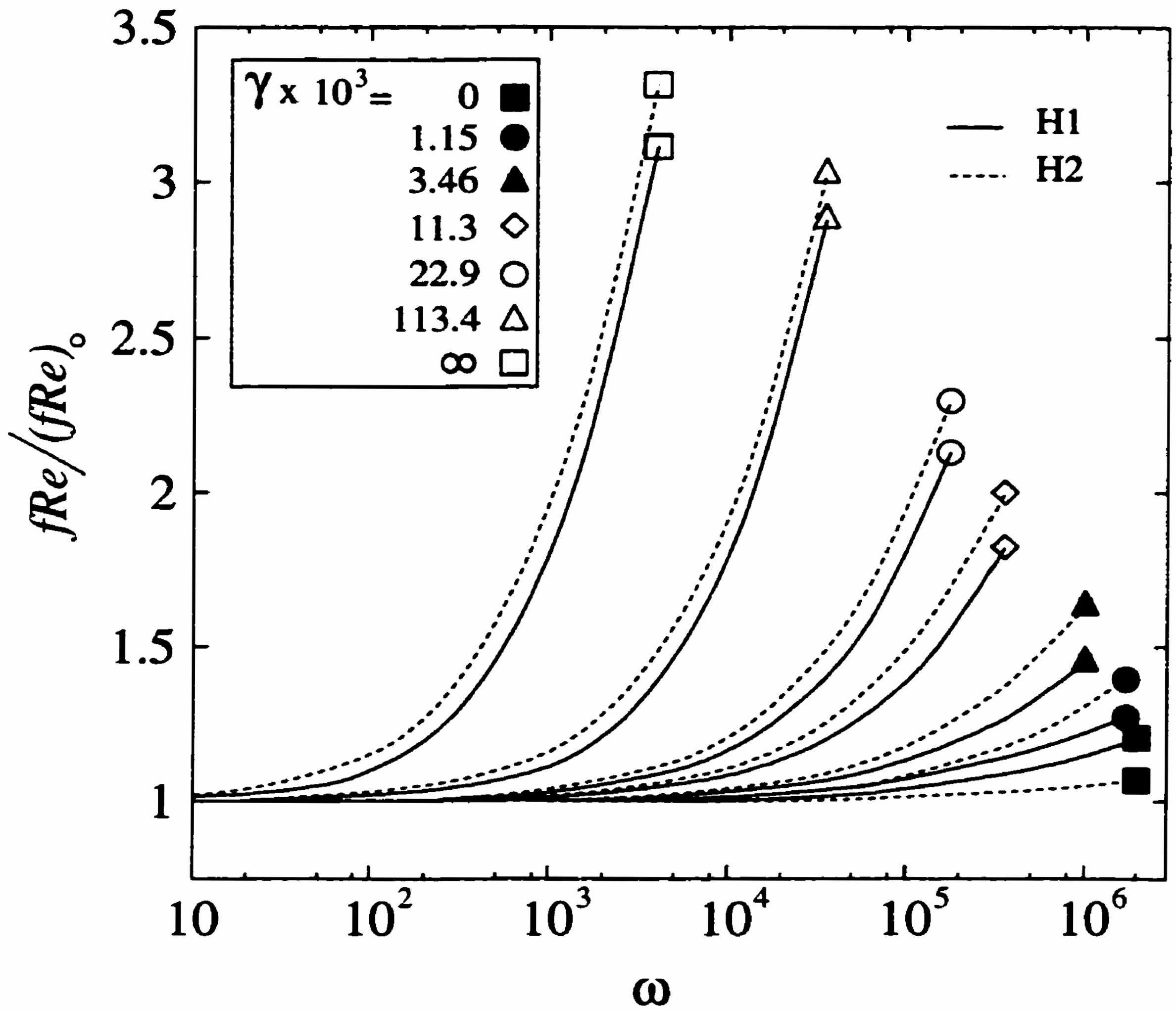


Figure 4.43: Friction factor results for upward inclinations, $Pr = 7$

results reverses with $(fRe)_{H2}$ exceeding $(fRe)_{H1}$. For high inclinations corresponding to larger values of γ the effect of the thermal boundary condition appears to be fairly small.

4.5.2 Friction Factor for Downward Inclination

For downward inclinations, the friction-factor results are shown in figure 4.44 with some expected trends. The value of $(fRe)_{H1}$ exceeds $(fRe)_{H2}$ for all combinations of γ and ω. Also for both boundary conditions, the value of $fRe/(fRe)_o$ is highest for the horizontal orientation and it decreases as the downward inclination increases.

4.5.3 Nusselt Number for Upward Inclination

The results for Nusselt number in upward inclinations are presented in figures 4.45 and 4.46. Consideration was given to the use of γ and ω as independent parameters, however, the behavior of the results is such that this form of presentation makes it difficult to assess the individual effects of α, Re, and Gr. Figure 4.45 shows Nu versus α at various values of Gr for both thermal boundary conditions with $Re = 500$. We can see from these results that at low Gr (e.g., $Gr = 1 \times 10^4$), Nu_{H1} is always larger than Nu_{H2} and they both decrease monotonically with increasing α. At a higher Gr (e.g., $Gr = 1 \times 10^5$), we note that $Nu_{H1} > Nu_{H2}$ is still valid, but whereas Nu_{H1} still decreasing monotonically with α, Nu_{H2} experiences a gentle increase with α up to a maximum near $\alpha = 45°$ and then decreases with further increase in α. As Gr increases further, the increase in Nu_{H2} with α becomes sharper near $\alpha = 0°$ and the location of the maximum Nusselt number shifts to lower values of α. The trend in Nu_{H1} is similar but with much smaller gradients near $\alpha = 0°$. It is believed that the reason for the sharp gradients in Nu_{H2} with α is that thermal stratification, which inhibits

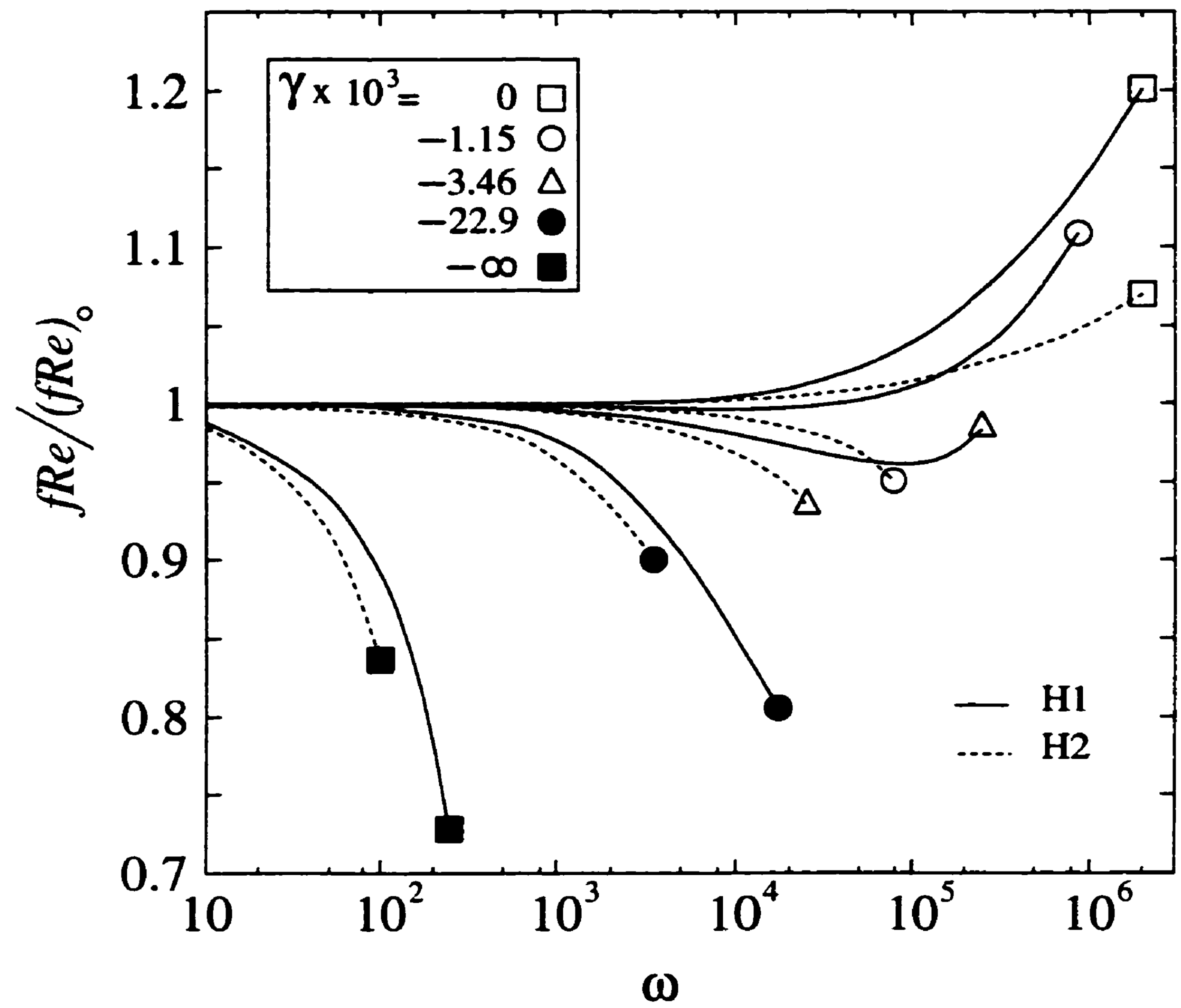


Figure 4.44: Friction factor results for downward inclinations, $Pr = 7$

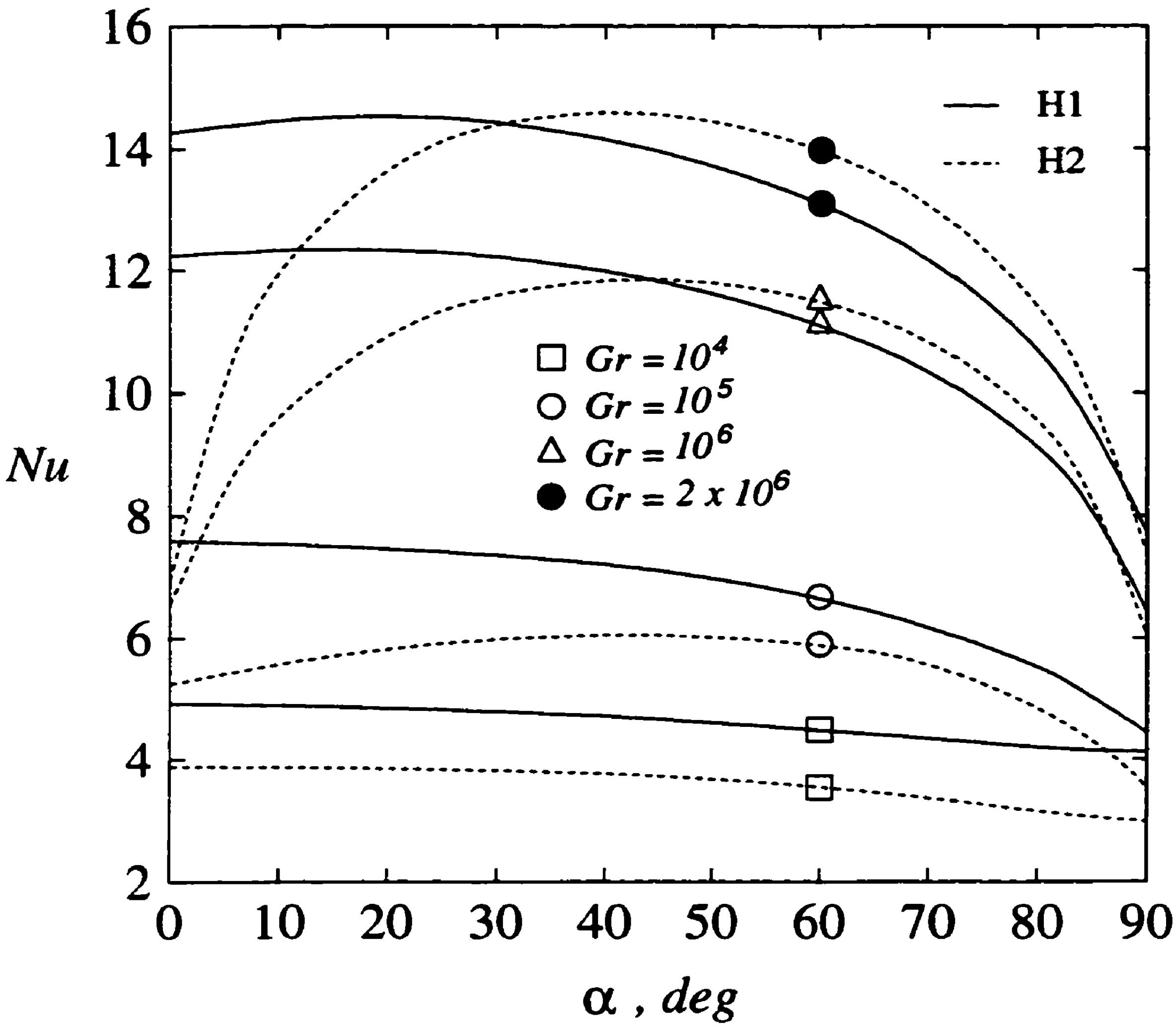


Figure 4.45: Nusselt number for upward inclinations with $Re = 500$ and $Pr = 7$

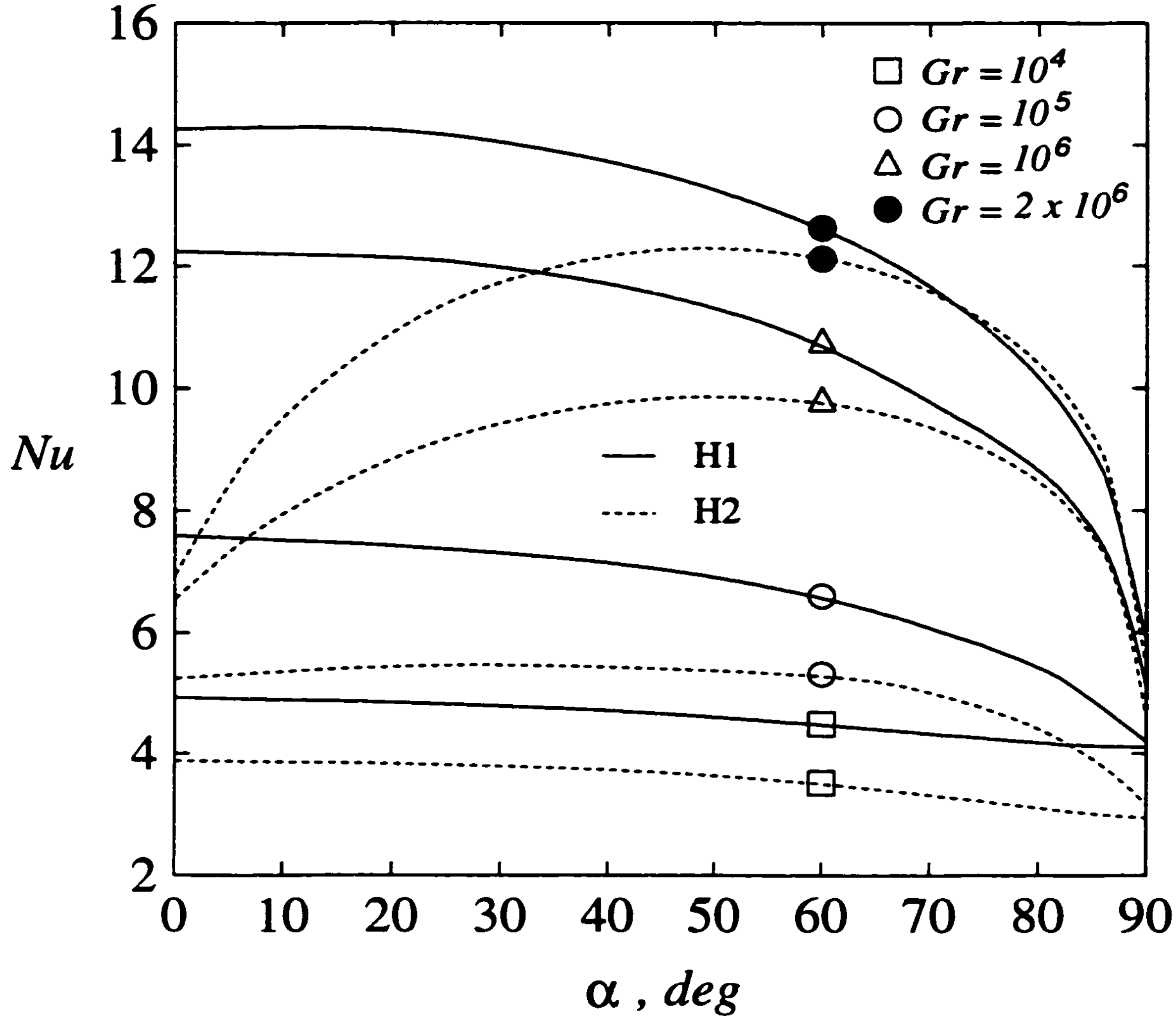


Figure 4.46: Nusselt number for upward inclinations with $Re = 1500$ and $Pr = 7$

the secondary flow currents and depresses the value of Nu_{H2} at $\alpha = 0°$, disappears with duct inclination at a rate that is accelerated by increasing Gr. At $Gr \geq 1 \times 10^6$, we can see that Nu_{H2} exceeds Nu_{H1} over a wide range of steep inclinations.

For higher Reynolds numbers (e.g., $Re = 1500$), figure 4.46 shows that the trends in Nu-results are similar to those in figure 4.45. At $\alpha = 0°$, both Nu_{H1} and Nu_{H2} are not affected by Re. For $\alpha > 0°$, values of Nu decrease with an increase in Re because of the decrease in the intensity of the secondary flow at high Re. This Re-effect becomes more pronounced for both boundary conditions as Gr increases. In general, the Re-effect is more significant for the H2 boundary condition, probably because thermal stratification can be eliminated faster at low Re.

4.5.4 Nusselt Number for Downward Inclination

For downward inclinations, figure 4.47 shows the behavior of Nu as a function of γ and ω. The trend is similar for the H1 and H2 boundary conditions while Nu_{H1} is always higher than Nu_{H2} for any combination of ω and γ. For all downward inclinations, values of Nusselt number are lower than those of the horizontal orientation. The large deviation between Nu_{H1} and Nu_{H2} for $\gamma = 0$ is evident in figure 4.47.

4.5.5 Comparison With the Geometry of Smooth Tubes

In order to assess the effect of duct geometry on the heat transfer results, two comparisons were made with Orfi et al. [45] for upwardly inclined circular tubes with H2 boundary condition. The first comparison is based on equal values of Re, Pr, and Gr. Therefore, this comparison applies to circular and semicircular ducts with the same q', r_o, and fluid properties. However, D_h and $\dot{m}$ will not be the same for both ducts. Results of this comparison are shown in figure 4.48 and they suggest that

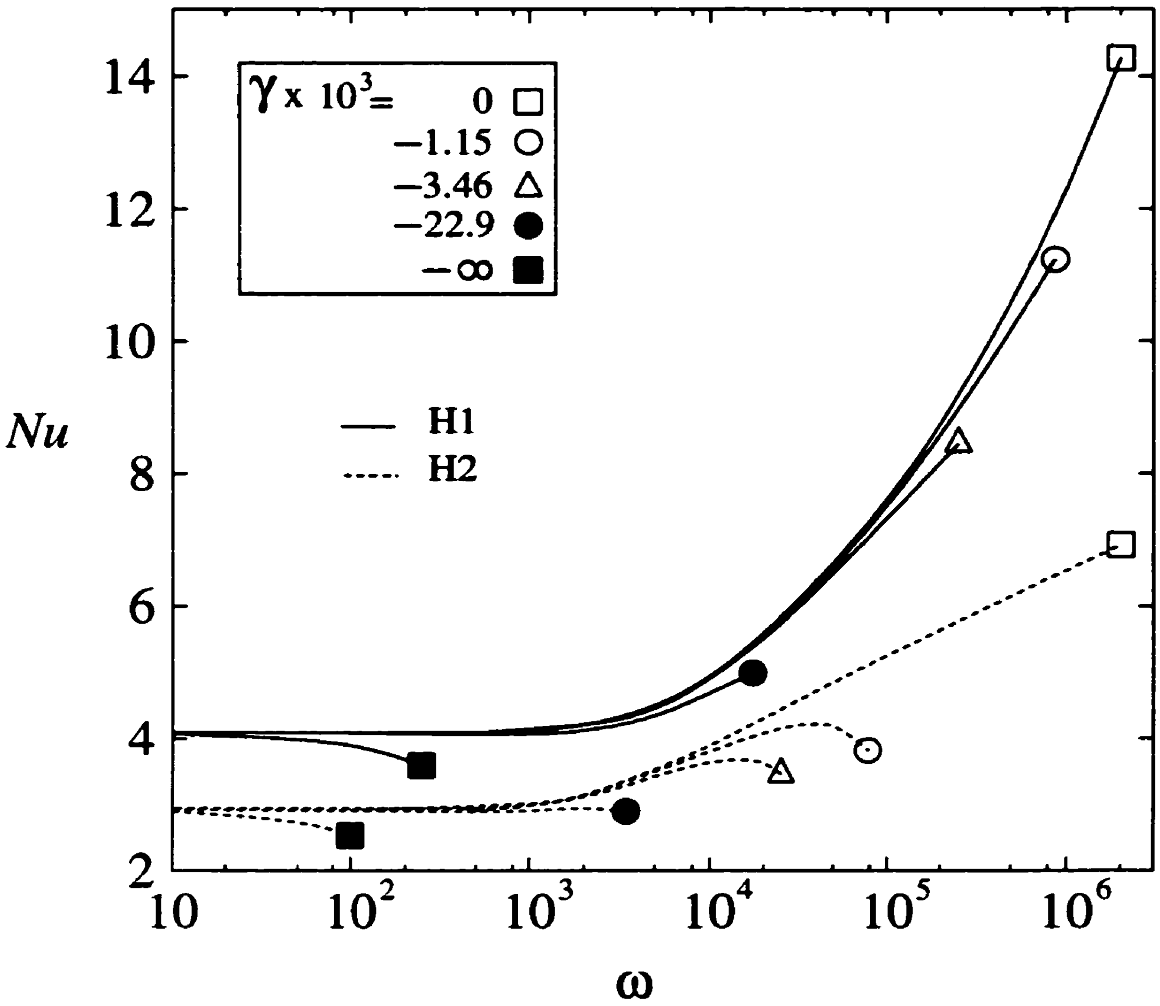


Figure 4.47: Nusselt number for downward inclinations with $Pr = 7$

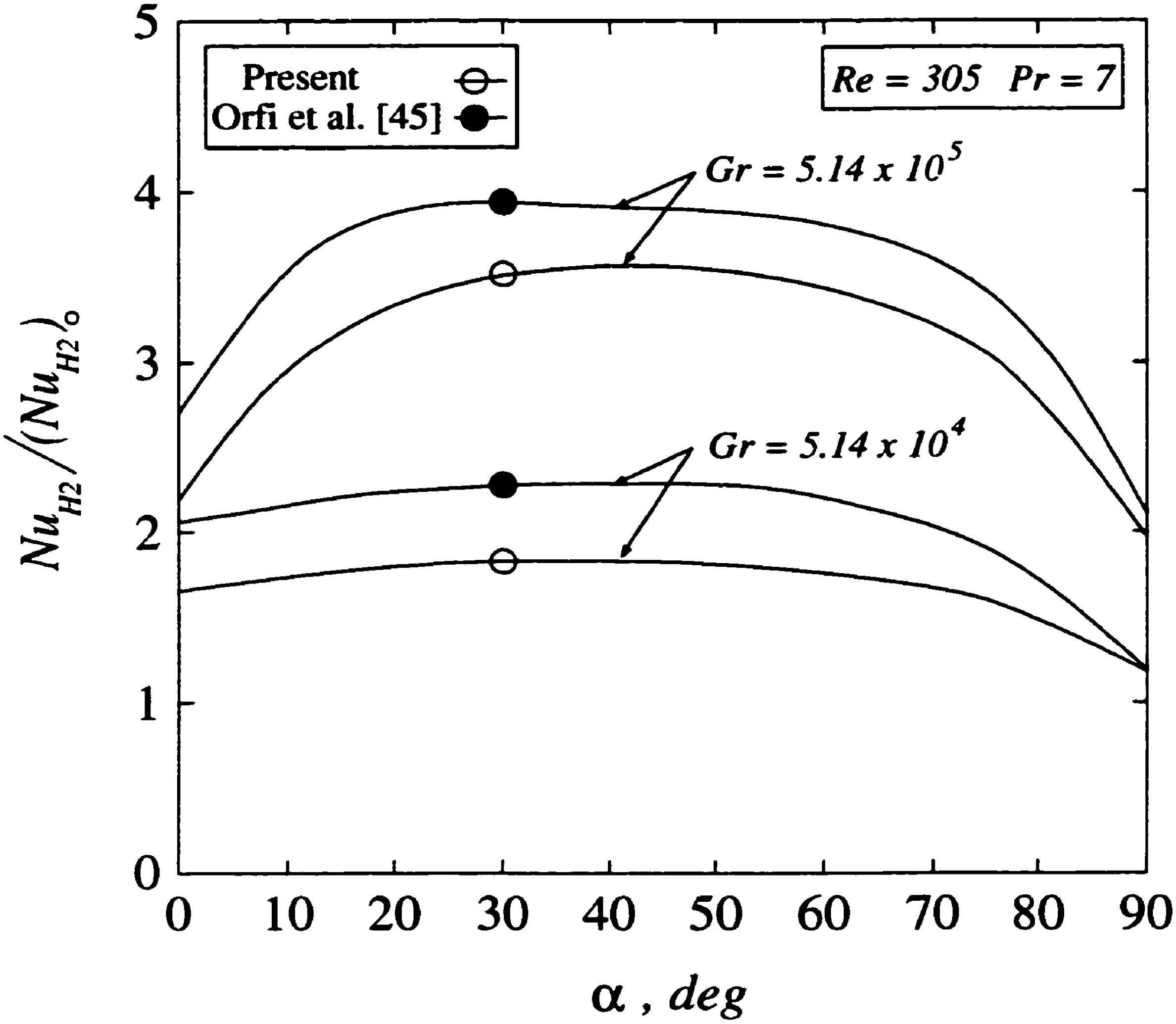


Figure 4.48: Comparison with Orfi et al. [45] for the same Re, Pr, and Gr

the circular cross-section would experience more enhancement than the semicircular cross-section due to free convection. Figure 4.48 shows that the two sets of results are similar in trend including the sharper increase in Nu with α near the horizontal orientation that is associated with high Gr.

A second comparison was made based on equal values of $\dot{m}$, q', D_h, and fluid properties. From the condition of equal D_h, we get

$$(r_o)_{semicircular} = 1.637(r_o)_{circular}.$$

Adding the condition of equal $\dot{m}$, we get

$$(Re)_{semicircular} = 0.747(Re)_{circular}.$$

Applying the above conditions, together with equal q', we get

$$(Gr)_{semicircular} = 4.38(Gr)_{circular}.$$

The condition of the same fluid properties implies the same Pr.

Results based on the above conditions are shown in figure 4.49, indicating better heat transfer enahancement for the semicircular duct than the circular one, except at $\alpha = 0$ where thermal stratification hinders heat transfer in the semicircular duct, but not the circular one. These results are extremely interesting in that they show a possible advantage for using the semicircular geometry in compact heat exchangers.

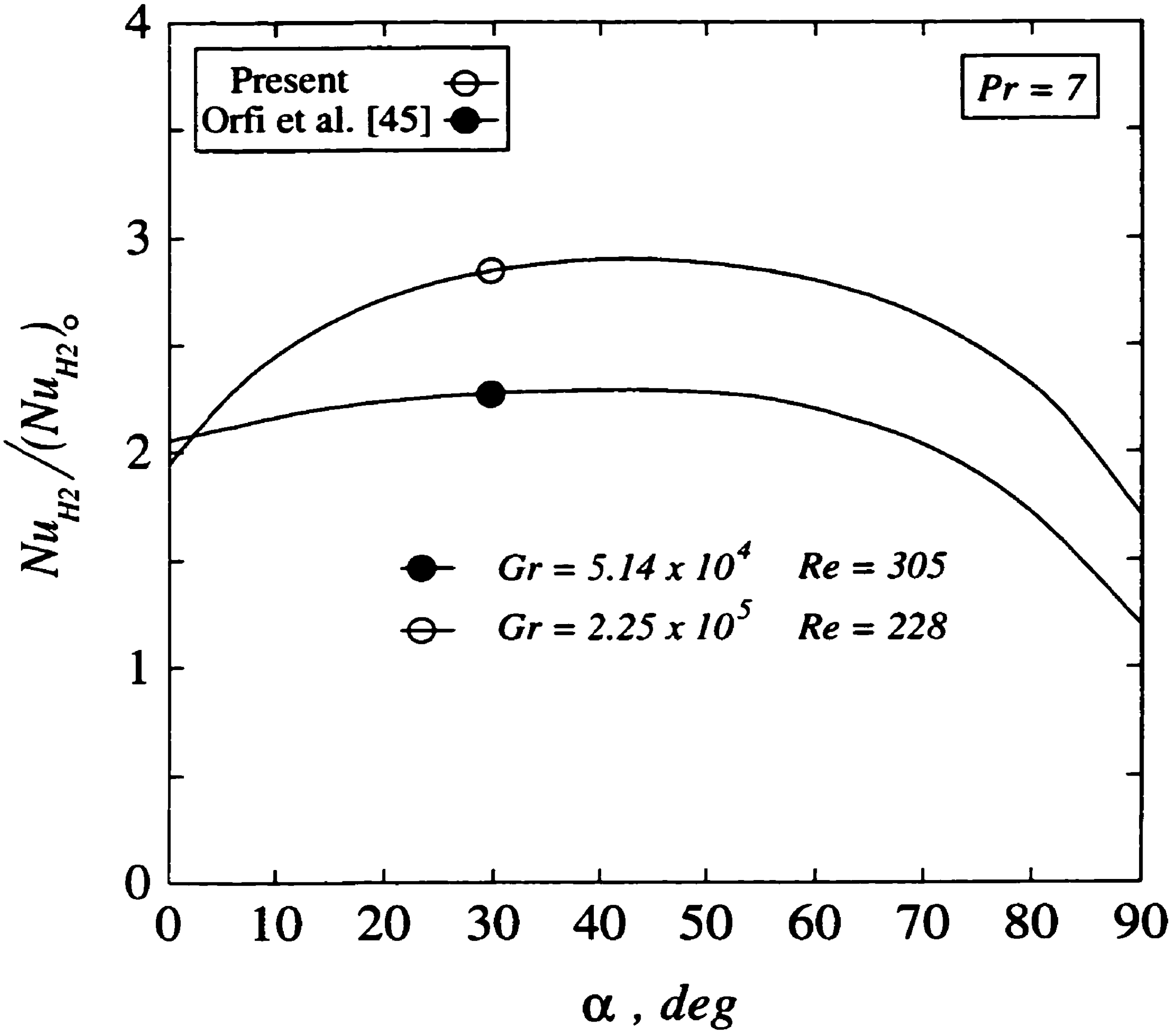


Figure 4.49: Comparison with Orfi et al. [45] for the same $\dot{m}$, q', D_h, and Pr

CHAPTER 5

EXPERIMENTAL INVESTIGATION

The experiment was designed for determining the effect of inclination in upward and downward flows within $\pm 20°$ on the heat transfer and pressure drop characteristics of laminar mixed convection in a semicircular duct oriented with the flat surface on the vertical position. The range of inclination angles was limited by the space in the lab. Using water as the working fluid, the duct was subjected to the boundary condition of uniform heat input axially. The test matrix for which results were obtained included five inclinations ($\alpha = 20°, 10°, 0°, -10°, -20°$), three Reynolds numbers for each inclination ($Re_m = 500, 1000, 1500$) and a wide range of Grashof numbers for each combination of α and Re_m. For each combination of Re_m, α, and Gr_m, the measured parameters include the axial and circumferential variation of wall temperature, the local Nusselt number, the fully-developed Nusselt number, and the overall pressure drop across the test section.

5.1 Experimental Apparatus and Procedure

5.1.1 Flow Loop

The test facility used in this experimental investigation is shown in figure 5.1. Distilled water (used as the working fluid) was circulated around the loop by a centrifugal pump. The flow rate through the test section was regulated by a by-pass line

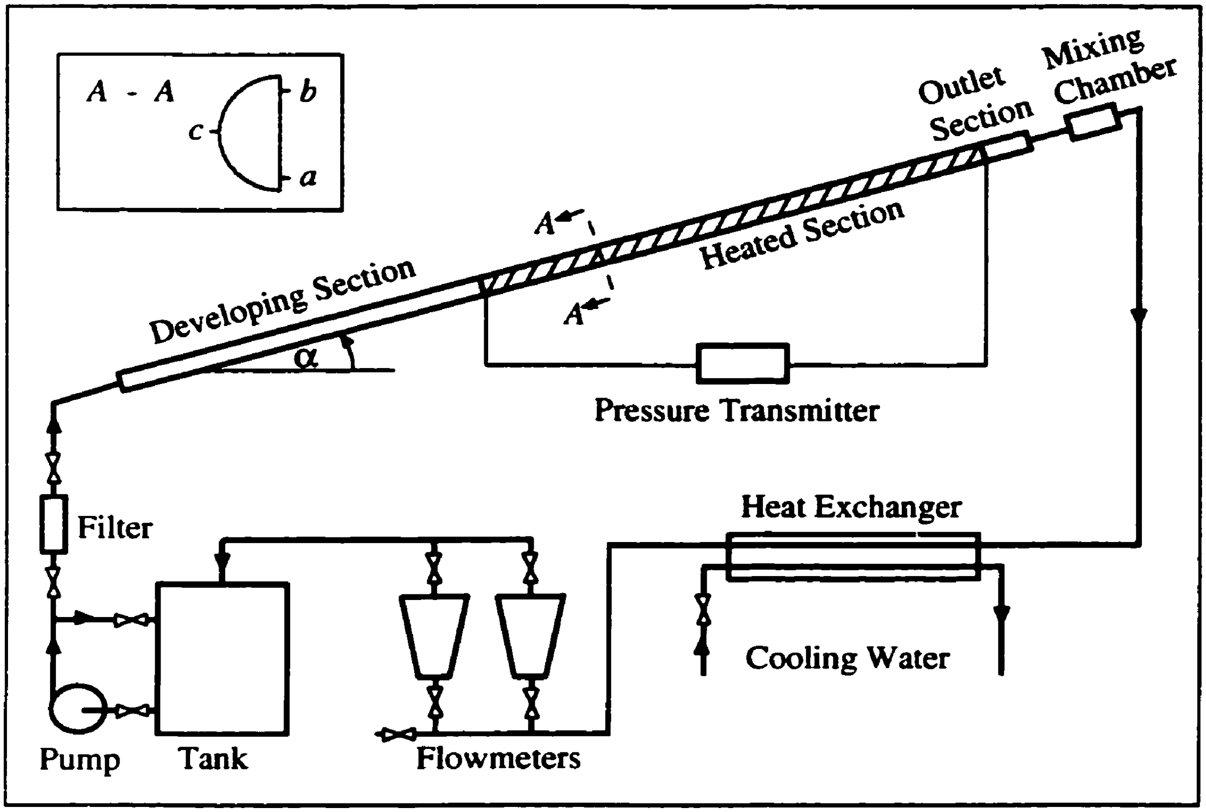


Figure 5.1: Schematic diagram of the experimental apparatus

around the pump and a filter was installed upstream of the test section. The test section was mounted on a rigid beam which was pivoted at the center (shown in figure 5.2) to allow for inclination in upward and downward positions within $\pm 20°$. Following the test section, the outlet bulk temperature was measured in a mixing chamber. The test fluid was then cooled in one or two heat exchangers and its flow rate was measured by variable-area type flowmeters before returning it to the accumulating tank.

5.1.2 Test Section

The semicircular test section was constructed using type K copper tubing ($49.8 - mm$ i.d. and $54.0 - mm$ o.d.) and brass plates ($3.2 - mm$ thick). The test section consisted of three parts: a hydrodynamic developing length of about 2.7 m, a heated length of about 4.7 m and an outlet length of about 0.3 m. The heat input (in the heated section) was generated by flat electric resistance wires with a total resistance of 6.85 Ω. The heated section was first covered by an electrical insulating varnish coating and then wrapped by a layer of fiber glass insulating tape to protect the varnish from the heater wires. Two wires were carefully wound in parallel and with a uniform pitch. The resistance of the twin heaters was axially uniform to within 5%.The heating wires were then covered with high-temperature, high-thermal-conductivity cement to insure that the wires remained firmly in place at all operating temperatures and also to uniformly distribute the input heat. The input power was regulated by an AC power variac and measured by a digital Wattmeter. The whole test section was covered by a $5 - cm$ thick layer of fiber glass thermal insulation. Heat loss through the insulation was measured by a heat flux meter (HEATPROBE, model HA-100) and found to be within 3% of the total heat input for the whole experimental range.

Wall temperatures were measured at 19 axial locations within the heated section

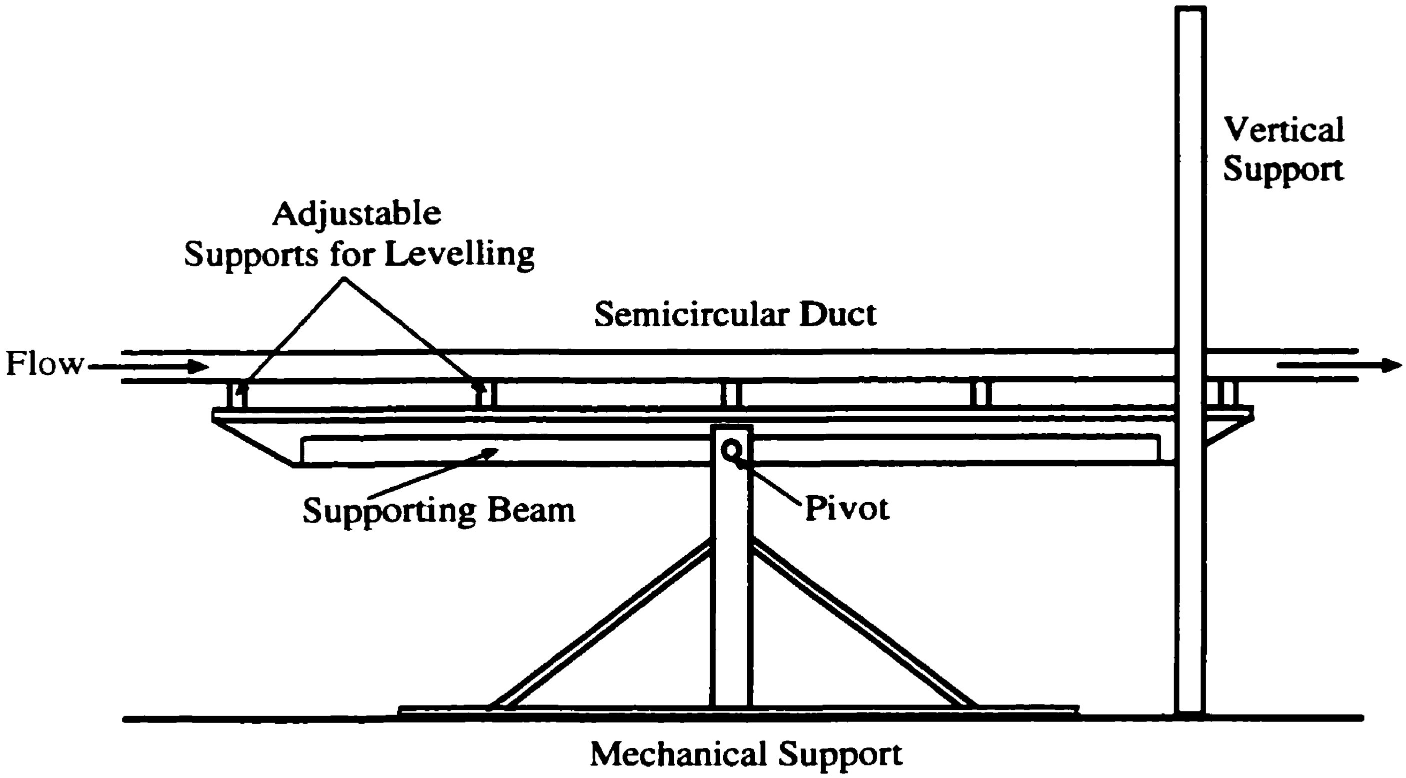


Figure 5.2: Supporting mechanism for the experimental rig

with three thermocouples (a,b, and c) at each location, as shown in figure 5.1. The axial distance between wall thermocouples varied from 100 mm at the beginning of the heated section, to 300 mm in the middle section, down to 200 mm in the last 5 stations, as shown in figure 5.3.

Errors in wall thermocouples readings were detected by conducting 10 calibration runs at different temperatures ranged from 20 to 65°C. These runs were carried out at maximum flow rate by closing the by-pass valve and isolating the flowmeters. The 10 readings of wall temperatures at each wall thermocouple with the corresponding bulk temperatures were used to generate a calibration formula to correct the readings of that particular thermocouple during the heat transfer tests.

The inlet bulk temperature was measured at the beginning of the hydrodynamic developing length and the measured axial gradient of wall temperature at the beginning of heating was used to correct this value. Following the procedure outlined by Rustum [63] the axial gradient of wall temperature at the beginning of heating was obtained by using the thermocouples at stations 1 and 2 located just before the beginning of heating and at the first station (station 3) in the heated section, see figure 5.3. The axial heat conduction was then evaluated at the beginning of heating to be added to the upstream bulk temperature to correct it. A similar procedure was used in correcting the outlet bulk temperature using the thermocouples at stations 22 and 23 located after the end of heating and at station 21 in the heated section. A straight line was fitted between the corrected inlet and outlet bulk temperatures. The pressure drop was measured across the entire heated section (thermally developing and fully-developed), using a pressure transducer (with a range of 0 to 38 mm of water). The pressure transducer was carefully calibrated against a micro-manometer and a dual display multi-meter (FLUKE 45) at room temperature 23°C. The distance between the pressure taps was about 4.9 m, as displayed in figure 5.3.

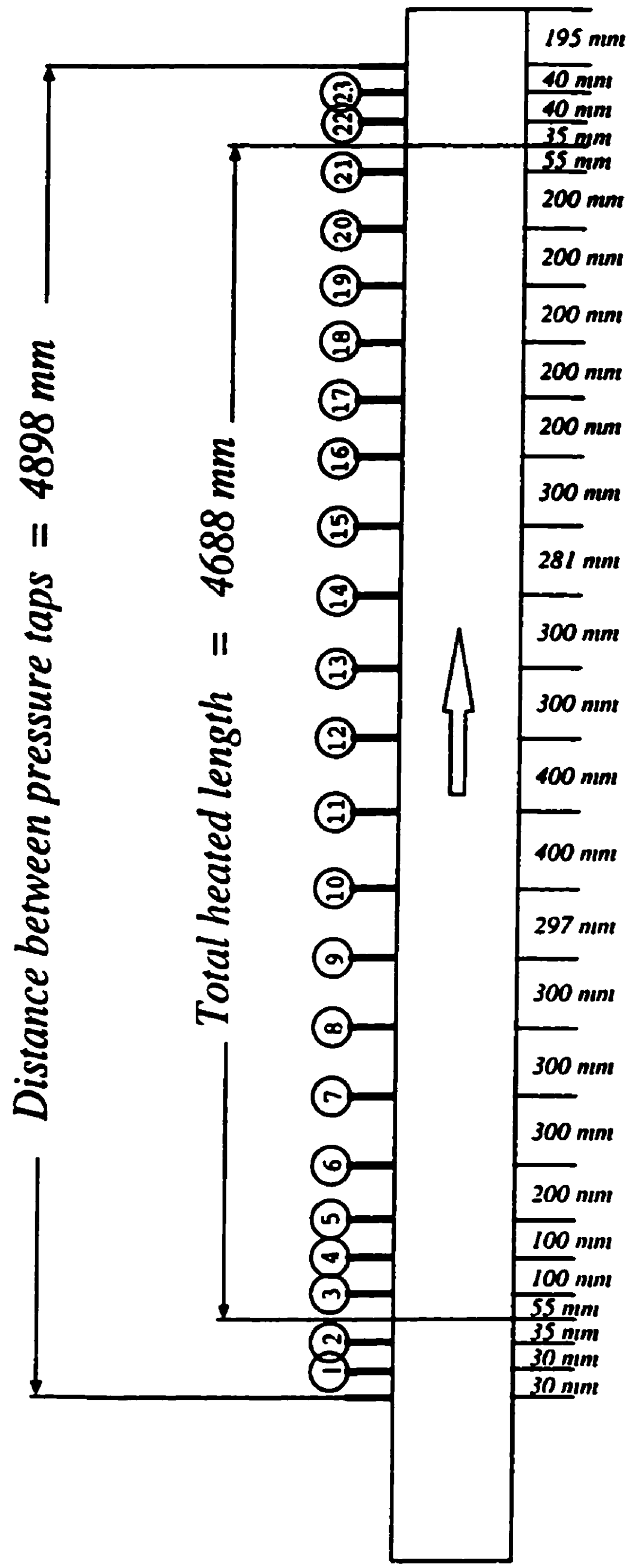


Figure 5.3: Heated test section showing the axial stations

5.2 Procedure and Data Reduction

The three independent parameters in this experiment are Reynolds number (controlled by the flow rate), Grashof number (controlled by the input power) and the inclination angle. After adjusting the desired values of these parameters, the experiment was allowed to run for at least 4 hours before steady-state conditions were achieved. When steady state was established, the readings of all thermocouples, flow meters, the input power, and the pressure transducer were recorded. Further, the heat losses through the insulation were recorded by placing the thermal electric heat flux transducer on the insulation at six axial locations. The rate of heat gain by the test fluid, Q_f, was then calculated from the formula $Q_f = \dot{m}\ c_p\ (T_{bulk,o} - T_{bulk,i})$, where $T_{bulk,i}$ and $T_{bulk,o}$ are the inlet and outlet bulk temperatures, respectively, corrected for axial wall conduction. The six readings of the heat flux meter (in W/m^2) were averaged and the average value was multiplied by 2.62 m^2, which is the outer surface area of the insulation, in order to get an estimate of the rate of heat lost by conduction through the insulation. The corrected input power, Q_e, was then obtained by subtracting the rate of heat loss through the insulation from the measured electric power input. The heat balance error was calculated as $[(Q_e - Q_f)/Q_e] \times 100$ and was found to be within ±6% for all test runs. Actually, the heat balance error was within ±3% for 84 % of the test runs.

The dimensionless independent parameters Re and Gr were calculated from the measured quantities using the following definitions:

$$Re = \frac{\dot{m}\ D_h}{\mu\ A_{fl}} \qquad \text{and} \qquad Gr = \frac{\beta\ g\ \rho^2\ q' r_o^3}{k\ \mu^2} \tag{5.1}$$

where q' is the heat input per unit length calculated as $q' = Q_f/$ total heated length.

The hydraulic diameter D_h and the cross-sectional flow area are given by

$$D_h = \frac{2\,\pi\,r_o}{(\pi+2)} \qquad \text{and} \qquad A_{fl} = \frac{\pi}{2}\,r_o^2 \tag{5.2}$$

All fluid properties in equation (5.1) were calculated at the average of the inlet and outlet bulk temperatures, which is indicated by the subscript m for Re_m and Gr_m in the following sections.

The local Nusselt number was calculated from the following definition:

$$Nu_{Z,i} = \frac{h_{Z,i}\,D_h}{k} = \frac{q'\,D_h}{r_o(\pi+2)\;k\;(T_{Z,i} - T_{Z,bulk})} \tag{5.3}$$

where i refers to wall thermocouple positions a, b, and c, as displayed in figure 5.1. The local average Nusselt number at each axial station was calculated in two ways: (i) by determining the length-mean average of $Nu_{Z,a}$,$Nu_{Z,b}$, and $Nu_{Z,c}$, and (ii) by determining the length-mean average ($\overline{T}_{Z,i}$) of the three wall temperatures and then using equation (5.3) for the local mean Nusselt number. The two values obtained from (i) and (ii) were very close and therefore, the local mean Nusselt number was taken as the average of these two values, i.e.,

$$Nu_Z = \left[\frac{\overline{h}_{Z,i}\,D_h}{k} + \frac{q'\,D_h}{r_o(\pi+2)\;k\;\left(\overline{T}_{Z,i} - T_{Z,bulk}\right)}\right]/2 \tag{5.4}$$

The value from equation (5.4) will be called "the local Nusselt number" in the following sections without using the word "mean" for briefness.

Using similar expressions to the ones in [32] (equations (2.1) and (2.2)), as mentioned earlier in section 2.2.2, the friction factor was determined using the inclination angle α as follows:

$$\Delta P_{dp} = \Delta P_f + (\rho_m - \rho_a)\ g\ L\ sin\alpha \tag{5.5}$$

$$f = \frac{\Delta P_f\ \rho_m\ A_{fl}^2}{\dot{m}^2}\ \frac{D_h}{2\ L} \tag{5.6}$$

The term ΔP_{dp} represents the differential pressure reading, ΔP_f is the frictional pressure drop, L is the distance between the pressure taps, and the last term in equation (5.5) is the static pressure difference. The last term is equal to zero for the horizontal orientation ($\alpha = 0°$) and for the isothermal condition with no heating, ($\rho_m = \rho_a$). The mean density ρ_m was evaluated at the average of the inlet and outlet bulk temperatures, and ρ_a was calculated at the room temperature during the experimental run. Due to the sensitivity of the pressure transducer, the static pressure difference must be obtained accurately otherwise, error will arise in the frictional pressure drop.

5.3 Experimental Uncertainty

The uncertainty bounds were estimated for the friction factor and all the local values of Re, Gr, and Nu for all 89 test runs using the method outlined by Kline and McClintock [64] and Moffat [65]. A sample calculation showing the procedure for estimating the uncertainty limits in these parameters is outlined in Appendix B. A summary of the results for all test runs is given in the following paragraph.

The uncertainty in f was found to be within $\pm 6.4\%$ and the uncertainty in Re was found to be within $\pm 3.5\%$ for all test runs. The uncertainty in α was estimated to be within $\pm 0.2°$. The uncertainty in Gr and Nu was found to be dependent on the values of Re and Gr. As Re increased and/or Gr decreased, the uncertainty in Nu and Gr was found to increase. The reason is that high Re (i.e., high water flow rate) and low Gr (i.e., low heat input) would result in low temperature differences between the wall and the bulk, and between outlet bulk and inlet bulk. For example, at $\alpha = 0°$, $Re_m = 1000$, and $Gr_m = 1.06 \times 10^8$, the uncertainty in Gr is within $\pm 8.4\%$ and the uncertainty in Nu is within $\pm 5.4\%$. These uncertainties are higher for $\alpha = 0°$, $Re_m = 1500$, and $Gr_m = 4.58 \times 10^6$, where the uncertainty in Gr is within $\pm 19.1\%$ and the uncertainty in Nu is within $\pm 26.5\%$. The highest uncertainties were found at $\alpha = 0°$, $Re_m = 1500$, and $Gr_m = 2.36 \times 10^6$, where the uncertainty in Gr was found to be within $\pm 33\%$ and the uncertainty in Nu to be within $\pm 42\%$.

5.4 Experimental Results

A total of 89 test runs were conducted in this investigation covering the following ranges of the independent parameters:

$$\begin{aligned} Re_m &= 500, \quad 1000, \quad \text{and} \quad 1500 \\ Pr_m &= 4.6 \quad - \quad 6.5 \qquad \text{(water)} \\ Gr_m &= 1.54 \times 10^6 \quad - \quad 1.15 \times 10^8 \\ \alpha &= 20°, 10°, 0°, -10°, \text{ and } -20° \end{aligned}$$

A different range of Gr_m was covered for each combination of α and Re_m. For example, at $\alpha = -20°$ and $Re_m = 500$, it was not possible to go beyond $Gr_m = 8.61 \times 10^6$ due to oscillations in thermocouple readings indicating flow instabilities. In general, the maximum Gr_m for which steady readings were possible increased as Re_m increased, and was much higher for upward inclinations than for downward inclinations. Table

5.1 summarizes the ranges of the independent parameters covered in the experiment. The reduced data for all experimental runs are listed in Appendices C to G. In the remaining part of this chapter, the nominal values of $Re_m = 500, 1000$, and 1500 will be used since the actual values of Re_m (listed in Table 5.1) do not deviate much from the nominal values.

5.4.1 Wall Temperature

5.4.1.1 Horizontal Orientation

Results of the wall-temperature measurement for $\alpha = 0°$ and $Re_m = 1000$ are shown in figure 5.4 for four values of Gr_m. The circumferential variation of wall temperature at each axial station is indicated by the readings of the three thermocouples a, b, and c (see figure 5.1 for locations), and the slope of the bulk temperature is shown for each Gr_m. Figure 5.4 shows that the circumferential variation of wall temperature increases as Gr_m increases. The trend in these results is that $T_{Z,b} > T_{Z,c} > T_{Z,a}$. This trend is consistent with the physics of the problem whereby the cross-sectional secondary flow current pushes the heavier (cooler) fluid towards the bottom of the cross-section, while the lighter (warmer) fluid rises [53]. For each Gr_m, a fully-developed region is reached where the wall and bulk temperatures appear to be increasing at the same linear rate with Z. Similar trends were noted for all data of the horizontal orientations ($Re_m = 500$ and 1500).

5.4.1.2 Upward Inclination

A representative example of the results for upward inclinations is shown in figures 5.5 and 5.6 using the data for $\alpha = 20°$ and $\alpha = 10°$ with $Re_m = 1000$. These data show

Table 5.1: Ranges of the independent parameters

α	Gr_m	Re_m	Pr_m	*No. of runs*
$0°$	$2.30 \times 10^6 - 2.54 \times 10^7$	499 - 506	5.27 - 6.36	4
	$2.27 \times 10^6 - 1.06 \times 10^8$	999 - 1006	4.56 - 6.36	7
	$2.36 \times 10^6 - 1.13 \times 10^8$	1495 - 1500	5.27 - 6.49	5
$10°$	$2.17 \times 10^6 - 2.47 \times 10^7$	497 - 502	5.29 - 6.39	4
	$2.13 \times 10^6 - 1.03 \times 10^8$	998 - 1002	4.59 - 6.39	7
	$2.28 \times 10^6 - 1.11 \times 10^8$	1492 - 1505	4.86 - 6.48	7
$20°$	$2.25 \times 10^6 - 2.54 \times 10^7$	499 - 508	5.28 - 6.36	4
	$2.14 \times 10^6 - 1.01 \times 10^8$	1000 - 1006	4.59 - 6.39	7
	$2.26 \times 10^6 - 1.15 \times 10^8$	1497 - 1503	4.82 - 6.52	7
$-10°$	$2.24 \times 10^6 - 2.40 \times 10^7$	497 - 507	5.30 - 6.32	7
	$2.15 \times 10^6 - 2.40 \times 10^7$	997 - 1005	5.69 - 6.42	6
	$2.27 \times 10^6 - 2.39 \times 10^7$	1501 - 1506	5.98 - 6.49	6
$-20°$	$1.54 \times 10^6 - 8.61 \times 10^6$	498 - 501	5.93 - 6.32	6
	$1.76 \times 10^6 - 1.10 \times 10^7$	997 - 1000	6.06 - 6.39	6
	$1.89 \times 10^6 - 1.12 \times 10^7$	1498 - 1505	6.16 - 6.42	6

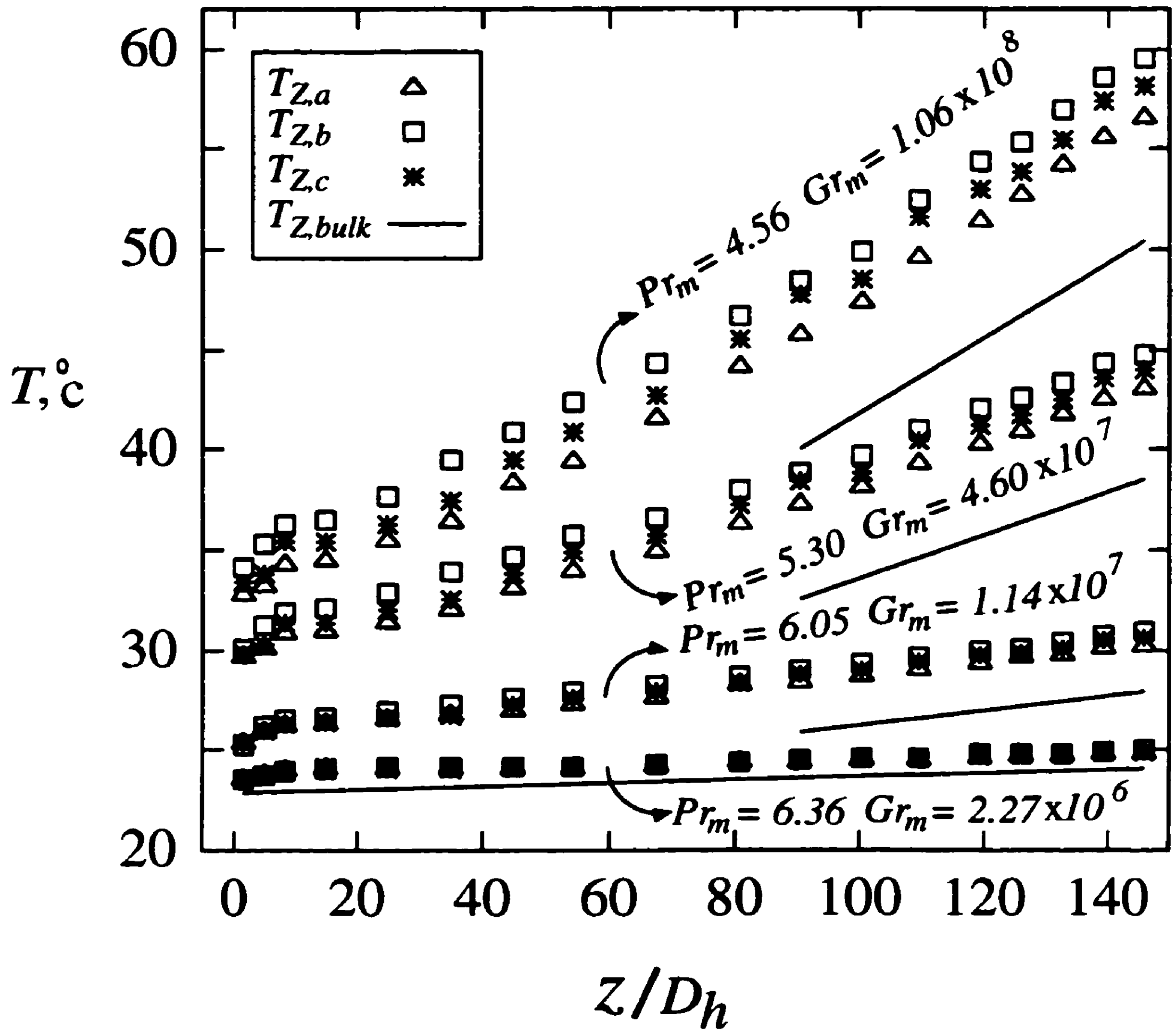


Figure 5.4: Variation of wall temperature for $\alpha = 0°$ and $Re_m = 1000$

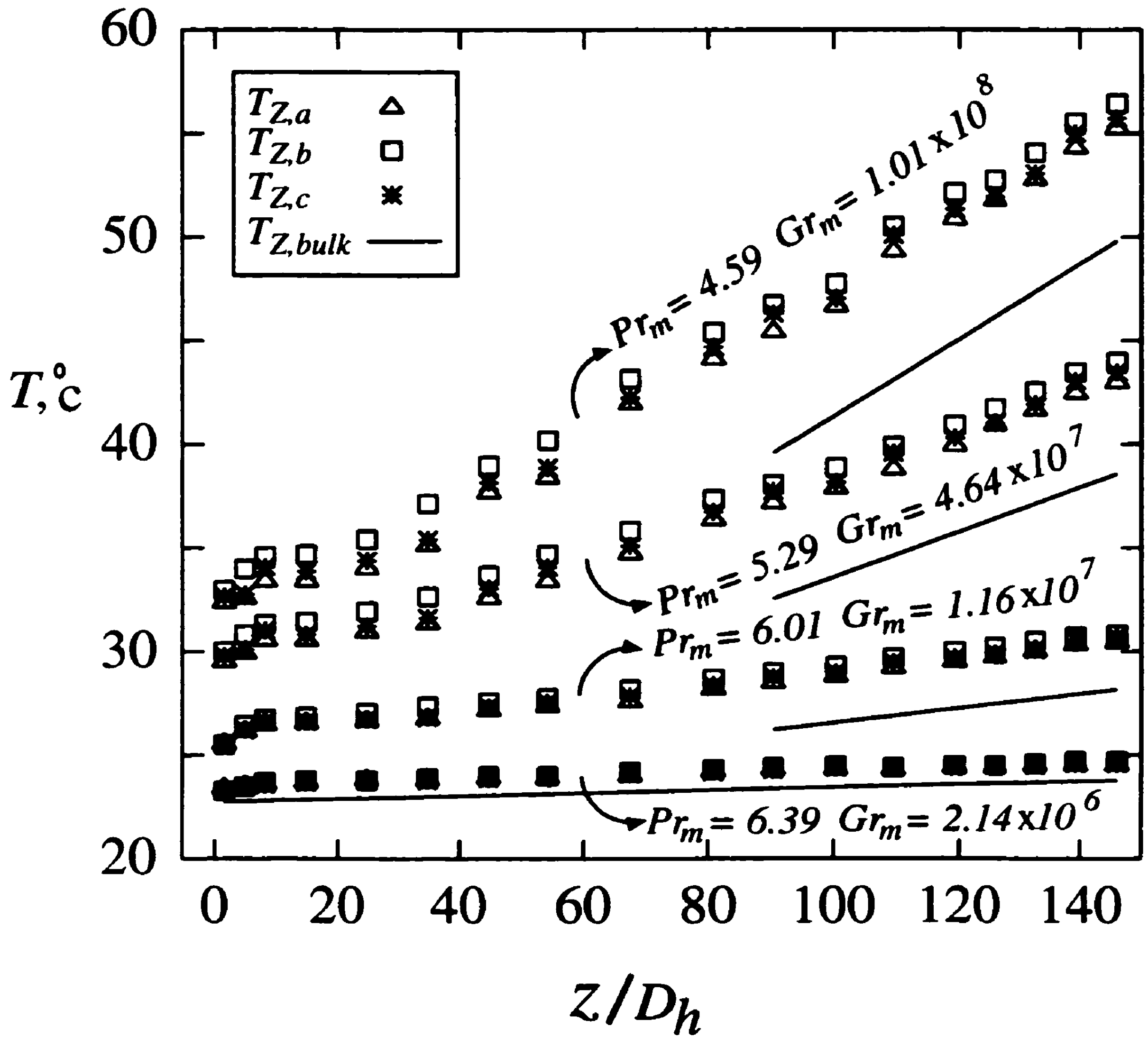


Figure 5.5: Variation of wall temperature for $\alpha = 20°$ and $Re_m = 1000$

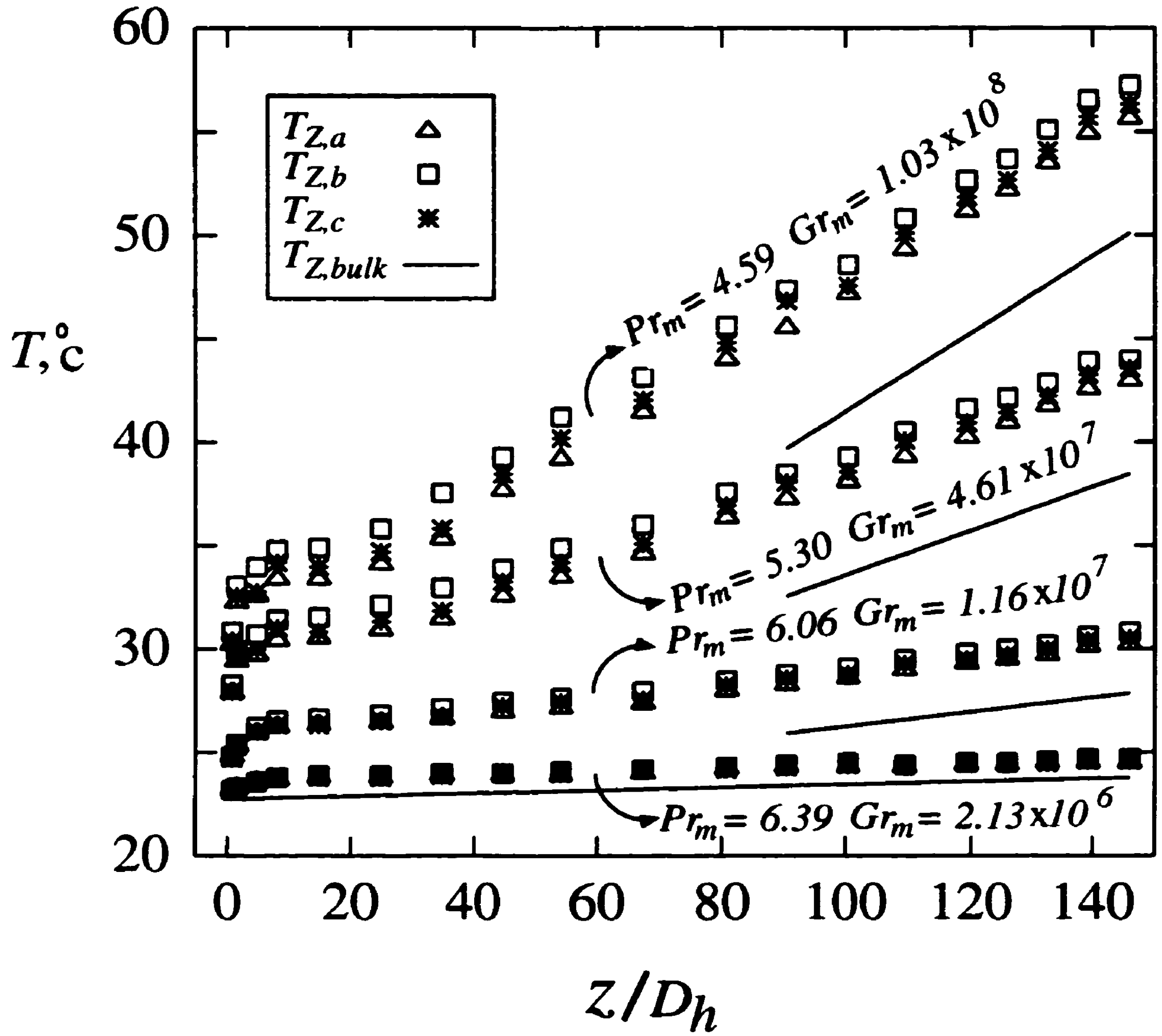


Figure 5.6: Variation of wall temperature for $\alpha = 10°$ and $Re_m = 1000$

similar trend as those in figure 5.4 (i.e., $T_{Z,b} > T_{Z,c} > T_{Z,a}$), and the circumferential variation of wall temperature increasing with Gr_m. However, comparing results of similar Gr_m (e.g., $Gr_m = 1.06 \times 10^8$ in figure 5.4, $Gr_m = 1.01 \times 10^8$ in figure 5.5 and $Gr_m = 1.03 \times 10^8$ in figure 5.6), we notice that the magnitude of circumferential variation is lower for upward inclinations than the horizontal orientation. This can be attributed to the fact that only a component of the net body force is driving the cross-sectional secondary flow due to inclination, resulting in a weaker secondary flow current and less circumferential variation of wall temperature.

It can be noted that, as the inclination angle increases from $\alpha = 10°$ to $20°$ with similar high Gr_m and same Re_m the circumferential variation of wall temperature continues to decrease but at a slower rate. The reason is that, the component of the net body force, which acts normal to the heated surface, becomes less important (in driving the secondary flow) with increasing α, resulting in a weaker free convection current within the cross-section.

5.4.1.3 Downward Inclination

For the downward inclination, the net body force has two components; one normal to the main flow direction (driving the secondary flow within the cross-section), and the other component acts opposite to the main flow direction. The second component would influence the velocity and temperature profiles in the heated section and may give rise to flow reversal in the upper part of the cross-section at high Gr_m and low Re_m [55]. The temperature development for $Re_m = 500$ and 1500 are shown in figures 5.7 and 5.8 for $\alpha = -20°$ and $-10°$, respectively. For $Re_m = 1500$, and Gr_m up to 1.12×10^7 in figure 5.7 and Gr_m up to 2.39×10^7 in figure 5.8 the wall-temperature development looks similar to the horizontal and upward inclinations. It was not possible to extend Gr_m to higher values due to temperature oscillations.

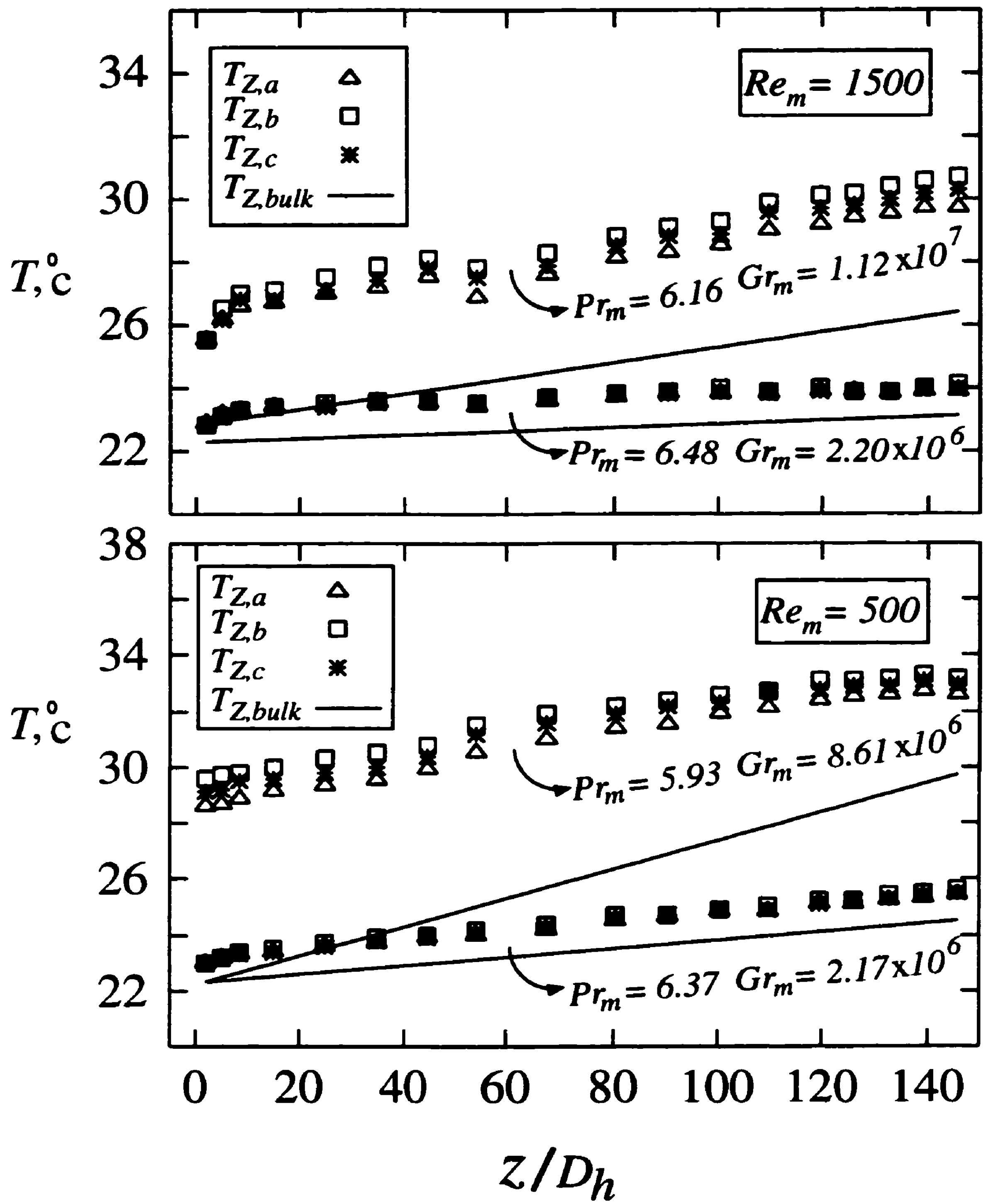


Figure 5.7: Variation of wall temperature for $\alpha = -20°$ and $Re_m = 500$ and 1500

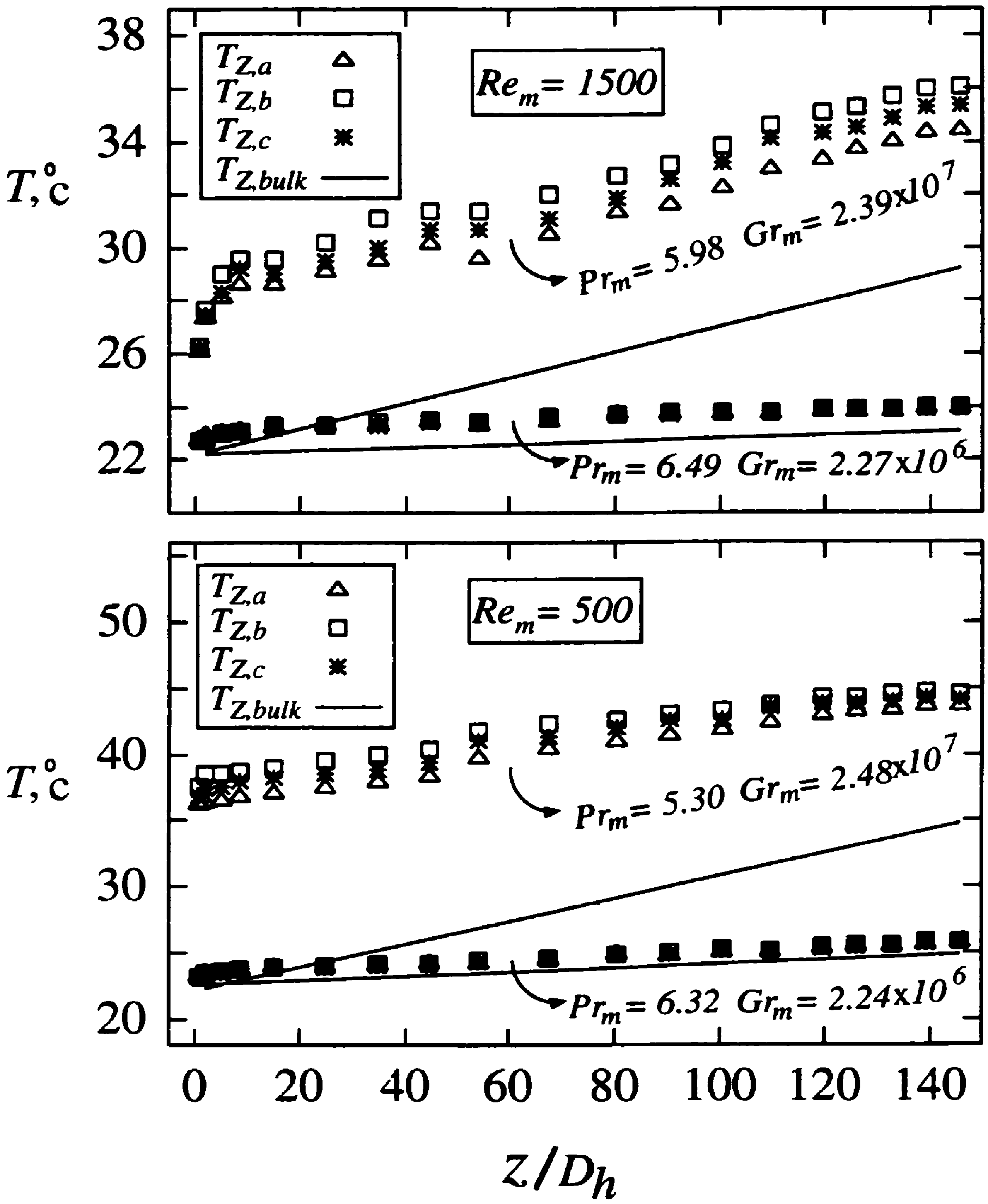


Figure 5.8: Variation of wall temperature for $\alpha = -10°$ and $Re_m = 500$ and 1500

For $Re_m = 500$, the component of adverse net body force has a much stronger influence on the development of the hydrodynamic and thermal boundary layers as evidenced by the wall-temperature distribution. The wall-to-bulk temperature difference is large at the beginning of heating and it decreases continuously along the heated length without reaching fully developed conditions for $Gr_m > 5 \times 10^6$ with $\alpha = -20°$ and for $Gr_m \geq 1 \times 10^7$ with $\alpha = -10°$. In the theoretical analysis, it was found that, when $\alpha = -20°$, flow reversal starts at $Gr_m = 2 \times 10^6$ under the present conditions of Pr and Re, while decreasing the tilt angle to $\alpha = -10°$ the flow reversal starts at Gr three times higher than that for $\alpha = -20°$ under same conditions of Pr and Re. Therefore, it is postulated that the temperature distribution shown in figures 5.7 and 5.8 for $Re_m = 500$ is due to the flow reversal current moving hot fluid from the end of the heated section backward towards the beginning of the heated section.

With $\alpha = -10°$ and $Re_m = 1500$, it can be seen that Gr_m is advanced further with steady laminar flow up to $Gr_m = 2.39 \times 10^7$ as compared with $\alpha = -20°$. At this value of Gr_m, fully-developed conditions are reached, as shown in figure 5.8. This is because the flow reversal develops earlier (at lower Gr_m) for $\alpha = -20°$ than that for $\alpha = -10°$ at same Re_m.

5.4.2 Local Nusselt Number

Results of the local Nusselt number, Nu_Z, are presented in this section in a manner that can illustrate the effects of the independent parameters Gr_m, α, and Re_m. The forced-convection results presented with the experimental data are for the H1 condition [6].

5.4.2.1 Effect of Inclination on Nu_Z

Figure 5.9 corresponds to $Re_m = 500$, $\alpha = 0°$ and four different values of Gr_m. For $\alpha = 0°$, Nu_Z is close to the forced-convection value at low Z^+, decreases to a minimum as Z^+ increases, and then rises due to the effect of free convection before reaching a nearly constant (fully developed) value. This behavior is similar to the one noted by Maughan and Incropera [54] and Lei and Trupp [7]. It is also clear that Gr_m has a strong effect on Nu_Z whereby Nu_Z increases significantly with Gr_m in both the developing and the fully-developed regions.

For upward inclinations (represented by $\alpha = 20°$ in figure 5.10), the axial variation of Nu_Z is similar to the horizontal orientation. However, for approximately the same values of Gr_m in figures 5.9 and 5.10, values of Nu_Z are slightly higher for the upward inclination in both the developing and the fully-developed regions. This is because the net body force has a component in the axial flow direction which accelerates the fluid resulting in an increase in the heat transfer coefficient. Again, this trend is consistent with the results of Maughan and Incropera [54].

For downward inclinations (represented by $\alpha = -20°$ in figure 5.10), a component of the net body force acts opposite to the axial flow direction, thus retarding the flow and possibly causing flow reversal in the upper part of the cross-section. For large Gr_m, this axial secondary flow loop may extend over most of the heated section causing significant effects on the velocity and temperature profiles. Under these conditions, figure 5.10 shows that Nu_Z decreases continuesly with Gr_m to the degree that values lower than the forced-convection value are encountered in the developing region. At high Gr_m, the flow does not reach fully-developed conditions with Nu_Z increasing continuesly with Z^+.

Figure 5.11 corresponds to $Re_m = 500$, $\alpha = 10°$ and $-10°$, and the widest possible

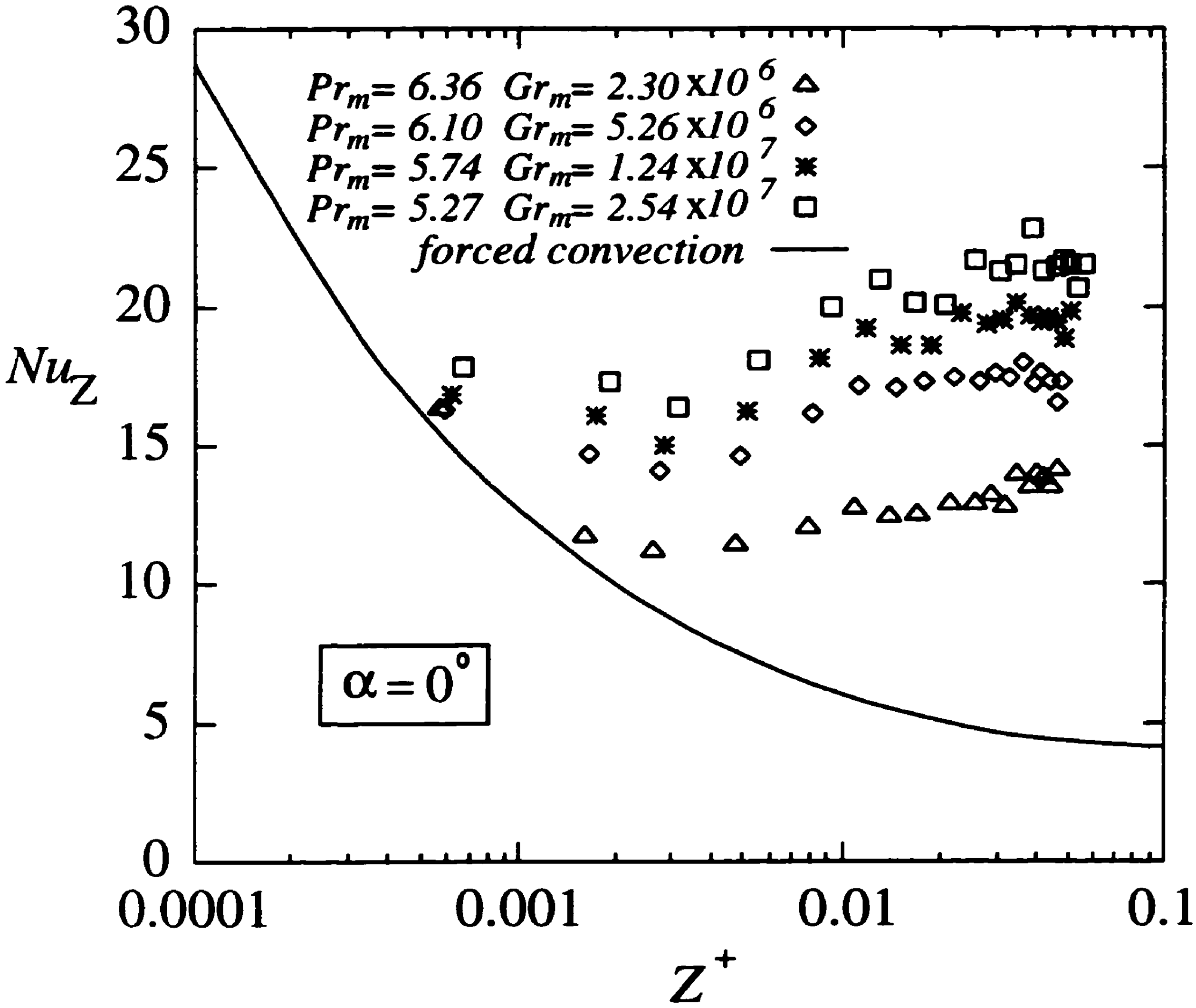


Figure 5.9: Local Nusselt number for $Re_m = 500$ and $\alpha = 0°$

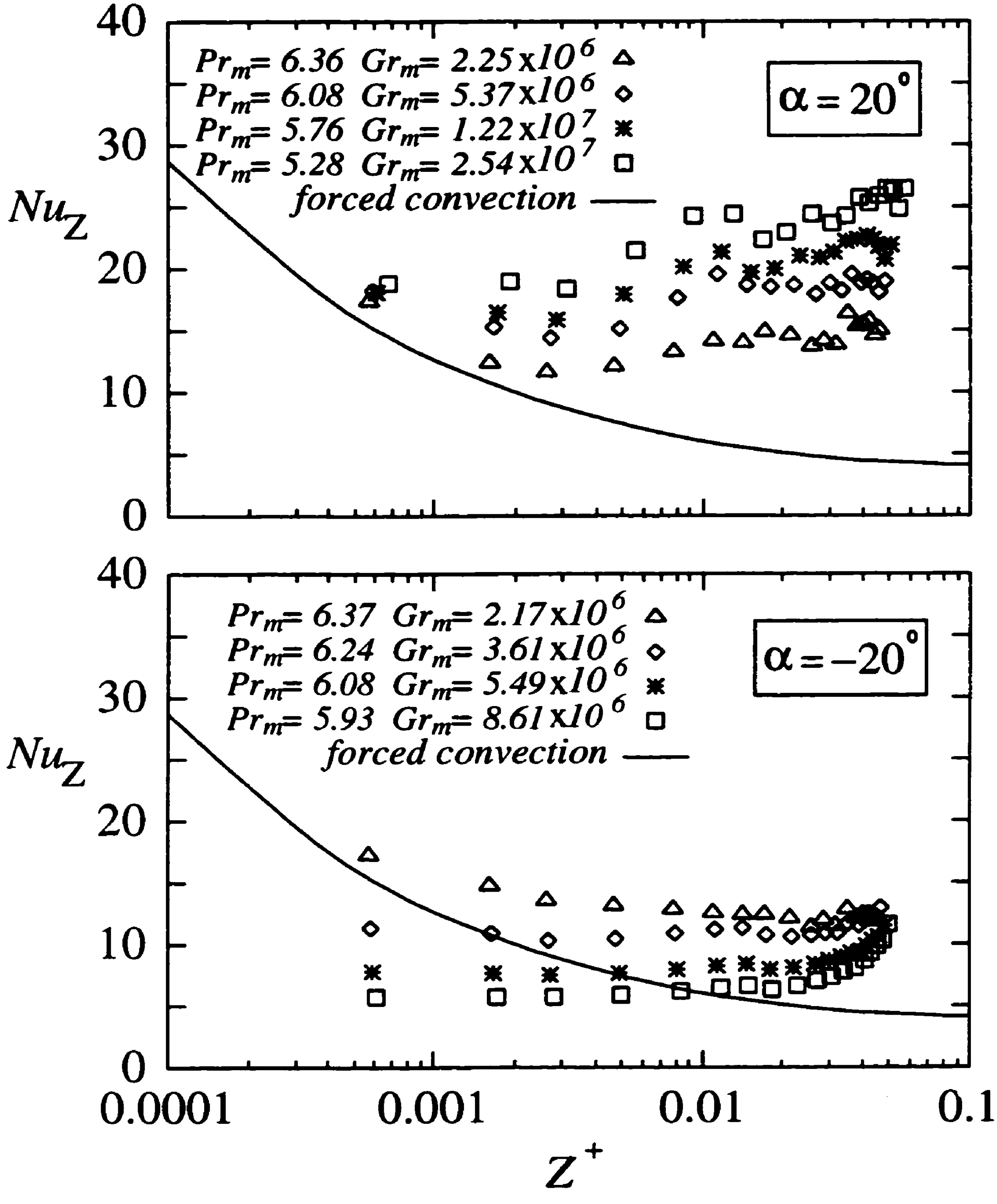


Figure 5.10: Effect of inclination on local Nusselt number for $Re_m = 500$

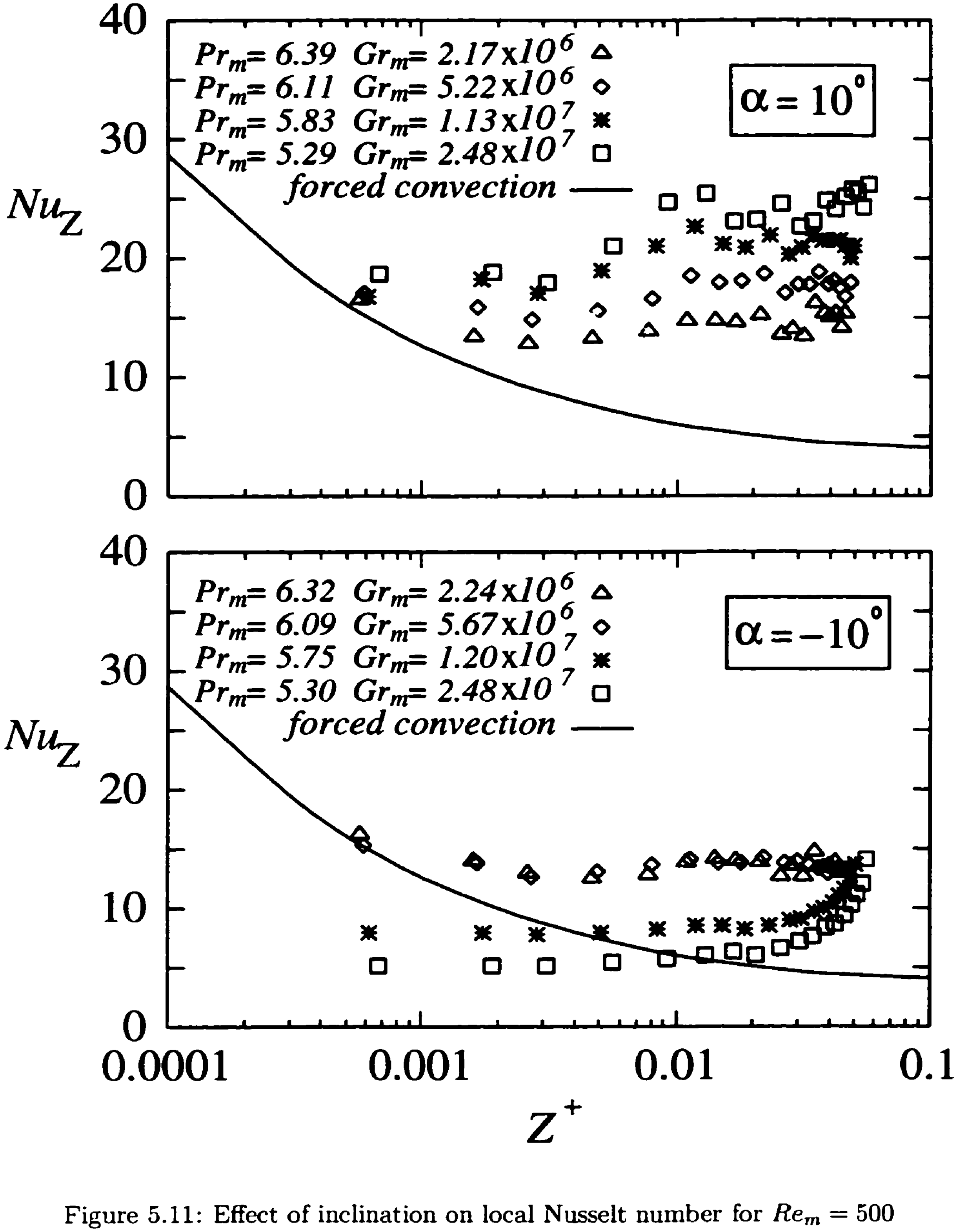


Figure 5.11: Effect of inclination on local Nusselt number for $Re_m = 500$

range of Gr_m. For $\alpha = 10°$, the axial variation of Nu_Z is similar to that for $\alpha = 20°$. For four different Grashof numbers ($2.17 \times 10^6 \leq Gr_m \leq 2.48 \times 10^7$), values of Nu_Z in figure 5.11 are also slightly higher than those for the horizontal orientation ($\alpha = 0°$) in both the developing and fully-developed regions. For $\alpha = 10°$, at high Gr_m (e.g., $Gr_m = 2.48 \times 10^7$ in figure 5.11) Nu_Z in the fully-developed region is 15% higher than that for $\alpha = 0°$ with $Gr_m = 2.54 \times 10^7$, while at $\alpha = 20°$ with similar Gr_m (e.g., $Gr_m = 2.54 \times 10^7$ in figure 5.10), the enhancement in the fully-developed Nusselt number has increased to 17%. Therefore, for the range of Gr_m investigated with $Re_m = 500$, it can be concluded that values of Nu_Z increase slightly when the upward inclination changes from $\alpha = 10°$ to $20°$.

Figure 5.11 shows the case of downward inclination for $\alpha = -10°$, $Re_m = 500$ and four different values of Gr_m. The change in heat transfer is very small along the heated section as Gr_m increases from $Gr_m = 2.24 \times 10^6$ to $Gr_m = 5.67 \times 10^6$, while a further increase in Gr_m resulted in a decrease in Nu_Z. It can be seen that, at higher Gr_m the data in the developing region are lower than the pure forced-convection solution.

5.4.2.2 Effect of Re_m on Nu_Z for Downward Inclination

The behavior of Nu_Z for downward inclinations was found to be very sensitive to the value of Re_m. This is illustrated in figure 5.12 for $\alpha = -20°$ using $Re_m = 1000$ and 1500 (data for $Re_m = 500$ are in figure 5.10). In all cases, the net body force acts to retard the flow, however, the effect on heat transfer depends on the mean velocity of the flow. For $Re_m = 1500$, there is enhancement in heat transfer as Gr_m increases from 1.89×10^6 to 3.50×10^6. However, a further increase in Gr_m from 3.50×10^6 to 1.12×10^7 resulted in very small change in heat transfer. For $Re_m = 1000$, values of Nu_Z start out increasing with Gr_m up to a maximum followed by a decrease in

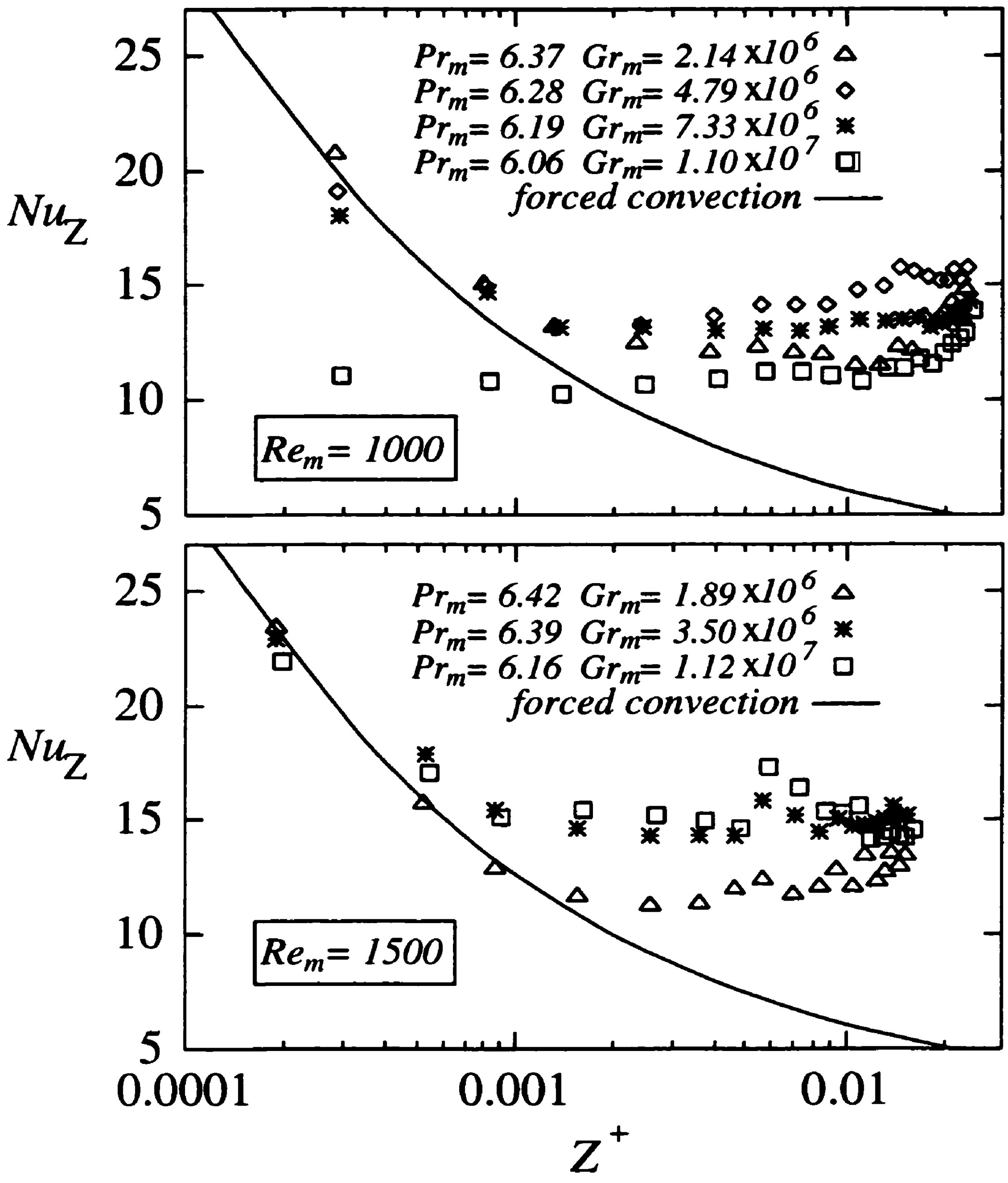


Figure 5.12: Effect of Reynolds number on local Nusselt number for $\alpha = -20°$

Nu_Z with further increase in Gr_m. This is consistent with the reasoning that when the adverse buoyancy effect gets strong enough to cause a flow-reversal region within the cross-section, the heat-transfer performance begins declining. The reasoning is consistent with the present theoretical results for the fully-developed region. As Re_m decreases, the value of Gr_m at which Nusselt number begins declining decreases, as evidenced by the results for $Re_m = 500$ in figure 5.10 corresponding to $\alpha = -20°$.

Figure 5.13 illustrates the effect of Re_m on Nu_Z for the downward inclination $\alpha = -10°$. For $Re_m = 1500$, there is enhancement in heat transfer due to free convection with Nu_Z increasing with Gr_m up to 1.16×10^7. However, increasing Gr_m from 1.16×10^7 to 2.39×10^7 resulted in a small change in heat transfer up to $Z^+ \approx 0.01$. For $Z^+ > 0.01$, values of Nu_Z at $Gr_m = 2.39 \times 10^7$ dropped and became lower than those for $Gr_m = 1.16 \times 10^7$.

Comparing results of $\alpha = -20°$ and $\alpha = -10°$ for $Re_m = 1500$ with similar Gr_m (e.g., $Gr_m = 1.12 \times 10^7$ in figure 5.12 and $Gr_m = 1.16 \times 10^7$ in figure 5.13), we notice that Nu_Z in the fully-developed region for $\alpha = -10°$ is 25% higher than that for $\alpha = -20°$. Therefore, tilting the duct downward from horizontal has significant effect on Nu_Z, particularly in the fully developed region, which is consistent with the present theoretical results. Also, comparing the experimental data of $Re_m = 1000$ with similar Gr_m (e.g., $Gr_m = 1.10 \times 10^7$ in figure 5.12 and $Gr_m = 1.13 \times 10^7$ in figure 5.13), we observe that values of Nu_Z are significantly higher for $\alpha = -10°$ than those for $\alpha = -20°$. For the same Re_m, the behavior of Nu_Z for $\alpha = -20°$ was found to be more sensitive to the value of Gr_m than that for $\alpha = -10°$. Therefore, the effect of Gr_m on Nu_Z for downward inclination is strongly dependent on Re_m and α.

5.4.2.3 Effect of Re_m on Nu_Z for Horizontal and Upward Inclinations

Typical results on the effect of Re_m on Nu_Z for the horizontal and upward incli-

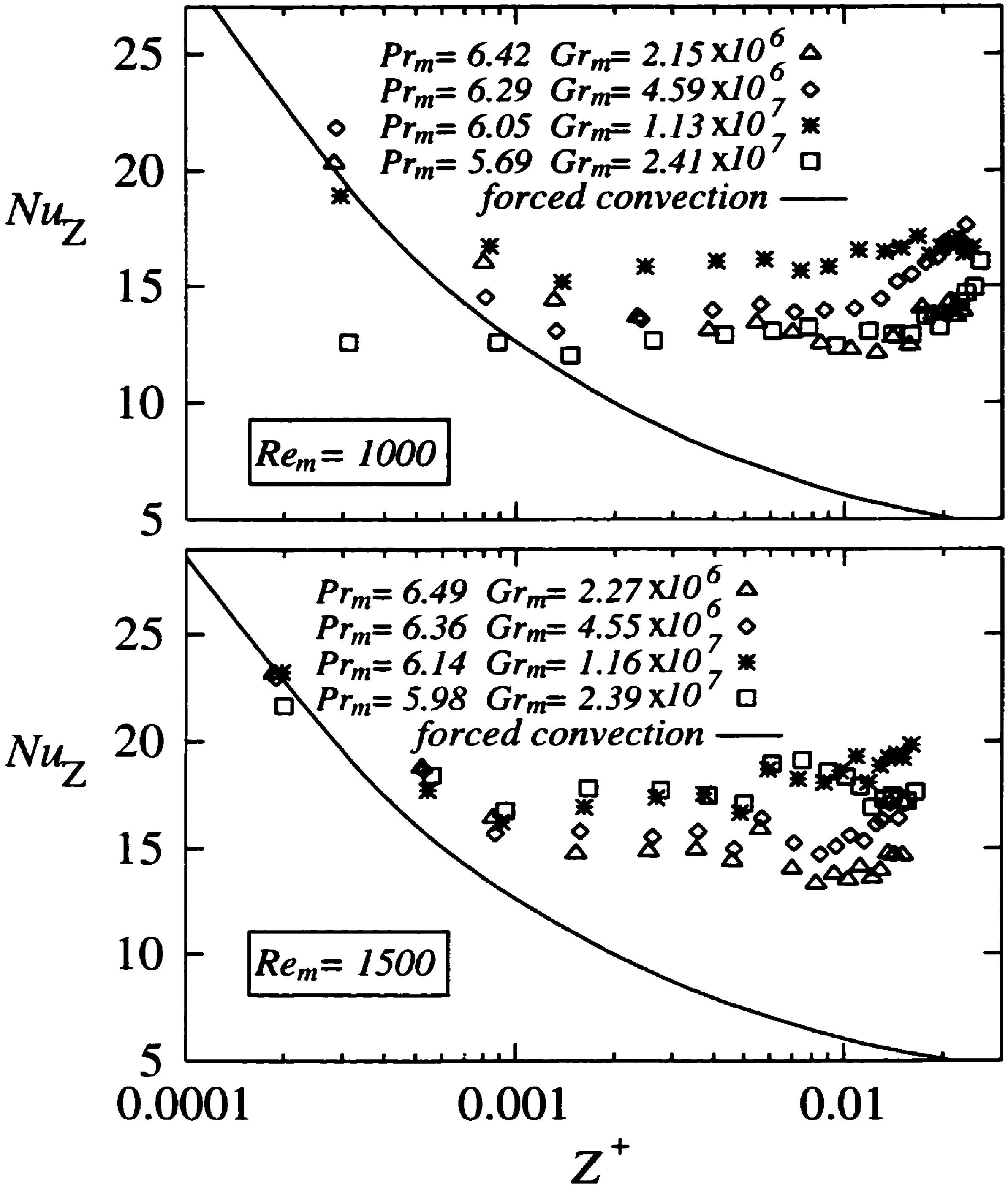


Figure 5.13: Effect of Reynolds number on local Nusselt number for $\alpha = -10°$

nations are shown in figure 5.14 using Gr_m of about 1.2×10^7 and the three values of Re_m. Early in the developing region ($Z/D_h < 8$) where forced convection is dominant, we note that Nu_Z increases slightly with Re_m. In this region, Nu_Z decreases with Z for all Re_m due to the thickening of the boundary layer. As the wall-to bulk temperature difference increases, free convection becomes significant and Nu_Z starts increasing with Z beyond $Z/D_h = 8$. It can be noted that the rate of increase of Nu_Z with Z increases as Re_m decreases. This is a logical behavior since the impact of free convection is expected to be stronger for slower flows. Beyond a certain value of Z/D_h, the value of Nu_Z becomes nearly constant (fully developed) and the effect of Re_m on Nu_Z is fairly small in this region. These observations are consistent with the results in [54] for horizontal and upwardly inclined parallel plate. It is also fair to state that the effect of Re_m on Nu_Z for the horizontal and upward inclinations is certainly much less significant than that for downward inclinations.

5.4.3 Fully-Developed Nusselt Number

Fully-developed conditions were established in all test runs in the horizontal and upward inclinations, as well as most test runs in the downward inclinations (except these runs of high Gr_m and low Re_m). Figures 5.10 to 5.14 showed some fluctuations in Nu_Z in the fully-developed region which may be attributed to property variations and buoyancy-induced fluctuations. Values of Nu_{fd} were calculated as the length-mean average of Nu_Z of the six axial stations precedings the last station in the heated section.

The experimental values of Nu_{fd} for all values of α and Re_m are presented in figure 5.15 and lines of least-squares fit are drawn through the data. Judging by the amount of scatter in the data of $\alpha = 0°$, $10°$, and $20°$, it may be concluded that Re_m has a small effect on Nu_{fd} for these orientations. Also, going from $\alpha = 0°$ to $\alpha = 10°$,

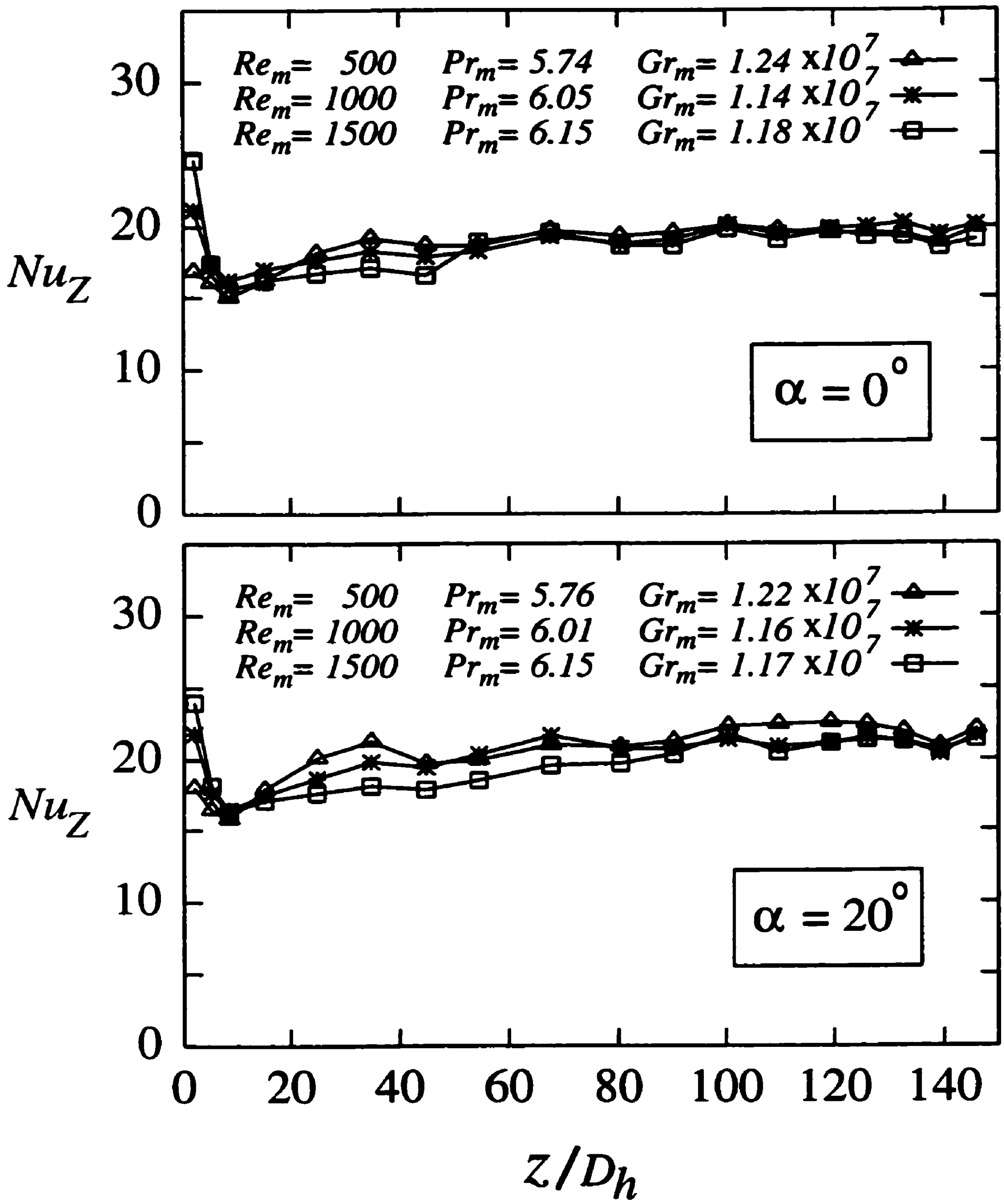


Figure 5.14: Effect of Reynolds number on local Nusselt number for $\alpha = 0°$ and $\alpha = 20°$

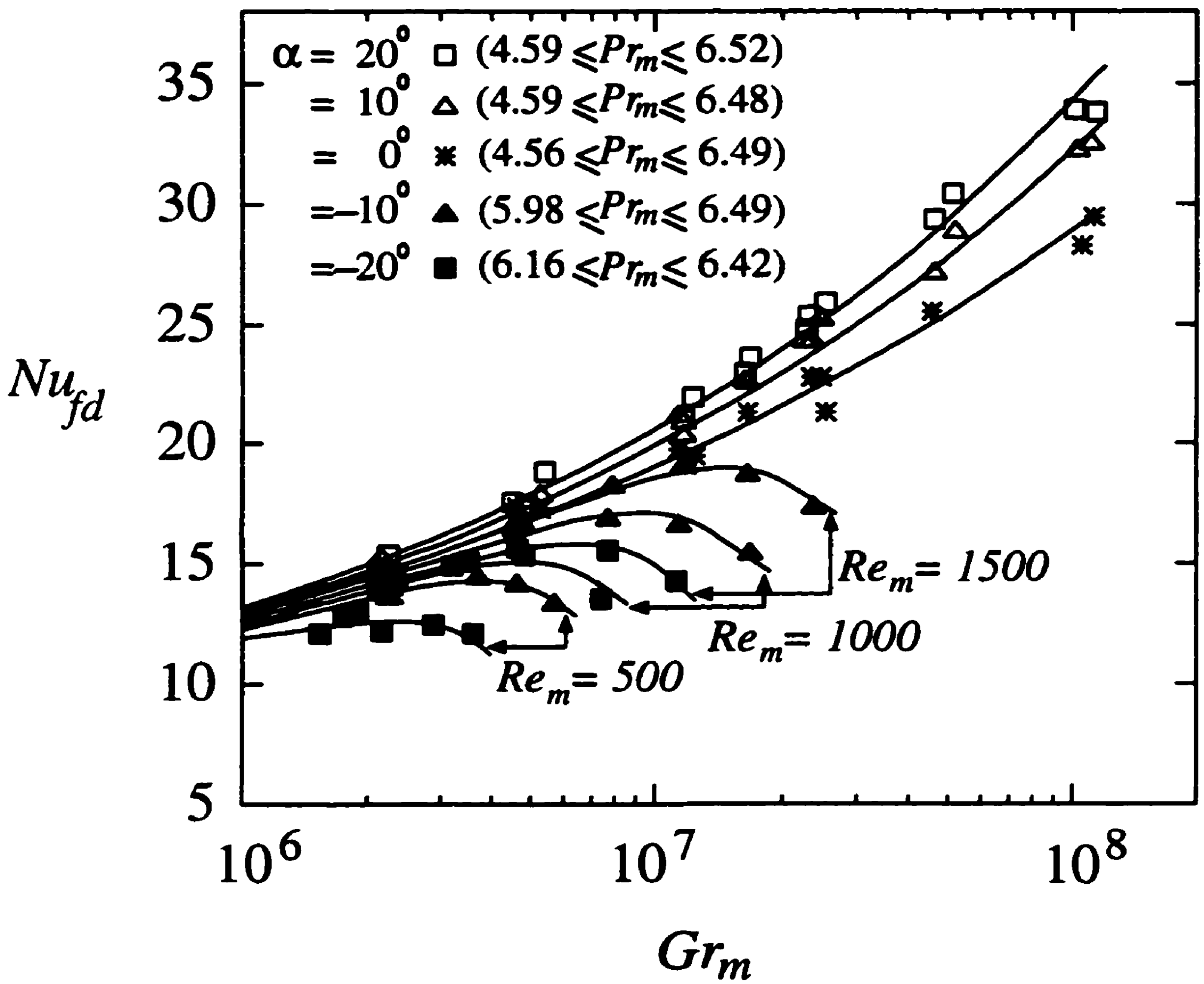


Figure 5.15: Fully-developed Nusselt number for all values of α and Re_m

there is a noticeable increase in Nu_{fd} at high values of Gr_m. The value of Nu_{fd} continues to increase, but at a slower rate, as α increases from 10° to 20°. Keeping in mind that for the forced convection case, $Nu_{fd} = 4.089$ [62] we can see that free convection can enhance Nu_{fd} by a factor of up to 8 for $0° \leq \alpha \leq 20°$.

For the downward inclinations of $\alpha = -10°$ and $-20°$, figure 5.15 shows that Nu_{fd} is strongly dependent on Re_m. For any combination of α and Re_m, Nu_{fd} appears to follow the correlation curve for $\alpha = 0°$ up to a certain value of Gr_m where Nu_{fd} for the downward inclination starts deviating, reaches a maximum and then starts dropping with further increase in Gr_m. The value of Gr_m at which this deviation occurs increases with Re_m but it decreases with $|\alpha|$.

5.4.4 Comparison of Experimental Nu_{fd} With Theoretical Predictions

All the trends discussed earlier for Nu_{fd} in the upward and downward inclinations are consistent with the theoretical results reported in chapter 4. As a further confirmation, quantitative comparisons were made between the present experimental results and the theory for the case of the H1 thermal boundary condition. These comparisons are presented in this section.

Figure 5.16, for $\alpha = 0°$, demonstrates very good agreement between the predicted and the experimental results for the three values of Re_m. Figure 5.16 confirms the small dependence of the experimental Nu_{fd} on Re_m for the horizontal orientation, which is consistent with the theoretical results.

Figures 5.17 and 5.18 present the values of Nu_{fd} for $\alpha = \pm 20°$. The experimental data in upward inclination agree very well with the predicted curves for $Re_m = 500$, 1000 and 1500. For $\alpha = -20°$ and $Re_m = 500$, the data agree well with the predicted results for $Pr = 6.3$. It can be seen that, the experimental range of Gr_m is low

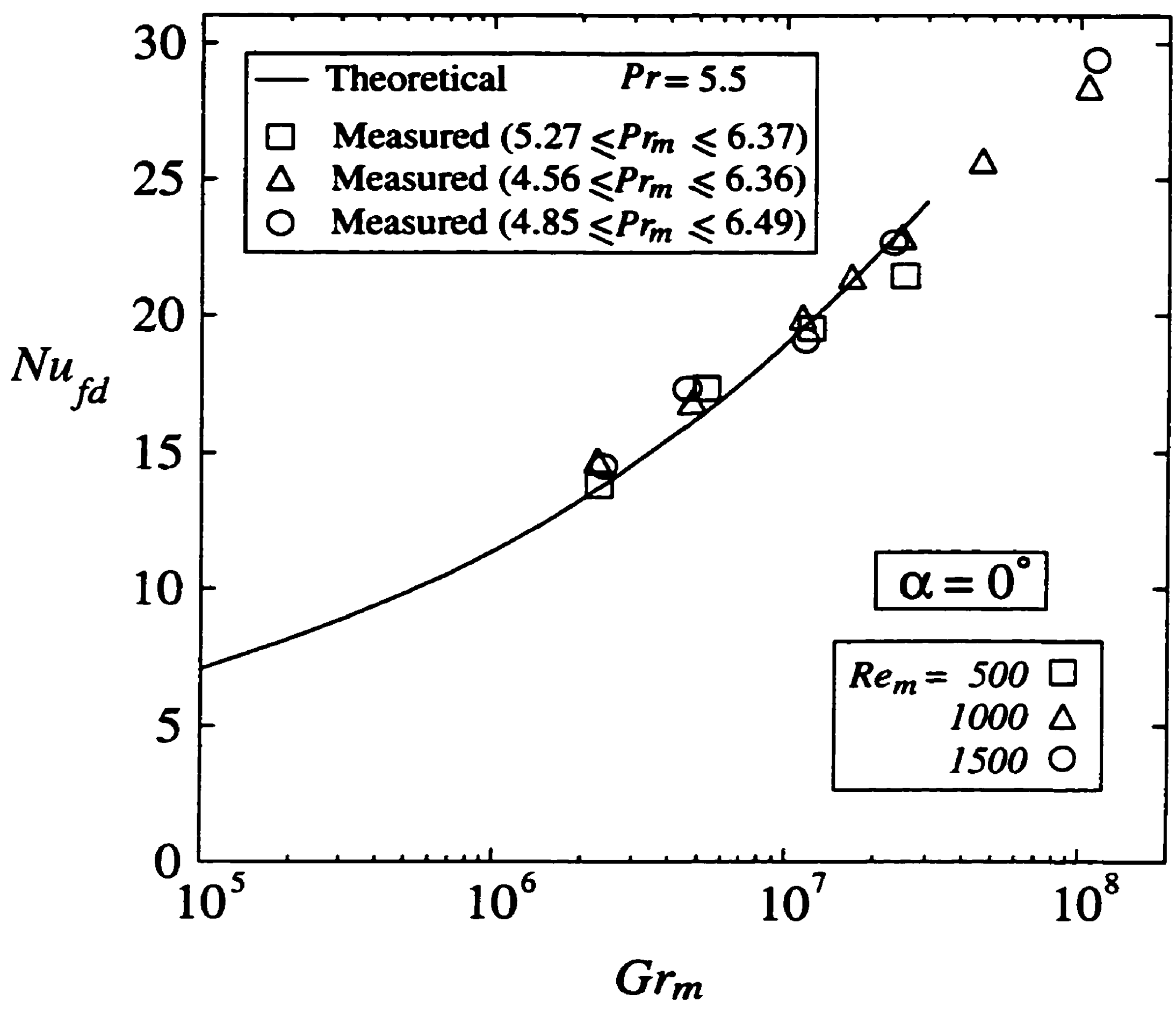


Figure 5.16: Comparison between data and prediction of Nu_{fd} for $\alpha = 0°$

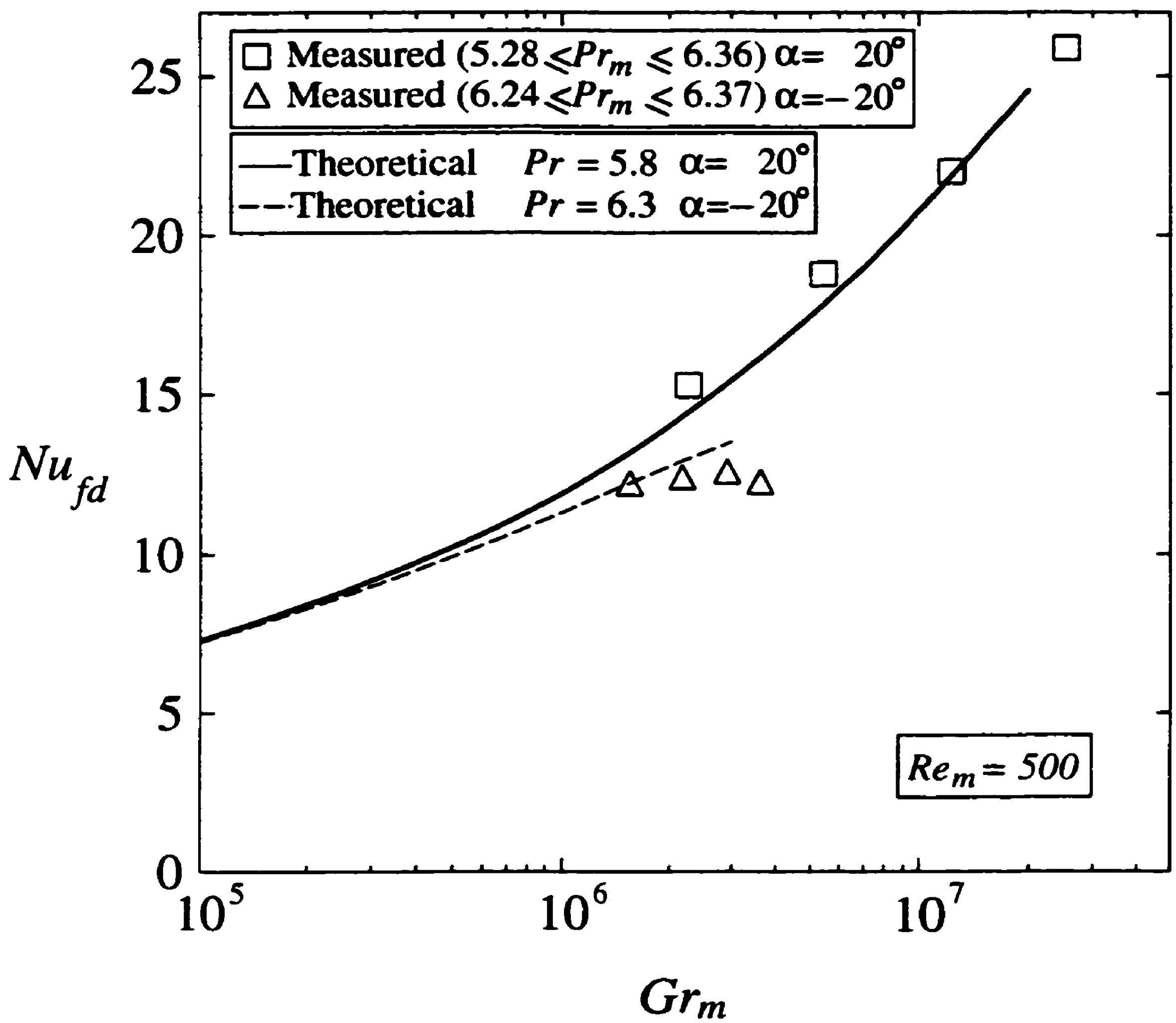


Figure 5.17: Comparison between data and prediction of Nu_{fd} for $\alpha = \pm 20°$ and $Re_m = 500$

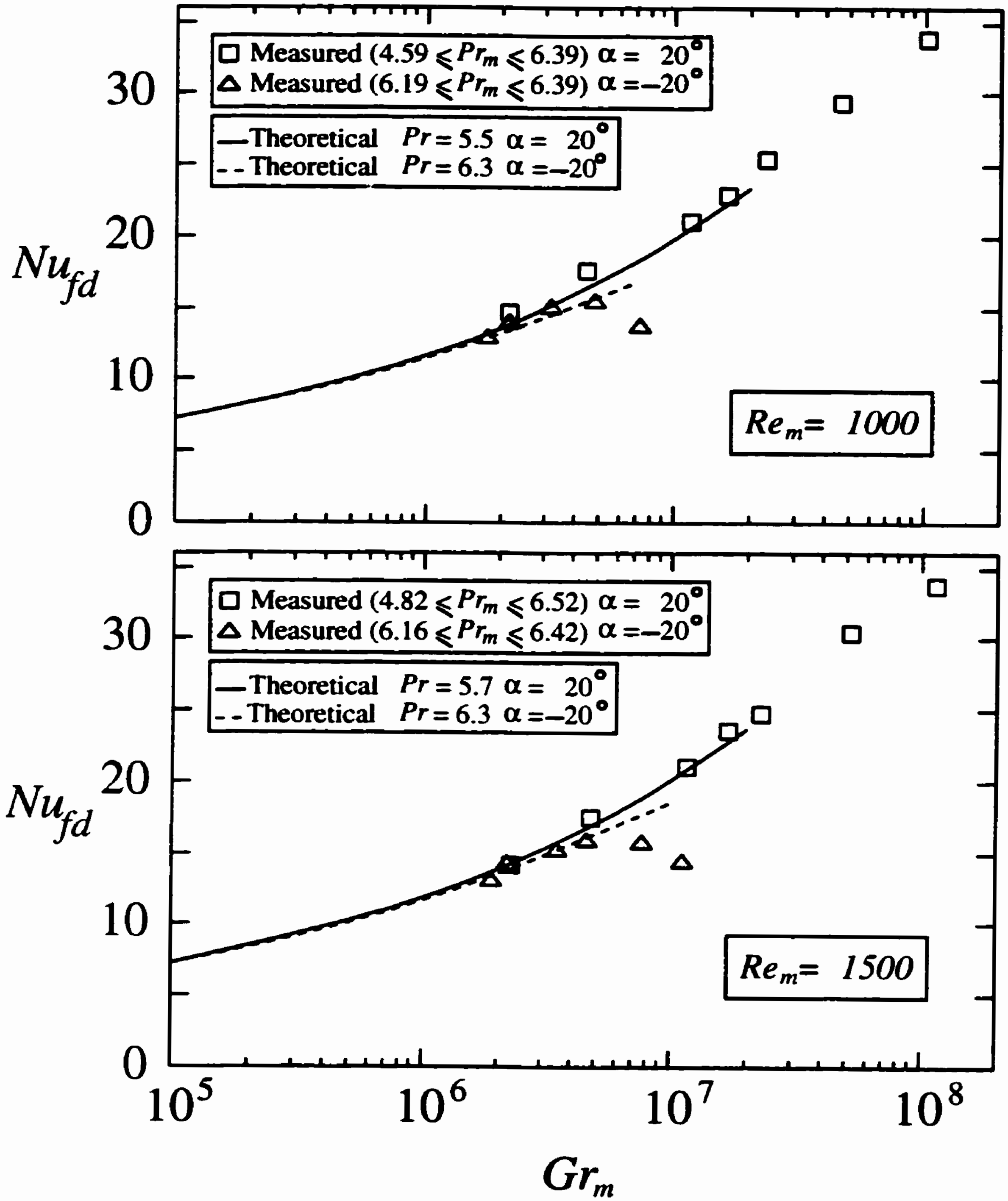


Figure 5.18: Comparison between data and prediction of Nu_{fd} for $\alpha = \pm 20°$ and $Re_m = 1000, 1500$

($1.54 \times 10^6 \leq Gr_m \leq 3.61 \times 10^6$). The experiment was carried out further for a narrow range of Gr_m up to 8.61×10^6 (see Appendix G) however, fully-developed conditions were not reached. Beyond $Gr_m = 8.61 \times 10^6$ flow instability was assumed due to oscillations in thermocouple readings.

For $Re_m = 1000$ and 1500, and $\alpha = -20°$, figure 5.18 shows good agreement between the predicted and the experimental results at low Gr_m (up to $Gr_m = 5 \times 10^6$). However, for Gr_m higher than 5×10^6 the experimental values of Nu_{fd} start deviating from the predicted curves and begin declining with further increase in Gr_m. The theoretical curves extend up to the onset of flow reversal, while the experimental data may include cases of flow reversal. This may be the reason for the deviation beyond $Gr_m = 5 \times 10^6$.

Similar trends can be observed for $\alpha = \pm 10°$ in figures 5.19 and 5.20 for upward and downward inclinations. Again, the deviation between experiment and theory for the downward inclination at high Gr_m is attributed to the same reason mentioned above.

5.4.5 Isothermal Pressure Drop

Measurements of the pressure drop were made at various flow rates, starting with low Reynolds number ($Re \approx 200$ up to ≈ 5000). At each flow rate, readings of mass flow rate, upstream and downstream bulk temperatures and the pressure drop were recorded when steady state conditions were established. The upstream and downstream bulk temperatures were approximately the same for each experimental run and they were nearly equal to the room temperature. Values of the friction factor f and Reynolds number Re were calculated from equations (5.6) and (5.1), respectively.

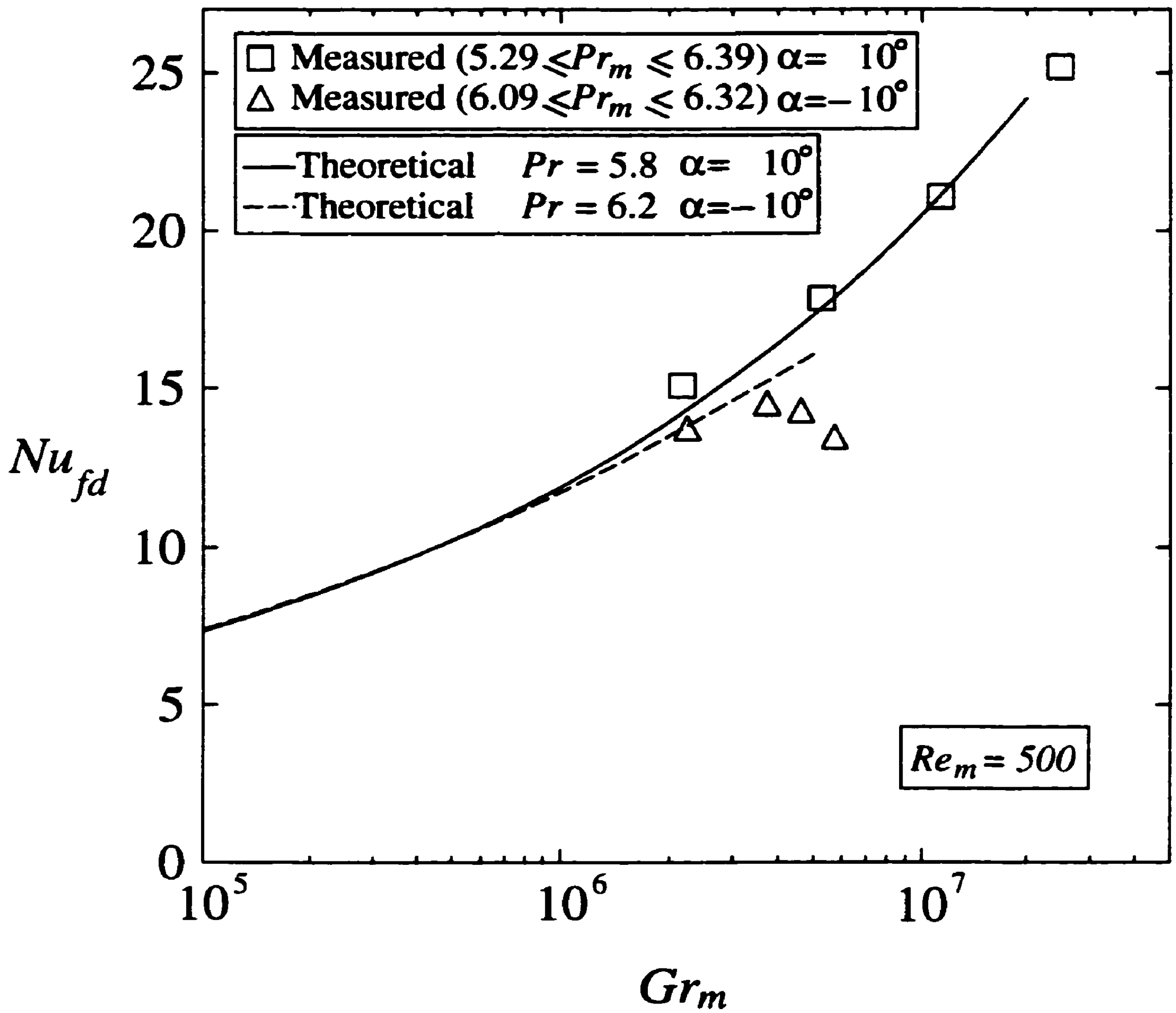


Figure 5.19: Comparison between data and prediction of Nu_{fd} for $\alpha = \pm 10°$ and $Re_m = 500$

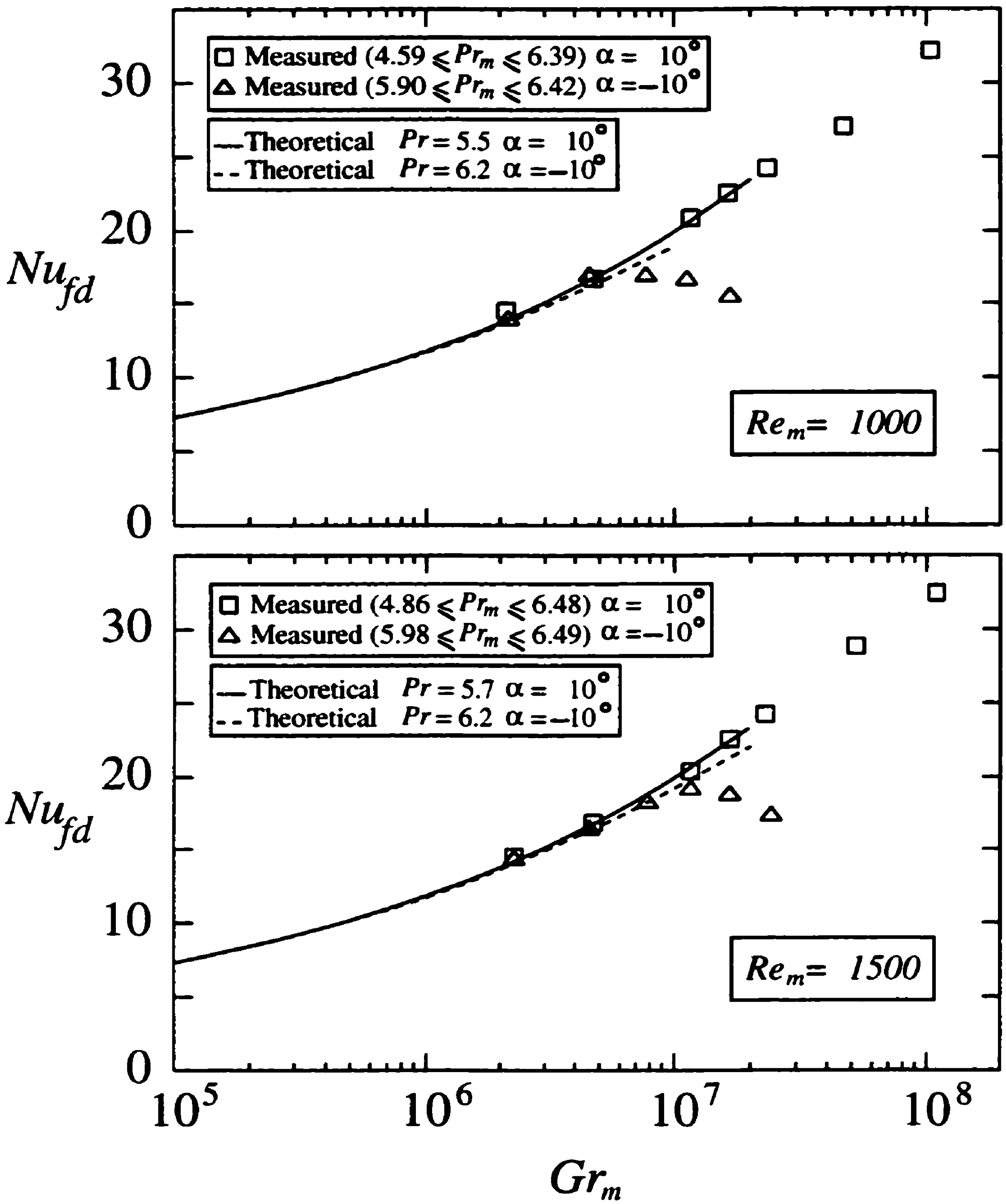


Figure 5.20: Comparison between data and prediction of Nu_{fd} for $\alpha = \pm 10^\circ$ and $Re_m = 1000, 1500$

Results of the friction factor for $\alpha = 20°$, $0°$, and $-20°$ against Reynolds number are shown in figure 5.21 for $Gr = 0$ (no heating). A very good agreement was achieved by comparing the experimental data with the analytical curve of the pure forced convection [66, 67] which is valid for laminar flow up to the critical Reynolds number, $Re \approx 2100$. The exact value of the friction factor is $15.77/Re$. Beyond the critical value, the experimental data shift from the analytical curve indicating that the flow is no longer laminar. It can be seen that for $Gr = 0$, the inclination angle has no effect on the frictional losses. It should also be noted that the pressure drop was measured across the fully-developed region (following the hydrodynamic developing length), which explains the good agreement between experiment and theory.

5.4.6 Pressure Drop With Heating

Measurements of the pressure drop were obtained for the whole range of α, Re_m and Gr_m listed in Table 5.1. The pressure drop was measured across the heated length and therefore, it includes the thermally developing and fully-developed zones. The experimental results of the friction factor for all values of Gr_m and Re_m with heating in upward and downward inclinations are presented in this section in order to illustrate the effects of all independent parameters. Lines of least-square fit are included in the figures for each combination of α and Re_m.

5.4.6.1 Upward Inclination

Figure 5.22 presents the effect of Grashof number and the inclination angle on fRe for $Re_m = 500$, 1000, and 1500. For $Re_m = 500$, and $\alpha = 0°$, $10°$, and $20°$, values of fRe increase continuously with Gr_m. As α increases to $20°$, the increase of fRe is substantial particularly at higher values of Gr_m. From $\alpha = 0°$ to $\alpha = 10°$, there is a

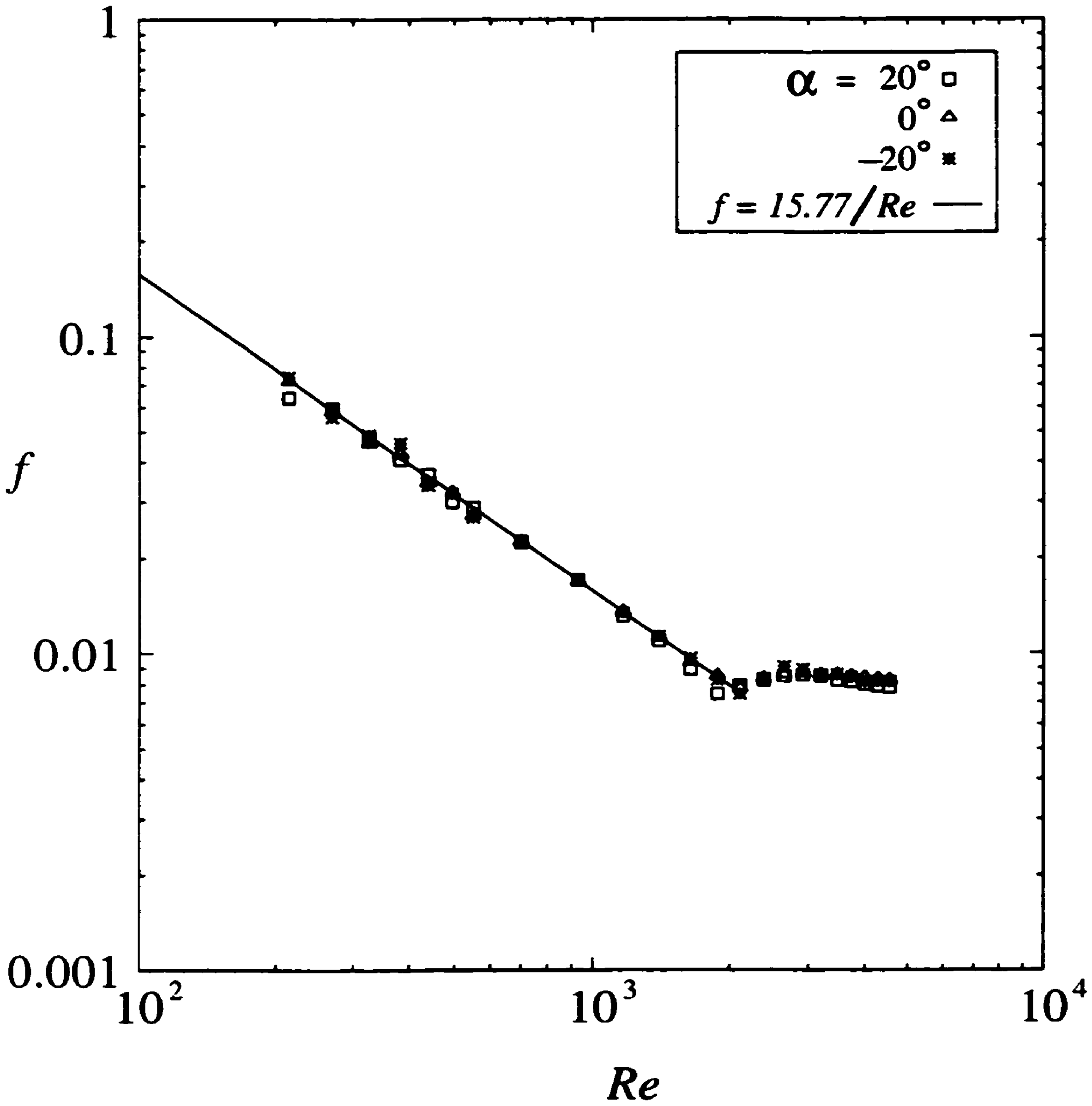


Figure 5.21: Comparison between data and analysis of the isothermal friction factor

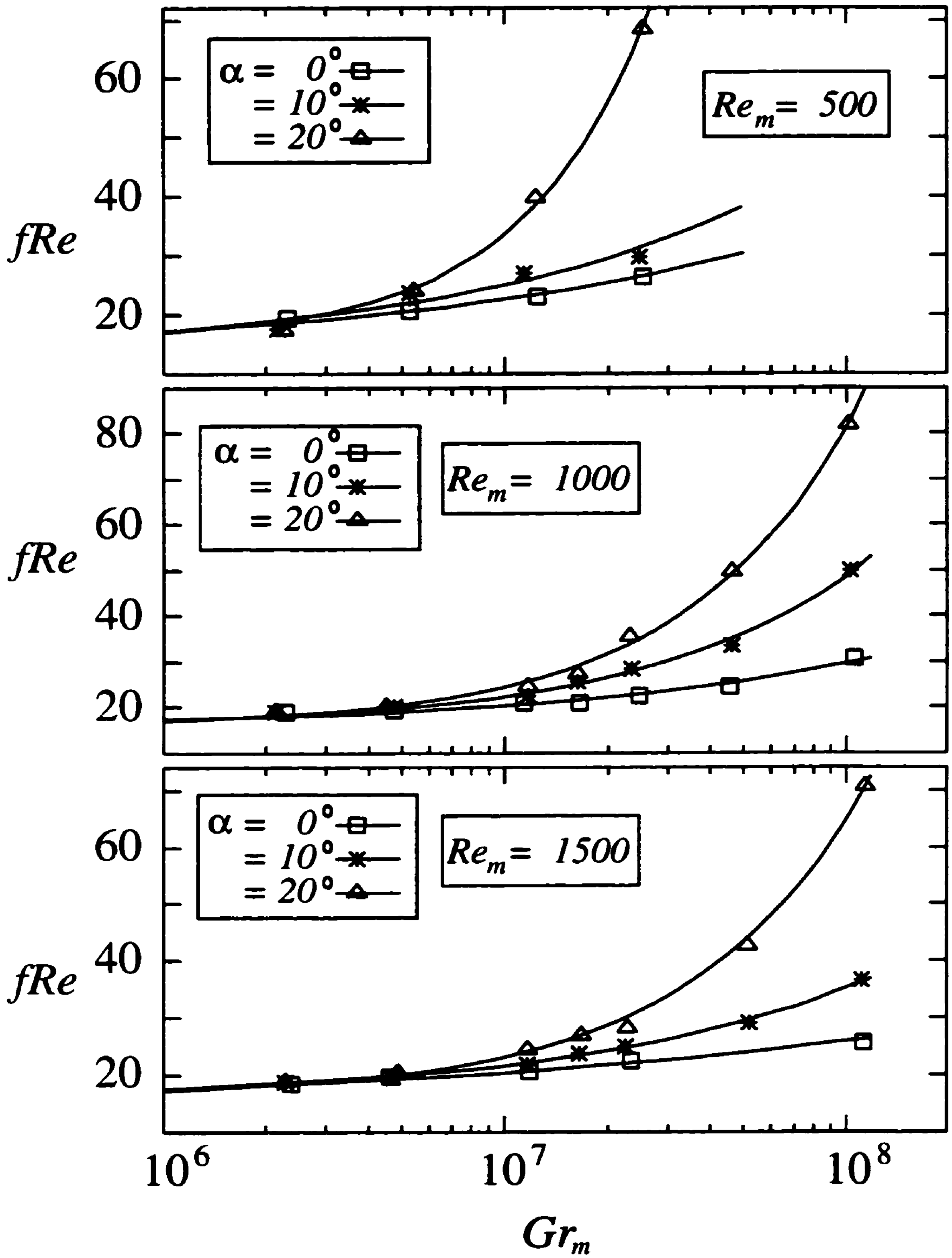


Figure 5.22: Experimental data of fRe for upward inclinations

noticeable increase in fRe with Gr_m but at a slower rate than that between $\alpha = 10°$ and $\alpha = 20°$. Similar trends can be observed for $Re_m = 1000$ and 1500, however the magnitude of the increase in fRe is lower than that for $Re_m = 500$ at the same Gr_m. This is consistent with the reasoning that when Re_m decreases, the effect of free convection on fRe becomes stronger. We know that for the forced-convection case, the exact value of fRe is 15.77, as displayed in figure 5.21. For $Re_m = 500$, we can see that the free convection can increase fRe (e.g., at $Gr_m = 2.5 \times 10^7$) by a factor of 4 for $\alpha = 20°$, while for $Re_m = 1000$ and 1500 at same value of Gr_m the free convection can enhance fRe by a factor of up to 2 for $\alpha = 20°$. At $Gr_m = 1 \times 10^8$ with $\alpha = 20°$, fRe is 18% higher for $Re_m = 1000$ than for $Re_m = 1500$.

It can be observed that, fRe in figure 5.22 is strongly dependent on Re_m and α. The general trend in these results is that fRe increases with Gr_m for any given α, and Re_m and the magnitude of this increase become larger as α increases and/or Re_m decreases. All these trends are consistent with the present theoretical results. However, a comparison between the predicted and experimental fRe is not appropriate because of the pressure drop was measured across the entire heated section which covers both the thermally developing and the fully-developed regions, while fRe was predicted for the fully-developed region. The other reason is that the independent parameters Re_m, Gr_m, and Pr_m were calculated at the average of the inlet and outlet bulk temperatures, while the numerical ones were computed at constant fluid properties.

5.4.6.2 Downward Inclination

The experimental data of fRe for all downward inclination angles ($\alpha = -10°$ and $-20°$) including $\alpha = 0°$ with the three values of Re_m (500, 1000, and 1500) are shown in figure 5.23. Values of fRe for $\alpha < 0°$ are lower than fRe at $\alpha = 0°$ for

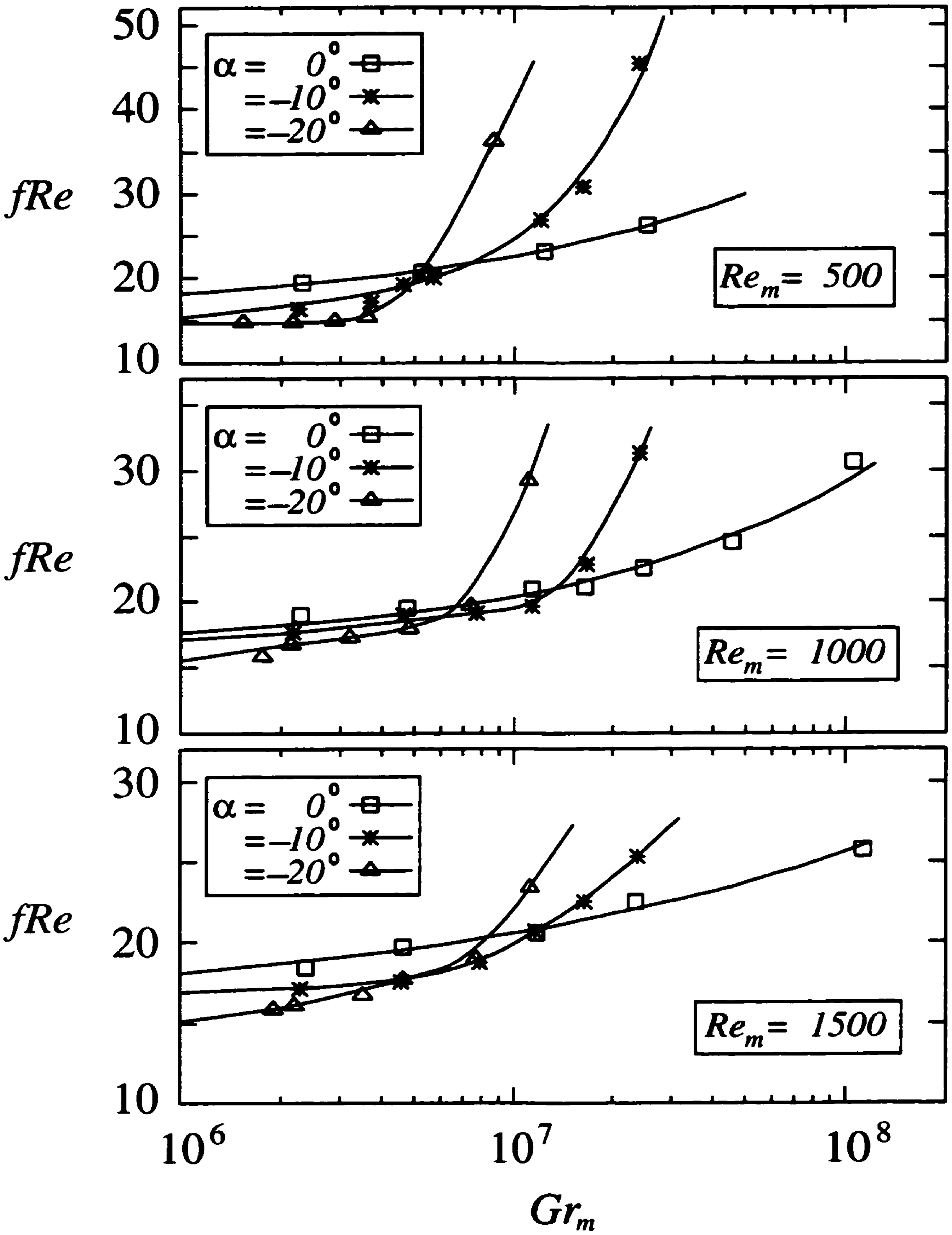


Figure 5.23: Experimental data of fRe for downward inclinations

all values of Re_m up to a critical value of Gr_m, which could be close to the onset of flow reversal, beyond which a sharp increase occurs in fRe for the three values of Re_m. This critical value of Gr_m decreases with increasing downward inclination at the same Re_m. Beyond the critical value of Gr_m the effect of free convection on fRe is significant, in particular at low Re_m. For $Re_m = 500$, fRe (e.g, at $Gr_m = 1 \times 10^7$) is 45% higher for $\alpha = -20°$ than that for $\alpha = 0°$. As Re_m increases the effect of free convection on fRe becomes less important. It can be seen that, at same α ($\alpha = -20°$) fRe is 24 % and 14 % higher for $Re_m = 1000$ and 1500, respectively, than that for $\alpha = 0°$. At $Gr_m = 2.5 \times 10^7$ with $\alpha = -10°$, fRe exceeds by 43% the horizontal curve for $Re_m = 500$, by 28% for $Re_m = 1000$, and by 14% for $Re_m = 1500$.

It is clearly observed that the enhancement in fRe decreases with increasing Re_m at higher values of Gr_m. Again a quantitative comparison between the measured fRe and the predicted results (shown in figure 4.44) is not appropriate because of the reasons mentioned earlier. It should be noted that, for downward inclinations the effect of α on fRe appears to be significant even for lower values of Gr_m, while for upward inclination this effect is significant only when Gr_m is high.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions for the Theoretical Study

A numerical, finite-control-volume approach has been utilized for solving the governing equations for laminar, fully-developed mixed convection in inclined semicircular ducts. Two thermal boundary conditions were used: uniform heat input axially with uniform wall temperature circumferentially (H1), and uniform heat input axially with uniform heat flux circumferentially (H2). Both buoyancy-assisted and buoyancy-opposed conditions were considered with the full range of the tube inclinations (from vertical upward to vertical downward). Results for W, T, fRe, and Nu were obtained for $Pr = 7$, $-90° \leq \alpha \leq 90°$, and wide ranges of Re and Gr. From these results, the following conclusions can be drawn:

1. Tube inclination and Gr have a strong effect on the distributions of W and T. The location of W_{max} shifts to the upper part of the cross-section and the location of the T_{min} shifts to the lower part in upward inclinations. For downward inclinations and the horizontal orientation, both W_{max} and T_{min} shift to the lower part of the cross-section. Thermal stratification was observed in the H2 boundary condition and it was found to inhibit secondary flow, thus decreasing

the magnitude of the enhancement in fRe and Nu. This stratification was found to decrease in upward inclinations by increasing Gr. On the other hand, increasing Gr for downward inclinations appears to intensify thermal stratification.

2. At high enough values of Gr, the onset of flow reversal was detected in the lower part of the cross-section for upward inclinations and in the upper part of the cross-section for downward inclinations. A preliminary map was developed that defines the regions of flow reversal in terms of γ and ω. This map shows that, for the same γ, flow reversal occurs at lower ω for H2 compared with H1. Also, for the same $|\gamma|$, flow reversal starts at lower ω in downward inclinations compared with upward inclinations. All results of velocity, temperature, fRe, and Nu presented in this study correspond to conditions of no flow reversal.

3. The value of fRe increases as γ and/or ω increase for both conditions in upward inclinations. At the horizontal orientation, fRe_{H1} exceeds fRe_{H2} due to the thermal stratification associated with H2. This trend reverses with $fRe_{H2} > fRe_{H1}$ for upward inclinations, especially at high Gr. For downward inclinations, fRe_{H2} is always lower than fRe_{H1} at the same conditions. For any value of γ in downward inclinations, $fRe/(fRe)_o$ is lower than its value at the horizontal orientation.

4. For upward inclinations and low Gr, Nu_{H1} is always larger than Nu_{H2} and they both decrease monotonically with α. As Gr increases, both Nu_{H1} and Nu_{H2} develop a trend whereby their value increases with α up to a maximum and then decrease with further increase in α. The initial increase with α is much more pronounced for the H2 boundary condition, particularly at high Gr. The reason for this behavior is that, for H2, strong thermal stratification exists in the horizontal orientation and as this condition disappears with α, a sharp

increase in Nu can occur.

5. For downward inclinations, both Nu_{H1} and Nu_{H2} start out increasing with Gr at a rate lower than that for the horizontal orientation. For any combination of γ and ω, the value of Nu_{H1} exceeds Nu_{H2}.

6.2 Conclusions for the Experimental Study and Comparison With Theory

An experimental study was performed to investigate the effect of inclination (upward and downward) on the pressure drop and heat transfer characteristics of laminar mixed convection in a semicircular duct with uniform heat input axially. Water was used as the test fluid and, therefore, only a narrow range of Prandtl number was covered. However, five duct inclinations were tested within ±20°, three Reynolds numbers for each orientation (500, 1000, 1500), and several values of Grashof number for each combination of α and Re_m. From these results, the following conclusions can be made:

1. The circumferential variation of wall temperature increases as Gr_m increases for all angles of inclinations. This is attributed to free convective currents that push hot fluid to the upper part of the cross-section and cold fluid to the lower part. Upward inclinations experience less circumferential variation of wall temperature compared to the horizontal orientation at the same Re_m and Gr_m due to the weaker free convection currents within the cross-section. For downward inclinations, the axial variation of wall temperature was found to be strongly dependent on α, Re_m, and Gr_m. At high Gr_m and low Re_m it was not possible to achieve fully-developed temperature profiles within the heated

section, possibly due to flow reversal and the accompanying secondary flow loop in the axial flow direction.

2. The axial variation of Nu_Z followed the trend noted earlier in [50, 53, 7, 54] for the horizontal and upward inclinations. Values of Nu_Z increased with α and Gr_m for these orientations. However, the behavior of Nu_Z for downward inclinations was found to be strongly dependent on the combination of Re_m, Gr_m, and α. For $Re_m = 500$ and $\alpha = -20°$, Nu_Z was found to decrease continuously with Gr_m while for $Re_m = 1000$ and 1500, Nu_Z may increase and then decrease with Gr_m.

3. Values of Nu_{fd} for the horizontal and upward inclinations (up to $\alpha = 20°$) were found to increase with Gr_m and to be weakly dependent on Re_m. For the downward inclinations, Nu_{fd} was found to be strongly dependent on α, Re_m and Gr_m. These results are consistent in magnitude and trend with the present theoretical prediction, except for high Gr_m in the downward inclination where a deviation is noted and discussed.

4. The isothermal friction factor for all inclination angles ($\alpha = \pm 20°$) in the laminar region agreed very well with the analytical curve of the pure forced convection. The experimental data of fRe are strongly dependent on Re_m and α. For upward inclinations fRe increases with Gr_m for any combination of α and Re_m and the magnitude of this increase becomes larger as α increases and/or Re_m decreases. For downward inclinations fRe is lower than its value at the horizontal orientation for all values of Re_m up to a critical values of Gr_m, which could be close to the onset of flow reversal. Beyond that a sharp increase occurs in fRe for the three values of Re_m.

6.3 Recommendations for Further Studies

Following the conclusion of the present investigation, it became apparent that several important issues require further investigation. The following points are recommended for further studies:

1. The numerical work on semicircular ducts should be extended to solve the thermally developing region as well as the adiabatic exit region so that more comparisons with the experimental data in the upward and downward inclinations can be made.

2. The present experimental work can be extended by investigating more downward inclinations, such as $\alpha = -5°$ and $-15°$ in order to get complete information of the effect of downward inclination on the pressure drop and heat transfer.

3. Flow visualization should be attempted in order to obtain a qualitative picture of the velocity profile and to show the existence of flow reversal. This will confirm the relationship between the flow situation and the overall quantities such as fRe and Nu.

4. For downward flow at higher values of Gr_m and lower values of Re_m, periodic conditions were found to occur in the thermocouple readings indicating flow instability. Therefore, it is suggested to use a data acquisition system to record all thermocouple readings simultaneously.

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Appendix A

Numerical Codes

A.1 Numerical Code for H1 Condition

```
C===================================================================
C                                H1.F
C===================================================================
C           NEW   = 1        START WITHOUT OLD PROFILE
C           NEW   = 0              WITH    OLD PROFILE
C           NEWGR = 1        START WITH    NEW GR
C           NEWGR = 0              WITH    OLD GR
      REAL*8 PI/3.141592654D0/,GROLD,PR/7.D0/,GR/0.D0/,THETA/90.D0/,
     &  ALPHA/60.D0/,FRE,CFRE,P(30,48),APAP(30,48),BOTTOM,RE/500.D0/
      REAL*8 DUP(30,48),DVP(30,48),FALSU(30,48),FALSV(30,48),MS(30,48)
      REAL*8 FCRUV/1.D-5/,
     &       FCRW/1.D-5/,FCRTH/1.D-5/,CRM/1.D-5/
      REAL*8 CRUV,CRW,CRTH,PHI/1.570796327D0/
      REAL*8 URFUV, URFW, URFTH,BRHO(5)/5*1.D0/,DH
      REAL*8 U,V,W,TH,R,DR,DF,RHO,CRHO,ALPA
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C===================================================================
          OPEN(UNIT=1, FILE = 'fort.1',STATUS='OLD')
      READ(1,*) NEW,BOTTOM
      READ(1,*) NEWGR, GR
      READ(1,*) URFUV, URFW, URFTH
      READ(1,*) MIT
      READ(1,*) FCRUV,FCRW,FCRTH,CRM
      ITOT = 30
      JTOT = 48
      FRE =  15.
      THETA = THETA*PI/180.D0
      ALPHA = ALPHA*PI/180.D0
      M=ITOT-1
      N=JTOT-1
      MM=M-1
      NN=N-1
      IC = ITOT/2
      JC = JTOT/2
      WRITE(24,9) URFUV, URFW, URFTH
 9    FORMAT('    URFuv = ',E10.3,'    URFw = ',
     *                    E10.3,'    URFth = ',E10.3/)
CLOSE(UNIT=1)
      CALL GRID(THETA,PHI,GR,PR,ALPHA)
      DO 10 I=1,ITOT
      DO 10 J=1,JTOT
         U(I,J)=0.D0
         V(I,J)=0.D0
```

```
         W(I,J)=0.D0
10     TH(I,J)=0.D0
C
C--INPUT U, V, W, AND TH FROM DATASETS AND PRINT OUT
C
       CALL DATAIN(NEW,INITO,ITNITO,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,
     &              GROLD,PR,FRE,ALPA,PHI)
       WRITE(24,999) FCRUV, FCRW, FCRTH, CRM
999     FORMAT(/'  FCRuv = ',E10.3,'  FCRw = ',E10.3,
     *          '  FCRth = ',E10.3,'  CRm   = ',E10.3/)
       IF(NEWGR .EQ. 0) GR = GROLD
       IF(NEWGR .EQ. 1) THEN
          INITO  = 0
          ITNITO = 0
       END IF
       DH = 2.D0*PHI/(1.D0+PHI)
       WRITE(24,*) '    * * * * * *          GR          * * * * *'
       WRITE(24,200)   GR,PR
       WRITE(24,*) '    * * *                                * * *'
C
C--THIS IS THE MAIN LOOP
***************************
       ITNIT = ITNITO + MIT
***************************
       NIT   = INITO
       NNTT = 0
C
20     CRUV=FCRUV
       CRW=FCRW
       CRTH=FCRTH
          NIT=NIT+1
          NNTT = NNTT + 1
          IINIT = NNTT/20
          IINIT = MOD(IINIT,5) + 1
          RHO = BRHO(IINIT)
          CRHO = 1.D0 - RHO
          CALL PSEUDO(DUP,DVP,FALSU,FALSV,GR,THETA,ALPHA)
          CALL PRESS(P,DUP,DVP,FALSU,FALSV)
          CALL UVMTUM(DUP,DVP,APAP,MS,P,GR,THETA,IYES,CRUV,CRM,URFUV,
     *               RHO,CRHO,BOTTOM,ALPHA)
          CALL WMTUM(APAP,FRE,CFRE,CRW,URFW,PHI,DH,ALPHA,GR,RE,THETA)
          CALL ENERGY(PR,CRTH,URFTH,PHI)
C          IF (NIT .EQ. (NIT/100)*100 .OR. NIT .EQ. ITNIT) THEN
C            CALL OUTPUT(NIT,ITOT,JTOT,U,V,W,TH,MS,CRUV,CRW,CRTH,CFRE,
C     *                 M,MM,N,NN,IYES)
C          END IF
C            WRITE(25,100) NIT,U(IC,JC),V(IC,JC),W(IC,JC),TH(IC,JC)
       IF ( ((CRUV*0.90D0 .GT. FCRUV) .OR. (CRW*0.90D0 .GT. FCRW)
     *    .OR. (IYES .EQ. 0) .OR. (CRTH*0.90D0 .GT. FCRTH) .OR.
     *    (DABS(CFRE) .GT. 1.D-4)) .AND. (NIT .LT. ITNIT)) GO TO 20
C
C--SAVE RESULT TO DATASETS AND CALCULATE NUSSELT NUMBER
C
       CALL DSAVE(NIT,ITNIT,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,
     *            GR,PR,FRE,ALPHA,THETA,DH,PHI,RE)
       CALL NUSSLT(ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,PHI)
       CALL LOCNUSS(NIT,ITNIT,ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,
     *                  ALPHA,PHI,DH,RE,FRE,PR,GR)
C
100    FORMAT(T2,I4,1X,4(D14.7,1X))
200    FORMAT(T2,'Gr No. = ',D8.2,2X,'Pr No. = ',F7.3)
```

```
      STOP
      END
C==================================================================
C* "GRID" GENERATES THE UNIFORM GRID COORDINATES (HALF NEAR BOUNDARY) *
C* IF "THETA" IS NOT = 0 & 180 DEG, SOLUTION IS FOR THE ENTIRE AREA   *
C==================================================================
      SUBROUTINE GRID(THETA,PHI,GR,PR,ALPHA)
      REAL*8 THETA,FTOT,PI/3.1415926535898D0/,GR,PR,PHI,CPHI,ALPHA
      REAL*8 U,V,W,TH,R,DR,DF,COH,DR2,FORP,ROFP,FNSIN,FNCOS
      COMMON/ENER/COH(4,30,48),DR2,FORP,ROFP
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      COMMON/PERI/FNSIN(50),FNCOS(50)
C
      R(ITOT)=1.0D0
      R(1)=0.D0
         FTOT=2.D0*PHI
         CPHI=PI/2.D0-PHI
      DR=R(ITOT)/(ITOT-2.D0)
      DF=FTOT/(JTOT-2.D0)
      R(2)=DR*.5D0
      R(ITOT-1)=R(ITOT)-DR*.5D0
      J=ITOT-2
      DO 10 I=3,J
10       R(I)=R(2)+DR*(I-2.D0)
C
      DR2 = DR*.5D0
      FORP = DF/DR/PR
      ROFP = DR/DF/PR
C
      DO 20 J = 2, N
        FNSIN(J) = DSIN((J-1.5D0)*DF+CPHI-THETA)*DCOS(ALPHA)
        FNCOS(J) = DCOS((J-1.0D0)*DF+CPHI-THETA)*DCOS(ALPHA)
   20 CONTINUE
      GGRR = -0.
      FAC = 180./PI
      WRITE(24,50) FTOT*FAC,ALPHA*FAC,PR,DR,DF
      DO 40 I=1,ITOT
40    WRITE(24,60) I,R(I)
50    FORMAT(//T15,'Laminar Mixed Convection Heat Transfer',//
     *'                for a Semicircular Duct with  2*Phi =',F7.1//
     *'                       inclined at the angle  Alpha =',F7.1//
     * T12,'Pr No. = ',F7.3,2X,'dR = ',
     * F7.5,2X,'dF = ',F7.5//T10,'==== R -- COORDINATE ===='/)
60    FORMAT(T10,I3,2X,F15.12)
      RETURN
      END
C==================================================================
C* "DATAIN" READS U,V,W,TH FROM DATASETS AND PRINTS THEM OUT         *
C* EACH DATASET CORRESPONDS TO THE FORMAT GIVEN IN SUBROUTINE "DSAVE" *
C==================================================================
      SUBROUTINE DATAIN(NEW,NIT,ITNIT,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,
     &                  GR,PR,FRE,THETA,PHI)
      REAL*8 U(ITOT,JTOT),V(ITOT,JTOT),W(ITOT,JTOT),TH(ITOT,JTOT),
     *        FRE,GR,PR,FAC,PHI2,DH,ALPA,THETA,PHI
C
      IF(NEW .EQ. 1) THEN
          NIT   = 0
          ITNIT = 0
          RETURN
```

```
      END IF
      FAC = 180.0/3.141592654
      READ(13,400) NIT,ITNIT,GR,PR,PHI2,ALPA
      DO 10 I=2,MM
10       READ(13,100)  (U(I,J),J=2,JTOT)
      READ(13,410) NIT,ITNIT,GR,PR,PHI2,ALPA
      DO 20 I=2,M
20       READ(13,100)  (V(I,J),J=2,NN)
      READ(13,420) NIT,ITNIT,GR,PR,PHI2,ALPA
      DO 40 I=2,M
40       READ(13,200)  (W(I,J),J=2,JTOT)
      READ(13,*) FRE
      READ(13,430) NIT,ITNIT,GR,PR,PHI2,ALPA
      DO 50 I=2,M
50       READ(13,100)  (TH(I,J),J=2,JTOT)
      DH = 2.D0*PHI/(1.D0+PHI)
      FRE = FRE/DH/DH
100   FORMAT(T8,10D15.7)
200   FORMAT(T8,10D15.7)
C    *        ' GR=',D9.3,' PR=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1)
400   FORMAT(34X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1)
410   FORMAT(34X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1)
420   FORMAT(34X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1)
425   FORMAT(12X,F23.15)
430   FORMAT(39X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1)
      RETURN
      END
C=====================================================================
C* "PSEUDO" CALCULATES FALSE VELOCITY BY SUBSTITUTING NEIGHBOR VALUES *
C=====================================================================
      SUBROUTINE PSEUDO(DUP,DVP,FALSU,FALSV,GR,THETA,ALPHA)
      REAL*8 DUP(ITOT,JTOT),DVP(ITOT,JTOT),FALSU(ITOT,JTOT),
     *     FALSV(ITOT,JTOT),GR,THETA,RE,ALPHA
      REAL*8 SB,AE,AW,AN,AS,XR,ASUM,Y,D1,D2
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C
C--CALCULATE THE PSEUDOVELOCITY OF U

      CALL SRCEGN(1,GR,THETA,RE,ALPHA,DH)
      CALL SRCEGN(2,GR,THETA,RE,ALPHA,DH)
      DO 10 I=2,MM
         XR=R(I)+0.50D0*DR
         D1 = 2.D0*DR*DF/XR
         D2 = DF*XR
         DO 10 J=2,N
            CALL COGN1(I,J)
            AE=COU(1)
            AW=COU(2)
            AN=COU(3)
            AS=COU(4)
            ASUM=AE+AW+AN+AS+D1
C                 CALL SOURCE(1,SB,I,J,GR,THETA)
            SB = SRC1(I,J)
            Y=AE*U(I+1,J)+AW*U(I-1,J)+AN*U(I,J+1)+AS*U(I,J-1)
            FALSU(I,J)=(Y+SB)/ASUM
10       DUP(I,J)=D2/ASUM
C--CALCULATE THE PSEUDOVELOCITY OF V
```

```
      DO 20 I=2,M
         D1 = DR*DF/R(I)
         DO 20 J=2,NN
            CALL COGN2(I,J)
            AE=COV(1)
            AW=COV(2)
            AN=COV(3)
            AS=COV(4)
            ASUM=AE+AW+AN+AS+D1
            SB = SRC2(I,J)
            Y=AE*V(I+1,J)+AW*V(I-1,J)+AN*V(I,J+1)+AS*V(I,J-1)
            FALSV(I,J)=(Y+SB)/ASUM
20       DVP(I,J)=DR/ASUM
      RETURN
      END
C=====================================================================
C* "COEFGN" GENERATES COEFFICIENTS OF a'S FOR U, V & W MOMENTUM EQ.S  *
C* "INDEX" = 1, 2, 3, 4 FOR EAST, W, N, S RESPECTIVELY (E-RADIAL)     *
C* THE POWER LAW IS USED                                              *
C=====================================================================
      SUBROUTINE COGN1(I,J)
      REAL*8 AP,XX,YY,FF,DD,U,V,W,TH,R,DR,DF,COU,COV,COW
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

      FF=DF*R(I+1)*(U(I,J)+U(I+1,J))*.5D0
            DD=2.D0*R(I+1)/DR*DF
              COU(1) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            FF=DF*R(I)*(U(I,J)+U(I-1,J))*.5D0
            DD=2.D0*R(I)/DR*DF
              COU(2) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
            FF=DR*(V(I+1,J)+V(I,J))*.5D0
            DD=DR/(R(I)+0.5D0*DR)/DF
            IF(J.EQ.JTOT-1) DD=2.D0*DD
              COU(3) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            FF=DR*(V(I,J-1)+V(I+1,J-1))*.5D0
                     DD=DR/(R(I)+0.5D0*DR)/DF
            IF(J.EQ.2) DD=2.D0*DD
              COU(4) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
      RETURN
      END
C=====================================================================
      SUBROUTINE COGN2(I,J)
      REAL*8 AP,XX,YY,FF,DD,XR,U,V,W,TH,R,DR,DF,COU,COV,COW
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

      XR=R(I)+0.5D0*DR
            FF=XR*DF*(U(I,J)+U(I,J+1))*.5D0
            DD=XR*DF/DR
            IF(I.EQ.ITOT-1) DD=2.D0*DD
              COV(1) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            IF(I.GT.2) GOTO 25
              COV(2) = 0.D0
              GOTO 26
```

```
 25       XR=R(I)-0.5D0*DR
            FF=XR*DF*(U(I-1,J)+U(I-1,J+1))*.5D0
            DD=XR*DF/DR
            COV(2) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
 26       FF=DR*(V(I,J)+V(I,J+1))*.5D0
          DD=2.D0*DR/R(I)/DF
            COV(3) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
          FF=DR*(V(I,J)+V(I,J-1))*.5D0
                        DD=2.D0*DR/R(I)/DF
            COV(4) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
      RETURN
      END
C=====================================================================
      SUBROUTINE COGN3(I,J,RE)
      REAL*8 AP,XX,YY,FF,DD,XR,U,V,W,TH,R,DR,DF,COU,COV,COW,RE
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *      SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

      XR=R(I)+0.5D0*DR
          FF=XR*DF*U(I,J)
          DD=XR*DF/DR
          IF(I.EQ.ITOT-1) DD=2.D0*DD
          COW(1) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
          IF(I.GT.2) GOTO 35
            COW(2) = 0.D0
            GOTO 36
 35       XR=R(I)-0.5D0*DR
            FF=XR*DF*U(I-1,J)
            DD=XR*DF/DR
            COW(2) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
 36       FF=DR*V(I,J)
          DD=DR/R(I)/DF
          IF(J.EQ.JTOT-1) DD=2.D0*DD
            COW(3) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
          FF=DR*V(I,J-1)
                          DD=DR/R(I)/DF
          IF(J.EQ.2) DD=2.D0*DD
          COW(4) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
      RETURN
      END
C=====================================================================
C* "SRCEGN" COMPUTES THE SOURCE TERMS FOR U-AND-V MOMENTUM EQUATION   *
C=====================================================================
      SUBROUTINE SRCEGN(INDEX,GR,THETA,RE,ALPHA,DH)
      REAL*8 SB,GR,THETA,RR,S1,S2,XX,DR3,RF,DR5,FNSIN,FNCOS
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW,ALPHA,RE,DH
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *      SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      COMMON/PERI/FNSIN(50),FNCOS(50)
C
      DR3 = DR*3.D0
      RF = DR*DF
      DR5 = DR*.5D0
      GO TO (1000,2000,3000), INDEX
1000  DO 10 I = 2, M
        RR=R(I)+DR5
```

```
        XX=RF*RR*GR*.5DO
        DO 10 J = 2, N
C             SB=-XX*DSIN((J-1.5DO)*DF-THETA)*(TH(I,J)+TH(I+1,J))
          SB=-XX*FNSIN(J)*(TH(I,J)+TH(I+1,J))
          SB=SB+V(I+1,J)-V(I,J)-V(I+1,J-1)+V(I,J-1)
          S1=(V(I+1,J)+V(I,J)-V(I+1,J-1)-V(I,J-1))*.5DO
          SB=SB-DR3/RR*S1
          S2=(V(I+1,J)+V(I,J)+V(I+1,J-1)+V(I,J-1))*.25DO
          SRC1(I,J) = SB+RF*S2*S2
  10  CONTINUE
      RETURN

2000  DO 20 I = 2, M
        YY=RF*R(I)*GR
        DO 20 J = 2, N
          SB=U(I,J+1)-U(I,J)-U(I-1,J+1)+U(I-1,J)
          SB=SB+DR3/R(I)*(U(I,J+1)-U(I,J)+U(I-1,J+1)-U(I-1,J))*.5DO
          S1=(U(I,J+1)+U(I-1,J+1)+U(I,J)+U(I-1,J))*.25DO
          SB=SB-RF*V(I,J)*S1
          S2=(TH(I,J)+TH(I,J+1))*.5DO
C           SRC2(I,J) = SB-YY*S2*DCOS((J-1)*DF-THETA)
          SRC2(I,J) = SB-YY*S2*FNCOS(J)
  20  CONTINUE
      RETURN
C
3000        DO 30 I = 2, M
YY=RF*R(I)*DH*(GR/RE)*DSIN(ALPHA)
        DO 30 J = 2, N
 S2 = TH(I,J)
c        S2=0.25DO*(TH(I,J)+TH(I-1,J)+(TH(I,J+1)+TH(I-1,J-1))
          SRC3(I,J) = YY*S2
  30  CONTINUE
      RETURN
      END
C===================================================================
C* "PRESS" SOLVES PRESSURE EQUATION OR PRESSURE CORRECTION EQUATION  *
C* --------------------DIRECT SOLVER---------(BAND STORAGE)--------  *
C===================================================================
      SUBROUTINE PRESS(P,DUP,DVP,FALSU,FALSV)
      REAL*8 DUP(30,48),DVP(30,48),FALSU(30,48),FALSV(30,48),P(30,48)
      REAL*8 Y,XE,XW,DR5, U,V,W,TH,R,DR,DF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C      REAL*8 A(784,57),X(784),XL(22736)
REAL*8 A(1288,57),X(1288),XL(37352)
C-- NOTE THAT A, X, XL NEED TO BE CHANGED WHEN THE MESH SIZE IS CHANGED
C-- A(MM*NN,MM*2+1),X(MM*NN),XL(MM*NN*(MM+1)),K=(J-2)*MM+I+1
C
      NROW=MM*NN
      NCOL=2*MM+1
      IDC=(1+NCOL)/2
      DR5 = DR*.5DO
C
C--INITIALIZATION OF A
      DO 10 I=1,NROW
      DO 10 J=1,NCOL
10    A(I,J)=0.DO
C
C--CALCULATE COEFFICIENTS ALONG J=2
C
      I=2
```

```
      J=2
      K=1
      XE=R(I)+DR5
      A(K,IDC+1)=DF*XE*DUP(I,J)
      A(K,IDC+MM)=DR*DVP(I,J)
      A(K,IDC)=-(A(K,IDC+1)+A(K,IDC+MM))
      Y=-DF*XE*FALSU(I,J)-DR*FALSV(I,J)
      X(K)=-Y
      I=M
      K=MM
      XW=R(I)-DR5
      A(K,IDC-1)=DF*XW*DUP(I-1,J)
      A(K,IDC+MM)=DR*DVP(I,J)
      A(K,IDC)=-(A(K,IDC-1)+A(K,IDC+MM))
      Y=DF*XW*FALSU(I-1,J)-DR*FALSV(I,J)
      X(K)=-Y
      DO 30 I=3,MM
         K=I-1
         XE=R(I)+DR5
         XW=R(I)-DR5
         A(K,IDC+1)=DF*XE*DUP(I,J)
         A(K,IDC-1)=DF*XW*DUP(I-1,J)
         A(K,IDC+MM)=DR*DVP(I,J)
         A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-1)+A(K,IDC+MM))
         Y=DF*(XW*FALSU(I-1,J)-XE*FALSU(I,J))-DP*FALSV(I,J)
30    X(K)=-Y
C
C--CALCULATE COEFFICIENTS ALONG J=3 AND J=JTOT-2
C
      DO 70 J=3,NN
         K=(J-2)*MM+1
         I=2
         XE=R(I)+DR5
         A(K,IDC+1)=DF*XE*DUP(I,J)
         A(K,IDC+MM)=DR*DVP(I,J)
         A(K,IDC-MM)=DR*DVP(I,J-1)
         A(K,IDC)=-(A(K,IDC+1)+A(K,IDC+MM)+A(K,IDC-MM))
         Y=-DF*XE*FALSU(I,J)+DR*(FALSV(I,J-1)-FALSV(I,J))
         X(K)=-Y
         I=M
         XW=R(I)-DR5
         K=(J-1)*MM
         A(K,IDC-1)=DF*XW*DUP(I-1,J)
         A(K,IDC+MM)=DR*DVP(I,J)
         A(K,IDC-MM)=DR*DVP(I,J-1)
         A(K,IDC)=-(A(K,IDC-1)+A(K,IDC+MM)+A(K,IDC-MM))
         Y=DF*XW*FALSU(I-1,J)+DR*(FALSV(I,J-1)-FALSV(I,J))
         X(K)=-Y
         DO 60 I=3,MM
            K=(J-2)*MM+I-1
            XE=R(I)+DR5
            XW=R(I)-DR5
            A(K,IDC+1)=DF*XE*DUP(I,J)
            A(K,IDC-1)=DF*XW*DUP(I-1,J)
            A(K,IDC+MM)=DR*DVP(I,J)
            A(K,IDC-MM)=DR*DVP(I,J-1)
            A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-1)+A(K,IDC+MM)+A(K,IDC-MM))
            Y=DF*(XW*FALSU(I-1,J)-XE*FALSU(I,J))
     *         +DR*(FALSV(I,J-1)-FALSV(I,J))
60       X(K)=-Y
70       CONTINUE
```

```
C
C--CALCULATE COEFFICIENTS ALONG J=JTOT-1
C
      I=2
      J=N
      XE=R(I)+DR5
      K=(NN-1)*MM+1
      A(K,IDC+1)=DF*XE*DUP(I,J)
      A(K,IDC-MM)=DR*DVP(I,J-1)
      A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-MM))
      Y=-DF*XE*FALSU(I,J)+DR*FALSV(I,J-1)
      X(K)=-Y
      I=M
      XW=R(I)-DR5
      K=MM*NN
      A(K,IDC-1)=DF*XW*DUP(I-1,J)
      A(K,IDC-MM)=DR*DVP(I,J-1)
      A(K,IDC)=-(A(K,IDC-1)+A(K,IDC-MM))
      Y=DF*XW*FALSU(I-1,J)+DR*FALSV(I,J-1)
      X(K)=-Y
      DO 80 I=3,MM
         K=(NN-1)*MM+I-1
         XE=R(I)+DR5
         XW=R(I)-DR5
         A(K,IDC+1)=DF*XE*DUP(I,J)
         A(K,IDC-1)=DF*XW*DUP(I-1,J)
         A(K,IDC-MM)=DR*DVP(I,J-1)
         A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-1)+A(K,IDC-MM))
         Y=DF*(XW*FALSU(I-1,J)-XE*FALSU(I,J))+DR*FALSV(I,J-1)
80    X(K)=-Y
C
C--SPECIFY A VALUE AT ONE POINT, CALL "LEQT1B" & SUBSTITUTE BACK TO P
      K=MM*NN
      A(K,IDC)=1.D0
      A(K,IDC-1)=0.D0
      A(K,IDC-MM)=0.D0
      X(K)=0.D0
      CALL LEQT1B(A,NROW,MM,MM,NROW,X,1,NROW,0,XL,IER)
      DO 95 I=2,M
      DO 95 J=2,N
95    P(I,J)=X((J-2)*MM+I-1)
      RETURN
      END
C=================================================================
C* "UVMTUM" SOLVES THE MOMENTUM EQUATIONS FOR VELOCITIES OF U AND V    *
C=================================================================
      SUBROUTINE UVMTUM(DUP,DVP,APAP,MS,P,GR,THETA,IYES,CRUV,CRM,URFUV,
     &                  RHO,CRHO,BOTTOM,ALPHA)
      REAL*8 DUP(30,48),DVP(30,48),APAP(30,48),P(30,48),MS(30,48)
      REAL*8 GR,THETA,CRUV,CRM,URFUV,RHO,CRHO,BOTTOM,ALPHA
      REAL*8 SB,AN,AS,XE,XW,Y
      REAL*8 A(50),B(50),C(50),D(50),T(50),D1,DR5
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *       SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C
C--SOLVE THE MOMENTUM EQUATIONS FOR U
C
      IUV=20
```

```
      IYES=1
      MORE=1
      NI=0
      DR5 = DR*.5D0
10    NI=NI+1
      IF (NI .LE. 5) GOTO 12
          CRUV=3.D0*CRUV
12     CONTINUE
             CALL SRCEGN(1,GR,THETA,RE,ALPHA,DH)
         A(1)=1.D0
         B(1)=0.D0
         C(1)=0.D0
         D(1)=0.D0
         A(M)=1.D0
         B(M)=0.D0
         C(M)=0.D0
         D(M)=0.D0
         D1 = 2.D0*DR*DF
      DO 35 J=2,N
         DO 20 I=2,MM
            XE=R(I)+DR5
            CALL COGN1(I,J)
            B(I)=COU(1)
            C(I)=COU(2)
            AN  =COU(3)
            AS  =COU(4)
            SB = SRC1(I,J)
            A(I)=(B(I)+C(I)+AN+AS+D1/XE)/URFUV
            Y=(1.D0-URFUV)*A(I)*U(I,J)
            DUP(I,J)=DF*XE/A(I)
20       D(I)=AN*U(I,J+1)+AS*U(I,J-1)+SB+DF*XE*(P(I,J)-P(I+1,J))+Y
         CALL TDMA(1,M,A,B,C,D,T)
         DO 30 I=2,MM
            IF (DABS(T(I)).LT.BOTTOM) GO TO 30
         IF (DABS((U(I,J)-T(I))/T(I)) .GT. CRUV) IYES=0
30       U(I,J)= RHO*T(I) + CRHO*U(I,J)
35    CONTINUE
C
C--SOLVE FOR V; F-DIRECTION SWEEP ALONG THE RADIUS
C
            CALL SRCEGN(2,GR,THETA,RE,ALPHA,DH)
         A(1)=1.D0
         B(1)=0.D0
         C(1)=0.D0
         D(1)=0.D0
         A(ITOT)=1.D0
         B(ITOT)=0.D0
         C(ITOT)=0.D0
         D(ITOT)=0.D0
      DO 90 J=2,NN
         DO 70 I=2,M
            CALL COGN2(I,J)
            B(I)=COV(1)
            C(I)=COV(2)
            AN  =COV(3)
            AS  =COV(4)
            SB = SRC2(I,J)
            A(I)=(B(I)+C(I)+AN+AS+DR*DF/R(I))/URFUV
            Y=(1.D0-URFUV)*A(I)*V(I,J)
            SB = SRC2(I,J)
            DVP(I,J)=DR/A(I)
```

```
70        D(I)=AN*V(I,J+1)+AS*V(I,J-1)+SB+DR*(P(I,J)-P(I,J+1))+Y
          CALL TDMA(1,ITOT,A,B,C,D,T)
          DO 80 I=2,M
             IF (DABS(T(I)).LT.BOTTOM) GO TO 80
          IF (DABS((V(I,J)-T(I))/T(I)) .GT. CRUV) IYES=0
80        V(I,J) = RHO*T(I) + CRHO*V(I,J)
90     CONTINUE
C
       IF (IYES .EQ. 0) GOTO 95
          MORE=0
95     IYES=1
       IF (MORE .EQ. 1 .AND. NI .LE. IUV) GOTO 10
C
C--CALCULATE THE MASS SOURCE B
C
       IYES=1
       AS=-100000.DO
       DO 240 I=2,M
          XE=R(I)+DR5
          XW=R(I)-DR5
          DO 230 J=2,N
             Y=DF*(XW*U(I-1,J)-XE*U(I,J)) + DR*(V(I,J-1)-V(I,J))
             IF (I. EQ. M .AND. J .EQ. N) GOTO 225
             IF (DABS(Y) .GT. CRM) IYES=0
             IF (DABS(Y) .LT. AS) GOTO 225
             AS=DABS(Y)
             ISI=I
             ISJ=J
225       CONTINUE
230       MS(I,J)=Y
240    CONTINUE
C
       WRITE(24,300) NI,CRUV,MORE,AS,ISI,ISJ,IYES
300    FORMAT(T2,'NI(uv)=',I3,', CRuv=',E10.3,', more=',I1,
     * ', Max Srce=',E10.3,' at I=',I2,' J=',I2,', IYES=',I1)
C
C--CORRECT U AND V IF THE MASS SOURCE ARE NOT SMALL ENOUGH
C
       IF (IYES .NE. 0) GOTO 400
          CALL PRESS(APAP,DUP,DVP,U,V)
C
C--CORRECT THE VELOCITY FIELD
C
          DO 320 I=2,MM
          DO 320 J=2,N
320       U(I,J)=U(I,J)+DUP(I,J)*(APAP(I,J)-APAP(I+1,J))
          DO 350 I=2,M
          DO 350 J=2,NN
350       V(I,J)=V(I,J)+DVP(I,J)*(APAP(I,J)-APAP(I,J+1))
400    CONTINUE
       RETURN
       END
C==================================================================
C* "TDMA" SOLVES LINEAR ALGEBRA EQ'S (TRIDIAGONAL-MATRIX ALGORITHM)  *
C==================================================================
       SUBROUTINE TDMA(M,N,A,B,C,D,T)
       REAL*8 A(50),B(50),C(50),D(50),T(50),P(50),Q(50)
C
       P(M)=B(M)/A(M)
       Q(M)=D(M)/A(M)
       J=M+1
```

```
      DO 10 I=J,N
         P(I)=B(I)/(A(I)-C(I)*P(I-1))
10       Q(I)=(D(I)+C(I)*Q(I-1))/(A(I)-C(I)*P(I-1))
      T(N)=Q(N)
      I=N-1
20       T(I)=P(I)*T(I+1)+Q(I)
         I=I-1
         IF (I .GE. M) GOTO 20
      RETURN
      END
C=====================================================================
C* "WMTUM" SOLVES THE MOMENTUM EQUATION FOR W (F-DIRECTION SWEEP)    *
C=====================================================================
      SUBROUTINE WMTUM(APAP,FRE,CFRE,CRW,URFW,PHI,DH,ALPHA,GR,RE,THETA)
      REAL*8 APAP(30,48),A(50),B(50),C(50),D(50),T(50),D1,PHI,DH
      REAL*8 FRE,CRW,URFW,CFRE,AE,AN,AS,BPW,Y,FINTEG,ALPHA,THETA
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW,GR,RE
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C
      IW=20
      NI=0
      IYES=1
      MORE=1
140   NI=NI+1
         IF (NI .LE. 5) GOTO 145
            CRW=CRW*3.0D0
145      CONTINUE
         CALL SRCEGN(3,GR,THETA,RE,ALPHA,DH)
            A(1)=1.D0
            B(1)=0.D0
            C(1)=0.D0
            D(1)=0.D0
            A(ITOT)=1.D0
            B(ITOT)=0.D0
            C(ITOT)=0.D0
            D(ITOT)=0.D0
            D1 = 2.D0*DR*DF
         DO 160 J=2,N
            DO 150 I=2,M
               CALL COGN3(I,J,RE)
               B(I)=COW(1)
               C(I)=COW(2)
               AN  =COW(3)
               AS  =COW(4)
               SB  =SRC3(I,J)
               A(I)=(B(I)+C(I)+AN+AS)/URFW
               Y=D1*R(I)
               BPW=Y*FRE+(1.0D0-URFW)*A(I)*W(I,J)
               APAP(I,J)=Y/A(I)
150         D(I)=AN*W(I,J+1)+AS*W(I,J-1)+BPW+SB
            CALL TDMA(1,ITOT,A,B,C,D,T)
            DO 155 I=2,M
         IF (DABS((W(I,J)-T(I))/T(I)) .GT. CRW) IYES=0
155         W(I,J)=T(I)
160      CONTINUE
         IF (IYES .EQ. 0) GOTO 190
            MORE=0
190      IYES=1
```

```
C
C--CORRECTION OF W AND FRE BY USING MASS CONSERVATION
C
         AE=PHI-FINTEG(ITOT,JTOT,W,R,DR,DF)
         CFRE=AE/FINTEG(ITOT,JTOT,APAP,R,DR,DF)
         Y=0.5D0
         IF(DABS(CFRE/FRE) .GT. 0.1D0) Y=0.01D0
         FRE=FRE+CFRE*Y
         DO 200 I=2,M
         DO 200 J=2,N
200      W(I,J)=W(I,J)+APAP(I,J)*CFRE*Y
      IF ((MORE .EQ. 1) .AND. (NI .LT. IW)) GOTO 140
      WRITE(24,300) NI,CRW,MORE,CFRE,FRE*DH*DH
300   FORMAT(T2,'NI(w)= ',I3,', CRw =',E10.3,', more=',I1,
     * ', CfRe=',E8.2,', fRe(Dh)=',F11.6)
      RETURN
      END
C=============================================================
C* "FINTEG" PERFORMS SIMPLE AREA INTEGRATION: II=SUMMATION OF XI*AI  *
C=============================================================
      DOUBLE PRECISION FUNCTION FINTEG(ITOT,JTOT,X,R,DR,DF)
      INTEGER ITOT,JTOT, I,J,M,N
      REAL*8 X(30,48),R(30),DR,DF
C
      M=ITOT-1
      N=JTOT-1
      FINTEG=0.0D0
      DO 10 I=2,M
      DO 10 J=2,N
10    FINTEG=FINTEG+X(I,J)*R(I)
      FINTEG=DR*DF*FINTEG
      RETURN
      END
C=============================================================
C* "ENERGY" SOLVES THE ENERGY EQUATION FOR TH BY "TDMA" (F-SWEEP)    *
C=============================================================
      SUBROUTINE ENERGY(PR,CRTH,URFTH,PHI)
      REAL*8 PR,CRTH,URFTH,AN,AS,BPTH,Y
      REAL*8 A(50),B(50),C(50),D(50),T(50),PI/3.1415926535898D0/,D1
      REAL*8 U,V,W,TH,R,DR,DF,COH
      REAL*8 DR2,FORP,ROFP,PHI
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      COMMON/ENER/COH(4,30,48),DR2,FORP,ROFP
C
      IYES=1
      MORE=1
      ITH=20
      NI=0
15    NI=NI+1
         IF (NI .LE. 5) GOTO 16
            CRTH=CRTH*3.0D0
16       CONTINUE
            A(1)=1.D0
            B(1)=0.D0
            C(1)=0.D0
            D(1)=0.D0
            A(ITOT)=1.D0
            B(ITOT)=0.D0
            C(ITOT)=0.D0
            D(ITOT)=0.D0
```

```
            D1 = DR*DF/PR/PHI
         DO 35 J=2,N
            DO 20 I=2,M
               CALL COTHGN(I,J,PR)
               B(I)=COH(1,I,J)
               C(I)=COH(2,I,J)
               AN  =COH(3,I,J)
               AS  =COH(4,I,J)
               A(I)=(B(I)+C(I)+AN+AS)/URFTH
               Y=(1.DO-URFTH)*A(I)
               BPTH=Y*TH(I,J)-D1*R(I)*W(I,J)
20          D(I)=AN*TH(I,J+1)+AS*TH(I,J-1)+BPTH
            CALL TDMA(1,ITOT,A,B,C,D,T)
            DO 30 I=2,M
            IF (DABS((TH(I,J)-T(I))/T(I)) .GT. CRTH) IYES=0
30          TH(I,J)=T(I)
35       CONTINUE
         IF (IYES .EQ. 0) GOTO 67
            MORE=0
67       IYES=1
      IF (MORE .EQ. 1 .AND. NI .LE. ITH) GOTO 15
      WRITE(24,100) NI,CRTH,MORE
100   FORMAT(T2,'NI(th)=',I3,', CRth=',D10.3,',more=',I2)
      RETURN
      END
C=======================================================================
C* FUNCTION "COTHGN" CALCULATES COEFFICIENTS OF A'S FOR TH-EQUATION    *
C=======================================================================
      SUBROUTINE  COTHGN(I,J,PR)
      REAL*8 PR,XX,YY,FF,DD,XR,AP
      REAL*8 U,V,W,TH,R,DR,DF,COH
      REAL*8 DR2,FORP,ROFP
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,R(30)
      COMMON/ENER/COH(4,30,48),DR2,FORP,ROFP
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.DO,(1.DO-0.1DO*DABS(XX/YY))**5)

        XR=R(I)+DR*.5DO
          FF=XR*DF*U(I,J)
          DD=XR*DF/DR/PR
          IF (I .EQ. ITOT-1) DD=2.DO*DD
            COH(1,I,J) = DD*AP(FF,DD)+DMAX1(0.DO,-FF)
          IF (I .GT. 2) GOTO 25
            COH(2,I,J) = 0.DO
            GOTO 30
  25      XR=R(I)-DR*.5DO
            FF=XR*DF*U(I-1,J)
            DD=XR*DF/DR/PR
            COH(2,I,J) = DD*AP(FF,DD)+DMAX1(0.DO,FF)
  30      FF=DR*V(I,J)
          DD=DR/(R(I)*DF*PR)
          IF (J .EQ. JTOT-1) DD=2.DO*DD
            COH(3,I,J) = DD*AP(FF,DD)+DMAX1(0.DO,-FF)
          FF=DR*V(I,J-1)
          DD=DR/(R(I)*DF*PR)
          IF (J .EQ. 2) DD=2.DO*DD
            COH(4,I,J) = DD*AP(FF,DD)+DMAX1(0.DO,FF)
      RETURN
      END
C=======================================================================
C* "DSAVE" STORES THE RESULTS TO DATABASE                              *
```

```
C===================================================================
      SUBROUTINE DSAVE(NIT,ITNIT,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,GR,PR,FRE,
     *                 ALPHA,THETA,DH,PHI,RE)
      REAL*8 U(ITOT,JTOT),V(ITOT,JTOT),W(ITOT,JTOT),TH(ITOT,JTOT),
     * FRE,GR,PR,ALPHA,THETA,DH,PHI,ALPA,PHII,FAC,RE
C

      FAC = 3.141592654/180.0
      ALPA = ALPHA/FAC
      PHII = 2.0*PHI/FAC
      WRITE(23,101) ALPA,THETA,PHI,ITOT,JTOT,RE
C
      WRITE(23,400) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 10 I=2,MM
10       WRITE(23,100)  (U(I,J),J=2,JTOT)
      WRITE(23,410) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 20 I=2,M
20       WRITE(23,100)  (V(I,J),J=2,NN)
      WRITE(23,420) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 40 I=2,M
40       WRITE(23,200)  (W(I,J),J=2,JTOT)
      WRITE(23,425) FRE*DH*DH
      WRITE(23,430) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 50 I=2,M
50       WRITE(23,100)  (TH(I,J),J=2,JTOT)
100   FORMAT(T8,10E15.7)
101   FORMAT(/,8X,3F15.11,2I7,4X,F6.1/)
200   FORMAT(T8,10E15.7)
400   FORMAT(T12,' ---- U VELOCITY  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
410   FORMAT(T12,' ---- V VELOCITY  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
420   FORMAT(T12,' ---- W VELOCITY  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
425   FORMAT(T12,F23.15,'  <=== FRE(Dh)')
430   FORMAT(T12,' ---- TH=(T-TC)/(Q/K)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
      RETURN
      END
C===================================================================
C* "NUSSLT" CALCULATES NUSSELT NUMBER NURO(H1) AND NU(DH,H1)         *
C===================================================================
      SUBROUTINE NUSSLT(ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,PHI)
      REAL*8 W(ITOT,JTOT),TH(ITOT,JTOT),R(ITOT),APAP(ITOT,JTOT),
     *       DR,DF,FINTEG,NURO,NUDH,PI/3.1415926535898D0/,PHI
      DO 500 I=2,M
      DO 500 J=2,N
500   APAP(I,J)=W(I,J)*TH(I,J)
      NURO=-PHI/2.D0/(1.D0+PHI)/FINTEG(ITOT,JTOT,APAP,R,DR,DF)
      NUDH=2.D0*PHI/(1.D0+PHI)*NURO
      WRITE(24,10)  NURO, NUDH
      WRITE(23,10) NURO, NUDH
10    FORMAT('  Nu(RO,H1) = ',F20.15,'     Nu(Dh,H1) = ',F20.15)
      WRITE(25,20) NURO, NUDH
20    FORMAT('  Nu(RO,H1) = ',F20.15,'     Nu(Dh,H1) = ',F20.15)
      RETURN
      END
```

```
C=================================================================
C* "LOCNUSS" CALCULATES LOCAL NUSSELT NUMBER AND SHEAR STRESS        *
C=================================================================
      SUBROUTINE LOCNUSS(NIT,ITNIT,ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,
     *                   ALPHA,PHI,DH,RE,FRE,PR,GR)
      REAL*8 W(ITOT,JTOT),TH(ITOT,JTOT),R(ITOT),APAP(ITOT,JTOT),
     *       DR,DF,FINTEG,PI/3.1415926535898D0/,PHI,DH,ALPHA,RE,
     *       NU1(50),NU2(50),NU3(50),FF(50),FRE,PR,GR,AVNU1,AVNU2,
     *       AVNU3,SHR1,SHR2,SHR3,RR1(50),RR2(50),RR3(50)
C
      SHR1=0.D0
      DO 550 J=2,N
      RR1(J)=2.D0*DH*W(M,J)*2.D0/DR
      SHR1=SHR1+DF*RR1(J)
550   CONTINUE
      SHR2=0.D0
      DO 560 I=2,M
      RR2(I)=2.D0*DH*W(I,2)*2.D0/DF/R(I)
      SHR2=SHR2+DR*RR2(I)
560   CONTINUE
      SHR3=0.D0
      DO 600 I=2,M
      RR3(I)=2.D0*DH*W(I,N)*2.D0/DF/R(I)
      SHR3=SHR3+DR*RR3(I)
600   CONTINUE
      DO 650 I=2,M
      DO 650 J=2,N
650   APAP(I,J)=W(I,J)*TH(I,J)
      DO 655 J=1,JTOT
655   NU1(J)=PHI*DH*TH(M,J)*2.D0/DR/
     *          FINTEG(ITOT,JTOT,APAP,R,DR,DF)
      DO 656 I=2,ITOT
656   NU2(I)=PHI*DH*TH(I,2)*2.D0/(DF*R(I))/
     *             FINTEG(ITOT,JTOT,APAP,R,DR,DF)
      DO 657 I=2,ITOT-1
657   NU3(I)=PHI*DH*TH(I,N)*2.D0/(DF*R(I))/
     *             FINTEG(ITOT,JTOT,APAP,R,DR,DF)
      AVNU1=0.D0
      DO 670 J=2,N
670   AVNU1=AVNU1+DF*NU1(J)
      AVNU2=0.D0
      AVNU3=0.D0
      DO 671 I=2,M
      AVNU2=AVNU2+DR*NU2(I)
      AVNU3=AVNU3+DR*NU3(I)
671   CONTINUE
C
      WRITE(25,330) (AVNU1+AVNU2+AVNU3)/(2.D0+2.D0*PHI)
330    FORMAT('  AVERAGE NU FROM LOCAL VALUES NU(Dh,H2)         = '
     *          ,F20.15)
C
        FF(JTOT)=2.D0*PHI
      FF(1) = 0.D0
      DF=(2.D0*PHI)/(JTOT-2.D0)
      FF(2)=DF*.5D0
      FF(JTOT-1)=FF(JTOT)-DF*.5D0
      DO 6 J=3,JTOT-2
6       FF(J)=FF(2)+DF*(J-2.D0)
C
      FAC = 3.141592654/180.0
      ALPA = ALPHA/FAC
```

```
      PHII = 2.0*PHI/FAC
      WRITE(25,400) NIT,ITNIT,GR,PR,PHII,ALPA,RE
         DO 10 J=1,JTOT
10    WRITE(25,200) FF(J) , RR1(J) , NU1(J)
      WRITE(25,410) NIT,ITNIT,GR,PR,PHII,ALPA,RE
DO 20 I=2,ITOT-1
20    WRITE(25,200) (1.D0-R(ITOT+1-I)+(2.D0*PHI)),
     *   RR3(ITOT+1-I) , NU3(ITOT+1-I)
      WRITE(25,420) NIT,ITNIT,GR,PR,PHII,ALPA,RE
         DO 40 I=2,ITOT
40    WRITE(25,200) (1.D0+R(I)+(2.D0*PHI)),
     *              RR2(I) , NU2(I)
      WRITE(25,425) FRE*DH*DH
      WRITE(25,430) NIT,ITNIT,GR,PR,PHII,ALPA,RE
DO 50 I=1,ITOT
50       WRITE(25,200)  R(I),(TH(I,24)+TH(I,25))/2.D0
100   FORMAT(T4,E15.7,4X,E15.7)
200   FORMAT(T4,E15.7,4X,E15.7,4X,E15.7)
400   FORMAT('LOCAL NU(CURVED WALL)   NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
410   FORMAT('LOCAL NU(BOTTOM WALL)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
420   FORMAT('LOCAL NU(TOP WALL)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
425   FORMAT(T12,F23.15,'  <=== FRE(Dh)')
430   FORMAT('TH=(T-TC)/(Q/K)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
C
      WRITE(25,215) (SHR1+SHR2+SHR3)/(2.D0+2.D0*PHI)
       WRITE(25,*) FINTEG(ITOT,JTOT,APAP,R,DR,DF)/PHI
215    FORMAT('  FRE (from average wall shear stress)          = '
     *,F20.15)
C
      WRITE(23,345) (SHR1+SHR2+SHR3)/(2.D0+2.D0*PHI)
345    FORMAT('  FRE (from average wall shear stress)          = '
     *,F20.15)
      RETURN
      END
C=================================================================
C*    CALL LEQT1B(A,N,NLC,NUC,IA,B,M,IB,IJOB,XL,IER)             *
C=================================================================
      SUBROUTINE LEQT1B(A,N,NLC,NUC,IA,B,M,IB,IJOB,XL,IER)
      REAL*8 A(IA,1), XL(N,1), B(IB,1)
      REAL*8 ZERO/0.D0/,ONE/1.D0/,P,Q,RN
      IER  = 0
      JBEG = NLC+1
      NLC1 = JBEG
      IF (IJOB .EQ. 2) GO TO 80
      RN = N
C           RESTORE THE MATRIX
C           FIND RECIPROCAL OF THE LARGEST ABSOLUTE VALUE IN ROW I
      I = 1
      NC = JBEG + NUC
      NN = NC
      JEND = NC
      IF (N .EQ. 1 .OR. NLC .EQ. 0) GO TO 25
   5  K = 1
```

```
      P = ZERO
      DO 10 J = JBEG, JEND
         A(I,K) = A(I,J)
         Q = DABS(A(I,K))
         IF (Q .GT. P) P = Q
         K = K + 1
   10 CONTINUE
      IF (P .EQ. ZERO) GO TO 135
      XL(I,NLC1) = ONE/P
      IF (K .GT. NC) GO TO 20
      DO 15 J = K, NC
         A(I,J) = ZERO
   15 CONTINUE
   20 I = I + 1
      JBEG = JBEG - 1
      IF (JEND-JBEG .EQ. N) JEND = JEND - 1
      IF (I .LE. NLC) GO TO 5
      JBEG = I
      NN = JEND
   25 JEND = N - NUC
      DO 40 I = JBEG, N
         P = ZERO
         DO 30 J = 1, NN
            Q = DABS(A(I,J))
            IF (Q .GT. P) P = Q
   30    CONTINUE
         IF (P .EQ. ZERO) GO TO 135
         XL(I,NLC1) = ONE/P
         IF(I .EQ. JEND) GO TO 37
         IF(I .LT. JEND) GO TO 40
         K = NN + 1
         DO 35 J = K, NC
            A(I,J) = ZERO
   35    CONTINUE
   37    NN = NN - 1
   40 CONTINUE
      L = NLC
C                               L - U DECOMPOSITION
      DO 75 K = 1, N
         P = DABS(A(K,1))*XL(K,NLC1)
         I = K
         IF (L .LT. N) L = L + 1
         K1 = K + 1
         IF (K1 .GT. L) GO TO 50
         DO 45 J = K1, L
            Q = DABS(A(J,1))*XL(J,NLC1)
            IF (Q .LE. P) GO TO 45
            P = Q
            I = J
   45    CONTINUE
   50    XL(I,NLC1) = XL(K,NLC1)
         XL(K,NLC1) = I
C                               DSINGULARITY FOUND
         Q = RN + P
         IF (Q .EQ. RN) GO TO 135
C                              INTERCHANGE ROWS I AND K
         IF (K .EQ. I) GO TO 60
         DO 55 J = 1, NC
            P = A(K,J)
            A(K,J) = A(I,J)
            A(I,J) = P
```

```
  55     CONTINUE
  60     IF (K1 .GT. L) GO TO 75
         DO 70 I = K1, L
            P = A(I,1)/A(K,1)
            IK = I - K
            XL(K1,IK) = P
            DO 65 J = 2, NC
               A(I,J-1) = A(I,J)-P*A(K,J)
  65        CONTINUE
            A(I,NC) = ZERO
  70     CONTINUE
  75  CONTINUE
      IF (IJOB .EQ. 1) GO TO 9005
C                               FORWARD SUBSTITUTION
  80  L = NLC
      DO 105 K = 1, N
         I = XL(K,NLC1)
         IF (I .EQ. K) GO TO 90
         DO 85 J = 1, M
            P = B(K,J)
            B(K,J) = B(I,J)
            B(I,J) = P
  85     CONTINUE
  90     IF (L .LT. N) L = L + 1
         K1 = K + 1
         IF (K1 .GT. L) GO TO 105
         DO 100 I = K1, L
            IK = I - K
            P = XL(K1,IK)
            DO 95 J = 1, M
               B(I,J) = B(I,J) - P*B(K,J)
  95        CONTINUE
 100     CONTINUE
 105  CONTINUE
C                              BACK SUBSTITUTION
      JBEG = NUC + NLC
      DO 125 J = 1, M
         L = 1
         K1 = N + 1
         DO 120 I = 1, N
            K = K1 - I
            P = B(K,J)
            IF (L .EQ. 1) GO TO 115
            DO 110 KK = 2, L
               IK = KK + K
               P = P - A(K,KK)*B(IK-1,J)
 110        CONTINUE
 115        B(K,J) = P/A(K,1)
            IF (L .LE. JBEG) L = L + 1
 120     CONTINUE
 125  CONTINUE
      GO TO 9005
 135  IER = 129
9000  CONTINUE
      WRITE(24,*) '    ERROR     IER = 129 '
      STOP
9005  RETURN
      END
C=================================================================
```

A.2 Numerical Code for H2 Condition

```
C=================================================================
C                                 H2.F
C=================================================================
C           NEW   = 1        START WITHOUT OLD PROFILE
C           NEW   = 0              WITH    OLD PROFILE
C           NEWGR = 1        START WITH    NEW GR
C           NEWGR = 0              WITH    OLD GR
      REAL*8 PI/3.141592654D0/,GROLD,PR/7.D0/,GR/0.D0/,THETA/90.D0/,
     &  ALPHA/30.D0/,FRE,CFRE,P(30,48),APAP(30,48),RE/500.D0/
      REAL*8 DUP(30,48),DVP(30,48),FALSU(30,48),FALSV(30,48),MS(30,48)
      REAL*8 FCRUV/1.D-5/,FCRW/1.D-5/,FCRTH/1.D-5/,CRM/1.D-5/
      REAL*8 CRUV,CRW,CRTH,PHI/1.570796327D0/
      REAL*8 URFUV, URFW, URFTH,DH,U,V,W,TH,R,DR,DF,ALPA,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *            R(30),TF(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C=================================================================
          OPEN(UNIT=1, FILE = 'fort.1',STATUS='OLD')
      READ(1,*) NEW
      READ(1,*) NEWGR, GR
      READ(1,*) URFUV, URFW, URFTH
      READ(1,*) MIT
      READ(1,*) FCRUV,FCRW,FCRTH,CRM
      ITOT = 30
      JTOT = 48
      FRE =  15.
      THETA = THETA*PI/180.D0
      ALPHA = ALPHA*PI/180.D0
      M=ITOT-1
      N=JTOT-1
      MM=M-1
      NN=N-1
      IC = ITOT/2
      JC = JTOT/2
      WRITE(24,9) URFUV, URFW, URFTH
 9    FORMAT('    URFuv = ',E10.3,'    URFw = ',
     *                   E10.3,'    URFth = ',E10.3/)
CLOSE(UNIT=1)
      CALL GRID(THETA,PHI,GR,PR,ALPHA)
      DO 10 I=1,ITOT
      DO 10 J=1,JTOT
         U(I,J)=0.D0
         V(I,J)=0.D0
         W(I,J)=0.D0
10    TH(I,J)=0.D0
C
C--INPUT U, V, W, AND TH FROM DATASETS AND PRINT OUT
C
      CALL DATAIN(NEW,INITO,ITNITO,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,
     &              GROLD,PR,FRE,ALPA,THETA,DH,PHI,RE)
      WRITE(24,999) FCRUV, FCRW, FCRTH, CRM
999    FORMAT(/'  FCRuv = ',E10.3,'  FCRw = ',E10.3,
     *         '  FCRth = ',E10.3,'  CRm   = ',E10.3/)
      IF(NEWGR .EQ. 0) GR = GROLD
      IF(NEWGR .EQ. 1) THEN
         INITO  = 0
         ITNITO = 0
      END IF
```

```
      DH = 2.DO*PHI/(1.DO+PHI)
      WRITE(24,*) '    * * * * * * *              GR              * * * * *'
      WRITE(24,200)   GR,PR
      WRITE(24,*) '    * * *                                            * * *'
C
C--THIS IS THE MAIN LOOP
***************************
      ITNIT = ITNITO + MIT
***************************
      NIT   = INITO
C
20    CRUV=FCRUV
      CRW=FCRW
      CRTH=FCRTH
         NIT=NIT+1
C
         CALL PSEUDO(DUP,DVP,FALSU,FALSV,GR,THETA,ALPHA)
         CALL PRESS(P,DUP,DVP,FALSU,FALSV)
         CALL UVMTUM(DUP,DVP,APAP,MS,P,GR,THETA,IYES,CRUV,CRM,URFUV,
     *            ALPHA)
         CALL WMTUM(APAP,FRE,CFRE,CRW,URFW,PHI,DH,ALPHA,GR,RE,THETA)
         CALL ENERGY(PR,CRTH,URFTH,PHI,TWA)
C
      IF ( ((CRUV*0.90D0 .GT. FCRUV) .OR. (CRW*0.90D0 .GT. FCRW)
     *   .OR. (IYES .EQ. 0) .OR. (CRTH*0.90D0 .GT. FCRTH) .OR.
     *   (DABS(CFRE) .GT. 1.D-4)) .AND. (NIT .LT. ITNIT)) GO TO 20
C
C--SAVE RESULT TO DATASETS AND CALCULATE NUSSELT NUMBER
C
      CALL DSAVE(NIT,ITNIT,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,
     *           GR,PR,FRE,ALPHA,THETA,DH,PHI,RE)
      CALL NUSSLT(ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,PHI,TWA)
      CALL LOCSHR(NIT,ITNIT,ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,
     *                  ALPHA,PHI,DH,RE,FRE,PR,GR)
C
100   FORMAT(T2,I4,1X,4(D14.7,1X))
200   FORMAT(T2,'Gr No. = ',D8.2,2X,'Pr No. = ',F7.3)

      STOP
      END
C=====================================================================
C* "GRID" GENERATES THE UNIFORM GRID COORDINATES (HALF NEAR BOUNDARY) *
C* IF "THETA" IS NOT = 0 & 180 DEG, SOLUTION IS FOR THE ENTIRE AREA   *
C=====================================================================
      SUBROUTINE GRID(THETA,PHI,GR,PR,ALPHA)
      REAL*8 THETA,FTOT,PI/3.1415926535898D0/,GR,PR,PHI,ALPHA
      REAL*8 U,V,W,TH,R,DR,DF,COH,DR2,FORP,ROFP,FNSIN,FNCOS,TF
      COMMON/ENER/COH(4,30,48),DR2,FORP,ROFP
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *           R(30),TF(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      COMMON/PERI/FNSIN(50),FNCOS(50)
C
      R(ITOT)=1.0D0
      R(1)=0.D0
         FTOT=2.D0*PHI
      DR=R(ITOT)/(ITOT-2.D0)
      DF=FTOT/(JTOT-2.D0)
      R(2)=DR*.5D0
      R(ITOT-1)=R(ITOT)-DR*.5D0
      J=ITOT-2
```

```
      DO 10 I=3,J
10       R(I)=R(2)+DR*(I-2.D0)
C
      DR2 = DR*.5D0
      FORP = DF/DR/PR
      ROFP = DR/DF/PR
C
      DO 20 J = 2, N
        FNSIN(J) = DSIN((J-1.5D0)*DF-THETA)*DCOS(ALPHA)
        FNCOS(J) = DCOS((J-1.0D0)*DF-THETA)*DCOS(ALPHA)
   20 CONTINUE
      GGRR = -0.
      FAC = 180./PI
      WRITE(24,50) FTOT*FAC,ALPHA*FAC,PR,DR,DF
      DO 40 I=1,ITOT
40    WRITE(24,60) I,R(I)
50    FORMAT(//T15,'Laminar Mixed Convection Heat Transfer',//
     *'                for a Semicircular Duct with  2*Phi =',F7.1//
     *'                       inclined at the angle  Alpha =',F7.1//
     * T12,'Pr No. = ',F7.3,2X,'dR = ',
     * F7.5,2X,'dF = ',F7.5//T10,'==== R -- COORDINATE ===='/)
60    FORMAT(T10,I3,2X,F15.12)
      RETURN
      END
C=====================================================================
C* "DATAIN" READS U,V,W,TH FROM DATASETS AND PRINTS THEM OUT          *
C* EACH DATASET CORRESPONDS TO THE FORMAT GIVEN IN SUBROUTINE "DSAVE" *
C=====================================================================
      SUBROUTINE DATAIN(NEW,NIT,ITNIT,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,
     &                  GR,PR,FRE,ALPA,THETA,DH,PHI,RE)
      REAL*8 U(ITOT,JTOT),V(ITOT,JTOT),W(ITOT,JTOT),TH(ITOT,JTOT),
     *      FRE,GR,PR,FAC,PHI2,DH,ALPA,THETA,PHI,RE
C
      IF(NEW .EQ. 1) THEN
          NIT   = 0
          ITNIT = 0
          RETURN
      END IF
      FAC = 180.0/3.141592654
      READ(13,101) ALPA,THETA,PHI,ITOT,JTOT,RE
      READ(13,400) NIT,ITNIT,GR,PR,PHI2,ALPA,RE
      DO 10 I=2,MM
10       READ(13,100)  (U(I,J),J=2,JTOT)
      READ(13,410) NIT,ITNIT,GR,PR,PHI2,ALPA,RE
      DO 20 I=2,M
20       READ(13,100)  (V(I,J),J=2,NN)
      READ(13,420) NIT,ITNIT,GR,PR,PHI2,ALPA,RE
      DO 40 I=2,M
40       READ(13,200)  (W(I,J),J=2,JTOT)
      READ(13,*) FRE
      READ(13,430) NIT,ITNIT,GR,PR,PHI2,ALPA,RE
      DO 50 I=2,M
50       READ(13,100)  (TH(I,J),J=2,JTOT)
      DH = 2.D0*PHI/(1.D0+PHI)
      FRE = FRE/DH/DH
101   FORMAT(/,8X,3F15.11,2I7,4X,F6.1/)
100   FORMAT(T8,10E15.7)
200   FORMAT(T8,10E15.7)
400   FORMAT(34X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1,4X,F6.1)
410   FORMAT(34X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1,4X,F6.1)
420   FORMAT(34X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1,4X,F6.1)
```

```
425   FORMAT(12X,F23.15)
430   FORMAT(39X,I5,8X,I5,4X,D9.3,4X,F5.1,7X,F6.1,7X,F6.1,4X,F6.1)
      RETURN
      END
C=====================================================================
C* "PSEUDO" CALCULATES FALSE VELOCITY BY SUBSTITUTING NEIGHBOR VALUES *
C=====================================================================
      SUBROUTINE PSEUDO(DUP,DVP,FALSU,FALSV,GR,THETA,ALPHA)
      REAL*8 DUP(ITOT,JTOT),DVP(ITOT,JTOT),FALSU(ITOT,JTOT),
     *     FALSV(ITOT,JTOT),GR,THETA,RE,ALPHA
      REAL*8 SB,AE,AW,AN,AS,XR,ASUM,Y,D1,D2
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *             R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *         SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C
C--CALCULATE THE PSEUDOVELOCITY OF U

      CALL SRCEGN(1,GR,THETA,RE,ALPHA,DH)
      CALL SRCEGN(2,GR,THETA,RE,ALPHA,DH)
      DO 10 I=2,MM
         XR=R(I)+0.50D0*DR
         D1 = 2.D0*DR*DF/XR
         D2 = DF*XR
         DO 10 J=2,N
            CALL COGN1(I,J)
            AE=COU(1)
            AW=COU(2)
            AN=COU(3)
            AS=COU(4)
            ASUM=AE+AW+AN+AS+D1
C                 CALL SOURCE(1,SB,I,J,GR,THETA)
            SB = SRC1(I,J)
            Y=AE*U(I+1,J)+AW*U(I-1,J)+AN*U(I,J+1)+AS*U(I,J-1)
            FALSU(I,J)=(Y+SB)/ASUM
10       DUP(I,J)=D2/ASUM
C--CALCULATE THE PSEUDOVELOCITY OF V
      DO 20 I=2,M
         D1 = DR*DF/R(I)
         DO 20 J=2,NN
            CALL COGN2(I,J)
            AE=COV(1)
            AW=COV(2)
            AN=COV(3)
            AS=COV(4)
            ASUM=AE+AW+AN+AS+D1
            SB = SRC2(I,J)
            Y=AE*V(I+1,J)+AW*V(I-1,J)+AN*V(I,J+1)+AS*V(I,J-1)
            FALSV(I,J)=(Y+SB)/ASUM
20       DVP(I,J)=DR/ASUM
      RETURN
      END
C=====================================================================
C* "COEFGN" GENERATES COEFFICIENTS OF a'S FOR U, V & W MOMENTUM EQ.S  *
C* "INDEX" = 1, 2, 3, 4 FOR EAST, W, N, S RESPECTIVELY (E-RADIAL)     *
C* THE POWER LAW IS USED                                              *
C=====================================================================
      SUBROUTINE COGN1(I,J)
      REAL*8 AP,XX,YY,FF,DD,U,V,W,TH,R,DR,DF,COU,COV,COW,TF
```

```
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *         R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *     SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

      FF=DF*R(I+1)*(U(I,J)+U(I+1,J))*.5D0
            DD=2.D0*R(I+1)/DR*DF
              COU(1) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            FF=DF*R(I)*(U(I,J)+U(I-1,J))*.5D0
            DD=2.D0*R(I)/DR*DF
              COU(2) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
            FF=DR*(V(I+1,J)+V(I,J))*.5D0
            DD=DR/(R(I)+0.5D0*DR)/DF
            IF(J.EQ.JTOT-1) DD=2.D0*DD
              COU(3) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            FF=DR*(V(I,J-1)+V(I+1,J-1))*.5D0
                       DD=DR/(R(I)+0.5D0*DR)/DF
            IF(J.EQ.2) DD=2.D0*DD
              COU(4) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
      RETURN
      END
C=======================================================================
      SUBROUTINE COGN2(I,J)
      REAL*8 AP,XX,YY,FF,DD,XR,U,V,W,TH,R,DR,DF,COU,COV,COW,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *         R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *     SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

      XR=R(I)+0.5D0*DR
            FF=XR*DF*(U(I,J)+U(I,J+1))*.5D0
            DD=XR*DF/DR
            IF(I.EQ.ITOT-1) DD=2.D0*DD
              COV(1) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            IF(I.GT.2) GOTO 25
              COV(2) = 0.D0
              GOTO 26
 25         XR=R(I)-0.5D0*DR
              FF=XR*DF*(U(I-1,J)+U(I-1,J+1))*.5D0
              DD=XR*DF/DR
              COV(2) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
 26         FF=DR*(V(I,J)+V(I,J+1))*.5D0
            DD=2.D0*DR/R(I)/DF
              COV(3) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            FF=DR*(V(I,J)+V(I,J-1))*.5D0
                          DD=2.D0*DR/R(I)/DF
              COV(4) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
      RETURN
      END
C=======================================================================
      SUBROUTINE COGN3(I,J,RE)
      REAL*8 AP,XX,YY,FF,DD,XR,U,V,W,TH,R,DR,DF,COU,COV,COW,RE,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *         R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *     SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
```

```
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

      XR=R(I)+0.5D0*DR
            FF=XR*DF*U(I,J)
            DD=XR*DF/DR
            IF(I.EQ.ITOT-1) DD=2.D0*DD
            COW(1) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            IF(I.GT.2) GOTO 35
              COW(2) = 0.D0
              GOTO 36
 35         XR=R(I)-0.5D0*DR
              FF=XR*DF*U(I-1,J)
              DD=XR*DF/DR
              COW(2) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
 36         FF=DR*V(I,J)
            DD=DR/R(I)/DF
            IF(J.EQ.JTOT-1) DD=2.D0*DD
              COW(3) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
            FF=DR*V(I,J-1)
                           DD=DR/R(I)/DF
            IF(J.EQ.2) DD=2.D0*DD
            COW(4) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
      RETURN
      END
C======================================================================
C* "SRCEGN" COMPUTES THE SOURCE TERMS FOR U-AND-V MOMENTUM EQUATION   *
C======================================================================
      SUBROUTINE SRCEGN(INDEX,GR,THETA,RE,ALPHA,DH)
      REAL*8 SB,GR,THETA,RR,S1,S2,XX,DR3,RF,DR5,FNSIN,FNCOS
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW,ALPHA,RE,DH,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *            R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      COMMON/PERI/FNSIN(50),FNCOS(50)
C
      DR3 = DR*3.D0
      RF = DR*DF
      DR5 = DR*.5D0
      GO TO (1000,2000,3000), INDEX
1000  DO 10 I = 2, M
        RR=R(I)+DR5
        XX=RF*RR*GR*.5D0
        DO 10 J = 2, N
          SB=-XX*FNSIN(J)*(TH(I,J)+TH(I+1,J))
          SB=SB+V(I+1,J)-V(I,J)-V(I+1,J-1)+V(I,J-1)
          S1=(V(I+1,J)+V(I,J)-V(I+1,J-1)-V(I,J-1))*.5D0
          SB=SB-DR3/RR*S1
          S2=(V(I+1,J)+V(I,J)+V(I+1,J-1)+V(I,J-1))*.25D0
          SRC1(I,J) = SB+RF*S2*S2
  10  CONTINUE
      RETURN

2000  DO 20 I = 2, M
        YY=RF*R(I)*GR
        DO 20 J = 2, N
          SB=U(I,J+1)-U(I,J)-U(I-1,J+1)+U(I-1,J)
          SB=SB+DR3/R(I)*(U(I,J+1)-U(I,J)+U(I-1,J+1)-U(I-1,J))*.5D0
          S1=(U(I,J+1)+U(I-1,J+1)+U(I,J)+U(I-1,J))*.25D0
          SB=SB-RF*V(I,J)*S1
```

```
          S2=(TH(I,J)+TH(I,J+1))*.5D0
          SRC2(I,J) = SB-YY*S2*FNCOS(J)
  20   CONTINUE
       RETURN
C
3000          DO 30 I = 2, M
YY=RF*R(I)*DH*(GR/RE)*DSIN(ALPHA)
        DO 30 J = 2, N
 S2 = TH(I,J)
          SRC3(I,J) = YY*S2
  30   CONTINUE
       RETURN
       END
C=====================================================================
C* "PRESS" SOLVES PRESSURE EQUATION OR PRESSURE CORRECTION EQUATION   *
C* --------------------DIRECT SOLVER---------(BAND STORAGE)--------   *
C=====================================================================
       SUBROUTINE PRESS(P,DUP,DVP,FALSU,FALSV)
       REAL*8 DUP(30,48),DVP(30,48),FALSU(30,48),FALSV(30,48),P(30,48)
       REAL*8 Y,XE,XW,DR5, U,V,W,TH,R,DR,DF,TF
       COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
      *            R(30),TF(30,48)
       COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C       REAL*8 A(784,57),X(784),XL(22736)
REAL*8 A(1288,57),X(1288),XL(37352)
C-- NOTE THAT A, X, XL NEED TO BE CHANGED WHEN THE MESH SIZE IS CHANGED
C-- A(MM*NN,MM*2+1),X(MM*NN),XL(MM*NN*(MM+1)),K=(J-2)*MM+I+1
C
       NROW=MM*NN
       NCOL=2*MM+1
       IDC=(1+NCOL)/2
       DR5 = DR*.5D0
C
C--INITIALIZATION OF A
       DO 10 I=1,NROW
       DO 10 J=1,NCOL
10     A(I,J)=0.D0
C
C--CALCULATE COEFFICIENTS ALONG J=2
C
       I=2
       J=2
       K=1
       XE=R(I)+DR5
       A(K,IDC+1)=DF*XE*DUP(I,J)
       A(K,IDC+MM)=DR*DVP(I,J)
       A(K,IDC)=-(A(K,IDC+1)+A(K,IDC+MM))
       Y=-DF*XE*FALSU(I,J)-DR*FALSV(I,J)
       X(K)=-Y
       I=M
       K=MM
       XW=R(I)-DR5
       A(K,IDC-1)=DF*XW*DUP(I-1,J)
       A(K,IDC+MM)=DR*DVP(I,J)
       A(K,IDC)=-(A(K,IDC-1)+A(K,IDC+MM))
       Y=DF*XW*FALSU(I-1,J)-DR*FALSV(I,J)
       X(K)=-Y
       DO 30 I=3,MM
          K=I-1
          XE=R(I)+DR5
          XW=R(I)-DR5
```

```
         A(K,IDC+1)=DF*XE*DUP(I,J)
         A(K,IDC-1)=DF*XW*DUP(I-1,J)
         A(K,IDC+MM)=DR*DVP(I,J)
         A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-1)+A(K,IDC+MM))
         Y=DF*(XW*FALSU(I-1,J)-XE*FALSU(I,J))-DR*FALSV(I,J)
30    X(K)=-Y
C
C--CALCULATE COEFFICIENTS ALONG J=3 AND J=JTOT-2
C
      DO 70 J=3,NN
         K=(J-2)*MM+1
         I=2
         XE=R(I)+DR5
         A(K,IDC+1)=DF*XE*DUP(I,J)
         A(K,IDC+MM)=DR*DVP(I,J)
         A(K,IDC-MM)=DR*DVP(I,J-1)
         A(K,IDC)=-(A(K,IDC+1)+A(K,IDC+MM)+A(K,IDC-MM))
         Y=-DF*XE*FALSU(I,J)+DR*(FALSV(I,J-1)-FALSV(I,J))
         X(K)=-Y
         I=M
         XW=R(I)-DR5
         K=(J-1)*MM
         A(K,IDC-1)=DF*XW*DUP(I-1,J)
         A(K,IDC+MM)=DR*DVP(I,J)
         A(K,IDC-MM)=DR*DVP(I,J-1)
         A(K,IDC)=-(A(K,IDC-1)+A(K,IDC+MM)+A(K,IDC-MM))
         Y=DF*XW*FALSU(I-1,J)+DR*(FALSV(I,J-1)-FALSV(I,J))
         X(K)=-Y
         DO 60 I=3,MM
            K=(J-2)*MM+I-1
            XE=R(I)+DR5
            XW=R(I)-DR5
            A(K,IDC+1)=DF*XE*DUP(I,J)
            A(K,IDC-1)=DF*XW*DUP(I-1,J)
            A(K,IDC+MM)=DR*DVP(I,J)
            A(K,IDC-MM)=DR*DVP(I,J-1)
            A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-1)+A(K,IDC+MM)+A(K,IDC-MM))
            Y=DF*(XW*FALSU(I-1,J)-XE*FALSU(I,J))
     *         +DR*(FALSV(I,J-1)-FALSV(I,J))
60       X(K)=-Y
70       CONTINUE
C
C--CALCULATE COEFFICIENTS ALONG J=JTOT-1
C
      I=2
      J=N
      XE=R(I)+DR5
      K=(NN-1)*MM+1
      A(K,IDC+1)=DF*XE*DUP(I,J)
      A(K,IDC-MM)=DR*DVP(I,J-1)
      A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-MM))
      Y=-DF*XE*FALSU(I,J)+DR*FALSV(I,J-1)
      X(K)=-Y
      I=M
      XW=R(I)-DR5
      K=MM*NN
      A(K,IDC-1)=DF*XW*DUP(I-1,J)
      A(K,IDC-MM)=DR*DVP(I,J-1)
      A(K,IDC)=-(A(K,IDC-1)+A(K,IDC-MM))
      Y=DF*XW*FALSU(I-1,J)+DR*FALSV(I,J-1)
      X(K)=-Y
```

```
      DO 80 I=3,MM
         K=(NN-1)*MM+I-1
         XE=R(I)+DR5
         XW=R(I)-DR5
         A(K,IDC+1)=DF*XE*DUP(I,J)
         A(K,IDC-1)=DF*XW*DUP(I-1,J)
         A(K,IDC-MM)=DR*DVP(I,J-1)
         A(K,IDC)=-(A(K,IDC+1)+A(K,IDC-1)+A(K,IDC-MM))
         Y=DF*(XW*FALSU(I-1,J)-XE*FALSU(I,J))+DR*FALSV(I,J-1)
80    X(K)=-Y
C
C--SPECIFY A VALUE AT ONE POINT, CALL "LEQT1B" & SUBSTITUTE BACK TO P
      K=MM*NN
      A(K,IDC)=1.DO
      A(K,IDC-1)=0.DO
      A(K,IDC-MM)=0.DO
      X(K)=0.DO
      CALL LEQT1B(A,NROW,MM,MM,NROW,X,1,NROW,0,XL,IER)
      DO 95 I=2,M
      DO 95 J=2,N
95    P(I,J)=X((J-2)*MM+I-1)
      RETURN
      END
C======================================================================
C* "UVMTUM" SOLVES THE MOMENTUM EQUATIONS FOR VELOCITIES OF U AND V   *
C======================================================================
      SUBROUTINE UVMTUM(DUP,DVP,APAP,MS,P,GR,THETA,IYES,CRUV,CRM,URFUV,
     &                  ALPHA)
      REAL*8 DUP(30,48),DVP(30,48),APAP(30,48),P(30,48),MS(30,48)
      REAL*8 GR,THETA,CRUV,CRM,URFUV,ALPHA
      REAL*8 SB,AN,AS,XE,XW,Y
      REAL*8 A(50),B(50),C(50),D(50),T(50),D1,DR5
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *             R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C
C--SOLVE THE MOMENTUM EQUATIONS FOR U
C
      IUV=20
      IYES=1
      MORE=1
      NI=0
      DR5 = DR*.5DO
10    NI=NI+1
      IF (NI .LE. 5) GOTO 12
          CRUV=3.DO*CRUV
12     CONTINUE
            CALL SRCEGN(1,GR,THETA,RE,ALPHA,DH)
         A(1)=1.DO
         B(1)=0.DO
         C(1)=0.DO
         D(1)=0.DO
         A(M)=1.DO
         B(M)=0.DO
         C(M)=0.DO
         D(M)=0.DO
         D1 = 2.DO*DR*DF
      DO 35 J=2,N
```

```
         DO 20 I=2,MM
            XE=R(I)+DR5
            CALL COGN1(I,J)
            B(I)=COU(1)
            C(I)=COU(2)
            AN  =COU(3)
            AS  =COU(4)
            SB = SRC1(I,J)
            A(I)=(B(I)+C(I)+AN+AS+D1/XE)/URFUV
            Y=(1.DO-URFUV)*A(I)*U(I,J)
            DUP(I,J)=DF*XE/A(I)
20       D(I)=AN*U(I,J+1)+AS*U(I,J-1)+SB+DF*XE*(P(I,J)-P(I+1,J))+Y
         CALL TDMA(1,M,A,B,C,D,T)
         DO 30 I=2,MM
         IF (DABS((U(I,J)-T(I))/T(I)) .GT. CRUV) IYES=0
30       U(I,J)= T(I)
35    CONTINUE
C
C--SOLVE FOR V; F-DIRECTION SWEEP ALONG THE RADIUS
C
            CALL SRCEGN(2,GR,THETA,RE,ALPHA,DH)
         A(1)=1.DO
         B(1)=0.DO
         C(1)=0.DO
         D(1)=0.DO
         A(ITOT)=1.DO
         B(ITOT)=0.DO
         C(ITOT)=0.DO
         D(ITOT)=0.DO
      DO 90 J=2,NN
         DO 70 I=2,M
            CALL COGN2(I,J)
            B(I)=COV(1)
            C(I)=COV(2)
            AN  =COV(3)
            AS  =COV(4)
            SB = SRC2(I,J)
            A(I)=(B(I)+C(I)+AN+AS+DR*DF/R(I))/URFUV
            Y=(1.DO-URFUV)*A(I)*V(I,J)
            SB = SRC2(I,J)
            DVP(I,J)=DR/A(I)
70       D(I)=AN*V(I,J+1)+AS*V(I,J-1)+SB+DR*(P(I,J)-P(I,J+1))+Y
         CALL TDMA(1,ITOT,A,B,C,D,T)
         DO 80 I=2,M
         IF (DABS((V(I,J)-T(I))/T(I)) .GT. CRUV) IYES=0
80       V(I,J) = T(I)
90    CONTINUE
C
      IF (IYES .EQ. 0) GOTO 95
         MORE=0
95    IYES=1
      IF (MORE .EQ. 1 .AND. NI .LE. IUV) GOTO 10
C
C--CALCULATE THE MASS SOURCE B
C
      IYES=1
      AS=-100000.DO
      DO 240 I=2,M
         XE=R(I)+DR5
         XW=R(I)-DR5
         DO 230 J=2,N
```

```
          Y=DF*(XW*U(I-1,J)-XE*U(I,J)) + DR*(V(I,J-1)-V(I,J))
          IF (I. EQ. M .AND. J .EQ. N) GOTO 225
          IF (DABS(Y) .GT. CRM) IYES=0
          IF (DABS(Y) .LT. AS) GOTO 225
          AS=DABS(Y)
          ISI=I
          ISJ=J
225     CONTINUE
230     MS(I,J)=Y
240   CONTINUE
C
      WRITE(24,300) NI,CRUV,MORE,AS,ISI,ISJ,IYES
300   FORMAT(T2,'NI(uv)=',I3,', CRuv=',E10.3,', more=',I1,
     * ', Max Srce=',E10.3,' at I=',I2,' J=',I2,', IYES=',I1)
C
C--CORRECT U AND V IF THE MASS SOURCE ARE NOT SMALL ENOUGH
C
      IF (IYES .NE. 0) GOTO 400
         CALL PRESS(APAP,DUP,DVP,U,V)
C
C--CORRECT THE VELOCITY FIELD
C
         DO 320 I=2,MM
         DO 320 J=2,N
320      U(I,J)=U(I,J)+DUP(I,J)*(APAP(I,J)-APAP(I+1,J))
         DO 350 I=2,M
         DO 350 J=2,NN
350      V(I,J)=V(I,J)+DVP(I,J)*(APAP(I,J)-APAP(I,J+1))
400   CONTINUE
      RETURN
      END
C=====================================================================
C* "TDMA" SOLVES LINEAR ALGEBRA EQ'S (TRIDIAGONAL-MATRIX ALGORITHM)   *
C=====================================================================
      SUBROUTINE TDMA(M,N,A,B,C,D,T)
      REAL*8 A(50),B(50),C(50),D(50),T(50),P(50),Q(50)
C
      P(M)=B(M)/A(M)
      Q(M)=D(M)/A(M)
      J=M+1
      DO 10 I=J,N
         P(I)=B(I)/(A(I)-C(I)*P(I-1))
10       Q(I)=(D(I)+C(I)*Q(I-1))/(A(I)-C(I)*P(I-1))
      T(N)=Q(N)
      I=N-1
20       T(I)=P(I)*T(I+1)+Q(I)
         I=I-1
         IF (I .GE. M) GOTO 20
      RETURN
      END
C=====================================================================
C* "WMTUM" SOLVES THE MOMENTUM EQUATION FOR W (F-DIRECTION SWEEP)     *
C=====================================================================
      SUBROUTINE WMTUM(APAP,FRE,CFRE,CRW,URFW,PHI,DH,ALPHA,GR,RE,THETA)
      REAL*8 APAP(30,48),A(50),B(50),C(50),D(50),T(50),D1,PHI,DH
      REAL*8 FRE,CRW,URFW,CFRE,AE,AN,AS,BPW,Y,FINTEG,ALPHA,THETA
      REAL*8 U,V,W,TH,R,DR,DF,COU,COV,COW,GR,RE,TF
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *            R(30),TF(30,48)
      COMMON/COEF/COU(4),COV(4),COW(4),SRC1(30,48),SRC2(30,48),
     *        SRC3(30,48)
```

```
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
C
      IW=20
      NI=0
      IYES=1
      MORE=1
140   NI=NI+1
         IF (NI .LE. 5) GOTO 145
            CRW=CRW*3.0D0
145      CONTINUE
         CALL SRCEGN(3,GR,THETA,RE,ALPHA,DH)
            A(1)=1.D0
            B(1)=0.D0
            C(1)=0.D0
            D(1)=0.D0
            A(ITOT)=1.D0
            B(ITOT)=0.D0
            C(ITOT)=0.D0
            D(ITOT)=0.D0
            D1 = 2.D0*DR*DF
         DO 160 J=2,N
            DO 150 I=2,M
               CALL COGN3(I,J,RE)
               B(I)=COW(1)
               C(I)=COW(2)
               AN  =COW(3)
               AS  =COW(4)
               SB  =SRC3(I,J)
               A(I)=(B(I)+C(I)+AN+AS)/URFW
               Y=D1*R(I)
               BPW=Y*FRE+(1.0D0-URFW)*A(I)*W(I,J)
               APAP(I,J)=Y/A(I)
150         D(I)=AN*W(I,J+1)+AS*W(I,J-1)+BPW+SB
            CALL TDMA(1,ITOT,A,B,C,D,T)
            DO 155 I=2,M
         IF (DABS((W(I,J)-T(I))/T(I)) .GT. CRW) IYES=0
155         W(I,J)=T(I)
160      CONTINUE
         IF (IYES .EQ. 0) GOTO 190
            MORE=0
190      IYES=1
C
C--CORRECTION OF W AND FRE BY USING MASS CONSERVATION
C
         AE=PHI-FINTEG(ITOT,JTOT,W,R,DR,DF)
         CFRE=AE/FINTEG(ITOT,JTOT,APAP,R,DR,DF)
         Y=0.5D0
         IF(DABS(CFRE/FRE) .GT. 0.1D0) Y=0.01D0
         FRE=FRE+CFRE*Y
         DO 200 I=2,M
         DO 200 J=2,N
200      W(I,J)=W(I,J)+APAP(I,J)*CFRE*Y
      IF ((MORE .EQ. 1) .AND. (NI .LT. IW)) GOTO 140
      WRITE(24,300) NI,CRW,MORE,CFRE,FRE*DH*DH
300   FORMAT(T2,'NI(w)= ',I3,', CRw =',E10.3,', more=',I1,
     * ', CfRe=',E8.2,', fRe(Dh)=',F11.6)
      RETURN
      END
C=====================================================================
C* "FINTEG" PERFORMS SIMPLE AREA INTEGRATION: II=SUMMATION OF XI*AI  *
C=====================================================================
```

```
      DOUBLE PRECISION FUNCTION FINTEG(ITOT,JTOT,X,R,DR,DF)
      INTEGER ITOT,JTOT, I,J,M,N
      REAL*8 X(30,48),R(30),DR,DF
C
      M=ITOT-1
      N=JTOT-1
      FINTEG=0.0D0
      DO 10 I=2,M
      DO 10 J=2,N
10    FINTEG=FINTEG+X(I,J)*R(I)
      FINTEG=DR*DF*FINTEG
      RETURN
      END
C======================================================================
C* "ENERGY" SOLVES THE ENERGY EQUATION FOR TH BY "TDMA" (F-SWEEP)      *
C======================================================================
      SUBROUTINE ENERGY(PR,CRTH,URFTH,PHI,TWA)
      REAL*8 PR,CRTH,URFTH,AN,AS,BPTH,Y
      REAL*8 A(50),B(50),C(50),D(50),T(50),PI/3.1415926535898D0/,D1
      REAL*8 U,V,W,TH,R,DR,DF,COH,TF,TWA
      REAL*8 DR2,FORP,ROFP,PHI,SUM1,SUM2,SUM3
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *            R(30),TF(30,48)
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      COMMON/ENER/COH(4,30,48),DR2,FORP,ROFP
C
      IYES=1
      MORE=1
      ITH=20
      NI=0
15    NI=NI+1
         IF (NI .LE. 5) GOTO 16
            CRTH=CRTH*3.0D0
16       CONTINUE
         DO 78 I = 2,M
78      TF(I,1)=TH(I,2)+DF*R(I)/2.D0/(2.D0*PHI+2.D0)
            D1 = DR*DF/PR/PHI
         DO 35 J=2,N
            A(ITOT)=1.D0
            B(ITOT)=0.D0
            C(ITOT)=1.D0
            D(ITOT)=DR/2.D0/(2.D0*PHI+2.D0)
            DO 20 I=2,M
               CALL COTHGN(I,J,PR)
               B(I)=COH(1,I,J)
               C(I)=COH(2,I,J)
               AN  =COH(3,I,J)
               AS  =COH(4,I,J)
               A(I)=(B(I)+C(I)+AN+AS)/URFTH
               Y=(1.D0-URFTH)*A(I)
               BPTH=Y*TH(I,J)-D1*R(I)*W(I,J)
20          D(I)=AN*TH(I,J+1)+AS*TH(I,J-1)+BPTH
            CALL TDMA(2,ITOT,A,B,C,D,T)
          DO 21 I=2,ITOT
21        TF(I,J) = T(I)
35       CONTINUE
            DO 79 I=2,M
79      TF(I,JTOT)=TH(I,JTOT-1)+DF*R(I)/2.D0/(2.D0*PHI+2.D0)
       SUM1=0.D0
       DO 550 J=2,N
550    SUM1=SUM1+DF*TF(ITOT,J)
```

```
      SUM2=0.D0
      SUM3=0.D0
      DO 560 I=2,M
      SUM2=SUM2+DR*TF(I,1)
      SUM3=SUM3+DR*TF(I,JTOT)
560   CONTINUE
      TWA=(SUM1+SUM2+SUM3)/(2.D0+2.D0*PHI)
          DO 61 I=2,ITOT
          DO 61 J=1,JTOT
        IF(I .EQ. ITOT .AND. J .EQ. 1) GOTO 61
        IF(I .EQ. ITOT .AND. J .EQ. JTOT) GOTO 61
          TF(I,J)=TF(I,J)-TWA
61        CONTINUE
          DO 30 J=1,JTOT
          DO 30 I=2,ITOT
        IF(I .EQ. ITOT .AND. J .EQ. 1) GOTO 30
        IF(I .EQ. ITOT .AND. J .EQ. JTOT) GOTO 30
        IF (DABS((TH(I,J)-TF(I,J))/TF(I,J)) .GT. CRTH) IYES=0
30        TH(I,J)=TF(I,J)
        IF (IYES .EQ. 0) GOTO 67
          MORE=0
67      IYES=1
     IF (MORE .EQ. 1 .AND. NI .LE. ITH) GOTO 15
       TH(ITOT,1)=TH(M,1)+(DR/2.D0)*(TH(ITOT,2)-TH(M,1))/
     *            (DR/2.D0+DF/2.D0)
       TH(ITOT,JTOT)=TH(M,JTOT)+(DR/2.D0)*(TH(ITOT,N)-
     *            TH(M,JTOT))/(DR/2.D0+DF/2.D0)
      WRITE(24,100) NI,CRTH,MORE
100   FORMAT(T2,'NI(th)=',I3,', CRth=',D10.3,',more=',I2)
      RETURN
      END
C=================================================================
C* FUNCTION "COTHGN" CALCULATES COEFFICIENTS OF A'S FOR TH-EQUATION  *
C=================================================================
      SUBROUTINE  COTHGN(I,J,PR)
      REAL*8 PR,XX,YY,FF,DD,XR,AP
      REAL*8 U,V,W,TH,R,DR,DF,COH,TF
      REAL*8 DR2,FORP,ROFP
      COMMON/PVAR/U(30,48),V(30,48),W(30,48),TH(30,48),DR,DF,
     *          R(30),TF(30,48)
      COMMON/ENER/COH(4,30,48),DR2,FORP,ROFP
      COMMON/MESH/ITOT,JTOT,M,MM,N,NN
      AP(XX,YY)=DMAX1(0.D0,(1.D0-0.1D0*DABS(XX/YY))**5)

        XR=R(I)+DR*.5D0
          FF=XR*DF*U(I,J)
          DD=XR*DF/DR/PR
          IF (I .EQ. ITOT-1) DD=2.D0*DD
            COH(1,I,J) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
          IF (I .GT. 2) GOTO 25
            COH(2,I,J) = 0.D0
            GOTO 30
 25       XR=R(I)-DR*.5D0
            FF=XR*DF*U(I-1,J)
            DD=XR*DF/DR/PR
            COH(2,I,J) = DD*AP(FF,DD)+DMAX1(0.D0,FF)
 30       FF=DR*V(I,J)
          DD=DR/(R(I)*DF*PR)
          IF (J .EQ. JTOT-1) DD=2.D0*DD
            COH(3,I,J) = DD*AP(FF,DD)+DMAX1(0.D0,-FF)
          FF=DR*V(I,J-1)
```

```
          DD=DR/(R(I)*DF*PR)
          IF (J .EQ. 2) DD=2.DO*DD
            COH(4,I,J) = DD*AP(FF,DD)+DMAX1(0.DO,FF)
      RETURN
      END
C======================================================================
C* "DSAVE" STORES THE RESULTS TO DATABASE                             *
C======================================================================
      SUBROUTINE DSAVE(NIT,ITNIT,ITOT,JTOT,M,MM,N,NN,U,V,W,TH,GR,PR,FRE,
     *                 ALPHA,THETA,DH,PHI,RE)
      REAL*8 U(ITOT,JTOT),V(ITOT,JTOT),W(ITOT,JTOT),TH(ITOT,JTOT),
     * FRE,GR,PR,ALPHA,THETA,DH,PHI,ALPA,PHII,FAC,RE
C
      FAC = 3.141592654/180.0
      ALPA = ALPHA/FAC
      PHII = 2.0*PHI/FAC
      WRITE(23,101) ALPA,THETA,PHI,ITOT,JTOT,RE
C
      WRITE(23,400) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 10 I=2,MM
10       WRITE(23,100)  (U(I,J),J=2,JTOT)
      WRITE(23,410) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 20 I=2,M
20       WRITE(23,100)  (V(I,J),J=2,NN)
      WRITE(23,420) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 40 I=2,M
40       WRITE(23,200)  (W(I,J),J=2,JTOT)
      WRITE(23,425) FRE*DH*DH
      WRITE(23,430) NIT,ITNIT,GR,PR,PHII,ALPA,RE
      DO 50 I=2,M
50       WRITE(23,100)  (TH(I,J),J=2,JTOT)
100   FORMAT(T8,10E15.7)
101   FORMAT(/,8X,3F15.11,2I7,4X,F6.1/)
200   FORMAT(T8,10E15.7)
400   FORMAT(T12,' ---- U VELOCITY  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
410   FORMAT(T12,' ---- V VELOCITY  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
420   FORMAT(T12,' ---- W VELOCITY  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
425   FORMAT(T12,F23.15,'  <=== FRE(Dh)')
430   FORMAT(T12,' ---- TH=(T-TC)/(Q/K)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F5.1,' 2*PHI=',F6.1,' ALPHA=',F6.1,
     *     ' Re=',F6.1)
      RETURN
      END
C======================================================================
C* "NUSSLT" CALCULATES NUSSELT NUMBER NURO(H1) AND NU(DH,H1)          *
C======================================================================
      SUBROUTINE NUSSLT(ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,PHI,TWA)
      REAL*8 W(ITOT,JTOT),TH(ITOT,JTOT),R(ITOT),APAP(ITOT,JTOT),
     *     TWA,DR,DF,FINTEG,NURO,NUDH,PI/3.1415926535898D0/,PHI
      DO 500 I=2,M
      DO 500 J=2,N
500   APAP(I,J)=W(I,J)*TH(I,J)
      NURO=1.DO/2.DO/(1.DO+PHI)/
     *(TWA-(FINTEG(ITOT,JTOT,APAP,R,DR,DF)/PHI))
```

```
      NUDH=2.D0*PHI/(1.D0+PHI)*NURO
      WRITE(24,10)  NURO, NUDH
      WRITE(23,10) NURO, NUDH
10    FORMAT('  Nu(RO,H2) = ',F20.15,'     Nu(Dh,H2) - ',F20.15)
      WRITE(25,20) NURO, NUDH
20    FORMAT('  Nu(RO,H2) = ',F20.15,'     Nu(Dh,H2) = ',F20.15)
      RETURN
      END
C=====================================================================
C* "LOCSHR" CALCULATES LOCAL SHEAR STRESS                             *
C=====================================================================
      SUBROUTINE LOCSHR(NIT,ITNIT,ITOT,JTOT,M,N,W,TH,APAP,R,DR,DF,
     *                  ALPHA,PHI,DH,RE,FRE,PR,GR)
      REAL*8 W(ITOT,JTOT),TH(ITOT,JTOT),R(ITOT),APAP(ITOT,JTOT),
     *      DR,DF,FINTEG,PI/3.1415926535898D0/,PHI,DH,ALPHA,RE,
     *    FF(50),FRE,PR,GR,RR3(50),SHR1,SHR2,SHR3,RR1(50),RR2(50)
C
      SHR1=0.D0
      DO 550 J=2,N
      RR1(J)=2.D0*DH*W(M,J)*2.D0/DR
      SHR1=SHR1+DF*RR1(J)
550   CONTINUE
      SHR2=0.D0
      DO 560 I=2,M
      RR2(I)=2.D0*DH*W(I,2)*2.D0/DF/R(I)
      SHR2=SHR2+DR*RR2(I)
560   CONTINUE
      SHR3=0.D0
      DO 600 I=2,M
      RR3(I)=2.D0*DH*W(I,N)*2.D0/DF/R(I)
      SHR3=SHR3+DR*RR3(I)
600   CONTINUE
        FF(JTOT)=2.D0*PHI
      FF(1) = 0.D0
      DF=(2.D0*PHI)/(JTOT-2.D0)
      FF(2)=DF*.5D0
      FF(JTOT-1)=FF(JTOT)-DF*.5D0
      DO 6 J=3,JTOT-2
6       FF(J)=FF(2)+DF*(J-2.D0)
C
      FAC = 3.141592654/180.0
      ALPA = ALPHA/FAC
      PHII = 2.0*PHI/FAC
      WRITE(25,400) NIT,ITNIT,GR,PR,PHII,ALPA,RE
         DO 10 J=1,JTOT
10    WRITE(25,200) FF(J) , RR1(J)
      WRITE(25,410) NIT,ITNIT,GR,PR,PHII,ALPA,RE
DO 20 I=2,ITOT-1
20    WRITE(25,200) (1.D0-R(ITOT+1-I)+(2.D0*PHI)),
     *    RR3(ITOT+1-I)
      WRITE(25,420) NIT,ITNIT,GR,PR,PHII,ALPA,RE
         DO 40 I=2,ITOT
40    WRITE(25,200) (1.D0+R(I)+(2.D0*PHI)),RR2(I)
      WRITE(25,425) FRE*DH*DH
      WRITE(25,430) NIT,ITNIT,GR,PR,PHII,ALPA,RE
DO 50 J=1,JTOT
50    WRITE(25,100) FF(J),TH(ITOT,J),(TH(ITOT,J)-TH(1,1)),
     * (TH(ITOT,J)-FINTEG(ITOT,JTOT,APAP,R,DR,DF)/PHI)
      WRITE(25,430) NIT,ITNIT,GR,PR,PHII,ALPA,RE
DO 60 I=2,ITOT-1
60    WRITE(25,100) (1.D0-R(ITOT+1-I)+(2.D0*PHI)),
```

```
     *TH(ITOT+1-I,JTOT), (TH(ITOT+1-I,JTOT)-TH(1,1)),
     *(TH(ITOT+1-I,JTOT)-FINTEG(ITOT,JTOT,APAP,R,DR,DF)/PHI)
      WRITE(25,430) NIT,ITNIT,GR,PR,PHII,ALPA,RE
         DO 70 I=2,ITOT
70    WRITE(25,100) (1.D0+R(I)+(2.D0*PHI)),TH(I,1),(TH(I,1)-
     * TH(1,1)),(TH(I,1)-FINTEG(ITOT,JTOT,APAP,R,DR,DF)/PHI)
100   FORMAT(T4,E15.7,3X,E15.7,3X,E15.7,3X,E15.7)
200   FORMAT(T4,E15.7,4X,E15.7)
400   FORMAT('LOCAL SHR(CURVED WALL)    NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
410   FORMAT('LOCAL SHR(BOTTOM WALL)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
420   FORMAT('LOCAL SHR(TOP WALL)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
425   FORMAT(T12,F23.15,'  <=== FRE(Dh)')
430   FORMAT('TH=(T-TC)/(Q/K)  NIT=',I5,' ITNIT==',I5,
     *        ' Gr=',D9.3,' Pr=',F3.1,' 2*PHI=',F5.1,' ALPHA=',F6.1,
     *   2X, 'Re=',F4)
c
       WRITE(25,215) (SHR1+SHR2+SHR3)/(2.D0+2.D0*PHI)
215    FORMAT('  FRE (from average wall shear stress)          = '
     *,F20.15)
c
       WRITE(23,345) (SHR1+SHR2+SHR3)/(2.D0+2.D0*PHI)
       WRITE(25,*) FINTEG(ITOT,JTOT,APAP,R,DR,DF)/PHI
345    FORMAT('  FRE (from average wall shear stress)          = '
     *,F20.15)
       RETURN
       END
C==================================================================
C*    CALL LEQT1B(A,N,NLC,NUC,IA,B,M,IB,IJOB,XL,IER)             *
C==================================================================
      SUBROUTINE LEQT1B(A,N,NLC,NUC,IA,B,M,IB,IJOB,XL,IER)
      REAL*8 A(IA,1), XL(N,1), B(IB,1)
      REAL*8 ZERO/0.D0/,ONE/1.D0/,P,Q,RN
      IER  = 0
      JBEG = NLC+1
      NLC1 = JBEG
      IF (IJOB .EQ. 2) GO TO 80
      RN = N
C           RESTORE THE MATRIX
C           FIND RECIPROCAL OF THE LARGEST ABSOLUTE VALUE IN ROW I
      I = 1
      NC = JBEG + NUC
      NN = NC
      JEND = NC
      IF (N .EQ. 1 .OR. NLC .EQ. 0) GO TO 25
    5 K = 1
      P = ZERO
      DO 10 J = JBEG, JEND
         A(I,K) = A(I,J)
         Q = DABS(A(I,K))
         IF (Q .GT. P) P = Q
         K = K + 1
   10 CONTINUE
      IF (P .EQ. ZERO) GO TO 135
      XL(I,NLC1) = ONE/P
      IF (K .GT. NC) GO TO 20
```

```
      DO 15 J = K, NC
         A(I,J) = ZERO
   15 CONTINUE
   20 I = I + 1
      JBEG = JBEG - 1
      IF (JEND-JBEG .EQ. N) JEND = JEND - 1
      IF (I .LE. NLC) GO TO 5
      JBEG = I
      NN = JEND
   25 JEND = N - NUC
      DO 40 I = JBEG, N
         P = ZERO
         DO 30 J = 1, NN
            Q = DABS(A(I,J))
            IF (Q .GT. P) P = Q
   30    CONTINUE
         IF (P .EQ. ZERO) GO TO 135
         XL(I,NLC1) = ONE/P
         IF(I .EQ. JEND) GO TO 37
         IF(I .LT. JEND) GO TO 40
         K = NN + 1
         DO 35 J = K, NC
            A(I,J) = ZERO
   35    CONTINUE
   37    NN = NN - 1
   40 CONTINUE
      L = NLC
C                               L - U DECOMPOSITION
      DO 75 K = 1, N
         P = DABS(A(K,1))*XL(K,NLC1)
         I = K
         IF (L .LT. N) L = L + 1
         K1 = K + 1
         IF (K1 .GT. L) GO TO 50
         DO 45 J = K1, L
            Q = DABS(A(J,1))*XL(J,NLC1)
            IF (Q .LE. P) GO TO 45
            P = Q
            I = J
   45    CONTINUE
   50    XL(I,NLC1) = XL(K,NLC1)
         XL(K,NLC1) = I
C                               DSINGULARITY FOUND
         Q = RN + P
         IF (Q .EQ. RN) GO TO 135
C                              INTERCHANGE ROWS I AND K
         IF (K .EQ. I) GO TO 60
         DO 55 J = 1, NC
            P = A(K,J)
            A(K,J) = A(I,J)
            A(I,J) = P
   55    CONTINUE
   60    IF (K1 .GT. L) GO TO 75
         DO 70 I = K1, L
            P = A(I,1)/A(K,1)
            IK = I - K
            XL(K1,IK) = P
            DO 65 J = 2, NC
               A(I,J-1) = A(I,J)-P*A(K,J)
   65       CONTINUE
            A(I,NC) = ZERO
```

```
   70      CONTINUE
   75   CONTINUE
        IF (IJOB .EQ. 1) GO TO 9005
C                              FORWARD SUBSTITUTION
   80   L = NLC
        DO 105 K = 1, N
           I = XL(K,NLC1)
           IF (I .EQ. K) GO TO 90
           DO 85 J = 1, M
              P = B(K,J)
              B(K,J) = B(I,J)
              B(I,J) = P
   85      CONTINUE
   90      IF (L .LT. N) L = L + 1
           K1 = K + 1
           IF (K1 .GT. L) GO TO 105
           DO 100 I = K1, L
              IK = I - K
              P = XL(K1,IK)
              DO 95 J = 1, M
                 B(I,J) = B(I,J) - P*B(K,J)
   95         CONTINUE
  100      CONTINUE
  105   CONTINUE
C                             BACK SUBSTITUTION
        JBEG = NUC + NLC
        DO 125 J = 1, M
           L = 1
           K1 = N + 1
           DO 120 I = 1, N
              K = K1 - I
              P = B(K,J)
              IF (L .EQ. 1) GO TO 115
              DO 110 KK = 2, L
                 IK = KK + K
                 P = P - A(K,KK)*B(IK-1,J)
  110         CONTINUE
  115         B(K,J) = P/A(K,1)
              IF (L .LE. JBEG) L = L + 1
  120      CONTINUE
  125   CONTINUE
        GO TO 9005
  135   IER = 129
 9000   CONTINUE
        WRITE(24,*) '    ERROR     IER = 129 '
        STOP
 9005   RETURN
        END
C=================================================================
```

Appendix B

Sample Calculation for the Error Analysis

A sample calculation for the error analysis, describing the method of estimating uncertainty in the experimental data, is presented in this Appendix. The procedure outlined by [64, 65] was used in estimating these uncertainty bounds.

$$
\begin{aligned}
\dot{m} &= 0.025 \pm 0.0005 \quad [kg\ s^{-1}] \\
D_h &= 0.0304 \pm 0.0006 \quad [m] \\
A_{wi} &= 0.60 \pm 0.001 \quad [m^2] \\
A_{fl} &= 9.723 \times 10^{-4} \pm 2 \times 10^{-5} \quad [m^2] \\
\Delta P_f &= 5.26 \pm 0.1 \quad [Pa] \\
\overline{T}_{Z.i} &= 42.50 \pm 0.2 \quad [^\circ C] \\
T_{Z.bulk} &= 37.08 \pm 0.2 \quad [^\circ C] \\
T_{bulk.o} &= 39.41 \pm 0.2 \quad [^\circ C] \\
T_{bulk.i} &= 22.76 \pm 0.2 \quad [^\circ C]
\end{aligned}
$$

The above data (presented in Appendix C) are for the experimental run HORIZONTAL ORIENTATION 6 - 1000 at station 18. We wish to estimate the uncertainty in the friction factor and the local values of Re, Gr and Nu_Z. All properties were calculated at the mean bulk temperature ($T_{bulk.m} = 31.10^\circ C$) and the uncertainty in these values was ignored.

$$
\begin{aligned}
\mu &= 7.821 \times 10^{-4} \quad [Pa.s] & k &= 0.619 \quad [W\ m^{-1}\ K^{-1}] \\
c_p &= 4178.15 \quad [J\ kg^{-1}\ K^{-1}] & \rho &= 995.33 \quad [kg\ m^{-3}] \\
\beta &= 3.138 \times 10^{-4} \quad [K^{-1}]
\end{aligned}
$$

B.1 Uncertainty in *Re*

The dimensionless independent parameter Re was defined in equation(5.1) as follows:

$$Re = \frac{\dot{m}\, D_h}{\mu\, A_{fl}}$$

Following the procedure in [64, 65] Re is a given function of $\dot{m}$, D_h, and A_{fl}. Thus,

$$Re = Re\,(\dot{m},\, D_h,\, A_{fl}) \tag{B.1}$$

and the uncertainty in Re is defined as

$$\omega_{Re} = \left[\left(\frac{\partial\, Re}{\partial\, \dot{m}}\, \omega_{\dot{m}}\right)^2 + \left(\frac{\partial\, Re}{\partial\, D_h}\, \omega_{D_h}\right)^2 + \left(\frac{\partial\, Re}{\partial\, A_{fl}}\, \omega_{A_{fl}}\right)^2\right]^{1/2} \tag{B.2}$$

Now evaluate the uncertainty in each term when the nominal value of Re is 1129.5

$$\frac{\partial\, Re}{\partial\, \dot{m}} = \frac{D_h}{\mu\, A_{fl}} = \frac{1129.5}{0.025} = 45180 \qquad [s\ kg^{-1}]$$

$$\frac{\partial\, Re}{\partial\, D_h} = \frac{\dot{m}}{\mu\, A_{fl}} = \frac{1129.5}{0.0304} = 37154.6 \qquad [m^{-1}]$$

$$\frac{\partial\, Re}{\partial\, A_{fl}} = -\frac{\dot{m}\, D_h}{\mu\, A_{fl}^2} = -\frac{1129.5}{9.723 \times 10^{-4}} = -1.16 \times 10^6 \qquad [m^{-2}]$$

Using equation (B.2), thus the uncertainty interval in Re is

$$\omega_{Re} = 39.31$$

and the fractional uncertainty interval in Re is

$$\frac{\omega_{Re}}{Re} = \frac{39.31}{1129.5} \times 100 = 3.5\%$$

B.2 Uncertainty in *f*

The friction factor is given by equation (5.6) as follows

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

Thus,

$$f = f(\dot{m},\ D_h,\ A_{fl},\ \Delta P_f) \tag{B.3}$$

and the uncertainty in f is defined as

$$\omega_f = \left[\left(\frac{\partial f}{\partial \dot{m}}\,\omega_{\dot{m}}\right)^2 + \left(\frac{\partial f}{\partial D_h}\,\omega_{D_h}\right)^2 + \left(\frac{\partial f}{\partial A_{fl}}\,\omega_{A_{fl}}\right)^2 + \left(\frac{\partial f}{\partial \Delta P_f}\,\omega_{\Delta P_f}\right)^2\right]^{1/2} \tag{B.4}$$

Determining the uncertainty in each term with the calculated value of $f = 0.024517$, we get

$$\frac{\partial f}{\partial \dot{m}} = -\frac{2}{\dot{m}}\ \frac{\Delta P_f\ \rho\ A_{fl}^2}{\dot{m}^2}\ \frac{D_h}{2\ L} = -\frac{2 \times 0.024517}{0.025} = -1.96 \qquad [s\ kg^{-1}]$$

$$\frac{\partial f}{\partial D_h} = \frac{\Delta P_f\ \rho\ A_{fl}^2}{\dot{m}^2}\ \frac{1}{2\ L} = \frac{0.024517}{0.0304} = 0.8065 \qquad [m^{-1}]$$

$$\frac{\partial f}{\partial A_{fl}} = \frac{2\ \Delta P_f\ \rho\ A_{fl}}{\dot{m}^2}\ \frac{D_h}{2\ L} = \frac{2 \times 0.024517}{9.723 \times 10^{-4}} = 50.43 \qquad [m^{-2}]$$

$$\frac{\partial f}{\partial \Delta P_f} = \frac{\rho\ A_{fl}^2}{\dot{m}^2}\ \frac{D_h}{2\ L} = \frac{0.024517}{5.26} = 0.00466 \qquad [Pa^{-1}]$$

Using equation (B.4), the uncertainty interval in f is

$$\omega_f = 0.0015664$$

and the fractional uncertainty interval in f is

$$\frac{\omega_f}{f} = \frac{0.0015664}{0.024517} \times 100 = 6.39\%$$

B.3 Uncertainty in Q_f

The computation for Gr and Nu_Z depends on the total heat gain, Q_f, which can be obtained using the following equation

$$Q_f = \dot{m}\ c_p\ (T_{bulk,o} - T_{bulk,i}) \tag{B.5}$$

where, $T_{bulk,i}$ and $T_{bulk,o}$ are the inlet and outlet bulk temperatures, respectively. The heat rate Q_f is a given function of $\dot{m}$, $T_{bulk,o}$, and $T_{bulk,i}$. Thus,

$$Q_f = Q_f(\dot{m},\ T_{bulk,o},\ T_{bulk,i}) \tag{B.6}$$

and the uncertainty in Q_f is defined as

$$\omega_{Q_f} = \left[\left(\frac{\partial Q_f}{\partial \dot{m}}\,\omega_{\dot{m}}\right)^2 + \left(\frac{\partial Q_f}{\partial T_{bulk,o}}\,\omega_{T_{bulk,o}}\right)^2 + \left(\frac{\partial Q_f}{\partial T_{bulk,i}}\,\omega_{T_{bulk,i}}\right)^2\right]^{1/2} \tag{B.7}$$

Determining the uncertainty in each term when the calculated value of Q_f is 1738.8 W, we get

$$\frac{\partial Q_f}{\partial \dot{m}} = c_p\,(T_{bulk,o} - T_{bulk,i}) = \frac{1738.8}{0.025} = 69552 \qquad [W\ s\ kg^{-1}]$$

$$\frac{\partial Q_f}{\partial T_{bulk,o}} = \dot{m}\,c_p = \frac{1738.8}{(39.41 - 22.76)} = 104.43 \qquad [W\ K^{-1}]$$

$$\frac{\partial Q_f}{\partial T_{bulk,i}} = -\dot{m}\,c_p = -\frac{1738.8}{(39.41 - 22.76)} = -104.43 \qquad [W\ K^{-1}]$$

Using equation (B.7), the uncertainty interval in Q_f is

$$\omega_{Q_f} = 45.627 \qquad [W]$$

and the fractional uncertainty interval in Q_f is

$$\frac{\omega_{Q_f}}{Q_f} = \frac{45.627}{1738.8} \times 100 = 2.6\%$$

B.4 Uncertainty in Gr

The dimensionless independent parameter Gr was defined in equation(5.1) and it can be modified by using the following expression

$$Gr = \frac{(\pi+2)^5}{(2\pi)^4}\ \frac{\beta\,g\,\rho^2\,Q_f\,D_h^4}{k\,\mu^2\,A_{wi}}$$

where, A_{wi} is the surface area. Thus,

$$Gr = Gr(Q_f,\ D_h,\ A_{wi}) \tag{B.8}$$

and the uncertainty in Gr is defined as

$$\omega_{Gr} = \left[\left(\frac{\partial Gr}{\partial Q_f} \omega_{Q_f} \right)^2 + \left(\frac{\partial Gr}{\partial D_h} \omega_{D_h} \right)^2 + \left(\frac{\partial Gr}{\partial A_{wi}} \omega_{A_{wi}} \right)^2 \right]^{1/2} \tag{B.9}$$

The uncertainty in each term for $Gr = 6.68 \times 10^7$ can be obtained as follows:

$$\frac{\partial Gr}{\partial Q_f} = \frac{(\pi+2)^5}{(2\pi)^4} \frac{\beta\, g\, \rho^2\, D_h^4}{k\, \mu^2\, A_{wi}} = \frac{6.68 \times 10^7}{1738.8} = 38417.3 \qquad [W^{-1}]$$

$$\frac{\partial Gr}{\partial D_h} = \frac{(\pi+2)^5}{(2\pi)^4} \frac{4\, \beta\, g\, \rho^2\, Q_f\, D_h^3}{k\, \mu^2\, A_{wi}} = \frac{4 \times 6.68 \times 10^7}{0.0304} = 8.79 \times 10^9 \qquad [m^{-1}]$$

$$\frac{\partial Gr}{\partial A_{wi}} = -\frac{(\pi+2)^5}{(2\pi)^4} \frac{\beta\, g\, \rho^2\, Q_f\, D_h^4}{k\, \mu^2\, A_{wi}^2} = -\frac{6.68 \times 10^7}{0.60} = -1.113 \times 10^8 \qquad [m^{-2}]$$

Using equation (B.9), the uncertainty interval in Gr is

$$\omega_{Gr} = 5.67 \times 10^6$$

and the fractional uncertainty interval in Gr is

$$\frac{\omega_{Gr}}{Gr} = \frac{5.67 \times 10^6}{6.68 \times 10^7} \times 100 = 8.5\%$$

B.5 Uncertainty in Nu_Z

The local mean Nusselt number was defined in equation (5.4) and it can be written as

$$Nu_{Z,i} = \frac{Q_f\, D_h}{k\, \left(\overline{T}_{Z,i} - T_{Z,bulk}\right)\, A_{wi}}$$

Thus,

$$Nu_Z = Nu_Z\left(Q_f,\, D_h,\, A_{wi}, \overline{T}_{Z,i}, T_{Z,bulk}\right) \tag{B.10}$$

and the uncertainty in Nu_Z is defined as

$$\omega_{Nu_Z} = \left[\left(\frac{\partial Nu_Z}{\partial Q_f} \omega_{Q_f} \right)^2 + \left(\frac{\partial Nu_Z}{\partial D_h} \omega_{D_h} \right)^2 + \left(\frac{\partial Nu_Z}{\partial A_{wi}} \omega_{A_{wi}} \right)^2 \right.$$

$$\left. + \left(\frac{\partial Nu_Z}{\partial \overline{T}_{Z,i}} \omega_{\overline{T}_{Z,i}} \right)^2 + \left(\frac{\partial Nu_Z}{\partial T_{Z,bulk}} \omega_{T_{Z,bulk}} \right)^2 \right]^{1/2} \tag{B.11}$$

The uncertainty in each term for $Nu_Z = 26.06$ can be obtained as follows:

$$\frac{\partial Nu_Z}{\partial Q_f} = \frac{D_h}{k \left(\overline{T}_{Z,i} - T_{Z,bulk} \right) A_{wi}} = \frac{26.06}{1738.8} = 0.015 \qquad [W^{-1}]$$

$$\frac{\partial Nu_Z}{\partial D_h} = \frac{Q_f}{k \left(\overline{T}_{Z,i} - T_{Z,bulk} \right) A_{wi}} = \frac{26.06}{0.0304} = 857.24 \qquad [m^{-1}]$$

$$\frac{\partial Nu_Z}{\partial A_{wi}} = -\frac{Q_f \ D_h}{k \left(\overline{T}_{Z,i} - T_{Z,bulk} \right) A_{wi}^2} = -\frac{26.06}{0.60} = -43.43 \qquad [m^{-2}]$$

$$\frac{\partial Nu_Z}{\partial \overline{T}_{Z,i}} = -\frac{Q_f \ D_h}{k \left(\overline{T}_{Z,i} - T_{Z,bulk} \right)^2 A_{wi}} = -\frac{26.06}{(42.50 - 37.08)} = -4.81 \qquad [K^{-1}]$$

$$\frac{\partial Nu_Z}{\partial T_{Z,bulk}} = \frac{Q_f \ D_h}{k \left(\overline{T}_{Z,i} - T_{Z,bulk} \right)^2 A_{wi}} = \frac{26.06}{(42.50 - 37.08)} = 4.81 \qquad [K^{-1}]$$

Substitute these values into equation (B.11) to obtain the uncertainty interval in Nu_Z

$$\omega_{Nu_Z} = 1.66$$

Thus the fractional uncertainty interval in Nu_Z is

$$\frac{\omega_{Nu_Z}}{Nu_Z} = \frac{1.66}{26.06} \times 100 = 6.4\%$$

Appendix C

Experimental Data for $\alpha = 0°$

The following notation applies to Appendices C to G

A, B, C	= thermocouples a, b, and c in figure 5.1
RE, PR, GR	= local Reynolds, Prandtl, and Grashof numbers
FREM, REM, GRM, PRM, RAM	= fRe, Re, Gr, Pr, and Ra calculated at the average of the inlet and outlet bulk temperatures
T	= indicating Nusselt number calculated at the length-mean average of the three wall temperatures
H	= indicating Nusselt number calculated as the length-mean average of the three $Nu_{Z,a}$, $Nu_{Z,b}$, and $Nu_{Z,c}$
T+H	= average of the T and H values

HORIZONTAL ORIENTATION _____ 1 - 500

INPUT ELECTRIC POWER = 151.3 W HEAT RATE GAINED BY WATER = 153.2 W HEAT BALANCE ERROR =-1.24%
MASS FLOW RATE = 14.7500 G/S PRESSURE DROP= 0.2985MMH20 FRICTION FACTOR = 0.039212 FREM = 19.5675

REM = 499.0 GRM = 0.23047E+07 UPSTREAM BULK TEMPERATURE = 22.28DEG C DOWNSTREAM BULK TEMPERATURE = 24.77DEG C
PRM = 6.356 RAM = 0.14647E+08 INLET BULK TEMPERATURE = 22.28DEG C OUTLET BULK TEMPERATURE = 24.77DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	AVERAGE H	AVERAGE T+H
3	5.5	23.12	23.08	23.10	23.10	22.31	485.8	6.55	0.208E+07	0.00057	15.89	16.66	16.27	16.27	16.27	16.27
4	15.5	23.46	23.47	23.46	23.46	22.36	486.3	6.54	0.209E+07	0.00160	11.72	11.57	11.72	11.68	11.68	11.68
5	25.5	23.54	23.62	23.54	23.56	22.42	486.9	6.53	0.210E+07	0.00264	11.37	10.60	11.44	11.20	11.21	11.21
6	45.5	23.63	23.70	23.62	23.64	22.52	488.0	6.51	0.212E+07	0.00471	11.58	10.87	11.63	11.42	11.43	11.43
7	75.5	23.71	23.82	23.73	23.75	22.68	489.7	6.49	0.215E+07	0.00782	12.50	11.23	12.22	12.02	12.04	12.03
8	105.5	23.81	23.95	23.82	23.85	22.84	491.5	6.46	0.218E+07	0.01093	13.23	11.57	13.00	12.66	12.70	12.68
9	135.5	23.98	24.09	24.03	24.03	23.00	493.2	6.44	0.221E+07	0.01404	13.07	11.72	12.44	12.40	12.42	12.41
10	165.2	24.11	24.24	24.19	24.18	23.16	494.9	6.41	0.224E+07	0.01712	13.41	11.77	12.43	12.48	12.51	12.49
11	205.2	24.27	24.42	24.39	24.37	23.37	497.3	6.38	0.228E+07	0.02128	14.25	12.18	12.51	12.82	12.86	12.84
12	245.2	24.59	24.60	24.56	24.58	23.58	499.7	6.35	0.232E+07	0.02544	12.67	12.52	13.08	12.83	12.84	12.84
13	275.2	24.61	24.77	24.73	24.71	23.74	501.5	6.32	0.235E+07	0.02856	14.71	12.34	12.94	13.17	13.23	13.20
14	305.2	24.82	25.00	24.89	24.90	23.90	503.3	6.30	0.238E+07	0.03168	13.83	11.61	12.86	12.74	12.79	12.77
15	333.3	24.90	25.01	24.98	24.97	24.06	505.0	6.27	0.241E+07	0.03461	15.03	13.28	13.68	13.89	13.92	13.90
16	363.3	25.11	25.20	25.15	25.15	24.21	506.8	6.25	0.244E+07	0.03774	14.12	12.87	13.50	13.49	13.50	13.49
17	383.3	25.21	25.27	25.22	25.23	24.31	508.0	6.23	0.246E+07	0.03983	14.23	13.29	14.08	13.91	13.92	13.91
18	403.3	25.33	25.41	25.32	25.34	24.42	509.3	6.21	0.248E+07	0.04192	14.06	12.87	14.10	13.76	13.78	13.77
19	423.3	25.39	25.53	25.48	25.47	24.53	510.5	6.20	0.250E+07	0.04401	14.72	12.72	13.33	13.48	13.52	13.50
20	443.3	25.47	25.60	25.54	25.54	24.63	511.8	6.18	0.252E+07	0.04610	15.16	13.11	14.06	14.05	14.09	14.07
21	463.3	25.67	25.65	25.75	25.71	24.74	513.0	6.16	0.255E+07	0.04820	13.61	13.94	12.51	13.11	13.15	13.13
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.23	25.34	25.28	25.28	24.36	508.6	6.22	0.247E+07	0.04070	14.55	13.02	13.79	13.76	13.79	13.78

HORIZONTAL ORIENTATION _____ 2 - 500

INPUT ELECTRIC POWER = 297.2 W HEAT RATE GAINED BY WATER = 307.0 W HEAT BALANCE ERROR =-3.31%
MASS FLOW RATE = 14.2389 G/S PRESSURE DROP= 0.2949MMH20 FRICTION FACTOR = 0.041558 FREM = 20.7622

REM = 499.6 GRM = 0.52587E+07 UPSTREAM BULK TEMPERATURE = 22.53DEG C DOWNSTREAM BULK TEMPERATURE = 27.69DEG C
PRM = 6.104 RAM = 0.32101E+08 INLET BULK TEMPERATURE = 22.53DEG C OUTLET BULK TEMPERATURE = 27.69DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	AVERAGE H	AVERAGE T+H
3	5.5	24.12	24.22	24.17	24.17	22.60	471.9	6.50	0.428E+07	0.00059	16.86	15.73	16.28	16.28	16.29	16.28
4	15.5	24.37	24.59	24.42	24.45	22.71	473.0	6.48	0.432E+07	0.00166	15.42	13.61	14.93	14.69	14.72	14.71
5	25.5	24.51	24.75	24.64	24.64	22.82	474.2	6.47	0.436E+07	0.00274	15.16	13.22	14.02	14.07	14.11	14.09
6	45.5	24.69	24.93	24.77	24.79	23.04	476.5	6.43	0.444E+07	0.00488	15.45	13.51	14.76	14.59	14.62	14.60
7	75.5	24.84	25.10	24.93	24.95	23.37	480.0	6.38	0.456E+07	0.00811	17.31	14.76	16.36	16.15	16.20	16.17
8	105.5	25.06	25.37	25.16	25.19	23.70	483.6	6.33	0.468E+07	0.01134	18.69	15.25	17.40	17.09	17.19	17.14
9	135.5	25.37	25.68	25.53	25.53	24.03	487.2	6.28	0.481E+07	0.01458	18.96	15.44	16.94	16.98	17.07	17.03
10	165.2	25.67	26.00	25.84	25.84	24.35	490.9	6.22	0.494E+07	0.01778	19.41	16.50	17.17	17.20	17.31	17.26
11	205.2	26.05	26.40	26.29	26.26	24.79	495.9	6.16	0.512E+07	0.02212	20.25	15.89	17.01	17.40	17.54	17.47
12	245.2	26.59	26.83	26.71	26.71	25.23	501.0	6.09	0.531E+07	0.02646	18.77	15.92	17.23	17.23	17.28	17.26
13	275.2	26.84	27.12	27.05	27.01	25.56	504.9	6.03	0.545E+07	0.02972	19.97	16.36	17.10	17.53	17.63	17.58
14	305.2	27.20	27.52	27.36	27.36	25.89	508.8	5.98	0.560E+07	0.03299	19.50	15.64	17.38	17.37	17.47	17.42
15	333.3	27.43	27.74	27.65	27.62	26.20	512.6	5.93	0.575E+07	0.03605	20.69	16.56	17.51	17.94	18.07	18.01
16	363.3	27.87	28.15	28.01	28.01	26.53	516.7	5.88	0.590E+07	0.03933	18.99	15.67	17.13	17.15	17.23	17.19
17	383.3	28.09	28.34	28.18	28.20	26.75	519.5	5.85	0.601E+07	0.04152	19.00	15.98	17.82	17.58	17.65	17.62
18	403.3	28.30	28.61	28.43	28.45	26.97	522.0	5.81	0.611E+07	0.04371	19.04	15.46	17.37	17.22	17.31	17.26
19	423.3	28.57	28.86	28.74	28.73	27.19	524.3	5.79	0.620E+07	0.04589	18.34	15.24	16.38	16.51	16.59	16.55
20	443.3	28.74	29.01	28.88	28.88	27.41	526.7	5.76	0.630E+07	0.04808	19.15	15.83	17.23	17.28	17.36	17.32
21	463.3	29.04	29.31	29.18	29.18	27.63	529.0	5.73	0.639E+07	0.05026	17.97	15.08	16.42	16.41	16.47	16.44
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.17	28.45	28.32	28.31	26.84	520.3	5.84	0.604E+07	0.04243	19.20	15.79	17.24	17.28	17.37	17.33

HORIZONTAL ORIENTATION _____ 3 - 500

INPUT ELECTRIC POWER = 581.7 W HEAT RATE GAINED BY WATER = 595.2 W HEAT BALANCE ERROR =-2.32%
MASS FLOW RATE = 13.6429 G/S PRESSURE DROP= 0.2978MMH20 FRICTION FACTOR = 0.045684 FREM = 23.1331

REM = 506.4 GRM = 0.12356E+08 UPSTREAM BULK TEMPERATURE = 22.35DEG C DOWNSTREAM BULK TEMPERATURE = 32.81DEG C
PRM = 5.738 RAM = 0.70890E+08 INLET BULK TEMPERATURE = 22.36DEG C OUTLET BULK TEMPERATURE = 32.80DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.31	25.57	25.44	25.44	22.49	451.0	6.52	0.822E+07	0.00062	17.60	16.14	16.84	16.84	16.86	16.85
4	15.5	25.64	26.15	25.72	25.81	22.71	453.2	6.48	0.837E+07	0.00173	16.97	14.43	16.50	16.04	16.10	16.07
5	25.5	25.99	26.43	26.28	26.24	22.93	455.5	6.45	0.853E+07	0.00286	16.23	14.19	14.85	14.99	15.03	15.01
6	45.5	26.26	26.69	26.39	26.44	23.38	460.0	6.38	0.885E+07	0.00510	17.19	14.95	16.45	16.22	16.26	16.24
7	75.5	26.59	27.04	26.74	26.78	24.04	467.0	6.27	0.934E+07	0.00848	19.44	16.51	18.35	18.10	18.16	18.13
8	105.5	27.04	27.69	27.23	27.30	24.71	474.2	6.17	0.987E+07	0.01186	21.21	16.59	19.64	19.12	19.27	19.19
9	135.5	27.77	28.30	28.04	28.04	25.38	481.7	6.06	0.104E+08	0.01526	20.65	16.91	18.55	18.57	18.66	18.62
10	165.2	28.36	28.98	28.73	28.70	26.04	489.3	5.96	0.110E+08	0.01864	21.23	16.77	18.37	18.55	18.68	18.62
11	205.2	29.12	29.72	29.45	29.44	26.93	499.7	5.82	0.118E+08	0.02321	22.48	17.68	19.54	19.67	19.81	19.74
12	245.2	30.09	30.63	30.38	30.37	27.82	508.9	5.71	0.126E+08	0.02777	21.65	17.51	19.24	19.30	19.41	19.36
13	275.2	30.66	31.22	31.08	31.01	28.49	515.9	5.62	0.132E+08	0.03120	22.67	17.97	18.92	19.46	19.62	19.54
14	305.2	31.31	31.89	31.61	31.61	29.16	523.2	5.54	0.138E+08	0.03464	22.82	17.94	19.94	20.02	20.16	20.09
15	333.3	31.94	32.53	32.33	32.28	29.79	530.2	5.46	0.144E+08	0.03787	22.69	17.85	19.21	19.59	19.74	19.66
16	363.3	32.66	33.25	32.98	32.97	30.45	537.9	5.38	0.151E+08	0.04133	22.08	17.43	19.30	19.39	19.53	19.46
17	383.3	33.12	33.69	33.40	33.40	30.90	543.1	5.32	0.155E+08	0.04364	21.96	17.47	19.53	19.50	19.62	19.56
18	403.3	33.62	34.15	33.84	33.86	31.34	548.5	5.26	0.160E+08	0.04595	21.44	17.36	19.53	19.36	19.46	19.41
19	423.3	34.08	34.65	34.42	34.39	31.79	554.0	5.21	0.165E+08	0.04827	21.28	17.04	18.53	18.73	18.85	18.79
20	443.3	34.39	34.99	34.70	34.70	32.24	558.8	5.16	0.170E+08	0.05061	22.54	17.66	19.70	19.75	19.90	19.83
21	463.3	34.74	35.31	35.09	35.06	32.68	563.7	5.10	0.175E+08	0.05297	23.57	18.46	20.14	20.42	20.58	20.50
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	33.30	33.88	33.61	33.60	31.08	545.4	5.30	0.158E+08	0.04461	22.00	17.47	19.30	19.38	19.52	19.45

HORIZONTAL ORIENTATION _____ 4 - 500

INPUT ELECTRIC POWER = 931.8 W HEAT RATE GAINED BY WATER = 945.9 W HEAT BALANCE ERROR =-1.52%
MASS FLOW RATE = 12.4500 G/S PRESSURE DROP= 0.2860MMH20 FRICTION FACTOR = 0.052602 FREM = 26.3151

REM = 500.3 GRM = 0.25429E+08 UPSTREAM BULK TEMPERATURE = 22.21DEG C DOWNSTREAM BULK TEMPERATURE = 40.42DEG C
PRM = 5.267 RAM = 0.13393E+09 INLET BULK TEMPERATURE = 22.23DEG C OUTLET BULK TEMPERATURE = 40.41DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.61	27.13	26.87	26.87	22.44	411.2	6.53	0.130E+08	0.00067	18.93	16.86	17.83	17.83	17.86	17.85
4	15.5	27.07	27.91	27.32	27.41	22.83	414.7	6.47	0.134E+08	0.00190	18.61	15.53	17.58	17.25	17.33	17.29
5	25.5	27.64	28.41	28.08	28.05	23.22	418.3	6.40	0.139E+08	0.00313	17.83	15.18	16.24	16.32	16.37	16.34
6	45.5	27.97	28.76	28.35	28.36	23.99	425.7	6.28	0.148E+08	0.00560	19.78	16.50	18.07	18.03	18.10	18.07
7	75.5	28.70	29.55	29.06	29.09	25.16	437.3	6.10	0.163E+08	0.00931	22.14	17.89	20.11	19.95	20.06	20.00
8	105.5	29.64	30.71	29.97	30.07	26.32	449.5	5.91	0.179E+08	0.01306	23.59	17.83	21.48	20.88	21.09	20.99
9	135.5	30.90	31.84	31.39	31.38	27.48	461.2	5.75	0.195E+08	0.01681	22.88	17.93	19.99	20.05	20.20	20.12
10	165.2	31.98	33.05	32.57	32.54	28.64	472.2	5.60	0.211E+08	0.02053	23.30	17.63	19.82	19.95	20.14	20.05
11	205.2	33.31	34.29	33.79	33.79	30.19	488.0	5.41	0.235E+08	0.02557	24.87	18.93	21.58	21.54	21.74	21.64
12	245.2	34.93	35.82	35.41	35.39	31.74	504.9	5.21	0.262E+08	0.03064	24.25	18.96	21.06	21.17	21.34	21.25
13	275.2	35.95	36.86	36.60	36.50	32.90	516.7	5.08	0.281E+08	0.03451	25.31	19.50	20.85	21.43	21.63	21.53
14	305.2	36.98	37.91	37.47	37.46	34.07	528.8	4.94	0.302E+08	0.03841	26.41	19.99	22.59	22.68	22.90	22.79
15	333.3	38.20	39.15	38.87	38.78	35.16	540.6	4.82	0.323E+08	0.04211	25.15	19.19	20.63	21.19	21.40	21.30
16	363.3	39.33	40.36	39.97	39.91	36.32	553.8	4.68	0.347E+08	0.04609	25.42	18.91	20.93	21.31	21.55	21.43
17	383.3	40.14	41.15	40.62	40.63	37.10	562.6	4.60	0.363E+08	0.04874	25.11	18.81	21.63	21.57	21.79	21.68
18	403.3	40.95	41.96	41.40	41.43	37.87	570.8	4.53	0.379E+08	0.05135	24.74	18.62	21.57	21.41	21.63	21.52
19	423.3	41.76	42.79	42.42	42.35	38.65	579.3	4.45	0.396E+08	0.05396	24.46	18.38	20.15	20.56	20.78	20.67
20	443.3	42.44	43.44	43.00	42.97	39.42	588.0	4.38	0.414E+08	0.05658	25.18	18.90	21.26	21.43	21.65	21.54
21	463.3	43.30	43.96	43.47	43.55	40.20	596.9	4.31	0.432E+08	0.05921	24.44	20.16	23.16	22.62	22.73	22.67
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	40.47	41.48	41.06	41.01	37.42	565.9	4.58	0.370E+08	0.04981	25.01	18.80	21.03	21.24	21.47	21.36

HORIZONTAL ORIENTATION _____ 1 - 1000

INPUT ELECTRIC POWER = 151.8 W HEAT RATE GAINED BY WATER = 151.3 W HEAT BALANCE ERROR = 0.317%
MASS FLOW RATE = 29.6962 G/S PRESSURE DROP= 0.5837MMH20 FRICTION FACTOR = 0.018919 FREM = 18.9875
REM = 1003.6 GRM = 0.22672E+07 UPSTREAM BULK TEMPERATURE = 22.87DEG C DOWNSTREAM BULK TEMPERATURE = 24.09DEG C
PRM = 6.363 RAM = 0.14426E+08 INLET BULK TEMPERATURE = 22.87DEG C OUTLET BULK TEMPERATURE = 24.09DEG C

STATION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.53	23.50	23.52	23.52	22.88	990.4	6.46	0.216E+07	0.00028	19.42	20.51	19.95	19.96	19.96	19.96
4	15.5	23.73	23.81	23.82	23.79	22.91	990.9	6.45	0.216E+07	0.00080	15.33	14.07	13.93	14.29	14.31	14.30
5	25.5	23.95	24.04	24.01	24.00	22.93	991.5	6.45	0.217E+07	0.00131	12.37	11.45	11.78	11.84	11.85	11.84
6	45.5	24.10	24.15	24.15	24.14	22.99	992.7	6.44	0.218E+07	0.00234	11.30	10.87	10.81	10.94	10.95	10.94
7	75.5	24.12	24.21	24.12	24.14	23.06	994.4	6.43	0.219E+07	0.00389	11.94	11.02	11.97	11.71	11.72	11.72
8	105.5	24.11	24.23	24.10	24.14	23.14	996.1	6.42	0.221E+07	0.00543	12.98	11.65	13.13	12.69	12.72	12.71
9	135.5	24.12	24.23	24.17	24.17	23.22	997.9	6.40	0.222E+07	0.00698	14.07	12.50	13.34	13.29	13.31	13.30
10	165.2	24.14	24.24	24.19	24.19	23.30	999.6	6.39	0.223E+07	0.00851	15.01	13.35	14.21	14.17	14.19	14.18
11	205.2	24.18	24.33	24.33	24.30	23.40	1001.9	6.37	0.225E+07	0.01057	16.17	13.52	13.53	14.10	14.19	14.14
12	245.2	24.37	24.43	24.39	24.39	23.51	1004.3	6.36	0.227E+07	0.01263	14.65	13.59	14.27	14.18	14.19	14.19
13	275.2	24.36	24.50	24.47	24.45	23.58	1006.0	6.35	0.229E+07	0.01418	16.30	13.83	14.15	14.55	14.61	14.58
14	305.2	24.46	24.63	24.58	24.56	23.66	1007.8	6.33	0.230E+07	0.01573	15.82	12.97	13.68	13.96	14.04	14.00
15	333.3	24.45	24.59	24.59	24.56	23.73	1009.5	6.32	0.232E+07	0.01718	17.58	14.72	14.72	15.35	15.44	15.39
16	363.3	24.64	24.75	24.67	24.68	23.81	1011.2	6.31	0.233E+07	0.01873	15.31	13.42	14.63	14.46	14.50	14.48
17	383.3	24.68	24.79	24.77	24.75	23.86	1012.4	6.30	0.234E+07	0.01976	15.50	13.57	13.89	14.17	14.21	14.19
18	403.3	24.71	24.85	24.79	24.78	23.92	1013.6	6.29	0.235E+07	0.02080	15.94	13.54	14.42	14.53	14.58	14.55
19	423.3	24.80	24.91	24.86	24.86	23.97	1014.8	6.29	0.236E+07	0.02183	15.08	13.36	14.09	14.13	14.15	14.14
20	443.3	24.80	24.95	24.86	24.87	24.02	1016.0	6.28	0.237E+07	0.02286	16.25	13.48	14.95	14.84	14.91	14.88
21	463.3	25.06	25.04	25.14	25.09	24.07	1017.2	6.27	0.238E+07	0.02390	12.82	12.96	11.82	12.33	12.35	12.34
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.68	24.81	24.76	24.75	23.89	1012.9	6.30	0.234E+07	0.02019	15.94	13.68	14.45	14.58	14.63	14.61

HORIZONTAL ORIENTATION _____ 2 - 1000

INPUT ELECTRIC POWER = 301.4 W HEAT RATE GAINED BY WATER = 293.4 W HEAT BALANCE ERROR = 2.67%
MASS FLOW RATE = 29.0453 G/S PRESSURE DROP= 0.5750MMH20 FRICTION FACTOR = 0.019479 FREM = 19.5155
REM = 1001.9 GRM = 0.47340E+07 UPSTREAM BULK TEMPERATURE = 23.17DEG C DOWNSTREAM BULK TEMPERATURE = 25.59DEG C
PRM = 6.221 RAM = 0.29448E+08 INLET BULK TEMPERATURE = 23.17DEG C OUTLET BULK TEMPERATURE = 25.59DEG C

STATION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.34	24.31	24.32	24.32	23.20	975.5	6.41	0.430E+07	0.00029	21.46	22.03	21.74	21.74	21.74	21.74
4	15.5	24.86	24.92	24.84	24.86	23.25	976.6	6.40	0.432E+07	0.00082	15.15	14.62	15.42	15.14	15.15	15.15
5	25.5	25.06	25.17	25.06	25.08	23.30	977.7	6.39	0.433E+07	0.00134	13.94	13.12	13.92	13.72	13.72	13.72
6	45.5	25.11	25.24	25.13	25.15	23.40	980.0	6.37	0.437E+07	0.00240	14.31	13.33	14.14	13.97	13.98	13.97
7	75.5	25.20	25.38	25.21	25.25	23.56	983.4	6.35	0.443E+07	0.00398	14.85	13.44	14.82	14.46	14.48	14.47
8	105.5	25.29	25.57	25.33	25.38	23.71	986.8	6.33	0.448E+07	0.00556	15.53	13.18	15.09	14.66	14.72	14.69
9	135.5	25.43	25.71	25.56	25.56	23.87	990.3	6.30	0.454E+07	0.00714	15.65	13.28	14.43	14.40	14.45	14.42
10	165.2	25.53	25.80	25.64	25.65	24.02	993.8	6.28	0.460E+07	0.00871	16.20	13.69	15.05	14.95	15.00	14.97
11	205.2	25.66	25.92	25.84	25.82	24.23	998.4	6.24	0.468E+07	0.01083	17.02	14.39	15.10	15.34	15.40	15.37
12	245.2	25.95	26.19	26.04	26.06	24.43	1003.2	6.21	0.476E+07	0.01294	16.08	13.88	15.19	15.04	15.08	15.06
13	275.2	26.00	26.25	26.18	26.16	24.59	1006.8	6.19	0.482E+07	0.01453	17.26	14.65	15.29	15.56	15.62	15.59
14	305.2	26.13	26.45	26.29	26.29	24.74	1010.4	6.16	0.488E+07	0.01612	17.51	14.24	15.74	15.72	15.81	15.77
15	333.3	26.26	26.48	26.40	26.39	24.89	1013.8	6.14	0.494E+07	0.01761	17.75	15.27	16.11	16.26	16.31	16.29
16	363.3	26.39	26.65	26.47	26.50	25.04	1017.4	6.12	0.500E+07	0.01921	18.06	15.18	17.06	16.77	16.84	16.80
17	383.3	26.47	26.71	26.59	26.59	25.15	1019.9	6.10	0.504E+07	0.02027	18.43	15.59	16.91	16.90	16.96	16.93
18	403.3	26.59	26.81	26.67	26.68	25.25	1022.3	6.08	0.508E+07	0.02133	18.15	15.55	17.16	16.95	17.01	16.98
19	423.3	26.70	26.95	26.83	26.83	25.35	1024.8	6.07	0.513E+07	0.02240	18.01	15.20	16.47	16.48	16.54	16.51
20	443.3	26.74	27.01	26.86	26.87	25.45	1027.3	6.05	0.517E+07	0.02346	18.97	15.63	17.33	17.23	17.32	17.28
21	463.3	27.08	27.15	27.16	27.13	25.56	1029.8	6.03	0.521E+07	0.02453	16.02	15.29	15.22	15.43	15.44	15.44
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	26.53	26.77	26.64	26.64	25.19	1020.9	6.09	0.506E+07	0.02071	18.23	15.40	16.84	16.77	16.83	16.80

HORIZONTAL ORIENTATION _____ 3 - 1000

INPUT ELECTRIC POWER = 662.8 W   HEAT RATE GAINED BY WATER = 645.7 W   HEAT BALANCE ERROR = 2.59%
MASS FLOW RATE = 28.3221 G/S   PRESSURE DROP= 0.5874MMH2O   FRICTION FACTOR = 0.020923   FREM = 20.9632
REM = 1001.9   GRM = 0.11381E+08   UPSTREAM BULK TEMPERATURE = 22.73DEG C   DOWNSTREAM BULK TEMPERATURE = 28.19DEG C
PRM = 6.049   RAM = 0.68846E+08   INLET BULK TEMPERATURE = 22.74DEG C   OUTLET BULK TEMPERATURE = 28.19DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.37	25.34	25.35	25.35	22.80	942.8	6.47	0.915E+07	0.00030	21.01	21.20	21.10	21.10	21.10	21.10
4	15.5	25.91	26.21	25.97	26.01	22.92	945.2	6.45	0.924E+07	0.00084	17.98	16.37	17.66	17.39	17.42	17.40
5	25.5	26.18	26.54	26.33	26.35	23.03	947.7	6.43	0.933E+07	0.00138	17.09	15.35	16.33	16.25	16.27	16.26
6	45.5	26.29	26.64	26.39	26.43	23.26	952.6	6.40	0.951E+07	0.00246	17.79	15.96	17.21	17.02	17.04	17.03
7	75.5	26.48	26.96	26.63	26.68	23.61	960.1	6.34	0.979E+07	0.00408	18.76	16.07	17.82	17.56	17.62	17.59
8	105.5	26.68	27.30	26.84	26.92	23.96	967.7	6.29	0.101E+08	0.00570	19.77	16.10	18.68	18.20	18.31	18.26
9	135.5	27.05	27.60	27.32	27.32	24.31	975.5	6.23	0.104E+08	0.00733	19.64	16.32	17.87	17.84	17.92	17.88
10	165.2	27.25	27.92	27.61	27.60	24.66	983.3	6.18	0.107E+08	0.00895	20.68	16.43	18.21	18.26	18.38	18.32
11	206.2	27.56	28.27	27.91	27.91	25.12	994.0	6.10	0.111E+08	0.01113	22.01	17.06	19.21	19.22	19.37	19.29
12	245.2	28.17	28.73	28.45	28.45	25.59	1004.9	6.03	0.115E+08	0.01331	20.71	17.04	18.74	18.72	18.81	18.76
13	275.2	28.40	28.99	28.82	28.75	25.94	1013.2	5.97	0.118E+08	0.01496	21.75	17.54	18.59	19.00	19.12	19.06
14	305.2	28.65	29.26	28.95	28.95	26.29	1021.7	5.92	0.122E+08	0.01660	22.62	18.01	20.05	20.05	20.18	20.12
15	333.3	29.02	29.63	29.43	29.38	26.61	1029.8	5.87	0.125E+08	0.01815	22.23	17.71	18.94	19.32	19.45	19.39
16	363.3	29.35	29.96	29.67	29.66	26.96	1038.1	5.82	0.128E+08	0.01980	22.39	17.78	19.71	19.77	19.90	19.83
17	383.3	29.60	30.14	29.88	29.87	27.20	1043.0	5.79	0.130E+08	0.02089	22.21	18.10	19.88	19.91	20.02	19.97
18	403.3	29.79	30.38	30.06	30.07	27.43	1047.9	5.76	0.133E+08	0.02199	22.54	18.04	20.28	20.16	20.29	20.22
19	423.3	30.05	30.70	30.45	30.42	27.66	1052.9	5.73	0.135E+08	0.02309	22.26	17.52	19.08	19.34	19.49	19.41
20	443.3	30.23	30.87	30.57	30.56	27.89	1057.9	5.70	0.137E+08	0.02419	22.83	17.88	19.90	19.98	20.13	20.05
21	463.3	30.56	31.22	30.91	30.90	28.13	1063.0	5.67	0.139E+08	0.02529	21.90	17.23	19.10	19.19	19.33	19.26
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	29.67	30.28	30.01	29.99	27.29	1044.9	5.78	0.131E+08	0.02135	22.41	17.84	19.63	19.75	19.88	19.81

HORIZONTAL ORIENTATION _____ 4 - 1000

INPUT ELECTRIC POWER = 889.5 W   HEAT RATE GAINED BY WATER = 875.8 W   HEAT BALANCE ERROR = 1.54%
MASS FLOW RATE = 27.8882 G/S   PRESSURE DROP= 0.5719MMH2O   FRICTION FACTOR = 0.021006   FREM = 21.1359
REM = 1006.2   GRM = 0.16514E+08   UPSTREAM BULK TEMPERATURE = 22.53DEG C   DOWNSTREAM BULK TEMPERATURE = 30.06DEG C
PRM = 5.918   RAM = 0.97730E+08   INLET BULK TEMPERATURE = 22.54DEG C   OUTLET BULK TEMPERATURE = 30.05DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.03	26.07	26.05	26.05	22.62	924.8	6.50	0.122E+08	0.00030	21.46	21.24	21.35	21.35	21.35	21.35
4	15.5	26.69	27.13	26.80	26.85	22.78	928.0	6.47	0.124E+08	0.00085	18.74	16.82	18.22	17.97	18.00	17.99
5	25.5	27.06	27.59	27.33	27.33	22.94	931.4	6.45	0.126E+08	0.00140	17.74	15.74	16.67	16.68	16.71	16.69
6	45.5	27.16	27.67	27.34	27.38	23.27	938.0	6.40	0.129E+08	0.00249	18.75	16.56	17.90	17.74	17.78	17.76
7	75.5	27.48	28.10	27.64	27.71	23.75	948.2	6.32	0.134E+08	0.00414	19.53	16.75	18.74	18.38	18.44	18.41
8	105.5	27.69	28.59	27.96	28.05	24.23	958.7	6.24	0.140E+08	0.00580	21.06	16.71	19.54	19.07	19.21	19.14
9	135.5	28.22	29.00	28.66	28.63	24.71	969.3	6.17	0.145E+08	0.00745	20.73	16.97	18.43	18.54	18.64	18.59
10	165.2	28.48	29.37	29.01	28.97	25.18	980.1	6.09	0.151E+08	0.00910	22.08	17.35	19.02	19.22	19.37	19.30
11	205.2	28.90	29.83	29.34	29.35	25.82	995.0	5.99	0.159E+08	0.01132	23.62	18.14	20.66	20.59	20.77	20.68
12	245.2	29.54	30.40	30.01	29.99	26.47	1010.4	5.89	0.167E+08	0.01355	23.61	18.40	20.44	20.56	20.72	20.64
13	275.2	29.96	30.77	30.55	30.46	26.95	1021.8	5.82	0.174E+08	0.01523	24.04	18.92	20.08	20.62	20.78	20.70
14	305.2	30.33	31.19	30.75	30.75	27.43	1031.8	5.76	0.180E+08	0.01690	24.95	19.23	21.79	21.76	21.94	21.85
15	333.3	30.88	31.69	31.44	31.36	27.88	1041.4	5.70	0.186E+08	0.01847	24.05	18.95	20.29	20.73	20.89	20.81
16	363.3	31.33	32.19	31.78	31.77	28.36	1051.8	5.64	0.192E+08	0.02015	24.32	18.82	21.12	21.17	21.35	21.26
17	383.3	31.64	32.40	32.00	32.01	28.68	1058.8	5.60	0.196E+08	0.02127	24.38	19.41	21.72	21.66	21.80	21.73
18	403.3	31.93	32.77	32.30	32.33	29.00	1065.9	5.56	0.201E+08	0.02239	24.60	19.10	21.85	21.67	21.85	21.76
19	423.3	32.35	33.19	32.84	32.81	29.32	1073.2	5.52	0.205E+08	0.02351	23.81	18.60	20.45	20.66	20.83	20.75
20	443.3	32.51	33.44	33.02	32.99	29.64	1080.5	5.48	0.210E+08	0.02463	25.11	18.95	21.32	21.46	21.68	21.57
21	463.3	33.17	33.81	33.61	33.55	29.96	1087.9	5.44	0.214E+08	0.02576	22.42	18.68	19.74	20.05	20.14	20.10
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	31.77	32.61	32.23	32.21	28.81	1061.9	5.58	0.198E+08	0.02174	24.38	18.97	21.12	21.23	21.40	21.31

HORIZONTAL ORIENTATION _____ 5 - 1000

INPUT ELECTRIC POWER = 1176.2 W HEAT RATE GAINED BY WATER = 1156.8 W HEAT BALANCE ERROR = 1.65%
MASS FLOW RATE = 26.8034 G/S PRESSURE DROP= 0.5653MMH20 FRICTION FACTOR = 0.022465 FREM = 22.5267
REM = 1002.7 GRM = 0.24664E+08 UPSTREAM BULK TEMPERATURE = 22.79DEG C DOWNSTREAM BULK TEMPERATURE = 33.14DEG C
PRM = 5.689 RAM = 0.14031E+09 INLET BULK TEMPERATURE = 22.80DEG C OUTLET BULK TEMPERATURE = 33.13DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	27.14	27.46	27.30	27.30	22.93	894.8	6.45	0.166E+08	0.00031	22.90	21.27	22.05	22.05	22.07	22.06
4	15.5	28.06	28.75	28.20	28.31	23.15	899.2	6.42	0.169E+08	0.00088	19.62	17.22	19.08	18.70	18.75	18.73
5	25.5	28.52	29.24	28.91	28.89	23.37	903.6	6.38	0.172E+08	0.00145	18.71	16.43	17.41	17.45	17.49	17.47
6	45.5	28.67	29.38	28.91	28.97	23.81	912.6	6.31	0.178E+08	0.00260	19.79	17.29	18.88	18.66	18.71	18.69
7	75.5	28.98	29.88	29.29	29.36	24.47	926.5	6.21	0.188E+08	0.00432	21.31	17.78	19.97	19.67	19.76	19.71
8	105.5	29.33	30.55	29.63	29.79	25.13	940.8	6.10	0.198E+08	0.00605	22.85	17.73	21.33	20.63	20.81	20.72
9	135.5	30.06	31.09	30.53	30.55	25.79	955.5	6.00	0.209E+08	0.00778	22.46	18.10	20.25	20.15	20.26	20.20
10	165.2	30.45	31.66	31.08	31.07	26.44	970.6	5.89	0.221E+08	0.00950	23.91	18.36	20.65	20.71	20.89	20.80
11	205.2	31.02	32.23	31.60	31.61	27.33	989.6	5.77	0.236E+08	0.01182	25.87	19.50	22.34	22.29	22.51	22.40
12	245.2	32.01	33.06	32.53	32.53	28.21	1007.7	5.66	0.251E+08	0.01414	25.08	19.67	22.06	22.05	22.22	22.13
13	275.2	32.49	33.59	33.30	33.17	28.87	1021.6	5.58	0.262E+08	0.01589	26.26	20.16	21.50	22.14	22.36	22.25
14	305.2	33.04	34.10	33.55	33.56	29.53	1036.0	5.49	0.275E+08	0.01764	27.10	20.79	23.66	23.59	23.80	23.70
15	333.3	33.81	34.92	34.56	34.46	30.15	1049.8	5.41	0.287E+08	0.01929	25.96	19.90	21.53	22.02	22.23	22.12
16	363.3	34.42	35.60	35.00	35.01	30.81	1065.0	5.33	0.300E+08	0.02105	26.25	19.81	22.60	22.59	22.81	22.70
17	383.3	34.85	35.89	35.32	35.36	31.25	1075.3	5.28	0.309E+08	0.02223	26.29	20.42	23.26	23.12	23.31	23.21
18	403.3	35.27	36.34	35.74	35.78	31.69	1085.9	5.22	0.319E+08	0.02340	26.40	20.34	23.34	23.15	23.35	23.25
19	423.3	35.81	36.88	36.44	36.39	32.13	1095.7	5.17	0.328E+08	0.02459	25.70	19.88	21.94	22.18	22.36	22.27
20	443.3	36.05	37.21	36.64	36.64	32.57	1105.1	5.12	0.337E+08	0.02579	27.12	20.33	23.19	23.21	23.46	23.34
21	463.3	36.90	37.91	37.25	37.33	33.01	1114.7	5.07	0.346E+08	0.02699	24.24	19.27	22.25	21.85	22.00	21.93
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	35.04	36.14	35.62	35.60	31.43	1079.5	5.25	0.313E+08	0.02272	26.28	20.11	22.64	22.71	22.92	22.82

HORIZONTAL ORIENTATION _____ 6 - 1000

INPUT ELECTRIC POWER = 1776.4 W HEAT RATE GAINED BY WATER = 1738.8 W HEAT BALANCE ERROR = 2.11%
MASS FLOW RATE = 25.0000 G/S PRESSURE DROP= 0.5374MMH20 FRICTION FACTOR = 0.024517 FREM = 24.5016
REM = 999.4 GRM = 0.45992E+08 UPSTREAM BULK TEMPERATURE = 22.74DEG C DOWNSTREAM BULK TEMPERATURE = 39.42DEG C
PRM = 5.296 RAM = 0.24359E+09 INLET BULK TEMPERATURE = 22.76DEG C OUTLET BULK TEMPERATURE = 39.41DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	29.56	30.15	29.85	29.85	22.96	835.1	6.44	0.250E+08	0.00034	21.98	20.18	21.05	21.05	21.06	21.06
4	15.5	30.05	31.24	30.33	30.49	23.31	841.8	6.39	0.257E+08	0.00095	21.51	18.30	20.67	20.21	20.29	20.25
5	25.5	30.75	31.93	31.37	31.36	23.67	848.5	6.33	0.265E+08	0.00156	20.45	17.52	18.81	18.84	18.90	18.87
6	45.5	30.89	32.09	31.37	31.43	24.38	862.4	6.22	0.281E+08	0.00279	22.21	18.74	20.68	20.50	20.58	20.54
7	75.5	31.40	32.88	31.97	32.06	25.44	884.0	6.05	0.306E+08	0.00464	24.23	19.40	22.12	21.83	21.97	21.90
8	105.5	32.01	33.93	32.54	32.75	26.51	906.7	5.88	0.334E+08	0.00651	26.15	19.39	23.88	23.05	23.33	23.19
9	135.5	33.13	34.71	33.82	33.87	27.57	927.7	5.74	0.361E+08	0.00837	25.84	20.11	22.99	22.80	22.98	22.89
10	165.2	33.90	35.76	34.89	34.86	28.63	948.1	5.61	0.388E+08	0.01022	27.18	20.09	22.86	22.98	23.25	23.11
11	205.2	34.87	36.63	35.74	35.75	30.06	977.1	5.43	0.428E+08	0.01273	29.60	21.69	25.07	25.05	25.36	25.21
12	245.2	36.35	37.99	37.23	37.20	31.47	1007.9	5.25	0.472E+08	0.01525	29.18	21.81	24.70	24.83	25.10	24.96
13	275.2	37.23	38.92	38.39	38.24	32.53	1030.0	5.12	0.506E+08	0.01716	30.22	22.22	24.22	24.90	25.22	25.06
14	305.2	38.07	39.73	38.90	38.90	33.60	1051.9	5.00	0.540E+08	0.01910	31.68	23.07	26.71	26.71	27.04	26.87
15	333.3	39.32	41.02	40.52	40.34	34.60	1073.2	4.88	0.574E+08	0.02093	29.90	21.99	23.86	24.58	24.90	24.74
16	363.3	40.30	42.12	41.24	41.22	35.66	1097.0	4.76	0.612E+08	0.02290	30.34	21.81	25.26	25.32	25.67	25.50
17	383.3	40.95	42.64	41.77	41.78	36.37	1113.4	4.68	0.640E+08	0.02422	30.73	22.41	26.05	25.98	26.31	26.14
18	403.3	41.65	43.43	42.47	42.50	37.08	1129.5	4.60	0.668E+08	0.02554	30.69	22.12	26.05	25.88	26.23	26.06
19	423.3	42.51	44.30	43.58	43.49	37.79	1144.6	4.53	0.694E+08	0.02684	29.70	21.54	24.23	24.59	24.92	24.76
20	443.3	42.98	44.82	43.95	43.93	38.50	1160.0	4.47	0.723E+08	0.02814	31.29	22.14	25.68	25.80	26.20	26.00
21	463.3	43.81	45.84	45.06	44.93	39.21	1175.9	4.40	0.752E+08	0.02944	30.41	21.10	23.96	24.43	24.86	24.64
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	41.29	43.05	42.25	42.21	36.67	1119.6	4.65	0.652E+08	0.02476	30.44	22.00	25.19	25.36	25.71	25.53

HORIZONTAL ORIENTATION _____ 7 - 1000

INPUT ELECTRIC POWER = 2666.6 W   HEAT RATE GAINED BY WATER = 2689.6 W   HEAT BALANCE ERROR =-0.86%
MASS FLOW RATE = 22.1025 G/S   PRESSURE DROP= 0.5230MMH20   FRICTION FACTOR = 0.030453   FREM = 30.6371
REM = 1006.0   GRM = 0.10658E+09   UPSTREAM BULK TEMPERATURE = 22.89DEG C   DOWNSTREAM BULK TEMPERATURE = 52.06DEG C
PRM = 4.562   RAM = 0.48163E+09   INLET BULK TEMPERATURE = 22.92DEG C   OUTLET BULK TEMPERATURE = 52.04DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	32.72	34.08	33.40	33.40	23.26	743.4	6.40	0.396E+08	0.00038	23.70	20.72	22.11	22.11	22.16	22.14
4	15.5	33.23	35.31	33.83	34.06	23.88	753.8	6.30	0.417E+08	0.00107	23.97	19.59	22.51	22.02	22.14	22.08
5	25.5	34.30	36.25	35.44	35.36	24.50	764.6	6.20	0.438E+08	0.00177	22.83	19.03	20.45	20.60	20.69	20.65
6	45.5	34.48	36.54	35.43	35.47	25.75	787.1	6.00	0.485E+08	0.00317	25.54	20.65	23.03	22.93	23.06	23.00
7	75.5	35.40	37.72	36.29	36.43	27.61	820.8	5.73	0.559E+08	0.00528	28.52	21.97	25.57	25.19	25.41	25.30
8	105.5	36.45	39.47	37.48	37.72	29.47	853.3	5.50	0.636E+08	0.00740	31.70	22.13	27.63	26.82	27.27	27.05
9	135.5	38.35	40.87	39.54	39.57	31.34	888.5	5.26	0.724E+08	0.00953	31.41	23.09	26.86	26.73	27.05	26.89
10	165.2	39.38	42.42	40.86	40.88	33.18	922.3	5.06	0.814E+08	0.01168	35.39	23.72	28.53	28.47	29.04	28.76
11	206.2	41.46	44.30	42.68	42.78	35.67	969.9	4.76	0.948E+08	0.01463	37.60	25.23	31.07	30.63	31.24	30.93
12	245.2	44.10	46.70	45.48	45.44	38.15	1018.8	4.50	0.110E+09	0.01759	36.41	25.34	29.55	29.71	30.21	29.96
13	275.2	45.68	48.44	47.69	47.37	40.02	1055.9	4.33	0.122E+09	0.01981	38.14	25.62	28.12	29.33	30.00	29.66
14	305.2	47.26	49.88	48.54	48.55	41.88	1095.8	4.16	0.135E+09	0.02204	39.96	26.90	32.31	32.23	32.87	32.55
15	333.3	49.62	52.49	51.62	51.34	43.63	1129.5	4.02	0.148E+09	0.02414	35.76	24.19	26.80	27.79	28.39	28.09
16	363.3	51.43	54.38	53.03	52.97	45.49	1168.0	3.88	0.162E+09	0.02640	35.98	24.01	28.34	28.57	29.17	28.87
17	383.3	52.69	55.43	53.94	54.00	46.73	1195.1	3.78	0.173E+09	0.02792	35.79	24.51	29.57	29.33	29.86	29.60
18	403.3	54.25	57.03	55.52	55.58	47.98	1221.0	3.69	0.183E+09	0.02943	33.91	23.49	28.17	27.96	28.44	28.20
19	423.3	55.58	58.57	57.40	57.24	49.22	1247.9	3.60	0.195E+09	0.03096	33.34	22.71	25.94	26.47	26.98	26.72
20	443.3	56.46	59.54	58.09	58.05	50.46	1275.9	3.52	0.207E+09	0.03249	35.34	23.34	27.75	27.93	28.54	28.24
21	463.3	58.32	61.61	59.96	59.96	51.70	1305.3	3.43	0.220E+09	0.03404	31.94	21.34	25.60	25.59	26.12	25.86
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	53.34	56.24	54.93	54.86	47.25	1206.2	3.75	0.178E+09	0.02856	35.02	23.71	27.76	28.01	28.56	28.29

HORIZONTAL ORIENTATION _____ 1 - 1500

INPUT ELECTRIC POWER = 165.2 W   HEAT RATE GAINED BY WATER = 168.7 W   HEAT BALANCE ERROR =-2.12%
MASS FLOW RATE = 45.2450 G/S   PRESSURE DROP= 0.8790MMH20   FRICTION FACTOR = 0.012276   FREM = 18.4289
REM = 1501.3   GRM = 0.23618E+07   UPSTREAM BULK TEMPERATURE = 22.21DEG C   DOWNSTREAM BULK TEMPERATURE = 23.10DEG C
PRM = 6.493   RAM = 0.15336E+08   INLET BULK TEMPERATURE = 22.21DEG C   OUTLET BULK TEMPERATURE = 23.10DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	22.81	22.80	22.81	22.81	22.22	1487.0	6.56	0.228E+07	0.00019	23.74	24.19	23.96	23.96	23.96	23.96
4	15.5	23.15	23.14	23.15	23.15	22.24	1487.6	6.56	0.228E+07	0.00052	15.38	15.68	15.38	15.45	15.45	15.45
5	25.5	23.32	23.35	23.29	23.31	22.25	1488.2	6.56	0.229E+07	0.00086	13.21	12.88	13.66	13.35	13.36	13.35
6	45.5	23.52	23.53	23.51	23.52	22.29	1489.4	6.55	0.229E+07	0.00153	11.53	11.38	11.57	11.51	11.51	11.51
7	75.5	23.54	23.60	23.50	23.54	22.35	1491.3	6.54	0.230E+07	0.00255	11.86	11.29	12.21	11.88	11.89	11.88
8	105.5	23.56	23.64	23.52	23.56	22.41	1493.2	6.53	0.231E+07	0.00356	12.26	11.45	12.69	12.25	12.27	12.26
9	135.5	23.53	23.64	23.55	23.57	22.46	1495.0	6.52	0.233E+07	0.00457	13.21	11.94	12.94	12.74	12.76	12.75
10	165.2	23.44	23.60	23.54	23.53	22.52	1496.9	6.51	0.234E+07	0.00557	15.28	13.04	13.81	13.94	13.98	13.96
11	205.2	23.51	23.72	23.69	23.65	22.60	1499.4	6.50	0.235E+07	0.00692	15.39	12.53	12.88	13.33	13.42	13.38
12	245.2	23.78	23.82	23.77	23.79	22.67	1501.9	6.49	0.237E+07	0.00827	12.69	12.29	12.79	12.64	12.64	12.64
13	275.2	23.74	23.83	23.77	23.78	22.73	1503.8	6.48	0.238E+07	0.00929	13.89	12.86	13.48	13.42	13.43	13.42
14	305.2	23.76	23.88	23.83	23.82	22.79	1505.7	6.47	0.239E+07	0.01030	14.48	12.92	13.55	13.60	13.62	13.61
15	333.3	23.76	23.87	23.84	23.82	22.84	1507.5	6.46	0.240E+07	0.01125	15.39	13.72	14.10	14.30	14.33	14.32
16	363.3	23.88	24.00	23.94	23.94	22.90	1509.4	6.45	0.241E+07	0.01227	14.29	12.78	13.45	13.47	13.49	13.48
17	383.3	23.89	23.98	23.93	23.94	22.94	1510.7	6.45	0.242E+07	0.01294	14.67	13.52	14.09	14.08	14.10	14.09
18	403.3	23.86	23.98	23.92	23.92	22.97	1512.0	6.44	0.243E+07	0.01362	15.82	14.04	14.84	14.86	14.89	14.87
19	423.3	23.91	24.02	23.96	23.96	23.01	1513.3	6.44	0.243E+07	0.01430	15.66	14.01	14.79	14.79	14.81	14.80
20	443.3	23.90	24.02	23.96	23.96	23.05	1514.5	6.43	0.244E+07	0.01497	16.65	14.44	15.40	15.43	15.47	15.45
21	463.3	24.07	24.01	24.18	24.11	23.09	1515.8	6.42	0.245E+07	0.01565	14.29	15.32	12.83	13.74	13.82	13.78
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	23.87	23.98	23.93	23.92	22.95	1511.2	6.45	0.242E+07	0.01322	15.41	13.75	14.45	14.49	14.52	14.50

HORIZONTAL ORIENTATION _____ 2 - 1500

INPUT ELECTRIC POWER = 310.7 W   HEAT RATE GAINED BY WATER = 305.6 W   HEAT BALANCE ERROR = 1.64%
MASS FLOW RATE = 44.5220 G/S   PRESSURE DROP= 0.9071MMH20   FRICTION FACTOR = 0.013080   FREM = 19.6802
REM = 1504.6   GRM = 0.45793E+07   UPSTREAM BULK TEMPERATURE = 22.65DEG C   DOWNSTREAM BULK TEMPERATURE = 24.30DEG C
PRM = 6.363   RAM = 0.29139E+08   INLET BULK TEMPERATURE = 22.65DEG C   OUTLET BULK TEMPERATURE = 24.30DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	B	T+B
3	5.5	23.81	23.78	23.79	23.79	22.67	1478.0	6.49	0.429E+07	0.00019	22.45	23.12	22.78	22.78	22.78	22.78
4	15.5	24.15	24.20	24.17	24.17	22.71	1479.1	6.48	0.430E+07	0.00053	17.75	17.15	17.42	17.43	17.43	17.43
5	25.5	24.31	24.45	24.37	24.37	22.74	1480.3	6.48	0.431E+07	0.00087	16.27	14.95	15.73	15.65	15.67	15.66
6	45.5	24.41	24.48	24.43	24.44	22.81	1482.6	6.47	0.434E+07	0.00156	15.96	15.28	15.74	15.68	15.68	15.68
7	75.5	24.48	24.63	24.51	24.53	22.92	1486.0	6.45	0.437E+07	0.00259	16.31	14.93	16.03	15.81	15.83	15.82
8	105.5	24.53	24.76	24.55	24.60	23.02	1489.5	6.43	0.441E+07	0.00362	16.90	14.71	16.70	16.20	16.25	16.23
9	135.5	24.65	24.87	24.75	24.76	23.13	1493.0	6.42	0.445E+07	0.00465	16.79	14.63	15.71	15.67	15.71	15.69
10	165.2	24.58	24.80	24.75	24.72	23.23	1496.5	6.40	0.449E+07	0.00567	18.88	16.26	16.84	17.15	17.21	17.18
11	205.2	24.77	25.09	24.98	24.95	23.37	1501.2	6.38	0.454E+07	0.00706	18.27	14.87	15.88	16.13	16.23	16.18
12	245.2	25.03	25.24	25.14	25.14	23.51	1505.9	6.36	0.459E+07	0.00843	16.76	14.73	15.61	15.65	15.68	15.66
13	275.2	25.06	25.33	25.20	25.20	23.62	1509.5	6.34	0.463E+07	0.00946	17.74	14.86	16.07	16.12	16.19	16.15
14	306.2	25.16	25.39	25.28	25.28	23.72	1513.0	6.32	0.467E+07	0.01049	17.76	15.28	16.32	16.37	16.42	16.40
15	333.3	25.23	25.48	25.37	25.36	23.82	1516.4	6.31	0.471E+07	0.01146	18.06	15.34	16.44	16.51	16.57	16.54
16	363.3	25.28	25.56	25.40	25.41	23.93	1520.0	6.29	0.475E+07	0.01250	18.85	15.58	17.23	17.15	17.22	17.18
17	383.3	25.35	25.58	25.44	25.45	24.00	1522.5	6.28	0.478E+07	0.01319	18.83	16.06	17.61	17.47	17.53	17.50
18	403.3	25.35	25.63	25.49	25.49	24.07	1524.9	6.27	0.481E+07	0.01388	19.78	16.23	17.87	17.85	17.94	17.89
19	423.3	25.47	25.75	25.59	25.60	24.14	1527.3	6.26	0.483E+07	0.01457	19.02	15.77	17.47	17.35	17.43	17.39
20	443.3	25.47	25.77	25.68	25.65	24.21	1529.8	6.25	0.486E+07	0.01526	20.12	16.25	17.29	17.63	17.74	17.68
21	463.3	25.70	25.82	25.92	25.84	24.28	1532.2	6.24	0.489E+07	0.01595	17.86	16.45	15.45	16.25	16.30	16.27
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.36	25.63	25.50	25.50	24.03	1523.5	6.28	0.479E+07	0.01347	19.11	15.87	17.32	17.33	17.40	17.37

HORIZONTAL ORIENTATION _____ 3 - 1500

INPUT ELECTRIC POWER = 695.2 W   HEAT RATE GAINED BY WATER = 704.2 W   HEAT BALANCE ERROR =-1.30%
MASS FLOW RATE = 43.0754 G/S   PRESSURE DROP= 0.8912MMH20   FRICTION FACTOR = 0.013725   FREM = 20.6178
REM = 1502.3   GRM = 0.11811E+08   UPSTREAM BULK TEMPERATURE = 22.89DEG C   DOWNSTREAM BULK TEMPERATURE = 26.81DEG C
PRM = 6.145   RAM = 0.72587E+08   INLET BULK TEMPERATURE = 22.90DEG C   OUTLET BULK TEMPERATURE = 26.81DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	B	T+B
3	5.5	25.34	25.34	25.34	25.34	22.94	1438.5	6.45	0.101E+08	0.00020	24.55	24.51	24.53	24.53	24.53	24.53
4	15.5	26.35	26.60	26.35	26.42	23.03	1441.2	6.43	0.102E+08	0.00055	17.66	16.45	17.66	17.34	17.36	17.35
5	25.5	26.71	27.04	26.89	26.88	23.11	1443.9	6.42	0.102E+08	0.00090	16.34	14.96	15.56	15.59	15.61	15.60
6	45.5	26.80	27.09	26.84	26.89	23.28	1449.3	6.39	0.104E+08	0.00162	16.69	15.42	16.48	16.25	16.27	16.26
7	75.5	26.93	27.32	26.97	27.05	23.53	1457.4	6.35	0.106E+08	0.00268	17.27	15.46	17.06	16.68	16.71	16.70
8	105.5	27.02	27.64	27.12	27.22	23.78	1465.7	6.32	0.108E+08	0.00375	18.11	15.20	17.55	17.02	17.10	17.06
9	135.5	27.35	27.83	27.51	27.55	24.03	1474.0	6.28	0.110E+08	0.00482	17.62	15.43	16.82	16.63	16.67	16.65
10	165.2	27.06	27.70	27.38	27.38	24.28	1482.4	6.24	0.113E+08	0.00588	21.06	17.11	18.87	18.87	18.98	18.92
11	205.2	27.34	27.99	27.55	27.61	24.61	1493.8	6.18	0.116E+08	0.00731	21.47	17.33	19.91	19.54	19.66	19.60
12	245.2	27.81	28.40	28.08	28.09	24.94	1505.4	6.13	0.119E+08	0.00874	20.38	16.94	18.64	18.57	18.65	18.61
13	275.2	27.98	28.57	28.40	28.34	25.19	1514.2	6.09	0.121E+08	0.00981	20.98	17.32	18.26	18.61	18.70	18.66
14	305.2	28.12	28.75	28.37	28.40	25.44	1523.1	6.05	0.124E+08	0.01089	21.84	17.66	20.00	19.76	19.88	19.82
15	333.3	28.40	28.99	28.82	28.76	25.68	1531.6	6.02	0.126E+08	0.01190	21.42	17.64	18.57	18.95	19.05	19.00
16	363.3	28.54	29.24	28.91	28.90	25.93	1540.7	5.98	0.129E+08	0.01298	22.36	17.63	19.56	19.64	19.78	19.71
17	383.3	28.81	29.41	29.13	29.12	26.10	1546.8	5.95	0.131E+08	0.01370	21.46	17.60	19.25	19.29	19.39	19.34
18	403.3	28.98	29.63	29.30	29.30	26.26	1553.0	5.92	0.132E+08	0.01442	21.47	17.34	19.19	19.19	19.30	19.24
19	423.3	29.27	29.92	29.58	29.59	26.43	1559.3	5.90	0.134E+08	0.01514	20.50	16.71	18.48	18.45	18.54	18.49
20	443.3	29.35	30.00	29.67	29.67	26.60	1565.6	5.87	0.136E+08	0.01587	21.12	17.12	18.95	18.93	19.04	18.99
21	463.3	29.63	30.24	29.93	29.93	26.76	1571.9	5.84	0.138E+08	0.01659	20.31	16.78	18.38	18.38	18.46	18.42
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.89	29.53	29.24	29.22	26.17	1549.5	5.94	0.131E+08	0.01400	21.39	17.34	19.00	19.08	19.18	19.13

HORIZONTAL ORIENTATION _____ 4 - 1500

INPUT ELECTRIC POWER = 1343.4 W HEAT RATE GAINED BY WATER = 1362.6 W HEAT BALANCE ERROR =-1.43%
MASS FLOW RATE = 42.7860 G/S PRESSURE DROP= 0.9611MMH20 FRICTION FACTOR = 0.015001 FREM = 22.5434
REM = 1502.8 GRM = 0.23429E+08 UPSTREAM BULK TEMPERATURE = 21.34DEG C DOWNSTREAM BULK TEMPERATURE = 28.97DEG C
PRM = 6.097 RAM = 0.14285E+09 INLET BULK TEMPERATURE = 21.35DEG C OUTLET BULK TEMPERATURE = 28.97DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.20	26.38	26.29	26.29	21.44	1380.6	6.70	0.172E+08	0.00020	23.97	23.11	23.53	23.53	23.54	23.53
4	15.5	27.07	27.72	27.21	27.30	21.60	1386.2	6.67	0.174E+08	0.00065	20.85	18.65	20.33	20.01	20.04	20.02
5	25.5	27.53	28.25	27.94	27.91	21.76	1391.9	6.64	0.177E+08	0.00091	19.76	17.58	18.47	18.54	18.57	18.55
6	45.5	27.58	28.29	27.76	27.85	22.09	1402.2	6.58	0.182E+08	0.00162	20.74	18.37	20.07	19.77	19.81	19.79
7	75.5	27.87	28.71	28.11	28.20	22.58	1417.3	6.51	0.190E+08	0.00269	21.49	18.54	20.55	20.22	20.28	20.25
8	105.5	28.08	29.26	28.35	28.51	23.06	1432.6	6.43	0.197E+08	0.00377	22.67	18.34	21.51	20.88	21.01	20.94
9	135.5	28.75	29.72	29.10	29.17	23.55	1448.4	6.35	0.205E+08	0.00485	21.84	18.40	20.45	20.21	20.28	20.24
10	165.2	28.53	29.79	29.18	29.17	24.03	1464.3	6.28	0.214E+08	0.00591	25.21	19.70	22.06	22.09	22.26	22.17
11	205.2	28.98	30.22	29.45	29.53	24.68	1486.3	6.17	0.225E+08	0.00736	26.34	20.46	23.75	23.39	23.58	23.48
12	245.2	29.93	31.13	30.49	30.51	25.33	1509.0	6.07	0.238E+08	0.00881	24.62	19.51	21.94	21.85	22.00	21.93
13	275.2	30.24	31.47	31.08	30.97	25.82	1526.4	5.99	0.247E+08	0.00990	25.58	19.99	21.46	21.94	22.12	22.03
14	305.2	30.47	31.72	31.05	31.07	26.31	1544.3	5.92	0.257E+08	0.01099	27.13	20.84	23.77	23.67	23.88	23.78
15	333.3	31.19	32.50	32.08	31.96	26.77	1561.4	5.84	0.267E+08	0.01202	25.48	19.66	21.21	21.69	21.89	21.79
16	363.3	31.49	32.86	32.20	32.19	27.25	1577.4	5.78	0.276E+08	0.01311	26.55	20.06	22.77	22.81	23.04	22.93
17	383.3	31.86	33.04	32.42	32.44	27.58	1587.9	5.74	0.283E+08	0.01384	26.26	20.58	23.24	23.16	23.33	23.24
18	403.3	32.21	33.45	32.77	32.80	27.90	1598.5	5.70	0.289E+08	0.01457	26.09	20.27	23.07	22.95	23.13	23.04
19	423.3	32.60	33.89	33.36	33.30	28.23	1609.2	5.66	0.296E+08	0.01530	25.71	19.83	21.94	22.16	22.36	22.26
20	443.3	32.73	34.00	33.41	33.39	28.55	1620.1	5.62	0.302E+08	0.01603	26.86	20.60	23.11	23.21	23.42	23.32
21	463.3	33.17	34.33	33.83	33.79	28.88	1631.2	5.57	0.309E+08	0.01676	26.14	20.57	22.65	22.84	23.01	22.92
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	32.01	33.29	32.70	32.68	27.71	1592.4	5.72	0.286E+08	0.01414	26.16	20.17	22.56	22.66	22.86	22.76

HORIZONTAL ORIENTATION _____ 5 - 1500

INPUT ELECTRIC POWER = 3356.9 W HEAT RATE GAINED BY WATER = 3349.8 W HEAT BALANCE ERROR = 0.21%
MASS FLOW RATE = 34.6100 G/S PRESSURE DROP= 0.7259MMH20 FRICTION FACTOR = 0.017253 FREM = 25.7926
REM = 1494.9 GRM = 0.11256E+09 UPSTREAM BULK TEMPERATURE = 23.29DEG C DOWNSTREAM BULK TEMPERATURE = 46.49DEG C
PRM = 4.846 RAM = 0.54551E+09 INLET BULK TEMPERATURE = 23.32DEG C OUTLET BULK TEMPERATURE = 46.48DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	34.69	35.98	35.34	35.34	23.59	1172.6	6.35	0.507E+08	0.00024	25.13	22.52	23.75	23.75	23.79	23.77
4	15.5	35.07	37.18	35.52	35.82	24.08	1185.8	6.27	0.528E+08	0.00069	25.36	21.28	24.38	23.75	23.85	23.80
5	25.5	36.12	38.23	37.29	37.23	24.58	1199.3	6.19	0.549E+08	0.00113	24.13	20.39	21.90	22.00	22.08	22.04
6	45.5	36.13	38.33	36.91	37.07	25.57	1227.3	6.03	0.595E+08	0.00202	26.29	21.76	24.49	24.14	24.26	24.20
7	75.5	36.84	39.41	37.78	37.95	27.05	1270.7	5.81	0.670E+08	0.00337	28.28	22.40	25.81	25.40	25.58	25.49
8	105.5	37.65	40.95	38.48	38.89	28.53	1309.9	5.62	0.742E+08	0.00472	30.26	22.22	27.73	26.64	26.99	26.81
9	135.5	39.05	41.93	40.15	40.32	30.01	1351.6	5.43	0.823E+08	0.00607	30.45	23.07	27.13	26.69	26.95	26.82
10	165.2	39.88	43.31	41.42	41.51	31.48	1395.7	5.25	0.911E+08	0.00742	32.65	23.16	27.57	27.33	27.74	27.53
11	205.2	41.07	44.44	42.57	42.66	33.46	1452.1	5.01	0.103E+09	0.00927	35.84	24.84	29.95	29.64	30.14	29.89
12	245.2	43.21	46.42	44.90	44.86	35.43	1511.4	4.78	0.116E+09	0.01115	34.89	24.70	28.68	28.80	29.24	29.02
13	275.2	44.45	47.74	46.71	46.40	36.92	1558.9	4.61	0.127E+09	0.01259	35.89	24.98	27.60	28.50	29.02	28.76
14	305.2	45.45	48.70	47.02	47.06	38.40	1602.7	4.48	0.138E+09	0.01399	38.26	26.18	31.26	31.17	31.74	31.46
15	333.3	47.39	50.85	49.68	49.40	39.79	1646.1	4.35	0.150E+09	0.01531	35.36	24.32	27.19	27.98	28.52	28.25
16	363.3	48.58	52.10	50.39	50.36	41.27	1695.0	4.21	0.163E+09	0.01673	36.66	24.76	29.41	29.48	30.06	29.77
17	383.3	49.56	52.75	50.92	51.04	42.26	1727.0	4.13	0.172E+09	0.01769	36.67	25.50	30.88	30.48	30.99	30.73
18	403.3	50.82	53.97	51.97	52.18	43.25	1756.9	4.05	0.180E+09	0.01864	35.28	24.92	30.64	29.91	30.37	30.14
19	423.3	52.12	55.35	53.86	53.80	44.23	1787.9	3.97	0.189E+09	0.01960	33.82	23.99	27.70	27.88	28.30	28.09
20	443.3	52.66	56.07	54.35	54.36	45.22	1820.0	3.90	0.199E+09	0.02056	35.80	24.54	29.14	29.13	29.66	29.39
21	463.3	53.72	57.20	54.80	55.13	46.21	1853.3	3.82	0.209E+09	0.02153	35.38	24.18	30.92	29.78	30.35	30.07
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	50.19	53.51	51.86	51.86	42.67	1738.8	4.10	0.175E+09	0.01809	35.60	24.67	29.16	29.14	29.65	29.40

Appendix D

Experimental Data for $\alpha = 10°$

UPWARD INCLINATION ____ 1 - 500

INPUT ELECTRIC POWER = 148.1 W HEAT RATE GAINED BY WATER = 146.9 W HEAT BALANCE ERROR = 0.80%
MASS FLOW RATE = 14.7500 G/S PRESSURE DROP= 0.2680MMH20 FRICTION FACTOR = 0.035209 FREM = 17.4836
REM = 496.6 GRM = 0.21704E+07 UPSTREAM BULK TEMPERATURE = 22.11DEG C DOWNSTREAM BULK TEMPERATURE = 24.50DEG C
PRM = 6.390 RAM = 0.13869E+08 INLET BULK TEMPERATURE = 22.11DEG C OUTLET BULK TEMPERATURE = 24.50DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	22.89	22.88	22.89	22.89	22.14	484.0	6.57	0.197E+07	0.00067	16.33	16.56	16.45	16.45	16.45	16.45
4	15.5	23.10	23.14	23.10	23.11	22.19	484.5	6.57	0.198E+07	0.00160	13.57	13.03	13.57	13.43	13.44	13.44
5	25.5	23.18	23.24	23.20	23.21	22.24	485.0	6.56	0.199E+07	0.00264	13.06	12.33	12.79	12.74	12.74	12.74
6	45.5	23.26	23.31	23.26	23.27	22.35	486.1	6.54	0.200E+07	0.00471	13.38	12.75	13.43	13.24	13.25	13.25
7	75.5	23.37	23.43	23.37	23.38	22.50	487.7	6.52	0.203E+07	0.00781	14.04	13.14	14.15	13.85	13.87	13.86
8	105.5	23.44	23.58	23.46	23.49	22.65	489.4	6.49	0.206E+07	0.01092	15.44	13.16	15.12	14.65	14.71	14.68
9	135.5	23.59	23.70	23.64	23.64	22.80	491.0	6.47	0.208E+07	0.01403	15.63	13.66	14.71	14.64	14.68	14.66
10	165.2	23.75	23.85	23.79	23.80	22.95	492.7	6.45	0.211E+07	0.01711	15.42	13.64	14.60	14.54	14.56	14.55
11	205.2	23.85	24.08	23.97	23.97	23.16	494.9	6.41	0.214E+07	0.02127	17.76	13.23	15.06	15.11	15.28	15.19
12	245.2	24.26	24.32	24.25	24.27	23.36	497.2	6.38	0.218E+07	0.02542	13.68	12.74	13.77	13.48	13.49	13.48
13	275.2	24.33	24.44	24.39	24.39	23.51	498.9	6.36	0.221E+07	0.02854	14.99	13.21	13.94	13.99	14.02	14.01
14	305.2	24.54	24.63	24.58	24.59	23.67	500.6	6.33	0.224E+07	0.03167	13.96	12.64	13.33	13.30	13.31	13.31
15	333.3	24.51	24.62	24.56	24.56	23.81	502.2	6.31	0.226E+07	0.03459	17.50	15.09	16.21	16.21	16.25	16.23
16	363.3	24.75	24.78	24.76	24.76	23.96	504.0	6.29	0.229E+07	0.03772	15.54	14.93	15.33	15.28	15.28	15.28
17	383.3	24.82	24.93	24.88	24.88	24.06	505.1	6.27	0.231E+07	0.03981	16.19	14.02	14.89	14.96	14.99	14.97
18	403.3	24.93	25.02	24.96	24.97	24.16	506.3	6.25	0.233E+07	0.04189	15.92	14.34	15.38	15.23	15.25	15.24
19	423.3	25.08	25.16	25.14	25.13	24.27	507.5	6.24	0.235E+07	0.04398	14.94	13.61	13.91	14.08	14.09	14.08
20	443.3	25.13	25.24	25.14	25.16	24.37	508.7	6.22	0.237E+07	0.04607	15.94	14.05	15.72	15.32	15.36	15.34
21	463.3	25.39	25.30	25.42	25.38	24.47	509.9	6.21	0.239E+07	0.04816	13.23	14.62	12.87	13.36	13.39	13.38
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.87	24.96	24.91	24.91	24.10	505.6	6.26	0.232E+07	0.04068	16.00	14.34	15.24	15.18	15.21	15.19

UPWARD INCLINATION ____ 2 - 500

INPUT ELECTRIC POWER = 297.2 W HEAT RATE GAINED BY WATER = 306.0 W HEAT BALANCE ERROR =-2.97%
MASS FLOW RATE = 14.2389 G/S PRESSURE DROP= 0.3346MMH20 FRICTION FACTOR = 0.047156 FREM = 23.5322
REM = 499.0 GRM = 0.52222E+07 UPSTREAM BULK TEMPERATURE = 22.49DEG C DOWNSTREAM BULK TEMPERATURE = 27.64DEG C
PRM = 6.112 RAM = 0.31919E+08 INLET BULK TEMPERATURE = 22.49DEG C OUTLET BULK TEMPERATURE = 27.64DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.03	24.08	24.06	24.06	22.55	471.4	6.51	0.425E+07	0.00059	17.28	16.70	16.98	16.98	16.99	16.99
4	15.5	24.20	24.39	24.26	24.28	22.66	472.6	6.49	0.429E+07	0.00166	16.61	14.78	16.04	15.84	15.87	15.85
5	25.5	24.39	24.56	24.50	24.49	22.77	473.7	6.47	0.433E+07	0.00274	15.75	14.30	14.75	14.87	14.89	14.88
6	45.5	24.55	24.76	24.60	24.63	22.99	476.0	6.44	0.441E+07	0.00488	16.37	14.42	15.86	15.59	15.63	15.61
7	75.5	24.76	25.02	24.82	24.85	23.32	479.5	6.39	0.453E+07	0.00811	17.73	15.06	17.06	16.66	16.73	16.69
8	105.5	24.95	25.23	24.97	25.03	23.65	483.1	6.34	0.465E+07	0.01134	19.59	16.12	19.25	18.44	18.55	18.50
9	135.5	25.26	25.54	25.39	25.40	23.98	486.7	6.28	0.478E+07	0.01457	19.88	16.32	18.02	17.97	18.06	18.01
10	165.2	25.58	25.80	25.73	25.71	24.31	490.3	6.23	0.491E+07	0.01778	19.91	16.98	17.91	18.12	18.18	18.15
11	205.2	25.94	26.26	26.12	26.11	24.74	495.3	6.16	0.509E+07	0.02211	21.26	16.80	18.44	18.60	18.73	18.67
12	245.2	26.59	26.78	26.66	26.67	25.18	500.4	6.09	0.527E+07	0.02645	18.06	15.94	17.25	17.09	17.13	17.11
13	275.2	26.78	27.06	26.97	26.94	25.51	504.3	6.04	0.542E+07	0.02971	20.00	16.37	17.45	17.72	17.82	17.77
14	305.2	27.14	27.41	27.27	27.27	25.84	508.2	5.99	0.556E+07	0.03298	19.51	16.20	17.72	17.71	17.79	17.75
15	333.3	27.35	27.63	27.51	27.50	26.15	512.0	5.94	0.570E+07	0.03605	21.17	17.18	18.58	18.77	18.88	18.82
16	363.3	27.81	27.93	27.93	27.90	26.48	516.0	5.89	0.586E+07	0.03933	18.97	17.46	17.45	17.81	17.83	17.82
17	383.3	27.98	28.23	28.09	28.10	26.70	518.8	5.85	0.596E+07	0.04152	19.81	16.54	18.15	18.09	18.16	18.12
18	403.3	28.25	28.50	28.35	28.36	26.92	521.4	5.82	0.607E+07	0.04371	19.01	15.98	17.68	17.52	17.59	17.55
19	423.3	28.52	28.74	28.66	28.64	27.14	523.7	5.79	0.616E+07	0.04589	18.30	15.74	16.65	16.78	16.83	16.81
20	443.3	28.65	28.87	28.77	28.77	27.36	526.1	5.77	0.625E+07	0.04807	19.52	16.67	17.87	17.92	17.98	17.95
21	463.3	28.96	29.14	29.12	29.08	27.58	528.4	5.74	0.635E+07	0.05026	18.28	16.15	16.37	16.75	16.79	16.77
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.09	28.32	28.22	28.21	26.79	519.7	5.84	0.600E+07	0.04243	19.46	16.59	17.73	17.82	17.88	17.85

UPWARD INCLINATION _____ 3 - 500

INPUT ELECTRIC POWER = 581.7 W HEAT RATE GAINED BY WATER = 573.8 W HEAT BALANCE ERROR = 1.36%
MASS FLOW RATE = 13.7300 G/S PRESSURE DROP= 0.3555MMH20 FRICTION FACTOR = 0.053860 FREM = 27.0271
REM = 501.8 GRM = 0.11299E+08 UPSTREAM BULK TEMPERATURE = 21.81DEG C DOWNSTREAM BULK TEMPERATURE = 31.83DEG C
PRM = 5.834 RAM = 0.65917E+08 INLET BULK TEMPERATURE = 21.83DEG C OUTLET BULK TEMPERATURE = 31.83DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.73	24.87	24.80	24.80	21.94	448.6	6.61	0.757E+07	0.00061	17.24	16.42	16.82	16.82	16.83	16.82
4	15.5	24.70	24.98	24.73	24.78	22.16	450.6	6.57	0.771E+07	0.00172	18.87	17.00	18.67	18.27	18.30	18.29
5	25.5	25.03	25.36	25.17	25.18	22.37	452.7	6.54	0.785E+07	0.00283	18.04	16.05	17.13	17.06	17.09	17.07
6	45.5	25.17	25.52	25.30	25.32	22.80	457.0	6.47	0.813E+07	0.00506	20.19	17.60	19.12	18.96	19.01	18.98
7	75.5	25.57	25.99	25.66	25.72	23.44	463.6	6.37	0.857E+07	0.00841	22.47	18.74	21.56	20.98	21.08	21.03
8	105.5	25.98	26.52	26.14	26.20	24.08	470.4	6.27	0.903E+07	0.01177	25.03	19.56	23.12	22.53	22.71	22.62
9	135.5	26.77	27.19	26.98	26.98	24.72	477.3	6.17	0.952E+07	0.01514	23.25	19.32	21.04	21.07	21.16	21.11
10	165.2	27.42	27.90	27.61	27.63	25.35	484.4	6.07	0.100E+08	0.01849	23.02	18.71	21.12	20.87	20.99	20.93
11	205.2	28.15	28.68	28.36	28.39	26.20	494.3	5.93	0.107E+08	0.02302	24.48	19.16	22.03	21.76	21.92	21.84
12	245.2	29.20	29.57	29.40	29.39	27.06	504.2	5.80	0.115E+08	0.02756	22.10	18.89	20.27	20.32	20.38	20.35
13	275.2	29.74	30.13	30.02	29.98	27.70	510.8	5.72	0.120E+08	0.03097	23.23	19.45	20.39	20.77	20.86	20.82
14	305.2	30.33	30.74	30.47	30.50	28.34	517.6	5.64	0.125E+08	0.03438	23.76	19.67	22.21	21.86	21.96	21.91
15	333.3	30.91	31.24	31.19	31.13	28.94	524.1	5.57	0.131E+08	0.03758	23.92	20.46	20.96	21.50	21.58	21.54
16	363.3	31.58	32.00	31.78	31.78	29.58	531.2	5.49	0.137E+08	0.04100	23.57	19.46	21.44	21.38	21.48	21.43
17	383.3	32.03	32.37	32.20	32.20	30.00	536.1	5.43	0.141E+08	0.04329	23.25	19.92	21.48	21.47	21.53	21.50
18	403.3	32.46	32.91	32.66	32.68	30.43	541.1	5.38	0.145E+08	0.04558	23.13	18.95	21.07	20.95	21.06	21.00
19	423.3	32.99	33.44	33.21	33.21	30.86	546.1	5.33	0.149E+08	0.04788	22.06	18.17	19.99	19.96	20.06	20.01
20	443.3	33.32	33.75	33.49	33.51	31.28	551.2	5.27	0.154E+08	0.05018	23.03	19.05	21.24	21.05	21.14	21.09
21	463.3	33.87	34.22	34.05	34.06	31.71	556.5	5.22	0.158E+08	0.05249	21.72	18.73	20.02	20.07	20.12	20.09
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	32.22	32.62	32.42	32.42	30.18	538.3	5.41	0.143E+08	0.04425	23.16	19.34	21.03	21.05	21.14	21.10

UPWARD INCLINATION _____ 4 - 500

INPUT ELECTRIC POWER = 931.8 W HEAT RATE GAINED BY WATER = 933.0 W HEAT BALANCE ERROR =-0.13%
MASS FLOW RATE = 12.4500 G/S PRESSURE DROP= 0.3233MMH20 FRICTION FACTOR = 0.059472 FREM = 29.6301
REM = 498.2 GRM = 0.24761E+08 UPSTREAM BULK TEMPERATURE = 22.14DEG C DOWNSTREAM BULK TEMPERATURE = 40.11DEG C
PRM = 5.290 RAM = 0.13099E+09 INLET BULK TEMPERATURE = 22.17DEG C OUTLET BULK TEMPERATURE = 40.10DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.42	26.68	26.55	26.55	22.38	410.6	6.54	0.128E+08	0.00067	19.28	18.10	18.67	18.67	18.68	18.68
4	15.5	26.74	27.27	26.82	26.91	22.76	414.1	6.48	0.132E+08	0.00190	19.56	17.27	19.16	18.75	18.79	18.77
5	25.5	27.20	27.75	27.47	27.47	23.14	417.6	6.42	0.136E+08	0.00313	19.17	16.88	17.99	17.97	18.01	17.99
6	45.5	27.38	27.93	27.57	27.61	23.91	424.9	6.29	0.145E+08	0.00560	22.34	19.33	21.22	20.97	21.03	21.00
7	75.5	27.98	28.60	28.11	28.20	25.05	436.2	6.11	0.159E+08	0.00931	26.47	21.85	25.34	24.62	24.75	24.68
8	105.5	28.97	29.76	29.13	29.25	26.20	448.2	5.93	0.175E+08	0.01306	27.92	21.71	26.40	25.37	25.61	25.49
9	135.5	30.37	31.06	30.69	30.70	27.60	459.9	5.77	0.191E+08	0.01681	25.54	20.77	23.05	22.98	23.11	23.04
10	165.2	31.42	32.19	31.81	31.81	28.49	470.8	5.62	0.206E+08	0.02053	26.18	20.76	23.13	23.14	23.30	23.22
11	205.2	32.86	33.54	33.09	33.14	30.02	486.3	5.43	0.229E+08	0.02556	26.92	21.77	24.96	24.51	24.65	24.58
12	245.2	34.62	35.23	34.91	34.92	31.55	502.8	5.24	0.255E+08	0.03063	24.82	20.72	22.71	22.65	22.74	22.70
13	275.2	35.64	36.24	36.07	36.01	32.70	514.6	5.10	0.274E+08	0.03448	25.82	21.45	22.56	22.99	23.10	23.04
14	305.2	36.64	37.24	36.85	36.90	33.84	526.4	4.97	0.294E+08	0.03838	27.11	22.34	25.21	24.85	24.97	24.91
15	333.3	37.70	38.26	38.15	38.07	34.92	538.0	4.84	0.314E+08	0.04207	27.17	22.64	23.42	24.05	24.17	24.11
16	363.3	38.77	39.41	39.07	39.08	36.07	550.9	4.71	0.337E+08	0.04605	27.91	22.53	25.09	25.01	25.15	25.08
17	383.3	39.52	40.08	39.73	39.77	36.83	559.9	4.62	0.353E+08	0.04872	28.00	23.17	25.97	25.66	25.78	25.72
18	403.3	40.28	40.90	40.51	40.55	37.60	567.9	4.55	0.369E+08	0.05133	28.05	22.79	25.83	25.49	25.63	25.56
19	423.3	41.14	41.78	41.47	41.47	38.36	576.1	4.48	0.385E+08	0.05394	27.00	21.97	24.17	24.19	24.32	24.26
20	443.3	41.65	42.37	41.98	42.00	39.13	584.6	4.41	0.401E+08	0.05655	29.69	23.10	26.24	26.11	26.32	26.21
21	463.3	42.69	43.27	42.91	42.95	39.89	593.3	4.34	0.419E+08	0.05918	26.80	22.16	24.78	24.52	24.63	24.57
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	39.84	40.47	40.15	40.15	37.15	562.9	4.60	0.360E+08	0.04978	27.97	22.70	25.12	25.08	25.23	25.16

UPWARD INCLINATION _____ 1 - 1000

INPUT ELECTRIC POWER = 145.3 W HEAT RATE GAINED BY WATER = 144.3 W HEAT BALANCE ERROR = 0.66%
MASS FLOW RATE = 29.6962 G/S PRESSURE DROP= 0.5814MMH20 FRICTION FACTOR = 0.018844 FREM = 18.8351
REM = 999.5 GRM = 0.21300E+07 UPSTREAM BULK TEMPERATURE = 22.71DEG C DOWNSTREAM BULK TEMPERATURE = 23.88DEG C
PRM = 6.392 RAM = 0.13614E+08 INLET BULK TEMPERATURE = 22.71DEG C OUTLET BULK TEMPERATURE = 23.88DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.34	23.30	23.32	23.32	22.73	987.0	6.48	0.203E+07	0.00028	19.72	20.95	20.32	20.32	20.32	20.32
4	15.5	23.62	23.64	23.62	23.63	22.75	987.5	6.48	0.204E+07	0.00080	13.85	13.60	13.85	13.79	13.79	13.79
5	25.5	23.71	23.79	23.76	23.75	22.78	988.1	6.47	0.204E+07	0.00131	12.95	11.90	12.29	12.34	12.36	12.35
6	45.5	23.82	23.87	23.85	23.85	22.83	989.1	6.47	0.205E+07	0.00234	12.08	11.57	11.81	11.81	11.82	11.81
7	75.5	23.82	23.93	23.84	23.86	22.90	990.8	6.45	0.206E+07	0.00388	13.16	11.68	12.82	12.60	12.62	12.61
8	105.5	23.86	23.97	23.85	23.89	22.98	992.4	6.44	0.207E+07	0.00543	13.56	12.06	13.72	13.23	13.27	13.25
9	135.5	23.92	24.01	23.97	23.97	23.06	994.1	6.43	0.209E+07	0.00697	13.80	12.58	13.06	13.11	13.13	13.12
10	165.2	23.94	24.08	24.02	24.01	23.12	995.7	6.42	0.210E+07	0.00850	14.68	12.64	13.46	13.52	13.56	13.54
11	205.2	23.99	24.19	24.17	24.13	23.22	997.9	6.40	0.212E+07	0.01056	15.75	12.38	12.75	13.28	13.41	13.35
12	245.2	24.17	24.27	24.22	24.22	23.32	1000.1	6.39	0.213E+07	0.01263	14.15	12.74	13.37	13.39	13.41	13.40
13	275.2	24.30	24.38	24.33	24.34	23.40	1001.8	6.38	0.215E+07	0.01417	13.29	12.18	12.82	12.76	12.78	12.77
14	305.2	24.35	24.47	24.41	24.41	23.47	1003.5	6.36	0.216E+07	0.01572	13.73	12.09	12.73	12.80	12.82	12.81
15	333.3	24.28	24.40	24.37	24.35	23.54	1005.0	6.35	0.217E+07	0.01717	16.16	14.06	14.53	14.78	14.82	14.80
16	363.3	24.44	24.53	24.48	24.48	23.61	1006.7	6.34	0.219E+07	0.01872	14.65	13.15	13.93	13.88	13.89	13.88
17	383.3	24.43	24.54	24.52	24.50	23.66	1007.8	6.33	0.220E+07	0.01975	15.78	13.73	14.04	14.35	14.39	14.37
18	403.3	24.45	24.59	24.54	24.53	23.71	1009.0	6.33	0.220E+07	0.02079	16.24	13.65	14.58	14.70	14.76	14.73
19	423.3	24.50	24.66	24.61	24.59	23.76	1010.1	6.32	0.221E+07	0.02182	16.38	13.41	14.20	14.47	14.55	14.51
20	443.3	24.54	24.70	24.64	24.63	23.81	1011.2	6.31	0.222E+07	0.02285	16.47	13.53	14.56	14.71	14.78	14.74
21	463.3	24.77	24.73	24.89	24.82	23.86	1012.4	6.30	0.223E+07	0.02389	13.18	13.89	11.75	12.57	12.64	12.61
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.44	24.57	24.53	24.52	23.68	1008.3	6.33	0.220E+07	0.02018	15.93	13.59	14.31	14.48	14.53	14.51

UPWARD INCLINATION _____ 2 - 1000

INPUT ELECTRIC POWER = 300.8 W HEAT RATE GAINED BY WATER = 295.1 W HEAT BALANCE ERROR = 1.88%
MASS FLOW RATE = 29.1176 G/S PRESSURE DROP= 0.5926MMH20 FRICTION FACTOR = 0.019976 FREM = 20.0175
REM = 1002.1 GRM = 0.47215E+07 UPSTREAM BULK TEMPERATURE = 23.06DEG C DOWNSTREAM BULK TEMPERATURE = 25.49DEG C
PRM = 6.236 RAM = 0.29445E+08 INLET BULK TEMPERATURE = 23.07DEG C OUTLET BULK TEMPERATURE = 25.49DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.34	24.31	24.32	24.32	23.09	975.7	6.42	0.428E+07	0.00029	19.79	20.27	20.03	20.03	20.03	20.03
4	15.5	24.70	24.76	24.70	24.71	23.15	976.8	6.42	0.430E+07	0.00081	15.85	15.29	15.86	15.71	15.71	15.71
5	25.5	24.89	25.06	24.98	24.97	23.20	977.9	6.41	0.432E+07	0.00134	14.54	13.24	13.84	13.85	13.87	13.86
6	45.5	25.00	25.13	25.02	25.04	23.30	980.2	6.39	0.436E+07	0.00239	14.47	13.47	14.30	14.12	14.13	14.13
7	75.5	25.12	25.27	25.12	25.16	23.46	983.6	6.37	0.441E+07	0.00397	14.77	13.59	14.74	14.44	14.46	14.45
8	105.5	25.18	25.43	25.22	25.26	23.61	987.0	6.34	0.447E+07	0.00554	15.72	13.53	15.27	14.90	14.95	14.92
9	135.5	25.37	25.60	25.45	25.47	23.77	990.5	6.32	0.453E+07	0.00712	15.30	13.43	14.60	14.45	14.48	14.46
10	165.2	25.47	25.75	25.59	25.60	23.92	993.9	6.29	0.459E+07	0.00869	15.82	13.43	14.73	14.63	14.68	14.66
11	205.2	25.55	25.87	25.73	25.72	24.13	998.6	6.26	0.466E+07	0.01080	17.26	14.10	15.29	15.41	15.49	15.45
12	245.2	25.87	26.08	25.98	25.98	24.33	1003.4	6.23	0.474E+07	0.01291	16.00	14.06	14.87	14.92	14.95	14.93
13	275.2	25.95	26.20	26.13	26.10	24.49	1007.0	6.20	0.480E+07	0.01449	16.84	14.36	14.98	15.23	15.29	15.26
14	305.2	26.11	26.37	26.24	26.24	24.64	1010.6	6.18	0.486E+07	0.01608	16.76	14.20	15.40	15.39	15.44	15.42
15	333.3	26.15	26.40	26.34	26.31	24.79	1014.0	6.16	0.492E+07	0.01757	18.02	15.22	15.76	16.12	16.19	16.16
16	363.3	26.36	26.59	26.41	26.45	24.94	1017.6	6.13	0.499E+07	0.01915	17.26	14.88	16.67	16.32	16.37	16.34
17	383.3	26.41	26.62	26.47	26.50	25.05	1020.1	6.11	0.503E+07	0.02021	17.98	15.55	17.18	16.92	16.97	16.95
18	403.3	26.48	26.70	26.58	26.59	25.15	1022.5	6.10	0.507E+07	0.02127	18.47	15.79	17.10	17.06	17.12	17.09
19	423.3	26.65	26.87	26.75	26.75	25.25	1025.0	6.08	0.511E+07	0.02234	17.58	15.16	16.43	16.36	16.40	16.38
20	443.3	26.65	26.90	26.77	26.78	25.36	1027.5	6.07	0.516E+07	0.02340	18.90	15.89	17.28	17.27	17.34	17.30
21	463.3	26.91	27.01	27.07	27.01	25.46	1030.0	6.05	0.520E+07	0.02446	16.92	15.85	15.20	15.76	15.79	15.78
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	26.45	26.68	26.56	26.56	25.09	1021.1	6.11	0.505E+07	0.02066	18.04	15.41	16.74	16.68	16.73	16.70

UPWARD INCLINATION _____ 3 - 1000

INPUT ELECTRIC POWER = 662.8 W HEAT RATE GAINED BY WATER = 661.3 W HEAT BALANCE ERROR = 0.23%
MASS FLOW RATE = 28.2498 G/S PRESSURE DROP= 0.6332MMH20 FRICTION FACTOR = 0.022670 FREM = 22.6126
REM = 997.5 GRM = 0.11581E+08 UPSTREAM BULK TEMPERATURE = 22.58DEG C DOWNSTREAM BULK TEMPERATURE = 28.19DEG C
PRM = 6.062 RAM = 0.70200E+08 INLET BULK TEMPERATURE = 22.58DEG C OUTLET BULK TEMPERATURE = 28.18DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.31	25.37	25.34	25.34	22.65	937.3	6.49	0.926E+07	0.00030	20.76	20.30	20.52	20.52	20.53	20.53
4	15.5	25.94	26.21	25.97	26.02	22.77	939.8	6.47	0.935E+07	0.00084	17.41	16.05	17.26	16.97	16.99	16.98
5	25.5	26.16	26.51	26.33	26.33	22.89	942.3	6.46	0.944E+07	0.00138	16.89	15.22	16.03	16.02	16.04	16.03
6	45.5	26.29	26.58	26.34	26.39	23.13	947.3	6.42	0.963E+07	0.00246	17.43	15.96	17.18	16.92	16.94	16.93
7	75.5	26.43	26.82	26.49	26.56	23.49	954.9	6.36	0.992E+07	0.00409	18.74	16.52	18.33	17.93	17.98	17.96
8	105.5	26.57	27.13	26.73	26.79	23.84	962.7	6.30	0.102E+08	0.00572	20.20	16.74	19.09	18.69	18.78	18.74
9	135.5	26.94	27.44	27.15	27.17	24.20	970.6	6.25	0.105E+08	0.00735	20.13	17.01	18.66	18.55	18.62	18.58
10	165.2	27.09	27.70	27.38	27.39	24.56	978.5	6.19	0.108E+08	0.00897	21.74	17.49	19.47	19.43	19.54	19.49
11	205.2	27.34	27.99	27.63	27.65	25.04	989.4	6.12	0.113E+08	0.01115	23.87	18.60	21.13	21.02	21.18	21.10
12	245.2	27.95	28.51	28.25	28.24	25.51	1000.5	6.04	0.117E+08	0.01334	22.49	18.32	20.04	20.12	20.22	20.17
13	275.2	28.26	28.79	28.65	28.59	25.87	1009.0	5.98	0.120E+08	0.01499	22.96	18.76	19.74	20.19	20.30	20.24
14	305.2	28.59	29.09	28.81	28.83	26.23	1017.7	5.93	0.124E+08	0.01664	23.16	19.16	21.20	21.08	21.18	21.13
15	333.3	28.96	29.46	29.27	29.24	26.57	1026.0	5.87	0.127E+08	0.01819	22.84	18.89	20.25	20.46	20.56	20.51
16	363.3	29.26	29.83	29.53	29.54	26.92	1034.6	5.82	0.131E+08	0.01984	23.37	18.85	20.98	20.92	21.04	20.98
17	383.3	29.51	30.00	29.74	29.75	27.16	1039.6	5.79	0.133E+08	0.02094	23.25	19.25	21.21	21.13	21.23	21.18
18	403.3	29.74	30.24	29.97	29.98	27.40	1044.7	5.76	0.136E+08	0.02206	23.38	19.22	21.24	21.17	21.27	21.22
19	423.3	30.05	30.56	30.37	30.34	27.64	1049.8	5.73	0.138E+08	0.02315	22.61	18.68	20.00	20.23	20.32	20.28
20	443.3	30.20	30.76	30.49	30.48	27.88	1054.9	5.70	0.140E+08	0.02425	23.52	18.94	20.93	20.96	21.08	21.02
21	463.3	30.78	31.16	31.03	31.00	28.12	1060.1	5.67	0.142E+08	0.02535	20.47	17.94	18.76	18.94	18.98	18.96
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	29.62	30.14	29.89	29.89	27.26	1041.6	5.78	0.134E+08	0.02140	23.16	18.97	20.77	20.81	20.92	20.86

UPWARD INCLINATION _____ 4 - 1000

INPUT ELECTRIC POWER = 873.7 W HEAT RATE GAINED BY WATER = 874.8 W HEAT BALANCE ERROR =-0.13%
MASS FLOW RATE = 27.8882 G/S PRESSURE DROP= 0.6949MMH20 FRICTION FACTOR = 0.025523 FREM = 25.5825
REM = 1002.3 GRM = 0.16282E+08 UPSTREAM BULK TEMPERATURE = 22.37DEG C DOWNSTREAM BULK TEMPERATURE = 29.89DEG C
PRM = 5.943 RAM = 0.96768E+08 INLET BULK TEMPERATURE = 22.38DEG C OUTLET BULK TEMPERATURE = 29.89DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.89	26.04	25.97	25.97	22.47	921.6	6.52	0.121E+08	0.00030	21.34	20.46	20.89	20.89	20.89	20.89
4	15.5	26.57	26.96	26.60	26.69	22.63	924.8	6.50	0.122E+08	0.00085	18.51	16.85	18.38	18.00	18.03	18.02
5	25.5	26.87	27.34	27.13	27.12	22.79	928.1	6.47	0.124E+08	0.00140	17.88	16.05	16.80	16.86	16.88	16.87
6	45.5	26.96	27.45	27.15	27.18	23.11	934.8	6.42	0.127E+08	0.00249	18.93	16.81	18.06	17.93	17.96	17.95
7	75.5	27.15	27.71	27.30	27.37	23.59	944.9	6.35	0.132E+08	0.00414	20.47	17.68	19.62	19.29	19.35	19.32
8	105.5	27.35	28.11	27.54	27.63	24.07	955.2	6.27	0.138E+08	0.00579	22.18	18.00	20.99	20.42	20.54	20.48
9	135.5	27.83	28.50	28.16	28.16	24.55	965.8	6.19	0.143E+08	0.00745	22.18	18.43	20.17	20.15	20.24	20.19
10	165.2	28.06	28.84	28.45	28.45	25.02	976.5	6.12	0.149E+08	0.00910	23.94	19.02	21.23	21.22	21.36	21.29
11	205.2	28.45	29.24	28.84	28.84	25.67	991.3	6.02	0.157E+08	0.01132	26.03	20.28	22.88	22.84	23.01	22.93
12	245.2	29.23	29.82	29.51	29.52	26.31	1006.5	5.92	0.165E+08	0.01355	24.76	20.62	22.61	22.55	22.65	22.60
13	275.2	29.60	30.33	30.06	30.00	26.79	1018.2	5.84	0.172E+08	0.01522	25.74	20.43	22.18	22.48	22.63	22.55
14	305.2	30.05	30.74	30.35	30.37	27.27	1028.4	5.78	0.178E+08	0.01690	25.98	20.80	23.40	23.25	23.40	23.33
15	333.3	30.58	31.30	31.08	31.01	27.72	1037.9	5.72	0.183E+08	0.01846	25.24	20.14	21.48	21.93	22.08	22.01
16	363.3	31.08	31.78	31.38	31.40	28.20	1048.2	5.66	0.189E+08	0.02014	25.05	20.14	22.63	22.48	22.61	22.55
17	383.3	31.36	31.97	31.64	31.65	28.52	1055.2	5.62	0.194E+08	0.02126	25.36	20.85	23.09	22.98	23.10	23.04
18	403.3	31.68	32.35	31.99	32.00	28.84	1062.3	5.58	0.198E+08	0.02238	25.35	20.49	22.83	22.75	22.88	22.81
19	423.3	32.09	32.77	32.48	32.46	29.16	1069.5	5.54	0.202E+08	0.02350	24.50	19.90	21.67	21.82	21.94	21.88
20	443.3	32.25	32.96	32.59	32.60	29.48	1076.7	5.50	0.207E+08	0.02463	25.90	20.65	23.07	23.02	23.17	23.10
21	463.3	32.75	33.23	33.04	33.02	29.80	1084.1	5.46	0.212E+08	0.02575	24.36	20.90	22.13	22.31	22.38	22.35
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	31.51	32.19	31.86	31.85	28.65	1058.3	5.60	0.196E+08	0.02173	25.23	20.36	22.46	22.50	22.63	22.56

UPWARD INCLINATION _____ 5 - 1000

INPUT ELECTRIC POWER = 1140.0 W HEAT RATE GAINED BY WATER = 1125.7 W HEAT BALANCE ERROR = 1.25%
MASS FLOW RATE = 26.9480 G/S PRESSURE DROP= 0.7245MMH2O FRICTION FACTOR = 0.028490 FREM = 28.5054
REM = 1000.6 GRM = 0.23395E+08 UPSTREAM BULK TEMPERATURE = 22.59DEG C DOWNSTREAM BULK TEMPERATURE = 32.60DEG C
PRM = 5.735 RAM = 0.13418E+09 INLET BULK TEMPERATURE = 22.60DEG C OUTLET BULK TEMPERATURE = 32.60DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	27.34	27.56	27.44	27.44	22.72	895.5	6.48	0.158E+08	0.00031	20.35	19.46	19.90	19.90	19.90	19.90
4	15.5	27.68	28.25	27.82	27.89	22.93	899.7	6.45	0.161E+08	0.00088	19.79	17.68	19.23	18.95	18.98	18.97
5	25.5	28.14	28.74	28.44	28.44	23.15	904.0	6.42	0.164E+08	0.00146	18.81	16.78	17.75	17.74	17.77	17.76
6	45.5	28.20	28.79	28.38	28.44	23.57	912.7	6.35	0.170E+08	0.00258	20.28	17.97	19.51	19.28	19.32	19.30
7	75.5	28.43	29.16	28.64	28.72	24.21	926.0	6.25	0.179E+08	0.00429	22.23	18.94	21.13	20.79	20.86	20.82
8	105.5	28.69	29.71	28.91	29.05	24.85	939.8	6.15	0.189E+08	0.00601	24.36	19.26	23.07	22.26	22.44	22.35
9	135.5	29.34	30.20	29.74	29.76	25.49	953.9	6.04	0.199E+08	0.00773	24.29	19.85	21.95	21.90	22.01	21.96
10	165.2	29.73	30.71	30.21	30.22	26.12	968.4	5.94	0.209E+08	0.00944	25.89	20.33	22.81	22.79	22.96	22.88
11	205.2	30.32	31.28	30.68	30.74	26.98	988.0	5.81	0.224E+08	0.01176	27.82	21.64	25.13	24.73	24.93	24.83
12	245.2	31.37	32.22	31.78	31.78	27.83	1005.3	5.71	0.238E+08	0.01406	26.24	21.17	23.55	23.49	23.62	23.56
13	275.2	31.91	32.81	32.54	32.45	28.47	1018.7	5.63	0.248E+08	0.01580	26.97	21.36	22.79	23.30	23.48	23.39
14	305.2	32.48	33.23	32.85	32.85	29.11	1032.4	5.55	0.260E+08	0.01754	27.49	22.46	24.78	24.75	24.88	24.81
15	333.3	33.22	34.03	33.81	33.72	29.71	1045.6	5.47	0.271E+08	0.01917	26.33	21.41	22.57	23.08	23.22	23.15
16	363.3	33.78	34.65	34.19	34.20	30.35	1060.1	5.39	0.283E+08	0.02092	26.92	21.48	24.04	23.97	24.12	24.04
17	383.3	34.18	34.93	34.48	34.52	30.78	1069.9	5.34	0.291E+08	0.02209	27.08	22.21	24.37	24.64	24.76	24.70
18	403.3	34.57	35.42	34.90	34.96	31.20	1080.0	5.28	0.300E+08	0.02326	27.35	21.88	24.89	24.60	24.75	24.68
19	423.3	35.08	35.96	35.54	35.53	31.63	1090.3	5.23	0.309E+08	0.02443	26.66	21.25	23.54	23.59	23.75	23.67
20	443.3	35.29	36.20	35.72	35.73	32.05	1100.0	5.18	0.318E+08	0.02561	28.41	22.19	25.13	25.02	25.21	25.12
21	463.3	36.06	36.75	36.24	36.32	32.48	1109.1	5.13	0.326E+08	0.02680	25.67	21.51	24.44	23.91	24.02	23.96
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	34.36	35.20	34.77	34.77	30.95	1074.3	5.31	0.295E+08	0.02258	27.12	21.74	24.18	24.15	24.30	24.23

UPWARD INCLINATION _____ 6 - 1000

INPUT ELECTRIC POWER = 1765.2 W HEAT RATE GAINED BY WATER = 1746.3 W HEAT BALANCE ERROR = 1.07%
MASS FLOW RATE = 25.0000 G/S PRESSURE DROP= 0.7319MMH2O FRICTION FACTOR = 0.033395 FREM = 33.3540
REM = 998.8 GRM = 0.46101E+08 UPSTREAM BULK TEMPERATURE = 22.68DEG C DOWNSTREAM BULK TEMPERATURE = 39.42DEG C
PRM = 5.300 RAM = 0.24433E+09 INLET BULK TEMPERATURE = 22.70DEG C OUTLET BULK TEMPERATURE = 39.42DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	29.39	29.89	29.64	29.64	22.89	834.0	6.45	0.249E+08	0.00034	22.43	20.82	21.60	21.60	21.61	21.60
4	15.5	29.75	30.68	29.97	30.09	23.25	840.6	6.40	0.257E+08	0.00095	22.41	19.61	21.68	21.29	21.34	21.32
5	25.5	30.42	31.38	30.95	30.93	23.61	847.4	6.34	0.265E+08	0.00156	21.36	18.71	19.81	19.88	19.92	19.90
6	45.5	30.50	31.51	30.84	30.92	24.32	861.2	6.23	0.280E+08	0.00279	23.52	20.21	22.28	22.01	22.07	22.04
7	75.5	30.92	32.10	31.30	31.40	25.39	882.9	6.06	0.306E+08	0.00464	26.19	21.59	24.54	24.10	24.21	24.15
8	105.5	31.40	32.98	31.75	31.97	26.46	905.7	5.89	0.334E+08	0.00650	29.28	22.18	27.31	26.23	26.52	26.38
9	135.5	32.60	33.88	33.26	33.25	27.53	926.9	5.74	0.361E+08	0.00837	28.45	22.72	25.17	25.22	25.38	25.30
10	165.2	33.45	34.89	34.16	34.17	28.59	947.4	5.61	0.389E+08	0.01022	29.58	22.82	25.80	25.78	26.00	25.89
11	205.2	34.59	35.96	35.13	35.20	30.02	976.4	5.43	0.429E+08	0.01273	31.33	24.12	28.06	27.65	27.89	27.77
12	245.2	36.32	37.49	36.87	36.89	31.44	1007.3	5.25	0.473E+08	0.01525	29.31	23.63	26.35	26.26	26.41	26.33
13	275.2	37.20	38.48	38.06	37.95	32.51	1029.6	5.12	0.507E+08	0.01716	30.39	23.90	25.71	26.22	26.43	26.33
14	305.2	38.12	39.29	38.56	38.63	33.58	1051.5	5.00	0.541E+08	0.01910	31.30	24.93	28.55	28.14	28.33	28.24
15	333.3	39.29	40.49	40.13	40.01	34.59	1072.9	4.88	0.576E+08	0.02093	30.13	24.02	25.59	26.15	26.33	26.24
16	363.3	40.22	41.56	40.87	40.88	35.66	1096.8	4.76	0.615E+08	0.02290	30.98	23.94	27.11	27.06	27.28	27.17
17	383.3	40.89	42.06	41.35	41.41	36.37	1113.3	4.68	0.642E+08	0.02422	31.21	24.83	28.33	27.99	28.17	28.08
18	403.3	41.74	42.92	42.16	42.24	37.08	1129.5	4.60	0.670E+08	0.02554	30.25	24.13	27.74	27.29	27.47	27.38
19	423.3	42.57	43.85	43.30	43.25	37.79	1144.6	4.53	0.698E+08	0.02684	29.48	23.24	25.58	25.78	25.97	25.88
20	443.3	43.03	44.04	43.64	43.59	38.51	1160.1	4.47	0.726E+08	0.02814	31.06	25.42	27.36	27.66	27.80	27.73
21	463.3	43.81	44.68	44.48	44.37	39.22	1176.1	4.40	0.755E+08	0.02944	30.59	25.69	26.66	27.28	27.40	27.34
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	41.29	42.48	41.91	41.90	36.67	1119.5	4.65	0.654E+08	0.02476	30.52	24.26	26.95	26.99	27.17	27.08

UPWARD INCLINATION _____ 7 - 1000

INPUT ELECTRIC POWER = 2666.6 W HEAT RATE GAINED BY WATER = 2669.5 W HEAT BALANCE ERROR =-0.11%
MASS FLOW RATE = 22.1025 G/S PRESSURE DROP= 0.8584MMH20 FRICTION FACTOR = 0.049984 FREM = 50.0024
REM = 1000.4 GRM = 0.10303E+09 UPSTREAM BULK TEMPERATURE = 22.69DEG C DOWNSTREAM BULK TEMPERATURE = 51.63DEG C
PRM = 4.590 RAM = 0.47290E+09 INLET BULK TEMPERATURE = 22.72DEG C OUTLET BULK TEMPERATURE = 51.63DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	32.17	33.06	32.61	32.61	23.06	740.1	6.43	0.387E+08	0.00038	24.46	22.29	23.33	23.33	23.36	23.34
4	15.5	32.48	34.03	32.81	33.03	23.68	750.4	6.33	0.407E+08	0.00107	25.26	21.49	24.35	23.77	23.86	23.82
5	25.5	33.36	34.79	34.22	34.15	24.30	761.0	6.23	0.428E+08	0.00177	24.49	21.15	22.37	22.53	22.60	22.56
6	45.5	33.41	34.87	34.00	34.07	25.53	783.1	6.04	0.473E+08	0.00317	28.09	23.72	26.13	25.92	26.02	25.97
7	75.5	34.15	35.83	34.70	34.84	27.38	817.0	5.76	0.546E+08	0.00527	32.58	26.10	30.10	29.53	29.72	29.63
8	105.5	35.28	37.48	35.77	36.08	29.23	848.9	5.53	0.621E+08	0.00739	36.30	26.61	33.55	32.06	32.50	32.28
9	135.5	37.71	39.34	38.48	38.50	31.08	883.4	5.30	0.706E+08	0.00952	32.99	26.46	29.56	29.46	29.64	29.55
10	165.2	39.21	41.20	40.19	40.20	32.91	917.4	5.08	0.794E+08	0.01167	34.56	26.27	29.89	29.87	30.16	30.01
11	206.2	41.38	43.21	42.01	42.15	35.38	964.1	4.79	0.924E+08	0.01461	36.06	27.61	32.63	31.93	32.23	32.08
12	245.2	43.99	45.58	44.76	44.77	37.84	1012.9	4.53	0.107E+09	0.01758	34.99	27.78	31.11	31.04	31.25	31.15
13	275.2	45.54	47.27	46.77	46.58	39.69	1049.3	4.36	0.119E+09	0.01979	36.68	28.30	30.30	31.10	31.39	31.25
14	305.2	47.12	48.64	47.53	47.71	41.54	1088.4	4.19	0.132E+09	0.02202	38.28	30.08	35.69	34.66	34.93	34.80
15	333.3	49.31	50.76	50.07	50.06	43.28	1122.6	4.06	0.144E+09	0.02412	35.26	28.44	31.35	31.42	31.60	31.51
16	363.3	51.12	52.74	51.79	51.86	45.13	1160.2	3.90	0.158E+09	0.02638	35.39	27.86	31.83	31.50	31.73	31.61
17	383.3	52.13	53.65	52.65	52.77	46.36	1186.8	3.81	0.168E+09	0.02790	36.69	29.01	33.62	33.00	33.23	33.12
18	403.3	53.54	55.15	54.07	54.21	47.59	1213.0	3.72	0.179E+09	0.02942	35.49	27.96	32.62	31.93	32.17	32.06
19	423.3	54.86	56.50	55.69	55.68	48.83	1239.3	3.63	0.190E+09	0.03094	34.95	27.48	30.72	30.75	30.97	30.86
20	443.3	55.58	57.23	56.27	56.34	50.06	1266.7	3.55	0.201E+09	0.03247	38.08	29.36	33.89	33.52	33.81	33.66
21	463.3	56.69	58.61	57.06	57.35	51.29	1295.4	3.46	0.214E+09	0.03401	38.87	28.69	36.50	34.67	35.14	34.90
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	52.76	54.34	53.42	53.48	46.87	1198.1	3.78	0.173E+09	0.02854	35.98	28.35	32.34	32.02	32.25	32.13

UPWARD INCLINATION _____ 1 - 1500

INPUT ELECTRIC POWER = 165.2 W HEAT RATE GAINED BY WATER = 161.4 W HEAT BALANCE ERROR = 2.29%
MASS FLOW RATE = 45.2450 G/S PRESSURE DROP= 0.8999MMH20 FRICTION FACTOR = 0.012566 FREM = 18.9108
REM = 1504.9 GRM = 0.22795E+07 UPSTREAM BULK TEMPERATURE = 22.33DEG C DOWNSTREAM BULK TEMPERATURE = 23.19DEG C
PRM = 6.476 RAM = 0.14762E+08 INLET BULK TEMPERATURE = 22.33DEG C OUTLET BULK TEMPERATURE = 23.19DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	22.95	22.94	22.94	22.94	22.34	1491.1	6.54	0.220E+07	0.00019	22.28	22.66	22.47	22.47	22.47	22.47
4	15.5	23.18	23.19	23.18	23.18	22.36	1491.7	6.54	0.221E+07	0.00052	16.49	16.27	16.49	16.43	16.43	16.43
5	25.5	23.29	23.32	23.29	23.30	22.38	1492.3	6.54	0.221E+07	0.00086	14.76	14.33	14.88	14.71	14.71	14.71
6	45.5	23.43	23.45	23.43	23.43	22.42	1493.5	6.53	0.222E+07	0.00153	13.30	13.08	13.35	13.27	13.27	13.27
7	75.5	23.51	23.60	23.50	23.53	22.47	1495.3	6.52	0.223E+07	0.00255	12.97	11.96	13.05	12.74	12.76	12.75
8	105.5	23.56	23.67	23.55	23.58	22.53	1497.1	6.51	0.224E+07	0.00356	13.08	11.82	13.22	12.81	12.84	12.83
9	135.5	23.59	23.70	23.64	23.64	22.58	1498.9	6.50	0.225E+07	0.00457	13.39	12.04	12.77	12.72	12.74	12.73
10	165.2	23.61	23.71	23.65	23.66	22.64	1500.7	6.50	0.226E+07	0.00557	13.82	12.50	13.24	13.18	13.20	13.19
11	206.2	23.65	23.78	23.75	23.73	22.71	1503.1	6.48	0.227E+07	0.00693	14.28	12.61	12.97	13.17	13.20	13.19
12	245.2	23.84	23.88	23.80	23.83	22.78	1505.5	6.47	0.228E+07	0.00828	12.74	12.31	13.19	12.85	12.86	12.85
13	275.2	23.80	23.94	23.86	23.86	22.84	1507.3	6.46	0.229E+07	0.00929	13.96	12.22	13.16	13.10	13.13	13.11
14	305.2	23.87	23.99	23.94	23.93	22.89	1509.2	6.46	0.230E+07	0.01030	13.72	12.25	12.84	12.89	12.91	12.90
15	333.3	23.81	23.89	23.87	23.86	22.94	1510.9	6.45	0.231E+07	0.01125	15.48	14.12	14.55	14.66	14.67	14.66
16	363.3	23.91	24.00	23.94	23.95	23.00	1512.7	6.44	0.232E+07	0.01227	14.71	13.42	14.19	14.11	14.13	14.12
17	383.3	23.89	24.00	23.96	23.96	23.03	1513.9	6.43	0.233E+07	0.01295	15.60	13.84	14.47	14.57	14.59	14.58
18	403.3	23.89	24.00	23.98	23.96	23.07	1515.2	6.43	0.234E+07	0.01362	16.35	14.39	14.80	15.05	15.08	15.07
19	423.3	23.97	24.10	24.05	24.04	23.10	1516.4	6.42	0.235E+07	0.01430	15.63	13.52	14.27	14.38	14.42	14.40
20	443.3	24.01	24.11	24.06	24.05	23.14	1517.6	6.42	0.235E+07	0.01498	15.53	13.90	14.84	14.76	14.78	14.77
21	463.3	24.24	24.12	24.30	24.24	23.18	1518.9	6.41	0.236E+07	0.01565	12.65	14.25	12.03	12.68	12.74	12.71
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	23.91	24.02	23.97	23.97	23.05	1514.5	6.43	0.233E+07	0.01323	15.55	13.87	14.52	14.59	14.61	14.60

UPWARD INCLINATION _____ 2 - 1500

INPUT ELECTRIC POWER = 310.7 W HEAT RATE GAINED BY WATER = 313.6 W HEAT BALANCE ERROR =-0.94%
MASS FLOW RATE = 44.5220 G/S PRESSURE DROP= 0.9082MMH20 FRICTION FACTOR = 0.013097 FREM = 19.6994
REM = 1504.2 GRM = 0.46936E+07 UPSTREAM BULK TEMPERATURE = 22.62DEG C DOWNSTREAM BULK TEMPERATURE = 24.31DEG C
PRM = 6.365 RAM = 0.29876E+08 INLET BULK TEMPERATURE = 22.62DEG C OUTLET BULK TEMPERATURE = 24.30DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.75	23.72	23.74	23.74	22.64	1476.8	6.50	0.439E+07	0.00019	23.48	24.20	23.83	23.83	23.84	23.83
4	15.5	24.23	24.31	24.23	24.25	22.68	1478.0	6.49	0.440E+07	0.00063	16.85	16.03	16.85	16.64	16.65	16.64
5	25.5	24.48	24.62	24.59	24.57	22.71	1479.2	6.48	0.441E+07	0.00087	14.82	13.75	13.95	14.11	14.12	14.12
6	45.5	24.61	24.76	24.69	24.69	22.78	1481.5	6.47	0.444E+07	0.00156	14.34	13.22	13.76	13.76	13.77	13.76
7	75.5	24.68	24.85	24.68	24.72	22.89	1485.1	6.46	0.448E+07	0.00259	14.65	13.37	14.65	14.31	14.33	14.32
8	105.5	24.70	24.95	24.75	24.79	23.00	1488.7	6.44	0.452E+07	0.00362	15.37	13.39	14.98	14.64	14.68	14.66
9	135.5	24.81	25.01	24.86	24.89	23.11	1492.2	6.42	0.456E+07	0.00465	15.31	13.74	14.89	14.68	14.71	14.69
10	165.2	24.78	25.02	24.91	24.91	23.21	1495.8	6.40	0.460E+07	0.00567	16.72	14.45	15.38	15.44	15.48	15.46
11	205.2	25.38	25.14	25.03	25.15	23.36	1500.6	6.38	0.465E+07	0.00706	12.91	14.64	15.60	14.60	14.69	14.64
12	245.2	25.06	25.27	25.14	25.16	23.50	1505.5	6.36	0.471E+07	0.00843	16.75	14.77	15.90	15.80	15.83	15.81
13	275.2	25.05	25.33	25.20	25.20	23.61	1509.1	6.34	0.475E+07	0.00946	18.08	15.16	16.39	16.44	16.51	16.47
14	305.2	25.16	25.42	25.28	25.29	23.72	1512.8	6.33	0.479E+07	0.01049	18.14	15.35	16.67	16.65	16.71	16.68
15	333.3	25.23	25.51	25.37	25.37	23.82	1516.3	6.31	0.483E+07	0.01146	18.48	15.44	16.82	16.82	16.89	16.86
16	363.3	25.33	25.56	25.49	25.47	23.93	1520.0	6.29	0.488E+07	0.01250	18.55	15.97	16.71	16.94	16.99	16.96
17	383.3	25.40	25.69	25.55	25.55	24.00	1522.5	6.28	0.490E+07	0.01319	18.55	15.38	16.78	16.80	16.87	16.84
18	403.3	25.47	25.75	25.60	25.60	24.07	1525.0	6.27	0.493E+07	0.01388	18.69	15.56	17.02	17.00	17.07	17.04
19	423.3	25.59	25.81	25.76	25.73	24.14	1527.5	6.26	0.496E+07	0.01457	18.06	15.67	16.10	16.43	16.48	16.46
20	443.3	25.61	25.88	25.76	25.76	24.21	1530.0	6.25	0.499E+07	0.01526	18.65	15.61	16.84	16.92	16.98	16.95
21	463.3	25.87	25.97	26.03	25.98	24.28	1532.5	6.24	0.502E+07	0.01595	16.46	15.50	14.91	15.42	15.45	15.43
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.44	25.70	25.59	25.58	24.03	1523.5	6.28	0.492E+07	0.01347	18.50	15.61	16.71	16.82	16.88	16.85

UPWARD INCLINATION _____ 3 - 1500

INPUT ELECTRIC POWER = 695.2 W HEAT RATE GAINED BY WATER = 696.1 W HEAT BALANCE ERROR =-0.13%
MASS FLOW RATE = 43.0754 G/S PRESSURE DROP= 0.9474MMH20 FRICTION FACTOR = 0.014590 FREM = 21.9178
REM = 1502.2 GRM = 0.11675E+08 UPSTREAM BULK TEMPERATURE = 22.92DEG C DOWNSTREAM BULK TEMPERATURE = 26.79DEG C
PRM = 6.145 RAM = 0.71749E+08 INLET BULK TEMPERATURE = 22.92DEG C OUTLET BULK TEMPERATURE = 26.79DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.39	25.37	25.38	25.38	22.97	1439.2	6.44	0.100E+08	0.00020	23.93	24.16	24.04	24.04	24.04	24.04
4	15.5	26.30	26.54	26.33	26.37	23.06	1441.9	6.43	0.101E+08	0.00055	17.86	16.62	17.71	17.46	17.48	17.47
5	25.5	26.65	26.95	26.77	26.79	23.13	1444.5	6.42	0.101E+08	0.00090	16.49	15.19	15.93	15.87	15.89	15.88
6	45.5	26.68	26.95	26.73	26.77	23.30	1449.8	6.39	0.103E+08	0.00162	17.13	15.90	16.91	16.70	16.71	16.70
7	75.5	26.84	27.27	26.94	27.00	23.54	1457.9	6.35	0.105E+08	0.00268	17.58	15.58	17.08	16.79	16.83	16.81
8	105.5	26.96	27.53	27.01	27.13	23.79	1466.1	6.31	0.107E+08	0.00375	18.28	15.52	18.02	17.38	17.46	17.42
9	135.5	27.24	27.72	27.37	27.43	24.04	1474.4	6.27	0.109E+08	0.00482	18.08	15.76	17.37	17.10	17.14	17.12
10	165.2	27.09	27.70	27.41	27.40	24.28	1482.6	6.24	0.111E+08	0.00588	20.66	16.94	18.52	18.57	18.66	18.62
11	205.2	27.34	27.96	27.63	27.64	24.61	1493.9	6.18	0.114E+08	0.00731	21.25	17.29	19.15	19.11	19.21	19.16
12	245.2	27.76	28.28	28.00	28.01	24.94	1505.4	6.13	0.118E+08	0.00874	20.54	17.30	18.92	18.85	18.92	18.89
13	275.2	27.81	28.43	28.23	28.17	25.19	1514.1	6.09	0.120E+08	0.00981	22.03	17.83	19.02	19.36	19.48	19.42
14	305.2	27.98	28.56	28.25	28.26	25.44	1522.9	6.06	0.122E+08	0.01089	22.72	18.52	20.51	20.46	20.56	20.51
15	333.3	28.32	28.88	28.68	28.64	25.67	1531.2	6.02	0.125E+08	0.01190	21.76	17.99	19.15	19.42	19.51	19.46
16	363.3	28.48	29.07	28.72	28.75	25.92	1540.2	5.98	0.127E+08	0.01298	22.48	18.28	20.60	20.38	20.49	20.44
17	383.3	28.65	29.19	28.87	28.90	26.08	1546.3	5.95	0.129E+08	0.01370	22.48	18.58	20.64	20.49	20.59	20.54
18	403.3	28.75	29.34	29.02	29.03	26.25	1552.4	5.93	0.131E+08	0.01442	22.99	18.61	20.78	20.67	20.79	20.73
19	423.3	28.99	29.58	29.30	29.30	26.41	1558.6	5.90	0.133E+08	0.01514	22.31	18.17	19.93	19.98	20.09	20.03
20	443.3	29.07	29.66	29.39	29.38	26.58	1564.8	5.87	0.134E+08	0.01587	23.07	18.67	20.47	20.55	20.67	20.61
21	463.3	29.58	29.89	29.71	29.72	26.74	1571.1	5.85	0.136E+08	0.01659	20.32	18.29	19.41	19.33	19.36	19.34
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.71	29.29	29.00	29.00	26.15	1548.9	5.94	0.130E+08	0.01400	22.51	18.38	20.26	20.25	20.36	20.30

UPWARD INCLINATION _____ 4 - 1500

INPUT ELECTRIC POWER = 967.0 W   HEAT RATE GAINED BY WATER = 967.7 W   HEAT BALANCE ERROR =-0.08%
MASS FLOW RATE = 42.7860 G/S   PRESSURE DROP= 1.0165MMH20   FRICTION FACTOR = 0.015866   FREM = 23.7860
REM = 1499.2   GRM = 0.16500E+08   UPSTREAM BULK TEMPERATURE = 22.34DEG C   DOWNSTREAM BULK TEMPERATURE = 27.76DEG C
PRM = 6.114   RAM = 0.10087E+09   INLET BULK TEMPERATURE = 22.35DEG C   OUTLET BULK TEMPERATURE = 27.76DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.84	25.93	25.88	25.88	22.41	1412.2	6.53	0.133E+08	0.00020	23.61	23.00	23.30	23.30	23.30	23.30
4	15.5	26.60	27.05	26.71	26.77	22.53	1415.8	6.51	0.134E+08	0.00055	19.84	17.89	19.32	19.06	19.09	19.08
5	25.5	26.98	27.48	27.30	27.26	22.64	1419.4	6.49	0.135E+08	0.00091	18.63	16.72	17.35	17.49	17.51	17.50
6	45.5	27.02	27.53	27.20	27.24	22.88	1426.7	6.46	0.138E+08	0.00162	19.48	17.34	18.66	18.50	18.53	18.52
7	75.5	27.31	27.88	27.44	27.52	23.22	1437.7	6.40	0.142E+08	0.00270	19.71	17.33	19.12	18.77	18.82	18.80
8	105.5	27.46	28.25	27.65	27.75	23.57	1448.9	6.35	0.146E+08	0.00377	20.70	17.21	19.75	19.26	19.35	19.31
9	135.5	28.00	28.64	28.21	28.26	23.91	1460.3	6.29	0.150E+08	0.00485	19.74	17.06	18.75	18.52	18.58	18.55
10	165.2	27.92	28.84	28.45	28.41	24.26	1471.8	6.24	0.155E+08	0.00592	21.98	17.55	19.22	19.36	19.49	19.43
11	205.2	28.23	29.07	28.58	28.62	24.72	1487.5	6.17	0.161E+08	0.00736	22.91	18.46	20.80	20.62	20.74	20.68
12	245.2	28.62	29.93	28.95	29.11	25.18	1503.6	6.09	0.167E+08	0.00880	23.36	16.91	21.31	20.43	20.72	20.58
13	275.2	28.79	29.55	29.32	29.24	25.53	1515.8	6.04	0.171E+08	0.00989	24.61	19.97	21.16	21.59	21.72	21.66
14	305.2	28.96	29.76	29.29	29.32	25.87	1528.3	5.98	0.176E+08	0.01098	26.00	20.63	23.47	23.24	23.39	23.32
15	333.3	29.41	30.24	29.94	29.88	26.20	1540.2	5.93	0.181E+08	0.01200	24.97	19.81	21.43	21.76	21.91	21.83
16	363.3	29.63	30.47	30.01	30.03	26.54	1553.0	5.88	0.186E+08	0.01309	25.98	20.41	23.12	22.99	23.16	23.07
17	383.3	29.90	30.62	30.24	30.25	26.77	1561.8	5.84	0.190E+08	0.01382	25.57	20.80	23.08	23.01	23.13	23.07
18	403.3	30.13	30.92	30.51	30.52	27.01	1569.5	5.81	0.193E+08	0.01455	25.59	20.44	22.85	22.79	22.93	22.86
19	423.3	30.45	31.29	30.93	30.90	27.24	1576.9	5.78	0.196E+08	0.01527	24.91	19.72	21.63	21.82	21.97	21.90
20	443.3	30.59	31.47	31.05	31.04	27.47	1584.3	5.75	0.199E+08	0.01600	25.56	19.99	22.31	22.37	22.54	22.46
21	463.3	30.95	31.65	31.42	31.36	27.70	1591.8	5.72	0.202E+08	0.01673	24.55	20.22	21.47	21.81	21.92	21.87
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	30.02	30.83	30.45	30.44	26.87	1564.3	5.83	0.191E+08	0.01412	25.43	20.20	22.40	22.46	22.61	22.53

UPWARD INCLINATION _____ 5 - 1500

INPUT ELECTRIC POWER = 1324.0 W   HEAT RATE GAINED BY WATER = 1344.4 W   HEAT BALANCE ERROR =-1.54%
MASS FLOW RATE = 42.7860 G/S   PRESSURE DROP= 1.0769MMH20   FRICTION FACTOR = 0.016809   FREM = 25.1285
REM = 1494.9   GRM = 0.22695E+08   UPSTREAM BULK TEMPERATURE = 21.17DEG C   DOWNSTREAM BULK TEMPERATURE = 28.69DEG C
PRM = 6.133   RAM = 0.13919E+09   INLET BULK TEMPERATURE = 21.17DEG C   OUTLET BULK TEMPERATURE = 28.69DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.03	26.21	26.12	26.12	21.26	1374.6	6.73	0.167E+08	0.00020	23.62	22.78	23.19	23.19	23.19	23.19
4	15.5	26.91	27.55	27.02	27.12	21.42	1380.1	6.70	0.169E+08	0.00055	20.53	18.38	20.13	19.76	19.79	19.77
5	25.5	27.42	28.03	27.77	27.75	21.58	1385.6	6.67	0.172E+08	0.00091	19.28	17.47	18.19	18.26	18.28	18.27
6	45.5	27.38	28.04	27.57	27.64	21.90	1396.6	6.61	0.177E+08	0.00162	20.52	18.33	19.85	19.61	19.64	19.62
7	75.5	27.65	28.41	27.83	27.93	22.39	1411.3	6.54	0.184E+08	0.00269	21.34	18.65	20.62	20.26	20.31	20.28
8	105.5	27.80	28.90	28.01	28.18	22.87	1426.4	6.46	0.192E+08	0.00377	22.75	18.61	21.80	21.12	21.24	21.18
9	135.5	28.44	29.33	28.74	28.81	23.35	1441.8	6.38	0.199E+08	0.00484	22.00	18.73	20.78	20.50	20.57	20.53
10	165.2	28.36	29.54	29.01	28.98	23.82	1457.3	6.31	0.207E+08	0.00591	24.65	19.58	21.60	21.71	21.86	21.78
11	205.2	28.68	29.83	29.14	29.20	24.46	1478.8	6.21	0.218E+08	0.00735	26.55	20.85	23.89	23.62	23.79	23.71
12	245.2	29.40	30.46	29.90	29.91	25.11	1501.0	6.11	0.230E+08	0.00880	26.01	20.85	23.28	23.21	23.36	23.28
13	275.2	29.68	30.77	30.41	30.32	25.59	1518.0	6.03	0.239E+08	0.00989	27.24	21.50	23.11	23.56	23.74	23.65
14	305.2	29.96	31.06	30.41	30.46	26.07	1535.4	5.95	0.249E+08	0.01098	28.59	22.36	25.65	25.37	25.56	25.47
15	333.3	30.63	31.75	31.41	31.30	26.52	1552.1	5.88	0.258E+08	0.01201	27.05	21.29	22.74	23.27	23.45	23.36
16	363.3	31.02	32.14	31.55	31.57	27.00	1569.4	5.81	0.268E+08	0.01310	27.65	21.63	24.42	24.34	24.53	24.44
17	383.3	31.36	32.34	31.78	31.81	27.32	1579.6	5.77	0.274E+08	0.01383	27.50	22.13	24.92	24.72	24.87	24.79
18	403.3	31.68	32.77	32.13	32.18	27.64	1589.9	5.73	0.280E+08	0.01456	27.50	21.62	24.72	24.46	24.64	24.55
19	423.3	32.07	33.19	32.73	32.68	27.96	1600.4	5.69	0.286E+08	0.01529	27.02	21.20	23.26	23.51	23.68	23.60
20	443.3	32.25	33.33	32.76	32.78	28.28	1611.1	5.65	0.293E+08	0.01602	27.91	21.98	24.73	24.66	24.84	24.75
21	463.3	32.72	33.67	33.27	33.23	28.60	1621.8	5.61	0.299E+08	0.01675	26.90	21.87	23.73	23.93	24.06	23.99
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	31.50	32.59	32.06	32.05	27.45	1583.8	5.76	0.277E+08	0.01414	27.44	21.64	24.13	24.16	24.34	24.25

UPWARD INCLINATION _____ 6 - 1500

INPUT ELECTRIC POWER = 2234.8 W HEAT RATE GAINED BY WATER = 2254.9 W HEAT BALANCE ERROR =-0.90%
MASS FLOW RATE = 39.1700 G/S PRESSURE DROP= 1.0384MMH20 FRICTION FACTOR = 0.019313 FREM = 29.0149
REM = 1502.3 GRM = 0.52213E+08 UPSTREAM BULK TEMPERATURE = 22.26DEG C DOWNSTREAM BULK TEMPERATURE = 36.06DEG C
PRM = 5.539 RAM = 0.28918E+09 INLET BULK TEMPERATURE = 22.28DEG C OUTLET BULK TEMPERATURE = 36.05DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	30.14	30.68	30.41	30.41	22.44	1293.5	6.53	0.310E+08	0.00021	24.45	22.86	23.63	23.63	23.64	23.64
4	15.5	30.55	31.71	30.77	30.95	22.73	1301.9	6.48	0.318E+08	0.00060	24.08	20.96	23.42	22.90	22.97	22.94
5	25.5	31.22	32.32	31.84	31.80	23.02	1310.4	6.43	0.326E+08	0.00099	22.96	20.24	21.34	21.43	21.47	21.45
6	45.5	31.20	32.35	31.60	31.68	23.61	1327.8	6.34	0.342E+08	0.00178	24.77	21.51	23.53	23.27	23.33	23.30
7	75.5	31.62	32.99	32.05	32.18	24.49	1354.7	6.20	0.367E+08	0.00296	26.31	22.06	24.81	24.40	24.50	24.45
8	105.5	32.01	33.90	32.37	32.66	25.38	1382.8	6.06	0.395E+08	0.00414	28.19	21.94	26.76	25.68	25.91	25.79
9	135.5	32.96	34.41	33.45	33.57	26.26	1412.0	5.92	0.424E+08	0.00533	27.85	22.91	25.94	25.53	25.66	25.60
10	165.2	33.26	35.09	34.16	34.17	27.13	1440.5	5.79	0.454E+08	0.00651	30.41	23.41	26.49	26.47	26.70	26.59
11	205.2	33.84	35.63	34.67	34.65	28.31	1476.6	5.65	0.492E+08	0.00810	33.58	25.38	29.68	29.29	29.58	29.43
12	245.2	35.12	36.77	35.94	35.94	29.48	1512.4	5.50	0.534E+08	0.00970	32.85	25.44	28.68	28.68	28.91	28.79
13	275.2	35.87	37.53	36.97	36.83	30.36	1541.3	5.39	0.567E+08	0.01090	33.61	25.82	28.02	28.60	28.86	28.73
14	305.2	36.50	38.08	37.16	37.23	31.24	1571.3	5.28	0.603E+08	0.01211	35.10	27.00	31.20	30.86	31.12	30.99
15	333.3	37.62	39.26	38.71	38.57	32.07	1599.4	5.17	0.637E+08	0.01325	33.20	25.62	27.77	28.33	28.59	28.46
16	363.3	38.41	40.17	39.27	39.28	32.95	1627.1	5.07	0.673E+08	0.01448	33.69	25.48	29.09	29.05	29.34	29.20
17	383.3	39.02	40.53	39.65	39.71	33.54	1646.1	5.00	0.697E+08	0.01531	33.51	26.25	30.05	29.74	29.96	29.85
18	403.3	39.77	41.35	40.40	40.48	34.13	1665.6	4.94	0.723E+08	0.01614	32.47	25.39	29.24	28.86	29.08	28.97
19	423.3	40.56	42.17	41.47	41.42	34.71	1685.5	4.87	0.749E+08	0.01697	31.33	24.54	27.09	27.31	27.51	27.41
20	443.3	40.86	42.57	41.62	41.67	35.30	1705.9	4.80	0.777E+08	0.01781	32.85	25.14	28.93	28.71	28.96	28.83
21	463.3	41.23	43.15	41.96	42.08	35.89	1726.9	4.73	0.806E+08	0.01865	34.20	25.12	30.06	29.50	29.86	29.68
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	39.37	41.01	40.18	40.19	33.78	1654.9	4.98	0.709E+08	0.01566	32.84	25.40	28.69	28.67	28.91	28.79

UPWARD INCLINATION _____ 7 - 1500

INPUT ELECTRIC POWER = 3356.9 W HEAT RATE GAINED BY WATER = 3318.4 W HEAT BALANCE ERROR = 1.15%
MASS FLOW RATE = 34.6100 G/S PRESSURE DROP= 1.0316MMH20 FRICTION FACTOR = 0.024521 FREM = 36.5844
REM = 1491.9 GRM = 0.11084E+09 UPSTREAM BULK TEMPERATURE = 23.31DEG C DOWNSTREAM BULK TEMPERATURE = 46.28DEG C
PRM = 4.858 RAM = 0.53840E+09 INLET BULK TEMPERATURE = 23.33DEG C OUTLET BULK TEMPERATURE = 46.28DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	34.22	35.20	34.71	34.71	23.60	1172.8	6.34	0.502E+08	0.00024	26.02	23.82	24.87	24.87	24.90	24.89
4	15.5	34.52	36.29	34.91	35.16	24.09	1185.9	6.27	0.523E+08	0.00069	26.46	22.63	25.52	24.94	25.03	24.99
5	25.5	35.48	37.11	36.46	36.38	24.58	1199.3	6.19	0.544E+08	0.00113	25.29	22.01	23.21	23.37	23.43	23.40
6	45.5	35.37	37.08	36.02	36.12	25.56	1227.0	6.03	0.589E+08	0.00202	28.03	23.89	26.31	26.05	26.13	26.09
7	75.5	35.95	37.94	36.60	36.77	27.02	1270.1	5.81	0.663E+08	0.00337	30.73	25.13	28.64	28.13	28.28	28.21
8	105.5	36.56	39.21	37.06	37.47	28.49	1308.9	5.62	0.734E+08	0.00472	33.88	25.50	31.92	30.44	30.80	30.62
9	135.5	38.07	40.21	38.87	39.00	29.96	1350.1	5.44	0.812E+08	0.00607	33.61	26.60	30.60	30.14	30.35	30.24
10	165.2	38.85	41.39	40.00	40.06	31.41	1393.6	5.25	0.898E+08	0.00742	36.54	27.22	31.65	31.43	31.77	31.60
11	205.2	40.37	42.71	41.14	41.34	33.37	1449.7	5.02	0.102E+09	0.00927	38.62	28.94	34.80	33.92	34.29	34.11
12	245.2	42.68	44.89	43.69	43.74	35.33	1508.2	4.80	0.114E+09	0.01115	36.57	28.14	32.16	31.98	32.26	32.12
13	275.2	43.86	46.12	45.40	45.19	36.80	1555.3	4.63	0.125E+09	0.01258	37.92	28.73	31.17	31.91	32.25	32.08
14	305.2	44.86	46.93	45.65	45.77	38.27	1598.8	4.49	0.136E+09	0.01399	40.53	30.83	36.18	35.59	35.93	35.76
15	333.3	46.72	48.73	47.78	47.75	39.64	1641.5	4.36	0.147E+09	0.01531	37.63	29.33	32.74	32.85	33.11	32.98
16	363.3	48.25	50.34	49.12	49.21	41.11	1689.6	4.23	0.160E+09	0.01673	37.23	28.78	33.16	32.81	33.09	32.95
17	383.3	49.30	51.12	49.89	50.05	42.09	1722.0	4.14	0.169E+09	0.01768	36.77	29.37	34.00	33.31	33.53	33.42
18	403.3	50.59	52.45	51.15	51.34	43.07	1751.5	4.06	0.177E+09	0.01863	35.19	28.23	32.75	32.02	32.23	32.12
19	423.3	51.59	53.67	52.62	52.63	44.05	1782.0	3.99	0.186E+09	0.01959	35.04	27.46	30.81	30.80	31.03	30.92
20	443.3	52.09	54.35	53.31	53.27	45.03	1813.6	3.91	0.195E+09	0.02055	37.33	28.29	31.83	32.01	32.32	32.16
21	463.3	52.76	55.47	53.68	53.90	46.01	1846.3	3.84	0.205E+09	0.02152	38.96	27.82	34.31	33.36	33.85	33.60
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	49.76	51.78	50.65	50.71	42.50	1733.4	4.12	0.172E+09	0.01808	36.53	28.58	32.55	32.30	32.55	32.43

Appendix E

Experimental Data for $\alpha = 20°$

UPWARD INCLINATION _____ 1 - 500

INPUT ELECTRIC POWER = 151.4 W HEAT RATE GAINED BY WATER = 149.7 W HEAT BALANCE ERROR = 1.09%
MASS FLOW RATE = 14.7500 G/S PRESSURE DROP= 0.2619MMH20 FRICTION FACTOR = 0.034408 FREM = 17.1590
REM = 498.7 GRM = 0.22470E+07 UPSTREAM BULK TEMPERATURE = 22.28DEG C DOWNSTREAM BULK TEMPERATURE = 24.71DEG C
PRM = 6.360 RAM = 0.14291E+08 INLET BULK TEMPERATURE = 22.28DEG C OUTLET BULK TEMPERATURE = 24.71DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.03	23.02	23.03	23.03	22.31	485.7	6.55	0.204E+07	0.00057	17.29	17.53	17.41	17.41	17.41	17.41
4	15.5	23.37	23.39	23.37	23.38	22.36	486.3	6.54	0.205E+07	0.00160	12.36	12.20	12.36	12.32	12.32	12.32
5	25.5	23.46	23.51	23.48	23.48	22.41	486.8	6.53	0.205E+07	0.00264	11.95	11.35	11.72	11.68	11.69	11.68
6	45.5	23.54	23.59	23.54	23.55	22.52	487.9	6.51	0.207E+07	0.00471	12.18	11.67	12.23	12.07	12.08	12.08
7	75.5	23.59	23.71	23.59	23.62	22.67	489.6	6.49	0.210E+07	0.00782	13.55	12.05	13.64	13.18	13.22	13.20
8	105.5	23.67	23.83	23.69	23.72	22.83	491.3	6.47	0.213E+07	0.01092	14.86	12.41	14.57	14.03	14.10	14.07
9	135.5	23.84	23.95	23.86	23.88	22.98	493.0	6.44	0.215E+07	0.01404	14.60	12.90	14.24	13.97	14.00	13.98
10	165.2	23.94	24.06	23.96	23.98	23.14	494.7	6.42	0.218E+07	0.01712	15.48	13.71	15.14	14.83	14.87	14.85
11	205.2	24.10	24.28	24.22	24.21	23.34	497.0	6.38	0.222E+07	0.02127	16.55	13.35	14.21	14.49	14.58	14.53
12	245.2	24.42	24.54	24.45	24.46	23.55	499.3	6.35	0.226E+07	0.02543	14.32	12.55	13.95	13.66	13.69	13.68
13	275.2	24.55	24.63	24.59	24.59	23.71	501.1	6.33	0.229E+07	0.02856	14.75	13.43	14.17	14.11	14.13	14.12
14	305.2	24.71	24.83	24.75	24.76	23.86	502.8	6.30	0.232E+07	0.03168	14.70	12.88	14.02	13.87	13.90	13.89
15	333.3	24.70	24.81	24.79	24.77	24.01	504.5	6.28	0.234E+07	0.03461	17.94	15.46	16.01	16.31	16.36	16.33
16	363.3	24.94	25.06	24.95	24.98	24.16	506.3	6.25	0.237E+07	0.03774	15.98	13.91	15.73	15.29	15.34	15.31
17	383.3	25.01	25.13	25.08	25.08	24.27	507.5	6.24	0.239E+07	0.03983	16.68	14.40	15.33	15.39	15.43	15.41
18	403.3	25.13	25.21	25.15	25.16	24.37	508.7	6.22	0.241E+07	0.04192	16.42	14.78	15.87	15.71	15.73	15.72
19	423.3	25.25	25.39	25.34	25.33	24.47	509.9	6.21	0.243E+07	0.04401	16.01	13.63	14.36	14.54	14.59	14.56
20	443.3	25.33	25.46	25.43	25.41	24.58	511.1	6.19	0.246E+07	0.04610	16.52	14.07	14.67	14.93	14.98	14.96
21	463.3	25.53	25.56	25.64	25.60	24.68	512.4	6.17	0.248E+07	0.04819	14.61	14.09	12.94	13.61	13.64	13.63
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.06	25.18	25.12	25.12	24.31	508.0	6.23	0.240E+07	0.04070	16.59	14.37	15.33	15.36	15.41	15.38

UPWARD INCLINATION _____ 2 - 500

INPUT ELECTRIC POWER = 301.8 W HEAT RATE GAINED BY WATER = 309.3 W HEAT BALANCE ERROR =-2.48%
MASS FLOW RATE = 14.2389 G/S PRESSURE DROP= 0.3399MMH20 FRICTION FACTOR = 0.047900 FREM = 24.0254
REM = 501.6 GRM = 0.53730E+07 UPSTREAM BULK TEMPERATURE = 22.68DEG C DOWNSTREAM BULK TEMPERATURE = 27.88DEG C
PRM = 6.078 RAM = 0.32655E+08 INLET BULK TEMPERATURE = 22.68DEG C OUTLET BULK TEMPERATURE = 27.88DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.14	24.17	24.16	24.16	22.74	473.4	6.48	0.436E+07	0.00059	18.46	18.14	18.30	18.30	18.30	18.30
4	15.5	24.48	24.64	24.53	24.55	22.86	474.6	6.46	0.440E+07	0.00166	15.92	14.44	15.40	15.27	15.29	15.28
5	25.5	24.67	24.84	24.78	24.77	22.97	475.8	6.44	0.444E+07	0.00274	15.15	13.81	14.22	14.33	14.35	14.34
6	45.5	24.80	24.99	24.88	24.89	23.19	478.1	6.41	0.453E+07	0.00488	15.96	14.34	15.23	15.17	15.19	15.18
7	75.5	24.93	25.10	24.96	24.99	23.52	481.7	6.36	0.465E+07	0.00811	18.33	16.33	17.95	17.61	17.64	17.62
8	105.5	25.12	25.34	25.11	25.17	23.85	485.3	6.30	0.478E+07	0.01134	20.35	17.28	20.52	19.56	19.67	19.61
9	135.5	25.43	25.68	25.59	25.57	24.19	489.0	6.25	0.491E+07	0.01458	20.71	17.23	18.35	18.58	18.66	18.62
10	165.2	25.75	26.03	25.92	25.91	24.52	492.7	6.20	0.505E+07	0.01779	20.82	17.01	18.27	18.49	18.59	18.54
11	205.2	26.19	26.48	26.35	26.34	24.96	497.8	6.13	0.523E+07	0.02212	20.85	16.88	18.50	18.58	18.68	18.63
12	245.2	26.76	26.94	26.82	26.84	25.40	503.0	6.06	0.543E+07	0.02647	18.95	16.64	18.06	17.89	17.93	17.91
13	275.2	26.98	27.20	27.11	27.10	25.74	506.9	6.01	0.557E+07	0.02973	20.66	17.48	18.69	18.81	18.88	18.85
14	305.2	27.39	27.58	27.47	27.48	26.07	511.0	5.95	0.573E+07	0.03300	19.34	17.00	18.29	18.19	18.23	18.21
15	333.3	27.54	27.79	27.71	27.69	26.38	514.8	5.90	0.587E+07	0.03607	22.03	18.12	19.26	19.57	19.67	19.62
16	363.3	27.98	28.18	28.07	28.08	26.71	519.0	5.85	0.603E+07	0.03935	20.16	17.42	18.83	18.76	18.81	18.79
17	383.3	28.17	28.40	28.26	28.27	26.93	521.6	5.82	0.614E+07	0.04154	20.66	17.47	19.27	19.10	19.17	19.14
18	403.3	28.42	28.61	28.52	28.52	27.16	523.9	5.79	0.623E+07	0.04372	20.27	17.53	18.78	18.79	18.84	18.81
19	423.3	28.69	28.88	28.80	28.79	27.38	526.3	5.76	0.633E+07	0.04591	19.51	16.96	18.00	18.07	18.12	18.10
20	443.3	28.85	29.07	28.94	28.96	27.60	528.7	5.74	0.643E+07	0.04809	20.44	17.36	19.05	18.91	18.97	18.94
21	463.3	29.15	29.31	29.26	29.25	27.82	531.1	5.71	0.653E+07	0.05028	19.14	17.11	17.74	17.90	17.93	17.92
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.27	28.49	28.38	28.38	27.03	522.4	5.81	0.617E+07	0.04245	20.51	17.48	18.87	18.87	18.93	18.90

UPWARD INCLINATION _____ 3 - 500

INPUT ELECTRIC POWER = 581.7 W HEAT RATE GAINED BY WATER = 592.7 W HEAT BALANCE ERROR =-1.89%
MASS FLOW RATE = 13.7300 G/S PRESSURE DROP= 0.5157MMH20 FRICTION FACTOR = 0.078129 FREM = 39.6886
REM = 508.0 GRM = 0.12172E+08 UPSTREAM BULK TEMPERATURE = 22.25DEG C DOWNSTREAM BULK TEMPERATURE = 32.60DEG C
PRM = 5.757 RAM = 0.70077E+08 INLET BULK TEMPERATURE = 22.26DEG C OUTLET BULK TEMPERATURE = 32.59DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.06	25.20	25.13	25.13	22.38	452.9	6.54	0.812E+07	0.00061	18.50	17.57	18.02	18.02	18.03	18.03
4	15.5	25.53	25.76	25.55	25.60	22.60	455.1	6.50	0.826E+07	0.00172	16.94	15.68	16.78	16.53	16.54	16.53
5	25.5	25.77	26.10	25.94	25.94	22.82	457.3	6.47	0.842E+07	0.00284	16.79	15.10	15.86	15.88	15.90	15.89
6	46.5	25.90	26.22	26.00	26.03	23.26	461.8	6.40	0.873E+07	0.00507	18.77	16.73	18.06	17.87	17.91	17.89
7	75.5	26.26	26.63	26.33	26.38	23.93	468.7	6.29	0.922E+07	0.00842	21.14	18.26	20.56	20.07	20.13	20.10
8	105.5	26.74	27.22	26.84	26.91	24.59	475.9	6.19	0.973E+07	0.01179	22.91	18.73	21.87	21.22	21.34	21.28
9	135.5	27.61	27.94	27.74	27.75	25.25	483.3	6.08	0.103E+08	0.01516	20.87	18.29	19.77	19.63	19.67	19.65
10	165.2	28.17	28.59	28.36	28.37	25.90	490.8	5.98	0.108E+08	0.01852	21.67	18.26	19.97	19.89	19.97	19.93
11	205.2	28.90	29.35	29.12	29.12	26.78	501.3	5.84	0.116E+08	0.02306	23.18	19.08	21.03	20.98	21.08	21.03
12	245.2	29.84	30.21	30.01	30.02	27.67	510.5	5.73	0.124E+08	0.02759	22.48	19.23	20.85	20.79	20.85	20.82
13	275.2	30.40	30.77	30.66	30.63	28.33	517.5	5.64	0.130E+08	0.03100	23.51	19.96	20.90	21.24	21.32	21.28
14	305.2	31.03	31.39	31.17	31.19	28.99	524.7	5.56	0.136E+08	0.03441	23.94	20.35	22.39	22.19	22.26	22.23
15	333.3	31.58	31.91	31.83	31.79	29.61	531.6	5.48	0.142E+08	0.03762	24.70	21.12	21.92	22.34	22.41	22.38
16	363.3	32.27	32.64	32.39	32.43	30.27	539.2	5.40	0.148E+08	0.04105	24.24	20.50	22.88	22.54	22.63	22.58
17	383.3	32.73	33.07	32.87	32.88	30.71	544.3	5.34	0.153E+08	0.04335	24.06	20.57	22.53	22.35	22.42	22.38
18	403.3	33.22	33.56	33.36	33.38	31.15	549.6	5.29	0.157E+08	0.04564	23.41	20.13	21.92	21.79	21.85	21.82
19	423.3	33.71	34.12	33.94	33.93	31.59	555.0	5.23	0.162E+08	0.04794	22.83	19.20	20.65	20.75	20.83	20.79
20	443.3	34.05	34.40	34.25	34.24	32.03	560.2	5.18	0.167E+08	0.05026	23.94	20.48	21.80	21.93	22.00	21.97
21	463.3	34.68	34.99	34.81	34.83	32.47	566.0	5.13	0.172E+08	0.05260	21.86	19.18	20.68	20.56	20.60	20.58
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	32.93	33.28	33.11	33.11	30.89	546.7	5.32	0.155E+08	0.04431	23.86	20.33	21.95	21.95	22.02	21.99

UPWARD INCLINATION _____ 4 - 500

INPUT ELECTRIC POWER = 931.8 W HEAT RATE GAINED BY WATER = 947.1 W HEAT BALANCE ERROR =-1.64%
MASS FLOW RATE = 12.4500 G/S PRESSURE DROP= 0.7426MMH20 FRICTION FACTOR = 0.136598 FREM = 68.2419
REM = 499.6 GRM = 0.25351E+08 UPSTREAM BULK TEMPERATURE = 22.13DEG C DOWNSTREAM BULK TEMPERATURE = 40.36DEG C
PRM = 5.275 RAM = 0.13372E+09 INLET BULK TEMPERATURE = 22.15DEG C OUTLET BULK TEMPERATURE = 40.36DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.45	26.71	26.58	26.58	22.37	410.5	6.54	0.130E+08	0.00067	19.39	18.22	18.79	18.79	18.80	18.79
4	15.5	26.74	27.30	26.85	26.93	22.76	414.0	6.48	0.134E+08	0.00190	19.84	17.41	19.31	18.92	18.97	18.94
5	25.5	27.20	27.67	27.47	27.45	23.14	417.6	6.42	0.138E+08	0.00313	19.47	17.46	18.28	18.34	18.37	18.36
6	45.5	27.36	27.90	27.57	27.60	23.92	425.0	6.29	0.147E+08	0.00560	22.96	19.83	21.62	21.45	21.51	21.48
7	75.5	28.12	28.68	28.28	28.34	25.09	436.6	6.11	0.162E+08	0.00931	25.92	21.86	24.62	24.16	24.26	24.21
8	105.5	29.25	29.93	29.35	29.47	26.25	448.7	5.92	0.178E+08	0.01305	26.16	21.32	25.29	24.36	24.52	24.44
9	135.5	30.67	31.20	30.89	30.91	27.42	460.5	5.76	0.194E+08	0.01681	24.01	20.67	22.53	22.37	22.44	22.41
10	165.2	31.65	32.30	31.98	31.98	28.57	471.6	5.61	0.210E+08	0.02053	25.37	20.91	22.89	22.91	23.02	22.96
11	205.2	33.03	33.68	33.28	33.32	30.12	487.4	5.42	0.234E+08	0.02556	26.75	21.89	24.62	24.34	24.47	24.41
12	245.2	34.71	35.23	34.94	34.95	31.68	504.2	5.22	0.261E+08	0.03063	25.58	21.79	23.77	23.65	23.73	23.69
13	275.2	35.70	36.24	36.10	36.03	32.84	516.1	5.08	0.281E+08	0.03450	27.04	22.71	23.73	24.20	24.30	24.25
14	305.2	36.81	37.32	36.94	37.00	34.01	528.1	4.95	0.301E+08	0.03841	27.48	23.22	26.28	25.71	25.81	25.76
15	333.3	37.84	38.34	38.18	38.14	35.10	540.0	4.82	0.322E+08	0.04210	27.98	23.66	24.95	25.29	25.39	25.34
16	363.3	39.02	39.55	39.19	39.24	36.26	553.2	4.69	0.346E+08	0.04608	27.77	23.27	26.20	25.75	25.86	25.81
17	383.3	39.74	40.22	39.87	39.93	37.04	562.1	4.60	0.363E+08	0.04874	28.27	24.02	27.00	26.47	26.57	26.52
18	403.3	40.56	41.01	40.68	40.73	37.82	570.3	4.53	0.379E+08	0.05134	27.84	23.91	26.70	26.21	26.29	26.25
19	423.3	41.39	41.98	41.67	41.68	38.59	578.7	4.46	0.396E+08	0.05396	27.21	22.53	24.81	24.73	24.84	24.78
20	443.3	41.99	42.51	42.24	42.24	39.37	587.4	4.39	0.413E+08	0.05658	29.05	24.21	26.54	26.48	26.59	26.53
21	463.3	42.83	43.41	42.97	43.05	40.15	596.3	4.32	0.432E+08	0.05921	28.37	23.26	26.92	26.22	26.37	26.29
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	40.09	40.60	40.30	40.33	37.36	565.3	4.58	0.370E+08	0.04980	28.02	23.60	26.03	25.82	25.92	25.87

UPWARD INCLINATION _____ 1 - 1000

INPUT ELECTRIC POWER = 145.3 W HEAT RATE GAINED BY WATER = 144.6 W HEAT BALANCE ERROR = 0.45%
MASS FLOW RATE = 29.6962 G/S PRESSURE DROP= 0.5827MMH20 FRICTION FACTOR = 0.018887 FREM = 18.8821
REM = 999.8 GRM = 0.21360E+07 UPSTREAM BULK TEMPERATURE = 22.72DEG C DOWNSTREAM BULK TEMPERATURE = 23.89DEG C
PRM = 6.390 RAM = 0.13649E+08 INLET BULK TEMPERATURE = 22.72DEG C OUTLET BULK TEMPERATURE = 23.89DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.37	23.33	23.35	23.35	22.74	987.2	6.48	0.204E+07	0.00028	19.19	20.34	19.75	19.75	19.76	19.75
4	15.5	23.48	23.50	23.48	23.49	22.76	987.7	6.48	0.204E+07	0.00080	16.72	16.39	16.72	16.64	16.64	16.64
5	25.5	23.60	23.65	23.62	23.62	22.79	988.3	6.47	0.205E+07	0.00131	14.89	13.95	14.50	14.45	14.46	14.46
6	45.5	23.71	23.76	23.71	23.72	22.84	989.4	6.46	0.206E+07	0.00234	13.79	13.13	13.86	13.65	13.66	13.66
7	75.5	23.76	23.85	23.78	23.79	22.91	991.0	6.45	0.207E+07	0.00388	14.20	12.87	13.82	13.66	13.68	13.67
8	105.5	23.78	23.95	23.82	23.84	22.99	992.6	6.44	0.208E+07	0.00543	15.19	12.56	14.38	14.06	14.13	14.09
9	135.5	23.87	23.98	23.94	23.93	23.06	994.3	6.43	0.209E+07	0.00697	14.96	13.12	13.65	13.82	13.85	13.83
10	165.2	23.92	24.02	23.99	23.98	23.13	995.9	6.42	0.211E+07	0.00850	15.42	13.61	14.10	14.28	14.31	14.29
11	205.2	24.01	24.17	24.14	24.11	23.23	998.1	6.40	0.212E+07	0.01066	15.44	12.91	13.32	13.68	13.75	13.71
12	245.2	24.17	24.27	24.22	24.22	23.33	1000.4	6.39	0.214E+07	0.01263	14.36	12.92	13.56	13.58	13.60	13.59
13	275.2	24.30	24.38	24.33	24.34	23.41	1002.0	6.37	0.215E+07	0.01417	13.48	12.34	12.99	12.94	12.95	12.94
14	305.2	24.35	24.47	24.41	24.41	23.48	1003.7	6.36	0.217E+07	0.01572	13.93	12.25	12.91	12.97	13.00	12.99
15	333.3	24.28	24.40	24.37	24.35	23.55	1005.3	6.35	0.218E+07	0.01717	16.44	14.27	14.76	15.01	15.06	15.03
16	363.3	24.44	24.53	24.48	24.48	23.63	1007.0	6.34	0.219E+07	0.01872	14.79	13.34	14.15	14.09	14.11	14.10
17	383.3	24.43	24.54	24.52	24.50	23.68	1008.1	6.33	0.220E+07	0.01975	16.05	13.94	14.25	14.58	14.62	14.60
18	403.3	24.45	24.59	24.54	24.53	23.73	1009.2	6.32	0.221E+07	0.02079	16.53	13.86	14.81	14.94	15.00	14.97
19	423.3	24.50	24.66	24.61	24.59	23.78	1010.4	6.32	0.222E+07	0.02182	16.68	13.61	14.42	14.70	14.78	14.74
20	443.3	24.54	24.70	24.64	24.63	23.82	1011.5	6.31	0.223E+07	0.02285	16.77	13.74	14.80	14.95	15.03	14.99
21	463.3	24.77	24.73	24.89	24.82	23.87	1012.7	6.30	0.224E+07	0.02389	13.37	14.11	11.91	12.76	12.83	12.79
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.44	24.57	24.53	24.52	23.70	1008.6	6.33	0.221E+07	0.02018	16.21	13.79	14.53	14.71	14.77	14.74

UPWARD INCLINATION _____ 2 - 1000

INPUT ELECTRIC POWER = 300.8 W HEAT RATE GAINED BY WATER = 283.3 W HEAT BALANCE ERROR = 5.80%
MASS FLOW RATE = 29.1176 G/S PRESSURE DROP= 0.5994MMH20 FRICTION FACTOR = 0.020204 FREM = 20.2203
REM = 1000.8 GRM = 0.45126E+07 UPSTREAM BULK TEMPERATURE = 23.06DEG C DOWNSTREAM BULK TEMPERATURE = 25.39DEG C
PRM = 6.245 RAM = 0.28182E+08 INLET BULK TEMPERATURE = 23.06DEG C OUTLET BULK TEMPERATURE = 25.39DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.23	24.20	24.21	24.21	23.09	975.5	6.42	0.411E+07	0.00029	20.70	21.27	20.98	20.98	20.98	20.98
4	15.5	24.64	24.64	24.62	24.63	23.14	976.5	6.42	0.413E+07	0.00081	15.67	15.66	15.96	15.81	15.81	15.81
5	25.5	24.81	24.97	24.89	24.89	23.18	977.6	6.41	0.414E+07	0.00134	14.56	13.21	13.84	13.84	13.86	13.85
6	45.5	24.92	24.99	24.91	24.93	23.28	979.8	6.39	0.418E+07	0.00239	14.46	13.87	14.53	14.34	14.35	14.34
7	75.5	24.98	25.15	25.01	25.04	23.43	983.1	6.37	0.423E+07	0.00397	15.24	13.71	14.94	14.69	14.71	14.70
8	105.5	25.04	25.26	25.11	25.13	23.58	986.4	6.35	0.428E+07	0.00554	16.24	14.06	15.46	15.26	15.30	15.28
9	135.5	25.21	25.40	25.25	25.28	23.73	989.7	6.32	0.433E+07	0.00712	16.00	14.13	15.49	15.24	15.28	15.26
10	165.2	25.25	25.53	25.36	25.38	23.88	993.0	6.30	0.439E+07	0.00869	17.19	14.32	15.89	15.76	15.82	15.79
11	205.2	25.38	25.64	25.48	25.50	24.08	997.5	6.27	0.446E+07	0.01080	18.07	15.04	16.80	16.60	16.67	16.64
12	245.2	25.62	25.80	25.68	25.69	24.28	1002.0	6.24	0.453E+07	0.01291	17.57	15.45	16.82	16.63	16.67	16.65
13	275.2	25.67	25.89	25.82	25.80	24.42	1005.5	6.21	0.459E+07	0.01449	18.96	16.07	16.89	17.14	17.20	17.17
14	305.2	25.83	26.03	25.90	25.92	24.57	1008.9	6.19	0.464E+07	0.01608	18.78	16.12	17.76	17.55	17.60	17.58
15	333.3	25.93	26.15	26.09	26.07	24.71	1012.2	6.17	0.470E+07	0.01756	19.39	16.39	17.05	17.40	17.47	17.43
16	363.3	26.09	26.34	26.19	26.20	24.86	1015.7	6.14	0.475E+07	0.01915	19.23	15.92	17.72	17.57	17.65	17.61
17	383.3	26.19	26.37	26.25	26.26	24.96	1018.0	6.13	0.479E+07	0.02021	19.19	16.70	18.24	18.05	18.09	18.07
18	403.3	26.25	26.48	26.42	26.39	25.06	1020.4	6.11	0.483E+07	0.02127	19.73	16.60	17.36	17.69	17.76	17.73
19	423.3	26.42	26.67	26.58	26.56	25.16	1022.7	6.10	0.487E+07	0.02233	18.60	15.53	16.60	16.76	16.83	16.80
20	443.3	26.48	26.67	26.61	26.59	25.26	1025.1	6.08	0.491E+07	0.02339	19.19	16.62	17.45	17.63	17.68	17.66
21	463.3	26.71	26.77	26.85	26.80	25.36	1027.5	6.07	0.495E+07	0.02445	17.37	16.59	15.78	16.36	16.38	16.37
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	26.23	26.45	26.36	26.35	25.00	1019.0	6.12	0.481E+07	0.02065	19.22	16.29	17.40	17.52	17.58	17.55

UPWARD INCLINATION _____ 3 - 1000

INPUT ELECTRIC POWER = 662.8 W   HEAT RATE GAINED BY WATER = 645.1 W   HEAT BALANCE ERROR = 2.68%
MASS FLOW RATE = 28.2498 G/S   PRESSURE DROP= 0.6757MMH20   FRICTION FACTOR = 0.024191   FREM = 24.3164
REM = 1005.2   GRM = 0.11603E+08   UPSTREAM BULK TEMPERATURE = 22.97DEG C   DOWNSTREAM BULK TEMPERATURE = 28.44DEG C
PRM = 6.010   RAM = 0.69732E+08   INLET BULK TEMPERATURE = 22.98DEG C   OUTLET BULK TEMPERATURE = 28.44DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.53	25.51	25.52	25.52	23.04	945.5	6.43	0.933E+07	0.00030	21.62	21.82	21.72	21.72	21.72	21.72
4	15.5	26.13	26.40	26.16	26.21	23.16	947.9	6.41	0.942E+07	0.00084	18.09	16.58	17.92	17.61	17.63	17.62
5	25.5	26.38	26.71	26.55	26.55	23.28	950.4	6.39	0.951E+07	0.00138	17.35	15.68	16.41	16.44	16.46	16.45
6	45.5	26.46	26.75	26.56	26.58	23.51	955.4	6.36	0.969E+07	0.00246	18.22	16.59	17.61	17.49	17.51	17.50
7	75.5	26.59	26.96	26.69	26.73	23.86	963.0	6.30	0.997E+07	0.00409	19.64	17.31	18.98	18.69	18.73	18.71
8	105.5	26.74	27.30	26.84	26.93	24.21	970.7	6.25	0.103E+08	0.00572	21.22	17.35	20.39	19.72	19.84	19.78
9	135.5	27.07	27.55	27.32	27.31	24.56	978.5	6.19	0.106E+08	0.00736	21.30	17.94	19.43	19.45	19.52	19.49
10	165.2	27.25	27.81	27.55	27.54	24.90	986.4	6.14	0.109E+08	0.00898	22.82	18.43	20.26	20.32	20.44	20.38
11	205.2	27.56	28.15	27.86	27.86	25.37	997.2	6.06	0.113E+08	0.01116	24.45	19.23	21.52	21.52	21.68	21.60
12	245.2	28.20	28.67	28.42	28.43	25.84	1008.2	5.99	0.117E+08	0.01336	22.60	18.84	20.71	20.63	20.72	20.67
13	275.2	28.48	28.96	28.82	28.77	26.19	1016.6	5.93	0.121E+08	0.01500	23.28	19.26	20.32	20.69	20.79	20.74
14	305.2	28.82	29.31	29.01	29.04	26.54	1025.2	5.88	0.124E+08	0.01665	23.39	19.23	21.58	21.34	21.45	21.39
15	333.3	29.16	29.66	29.46	29.43	26.86	1033.3	5.83	0.127E+08	0.01820	23.26	19.09	20.52	20.74	20.85	20.80
16	363.3	29.51	30.02	29.73	29.75	27.21	1040.7	5.78	0.131E+08	0.01985	23.16	18.99	21.20	21.03	21.14	21.09
17	383.3	29.74	30.20	29.91	29.94	27.45	1045.6	5.75	0.133E+08	0.02095	23.25	19.35	21.64	21.38	21.47	21.43
18	403.3	29.99	30.47	30.14	30.19	27.68	1050.6	5.73	0.135E+08	0.02206	23.03	19.09	21.62	21.24	21.34	21.29
19	423.3	30.28	30.73	30.57	30.54	27.91	1055.6	5.70	0.137E+08	0.02316	22.49	18.89	20.05	20.29	20.37	20.33
20	443.3	30.40	30.76	30.65	30.62	28.15	1060.7	5.67	0.139E+08	0.02426	23.63	20.34	21.20	21.52	21.59	21.56
21	463.3	30.78	31.16	31.03	31.00	28.38	1065.8	5.64	0.141E+08	0.02536	22.11	19.12	20.08	20.29	20.35	20.32
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	29.85	30.31	30.08	30.08	27.54	1047.7	5.74	0.134E+08	0.02141	23.14	19.29	21.04	21.03	21.13	21.08

UPWARD INCLINATION _____ 4 - 1000

INPUT ELECTRIC POWER = 873.7 W   HEAT RATE GAINED BY WATER = 875.4 W   HEAT BALANCE ERROR =-0.20%
MASS FLOW RATE = 27.8882 G/S   PRESSURE DROP= 0.7436MMH20   FRICTION FACTOR = 0.027313   FREM = 27.3582
REM = 1001.6   GRM = 0.16254E+08   UPSTREAM BULK TEMPERATURE = 22.34DEG C   DOWNSTREAM BULK TEMPERATURE = 29.86DEG C
PRM = 5.948   RAM = 0.96680E+08   INLET BULK TEMPERATURE = 22.35DEG C   OUTLET BULK TEMPERATURE = 29.86DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.81	25.90	25.85	25.85	22.44	920.9	6.53	0.120E+08	0.00030	21.68	21.11	21.39	21.39	21.39	21.39
4	15.5	26.52	26.93	26.60	26.66	22.60	924.2	6.50	0.122E+08	0.00085	18.63	16.85	18.25	17.97	17.99	17.98
5	25.5	26.84	27.31	27.11	27.09	22.76	927.5	6.48	0.124E+08	0.00140	17.88	16.04	16.80	16.85	16.88	16.87
6	45.5	26.94	27.34	27.06	27.10	23.08	934.1	6.43	0.127E+08	0.00249	18.92	17.14	18.31	18.15	18.17	18.16
7	75.5	27.09	27.63	27.22	27.29	23.56	944.2	6.35	0.132E+08	0.00414	20.63	17.92	19.92	19.54	19.60	19.57
8	105.5	27.24	27.97	27.40	27.50	24.04	954.5	6.27	0.137E+08	0.00579	22.75	18.52	21.68	21.03	21.16	21.10
9	135.5	27.72	28.30	27.99	28.00	24.52	965.1	6.20	0.143E+08	0.00745	22.76	19.24	20.98	20.92	20.99	20.95
10	165.2	27.98	28.70	28.31	28.32	24.99	975.8	6.12	0.149E+08	0.00910	24.39	19.60	21.95	21.84	21.97	21.91
11	205.2	28.40	29.13	28.72	28.74	25.64	990.6	6.02	0.156E+08	0.01132	26.29	20.77	23.50	23.35	23.52	23.44
12	245.2	29.26	29.82	29.45	29.50	26.28	1005.8	5.92	0.165E+08	0.01354	24.31	20.46	22.82	22.51	22.60	22.56
13	275.2	29.57	30.22	30.02	29.96	26.76	1017.5	5.84	0.171E+08	0.01522	25.75	20.93	22.19	22.63	22.77	22.70
14	305.2	30.05	30.63	30.30	30.32	27.24	1027.8	5.78	0.177E+08	0.01690	25.74	21.33	23.63	23.48	23.58	23.53
15	333.3	30.58	31.22	30.99	30.95	27.69	1037.3	5.72	0.183E+08	0.01846	25.01	20.47	21.85	22.18	22.30	22.24
16	363.3	31.05	31.69	31.33	31.35	28.17	1047.6	5.66	0.189E+08	0.02014	25.06	20.48	22.85	22.69	22.81	22.75
17	383.3	31.33	31.89	31.53	31.57	28.49	1054.6	5.62	0.193E+08	0.02126	25.38	21.21	23.74	23.42	23.52	23.47
18	403.3	31.65	32.27	31.85	31.90	28.81	1061.7	5.58	0.198E+08	0.02238	25.38	20.84	23.70	23.28	23.40	23.34
19	423.3	32.04	32.69	32.39	32.38	29.13	1068.9	5.54	0.202E+08	0.02350	24.76	20.24	22.07	22.17	22.28	22.22
20	443.3	32.23	32.82	32.51	32.52	29.45	1076.1	5.50	0.207E+08	0.02463	25.93	21.37	23.52	23.47	23.58	23.53
21	463.3	32.75	33.23	33.04	33.02	29.77	1083.5	5.46	0.211E+08	0.02575	24.15	20.76	21.96	22.14	22.21	22.18
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	31.48	32.10	31.77	31.78	28.62	1057.7	5.61	0.195E+08	0.02173	25.25	20.77	22.95	22.87	22.98	22.93

UPWARD INCLINATION _____ 5 - 1000

INPUT ELECTRIC POWER = 1140.0 W HEAT RATE GAINED BY WATER = 1104.4 W HEAT BALANCE ERROR = 3.12%
MASS FLOW RATE = 26.9480 G/S PRESSURE DROP= 0.8947[illegible]20 FRICTION FACTOR = 0.035175 FREM = 35.3815
REM = 1005.9 GRM = 0.23366E+08 UPSTREAM BULK TEMPERATURE = 22.94DEG C DOWNSTREAM BULK TEMPERATURE = 32.77DEG C
PRM = 5.703 RAM = 0.13326E+09 INLET BULK TEMPERATURE = 22.95DEG C OUTLET BULK TEMPERATURE = 32.76DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	27.14	27.46	27.30	27.30	23.07	902.5	6.43	0.160E+08	0.00031	22.62	20.96	21.76	21.76	21.78	21.77
4	15.5	28.06	28.55	28.09	28.20	23.28	906.7	6.39	0.163E+08	0.00088	19.24	17.46	19.13	18.71	18.74	18.72
5	25.5	28.41	28.96	28.71	28.70	23.49	910.9	6.36	0.166E+08	0.00145	18.69	16.81	17.62	17.66	17.69	17.67
6	45.5	28.48	29.02	28.53	28.69	23.91	919.6	6.30	0.171E+08	0.00259	20.11	17.99	19.46	19.23	19.26	19.24
7	75.5	28.68	29.35	28.81	28.91	24.53	932.9	6.20	0.180E+08	0.00430	22.17	19.06	21.47	20.97	21.04	21.01
8	105.5	28.89	29.79	29.02	29.18	25.16	946.6	6.10	0.190E+08	0.00601	24.61	19.81	23.78	22.83	22.99	22.91
9	135.5	29.50	30.28	29.86	29.87	25.79	960.7	6.00	0.200E+08	0.00774	24.66	20.39	22.51	22.41	22.52	22.46
10	165.2	29.89	30.77	30.30	30.31	26.41	975.0	5.90	0.210E+08	0.00945	26.25	20.98	23.53	23.42	23.57	23.50
11	205.2	30.52	31.33	30.77	30.85	27.25	993.4	5.78	0.224E+08	0.01176	27.90	22.33	25.94	25.36	25.53	25.44
12	245.2	31.43	32.16	31.75	31.77	28.08	1010.5	5.67	0.237E+08	0.01407	27.25	22.33	24.86	24.70	24.83	24.77
13	275.2	31.94	32.73	32.46	32.39	28.71	1023.8	5.60	0.248E+08	0.01580	28.20	22.65	24.29	24.70	24.85	24.78
14	305.2	32.48	33.23	32.79	32.82	29.34	1037.4	5.52	0.259E+08	0.01754	28.93	23.32	26.31	26.06	26.21	26.14
15	333.3	33.22	33.95	33.72	33.65	29.93	1060.5	5.44	0.270E+08	0.01918	27.53	22.57	23.90	24.34	24.47	24.41
16	363.3	33.75	34.54	34.08	34.11	30.55	1064.8	5.36	0.282E+08	0.02093	28.33	22.75	25.71	25.47	25.62	25.55
17	383.3	34.13	34.82	34.37	34.42	30.97	1074.6	5.31	0.290E+08	0.02209	28.70	23.54	26.61	26.23	26.37	26.30
18	403.3	34.57	35.33	34.88	34.91	31.39	1084.5	5.26	0.298E+08	0.02327	28.42	22.95	25.94	25.66	25.81	25.74
19	423.3	35.08	35.88	35.54	35.51	31.81	1094.7	5.21	0.307E+08	0.02444	27.60	22.20	24.21	24.41	24.56	24.48
20	443.3	35.32	36.14	35.77	35.75	32.23	1103.7	5.16	0.315E+08	0.02562	29.17	23.04	25.46	25.60	25.78	25.69
21	463.3	36.06	36.75	36.24	36.32	32.65	1112.7	5.11	0.323E+08	0.02682	26.40	21.95	25.07	24.51	24.62	24.57
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	34.35	35.11	34.73	34.73	31.15	1078.8	5.29	0.294E+08	0.02259	28.29	22.84	25.31	25.29	25.44	25.36

UPWARD INCLINATION _____ 6 - 1000

INPUT ELECTRIC POWER = 1765.2 W HEAT RATE GAINED BY WATER = 1753.2 W HEAT BALANCE ERROR = 0.68%
MASS FLOW RATE = 25.0000 G/S PRESSURE DROP= 1.0913[illegible]20 FRICTION FACTOR = 0.049789 FREM = 49.7791
REM = 999.8 GRM = 0.46434E+08 UPSTREAM BULK TEMPERATURE = 22.69DEG C DOWNSTREAM BULK TEMPERATURE = 39.50DEG C
PRM = 5.294 RAM = 0.24581E+09 INLET BULK TEMPERATURE = 22.71DEG C OUTLET BULK TEMPERATURE = 39.50DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	29.53	29.98	29.75	29.75	22.91	834.2	6.45	0.251E+08	0.00034	22.10	20.70	21.37	21.37	21.39	21.38
4	15.5	29.89	30.84	30.05	30.21	23.27	840.9	6.40	0.258E+08	0.00095	22.09	19.29	21.55	21.06	21.12	21.09
5	25.5	30.48	31.33	30.98	30.94	23.63	847.7	6.34	0.266E+08	0.00156	21.32	18.96	19.85	19.96	20.00	19.98
6	45.5	30.50	31.37	30.81	30.87	24.34	861.6	6.23	0.282E+08	0.00279	23.69	20.76	22.53	22.33	22.38	22.35
7	75.5	30.87	31.88	31.18	31.28	25.42	883.4	6.06	0.308E+08	0.00464	26.67	22.50	25.22	24.81	24.90	24.85
8	105.5	31.31	32.73	31.56	31.79	26.49	906.3	5.89	0.336E+08	0.00650	30.07	23.26	28.63	27.38	27.65	27.52
9	135.5	32.60	33.71	33.09	33.12	27.56	927.5	5.74	0.363E+08	0.00837	28.74	23.55	26.18	26.04	26.17	26.10
10	165.2	33.42	34.73	34.05	34.06	28.63	948.1	5.61	0.391E+08	0.01022	30.10	23.67	26.62	26.56	26.75	26.66
11	205.2	34.68	35.82	35.07	35.16	30.06	977.3	5.43	0.432E+08	0.01273	31.17	24.98	28.72	28.22	28.40	28.31
12	245.2	36.26	37.30	36.73	36.75	31.49	1008.4	5.25	0.477E+08	0.01525	30.07	24.71	27.40	27.27	27.40	27.33
13	275.2	37.06	38.14	37.83	37.72	32.57	1030.7	5.12	0.511E+08	0.01717	31.80	25.66	27.16	27.77	27.95	27.86
14	305.2	37.93	38.92	38.20	38.31	33.64	1052.7	4.99	0.545E+08	0.01910	33.27	27.02	31.30	30.54	30.72	30.63
15	333.3	38.76	39.88	39.60	39.46	34.65	1074.3	4.88	0.580E+08	0.02093	34.58	27.21	28.75	29.58	29.82	29.70
16	363.3	39.94	40.92	40.31	40.37	35.72	1098.3	4.75	0.620E+08	0.02290	33.63	27.29	30.93	30.52	30.69	30.61
17	383.3	40.92	41.72	41.02	41.17	36.44	1114.9	4.67	0.648E+08	0.02423	31.61	26.84	30.94	29.95	30.08	30.01
18	403.3	41.57	42.53	41.91	41.98	37.15	1131.0	4.59	0.676E+08	0.02554	32.01	26.32	29.74	29.31	29.45	29.38
19	423.3	42.43	43.46	43.10	43.02	37.87	1146.2	4.53	0.703E+08	0.02684	30.98	25.27	27.00	27.41	27.56	27.49
20	443.3	43.00	44.01	43.50	43.50	38.58	1161.8	4.46	0.732E+08	0.02814	31.92	26.01	28.68	28.67	28.82	28.75
21	463.3	43.81	45.23	44.48	44.50	39.30	1177.8	4.39	0.762E+08	0.02944	31.25	23.75	27.17	27.08	27.34	27.21
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	41.10	42.08	41.57	41.58	36.73	1121.1	4.65	0.660E+08	0.02476	32.45	26.49	29.34	29.24	29.40	29.32

UPWARD INCLINATION _____ 7 - 1000

INPUT ELECTRIC POWER = 2666.6 W   HEAT RATE GAINED BY WATER = 2633.6 W   HEAT BALANCE ERROR = 1.24%
MASS FLOW RATE = 22.1025 G/S   PRESSURE DROP= 1.4072MMH20   FRICTION FACTOR = 0.081942   FREM = 81.8974
REM = 999.5   GRM = 0.10137E+09   UPSTREAM BULK TEMPERATURE = 22.84DEG C   DOWNSTREAM BULK TEMPERATURE = 51.39DEG C
PRM = 4.594   RAM = 0.46572E+09   INLET BULK TEMPERATURE = 22.87DEG C   OUTLET BULK TEMPERATURE = 51.39DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	32.28	33.02	32.65	32.65	23.20	742.4	6.41	0.386E+08	0.00038	24.20	22.37	23.25	23.25	23.26	23.26
4	15.5	32.56	33.97	32.84	33.06	23.81	752.6	6.31	0.406E+08	0.00107	25.06	21.58	24.29	23.73	23.81	23.77
5	25.5	33.36	34.60	34.14	34.06	24.42	763.2	6.21	0.426E+08	0.00177	24.49	21.51	22.54	22.72	22.77	22.74
6	45.5	33.36	34.67	33.86	33.94	25.64	785.1	6.02	0.471E+08	0.00317	28.29	24.18	26.55	26.31	26.39	26.35
7	75.5	33.98	35.44	34.42	34.57	27.46	818.3	5.75	0.542E+08	0.00528	33.37	27.27	31.24	30.61	30.78	30.70
8	105.5	35.11	37.09	35.38	35.74	29.29	849.9	5.52	0.615E+08	0.00739	37.19	27.76	35.53	33.56	34.00	33.78
9	135.5	37.65	39.03	38.22	38.28	31.11	884.1	5.29	0.698E+08	0.00953	32.99	27.22	30.33	30.08	30.22	30.15
10	165.2	38.43	40.16	38.93	39.11	32.92	917.5	5.08	0.784E+08	0.01167	38.96	29.64	35.72	34.67	35.01	34.84
11	205.2	41.88	43.18	42.17	42.35	35.35	963.6	4.79	0.910E+08	0.01461	32.70	27.25	31.28	30.48	30.63	30.56
12	245.2	44.07	45.42	44.70	44.72	37.79	1011.8	4.53	0.105E+09	0.01758	33.75	27.80	30.69	30.59	30.73	30.66
13	275.2	45.40	46.74	46.26	46.17	39.61	1047.6	4.37	0.116E+09	0.01979	36.55	29.68	31.79	32.26	32.45	32.36
14	305.2	46.65	47.83	47.00	47.12	41.44	1086.1	4.20	0.129E+09	0.02202	40.43	32.95	37.90	37.09	37.30	37.19
15	333.3	49.31	50.46	50.09	49.99	43.14	1120.0	4.06	0.141E+09	0.02412	34.05	28.73	30.23	30.69	30.81	30.75
16	363.3	50.81	52.10	51.26	51.36	44.97	1157.0	3.92	0.155E+09	0.02637	35.82	29.36	33.30	32.78	32.95	32.86
17	383.3	51.68	52.84	51.90	52.08	46.19	1183.0	3.82	0.164E+09	0.02789	38.02	31.40	36.55	35.44	35.63	35.54
18	403.3	52.84	54.08	53.06	53.26	47.40	1209.0	3.73	0.175E+09	0.02941	38.33	31.22	36.85	35.59	35.81	35.70
19	423.3	54.27	55.52	54.96	54.92	48.62	1234.8	3.65	0.185E+09	0.03093	36.81	30.16	32.83	32.99	33.16	33.08
20	443.3	55.16	56.41	55.68	55.73	49.84	1261.7	3.56	0.196E+09	0.03246	39.00	31.59	35.55	35.23	35.43	35.33
21	463.3	56.61	58.04	57.06	57.18	51.05	1289.8	3.48	0.208E+09	0.03400	37.29	29.68	34.58	33.80	34.04	33.92
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	52.35	53.57	52.82	52.89	46.69	1194.3	3.79	0.169E+09	0.02853	37.00	30.41	34.22	33.79	33.96	33.88

UPWARD INCLINATION _____ 1 - 1500

INPUT ELECTRIC POWER = 165.2 W   HEAT RATE GAINED BY WATER = 163.5 W   HEAT BALANCE ERROR = 1.02%
MASS FLOW RATE = 45.2450 G/S   PRESSURE DROP= 0.8979MMH20   FRICTION FACTOR = 0.012539   FREM = 18.7662
REM = 1496.6   GRM = 0.22628E+07   UPSTREAM BULK TEMPERATURE = 22.08DEG C   DOWNSTREAM BULK TEMPERATURE = 22.94DEG C
PRM = 6.516   RAM = 0.14743E+08   INLET BULK TEMPERATURE = 22.08DEG C   OUTLET BULK TEMPERATURE = 22.94DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	22.70	22.66	22.68	22.68	22.09	1482.8	6.58	0.218E+07	0.00019	22.38	23.93	23.13	23.13	23.14	23.14
4	15.5	22.88	22.86	22.85	22.86	22.11	1483.4	6.58	0.219E+07	0.00052	17.77	18.26	18.43	18.22	18.22	18.22
5	25.5	23.07	23.10	23.07	23.08	22.13	1484.0	6.58	0.219E+07	0.00086	14.41	14.01	14.55	14.38	14.38	14.38
6	45.5	23.21	23.25	23.20	23.22	22.16	1485.2	6.57	0.220E+07	0.00153	13.09	12.55	13.14	12.97	12.98	12.98
7	75.5	23.29	23.38	23.25	23.29	22.22	1487.0	6.56	0.221E+07	0.00255	12.76	11.80	13.20	12.71	12.74	12.73
8	105.5	23.31	23.39	23.27	23.31	22.27	1488.8	6.55	0.222E+07	0.00356	13.24	12.28	13.76	13.23	13.26	13.25
9	135.5	23.31	23.39	23.33	23.34	22.33	1490.6	6.54	0.223E+07	0.00457	13.95	12.83	13.65	13.51	13.52	13.51
10	165.2	23.25	23.35	23.32	23.31	22.38	1492.4	6.54	0.224E+07	0.00557	15.80	14.13	14.64	14.78	14.80	14.79
11	205.2	23.37	23.50	23.47	23.45	22.46	1494.8	6.52	0.225E+07	0.00692	14.93	13.13	13.52	13.74	13.78	13.76
12	245.2	23.56	23.65	23.55	23.58	22.53	1497.2	6.51	0.227E+07	0.00827	13.27	12.19	13.40	13.04	13.06	13.05
13	275.2	23.49	23.66	23.58	23.58	22.59	1499.1	6.50	0.228E+07	0.00929	15.06	12.74	13.76	13.78	13.83	13.81
14	305.2	23.56	23.71	23.66	23.65	22.64	1500.9	6.49	0.229E+07	0.01030	14.80	12.79	13.43	13.58	13.61	13.59
15	333.3	23.59	23.70	23.64	23.64	22.69	1502.6	6.49	0.230E+07	0.01125	15.26	13.57	14.36	14.36	14.39	14.38
16	363.3	23.66	23.83	23.72	23.73	22.75	1504.5	6.48	0.231E+07	0.01226	14.98	12.61	14.06	13.87	13.93	13.90
17	383.3	23.70	23.78	23.74	23.74	22.79	1505.7	6.47	0.231E+07	0.01294	14.94	13.73	14.32	14.31	14.33	14.32
18	403.3	23.67	23.84	23.73	23.74	22.82	1506.9	6.47	0.232E+07	0.01361	16.17	13.48	15.11	14.90	14.97	14.93
19	423.3	23.77	23.90	23.85	23.84	22.86	1508.1	6.46	0.233E+07	0.01429	14.98	13.06	13.76	13.86	13.89	13.87
20	443.3	23.78	23.97	23.88	23.88	22.90	1509.4	6.45	0.234E+07	0.01497	15.40	12.73	13.89	13.91	13.97	13.94
21	463.3	23.99	24.01	24.07	24.03	22.93	1510.6	6.45	0.234E+07	0.01564	12.93	12.71	11.98	12.39	12.40	12.39
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	23.69	23.84	23.76	23.76	22.80	1506.2	6.47	0.232E+07	0.01322	15.29	13.20	14.25	14.20	14.25	14.22

UPWARD INCLINATION _____ 2 - 1500

INPUT ELECTRIC POWER = 310.7 W HEAT RATE GAINED BY WATER = 307.7 W HEAT BALANCE ERROR = 0.96%
MASS FLOW RATE = 43.8000 G/S PRESSURE DROP= 0.9125MMH20 FRICTION FACTOR = 0.013594 FREM = 20.3966
REM = 1500.4 GRM = 0.48425E+07 UPSTREAM BULK TEMPERATURE = 23.23DEG C DOWNSTREAM BULK TEMPERATURE = 24.92DEG C
PRM = 6.268 RAM = 0.30355E+08 INLET BULK TEMPERATURE = 23.24DEG C OUTLET BULK TEMPERATURE = 24.92DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.37	24.36	24.36	24.36	23.25	1472.9	6.40	0.453E+07	0.00019	23.09	23.13	23.11	23.11	23.11	23.11
4	15.5	24.75	24.81	24.70	24.74	23.29	1474.1	6.39	0.454E+07	0.00054	17.54	16.87	18.23	17.70	17.71	17.71
5	25.5	25.00	25.06	25.03	25.03	23.33	1475.3	6.39	0.455E+07	0.00089	15.33	14.84	15.05	15.06	15.07	15.07
6	45.5	25.09	25.16	25.11	25.11	23.40	1477.6	6.38	0.458E+07	0.00159	15.20	14.60	15.02	14.96	14.96	14.96
7	75.5	25.15	25.27	25.15	25.18	23.51	1481.2	6.36	0.462E+07	0.00264	15.60	14.57	15.57	15.31	15.33	15.32
8	105.5	25.20	25.43	25.22	25.27	23.61	1484.8	6.34	0.466E+07	0.00369	16.12	14.13	15.95	15.49	15.54	15.51
9	135.5	25.34	25.54	25.39	25.42	23.72	1488.4	6.32	0.470E+07	0.00474	15.78	14.08	15.32	15.10	15.12	15.11
10	165.2	25.36	25.55	25.47	25.47	23.83	1492.0	6.31	0.475E+07	0.00577	16.70	14.84	15.55	15.63	15.66	15.65
11	205.2	25.44	25.76	25.62	25.61	23.97	1496.9	6.28	0.480E+07	0.00717	17.46	14.34	15.53	15.64	15.71	15.67
12	245.2	25.73	25.94	25.79	25.81	24.11	1501.8	6.26	0.486E+07	0.00858	15.86	14.02	15.29	15.09	15.12	15.10
13	275.2	25.75	26.00	25.87	25.88	24.22	1505.5	6.25	0.490E+07	0.00963	16.74	14.38	15.48	15.48	15.52	15.50
14	305.2	25.77	26.06	25.90	25.91	24.33	1509.2	6.23	0.494E+07	0.01068	17.74	14.77	16.29	16.21	16.27	16.24
15	333.3	25.82	26.09	25.98	25.97	24.43	1512.7	6.21	0.499E+07	0.01167	18.46	15.37	16.48	16.63	16.70	16.66
16	363.3	25.89	26.17	25.97	26.00	24.54	1516.4	6.20	0.503E+07	0.01272	18.91	15.64	17.92	17.51	17.59	17.55
17	383.3	25.96	26.20	26.03	26.05	24.61	1518.9	6.18	0.506E+07	0.01342	18.88	16.06	18.03	17.69	17.75	17.72
18	403.3	25.97	26.25	26.11	26.11	24.68	1521.4	6.17	0.509E+07	0.01413	19.81	16.27	17.93	17.90	17.98	17.94
19	423.3	26.09	26.34	26.27	26.24	24.75	1524.0	6.16	0.512E+07	0.01483	19.13	16.13	16.87	17.18	17.25	17.22
20	443.3	26.15	26.39	26.27	26.27	24.82	1526.5	6.15	0.515E+07	0.01553	19.33	16.30	17.69	17.69	17.76	17.72
21	463.3	26.40	26.52	26.51	26.49	24.90	1529.0	6.14	0.518E+07	0.01624	16.96	15.78	15.82	16.08	16.10	16.09
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.98	26.24	26.10	26.11	24.64	1520.0	6.18	0.507E+07	0.01372	19.09	15.96	17.49	17.43	17.51	17.47

UPWARD INCLINATION _____ 3 - 1500

INPUT ELECTRIC POWER = 695.2 W HEAT RATE GAINED BY WATER = 696.4 W HEAT BALANCE ERROR =-0.17%
MASS FLOW RATE = 43.0754 G/S PRESSURE DROP= 1.0618MMH20 FRICTION FACTOR = 0.016352 FREM = 24.5660
REM = 1502.3 GRM = 0.11682E+08 UPSTREAM BULK TEMPERATURE = 22.92DEG C DOWNSTREAM BULK TEMPERATURE = 26.79DEG C
PRM = 6.145 RAM = 0.71790E+08 INLET BULK TEMPERATURE = 22.92DEG C OUTLET BULK TEMPERATURE = 26.79DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.37	25.43	25.40	25.40	22.97	1439.2	6.44	0.100E+08	0.00020	24.22	23.63	23.92	23.92	23.92	23.92
4	15.5	26.19	26.49	26.19	26.26	23.05	1441.9	6.43	0.101E+08	0.00055	18.50	16.89	18.50	18.07	18.10	18.09
5	25.5	26.54	26.82	26.72	26.70	23.13	1444.5	6.42	0.101E+08	0.00090	17.03	15.76	16.19	16.28	16.29	16.29
6	45.5	26.57	26.89	26.67	26.70	23.30	1449.9	6.39	0.103E+08	0.00162	17.73	16.16	17.20	17.05	17.07	17.06
7	75.5	26.70	27.07	26.77	26.83	23.54	1457.9	6.35	0.105E+08	0.00268	18.36	16.44	17.97	17.66	17.69	17.67
8	105.5	26.79	27.36	26.90	26.99	23.79	1466.1	6.31	0.107E+08	0.00375	19.32	16.26	18.68	18.15	18.23	18.19
9	135.5	27.10	27.55	27.26	27.29	24.04	1474.4	6.27	0.109E+08	0.00482	18.92	16.52	17.98	17.81	17.85	17.83
10	165.2	27.11	27.70	27.44	27.42	24.28	1482.6	6.24	0.111E+08	0.00588	20.47	16.96	18.37	18.46	18.54	18.50
11	205.2	27.28	27.88	27.58	27.58	24.61	1493.9	6.18	0.115E+08	0.00731	21.71	17.75	19.53	19.53	19.63	19.58
12	245.2	27.70	28.14	27.86	27.89	24.94	1505.4	6.13	0.118E+08	0.00874	20.97	18.07	19.85	19.63	19.68	19.66
13	275.2	27.73	28.29	28.09	28.05	25.19	1514.1	6.09	0.120E+08	0.00981	22.78	18.65	19.96	20.23	20.34	20.29
14	305.2	27.84	28.42	28.08	28.11	25.44	1522.9	6.05	0.123E+08	0.01089	24.06	19.41	21.83	21.66	21.79	21.72
15	333.3	28.15	28.74	28.54	28.50	25.67	1531.3	6.02	0.125E+08	0.01190	23.25	18.82	20.10	20.44	20.57	20.51
16	363.3	28.37	28.93	28.66	28.66	25.92	1540.3	5.98	0.127E+08	0.01298	23.53	19.14	21.05	21.08	21.19	21.14
17	383.3	28.54	29.07	28.76	28.78	26.08	1546.4	5.95	0.129E+08	0.01370	23.53	19.30	21.53	21.36	21.47	21.42
18	403.3	28.73	29.29	28.94	28.97	26.25	1552.5	5.93	0.131E+08	0.01442	23.28	18.97	21.45	21.17	21.29	21.23
19	423.3	28.94	29.47	29.25	29.23	26.41	1558.7	5.90	0.133E+08	0.01514	22.84	18.85	20.35	20.50	20.60	20.55
20	443.3	29.05	29.46	29.31	29.28	26.58	1564.9	5.87	0.134E+08	0.01587	23.36	19.97	21.13	21.33	21.40	21.36
21	463.3	29.60	29.72	29.65	29.66	26.74	1571.1	5.85	0.136E+08	0.01659	20.14	19.38	19.81	19.78	19.78	19.78
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.63	29.16	28.91	28.90	26.15	1549.0	5.94	0.130E+08	0.01400	23.30	19.18	20.93	20.98	21.09	21.03

UPWARD INCLINATION ____ 4 - 1500

INPUT ELECTRIC POWER = 975.2 W HEAT RATE GAINED BY WATER = 978.5 W HEAT BALANCE ERROR =-0.34%
MASS FLOW RATE = 42.7860 G/S PRESSURE DROP= 1.1486MMH20 FRICTION FACTOR = 0.017928 FREM = 26.9143
REM = 1501.2 GRM = 0.16765E+08 UPSTREAM BULK TEMPERATURE = 22.37DEG C DOWNSTREAM BULK TEMPERATURE = 27.85DEG C
PRM = 6.104 RAM = 0.10234E+09 INLET BULK TEMPERATURE = 22.38DEG C OUTLET BULK TEMPERATURE = 27.85DEG C

STA- TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER- AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.03	26.07	26.05	26.05	22.44	1413.1	6.53	0.135E+08	0.00020	22.77	22.55	22.66	22.66	22.66	22.66
4	15.5	26.71	27.13	26.77	26.84	22.56	1416.7	6.51	0.136E+08	0.00065	19.67	17.88	19.42	19.07	19.10	19.08
5	25.5	27.09	27.53	27.38	27.35	22.68	1420.4	6.49	0.137E+08	0.00091	18.50	16.83	17.35	17.49	17.51	17.50
6	45.5	27.13	27.56	27.26	27.30	22.91	1427.8	6.45	0.140E+08	0.00162	19.34	17.55	18.77	18.58	18.61	18.59
7	75.5	27.37	27.88	27.47	27.55	23.26	1438.9	6.40	0.144E+08	0.00270	19.85	17.66	19.38	19.03	19.07	19.05
8	105.5	27.44	28.20	27.62	27.72	23.61	1450.3	6.34	0.148E+08	0.00377	21.31	17.77	20.32	19.84	19.93	19.88
9	135.5	27.88	28.52	28.16	28.18	23.96	1461.8	6.29	0.153E+08	0.00485	20.76	17.85	19.42	19.30	19.36	19.33
10	165.2	27.95	28.70	28.28	28.30	24.31	1473.5	6.23	0.157E+08	0.00592	22.35	18.51	20.49	20.37	20.46	20.42
11	205.2	28.09	28.91	28.42	28.46	24.77	1489.4	6.16	0.163E+08	0.00736	24.52	19.67	22.32	22.07	22.20	22.14
12	245.2	28.59	29.26	28.87	28.90	25.24	1505.7	6.08	0.169E+08	0.00880	24.24	20.20	22.40	22.22	22.31	22.26
13	275.2	28.73	29.43	29.24	29.16	25.59	1518.1	6.03	0.174E+08	0.00989	25.83	21.11	22.26	22.74	22.87	22.80
14	305.2	28.93	29.65	29.26	29.28	25.94	1530.6	5.97	0.179E+08	0.01098	27.13	21.87	24.42	24.32	24.46	24.39
15	333.3	29.41	30.16	29.88	29.83	26.27	1542.8	5.92	0.184E+08	0.01200	25.82	20.83	22.43	22.74	22.88	22.81
16	363.3	29.65	30.41	30.01	30.02	26.62	1555.9	5.87	0.189E+08	0.01309	26.67	21.35	23.89	23.80	23.95	23.88
17	383.3	29.90	30.54	30.16	30.19	26.85	1564.7	5.83	0.193E+08	0.01382	26.51	21.96	24.47	24.24	24.35	24.30
18	403.3	30.16	30.86	30.45	30.48	27.09	1572.1	5.80	0.196E+08	0.01455	26.31	21.41	24.04	23.82	23.95	23.89
19	423.3	30.47	31.21	30.88	30.86	27.32	1579.5	5.77	0.199E+08	0.01528	25.62	20.80	22.72	22.84	22.97	22.90
20	443.3	30.59	31.32	30.99	30.98	27.55	1587.1	5.74	0.203E+08	0.01600	26.57	21.42	23.49	23.60	23.74	23.67
21	463.3	30.95	31.62	31.42	31.35	27.79	1594.6	5.71	0.206E+08	0.01673	25.51	21.06	22.23	22.64	22.76	22.70
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	30.03	30.75	30.39	30.39	26.95	1567.0	5.82	0.194E+08	0.01412	26.25	21.29	23.51	23.51	23.64	23.57

UPWARD INCLINATION ____ 5 - 1500

INPUT ELECTRIC POWER = 1324.0 W HEAT RATE GAINED BY WATER = 1344.5 W HEAT BALANCE ERROR =-1.55%
MASS FLOW RATE = 42.7860 G/S PRESSURE DROP= 1.2032MMH20 FRICTION FACTOR = 0.018781 FREM = 28.1850
REM = 1500.7 GRM = 0.23009E+08 UPSTREAM BULK TEMPERATURE = 21.33DEG C DOWNSTREAM BULK TEMPERATURE = 28.86DEG C
PRM = 6.106 RAM = 0.14050E+09 INLET BULK TEMPERATURE = 21.34DEG C OUTLET BULK TEMPERATURE = 28.86DEG C

STA- TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER- AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.11	26.32	26.22	26.22	21.43	1380.3	6.70	0.169E+08	0.00020	24.03	23.03	23.52	23.52	23.52	23.52
4	15.5	27.04	27.72	27.13	27.25	21.59	1385.8	6.67	0.172E+08	0.00055	20.63	18.37	20.33	19.87	19.91	19.89
5	25.5	27.53	28.16	27.94	27.89	21.75	1391.4	6.64	0.174E+08	0.00091	19.46	17.54	18.18	18.31	18.34	18.33
6	45.5	27.52	28.15	27.71	27.77	22.07	1401.7	6.59	0.179E+08	0.00162	20.61	18.49	19.94	19.72	19.75	19.73
7	75.5	27.73	28.49	27.92	28.01	22.55	1416.5	6.51	0.187E+08	0.00269	21.68	18.91	20.93	20.56	20.61	20.58
8	105.5	27.91	28.95	28.12	28.28	23.03	1431.7	6.43	0.194E+08	0.00377	23.00	18.95	22.03	21.39	21.50	21.45
9	135.5	28.55	29.39	28.85	28.91	23.51	1447.2	6.36	0.202E+08	0.00484	22.23	19.07	20.99	20.76	20.82	20.79
10	165.2	28.56	29.62	29.09	29.09	23.99	1462.9	6.28	0.210E+08	0.00591	24.50	19.87	21.94	21.94	22.06	22.00
11	205.2	28.79	29.83	29.20	29.25	24.63	1484.5	6.18	0.221E+08	0.00736	26.89	21.51	24.47	24.18	24.33	24.26
12	245.2	29.45	30.43	29.93	29.94	25.27	1506.8	6.08	0.233E+08	0.00881	26.70	21.63	23.97	23.93	24.07	24.00
13	275.2	29.76	30.80	30.41	30.35	25.75	1524.0	6.00	0.243E+08	0.00989	27.80	22.08	23.93	24.27	24.44	24.35
14	305.2	30.02	31.02	30.41	30.47	26.24	1541.6	5.93	0.252E+08	0.01099	29.43	23.27	26.67	26.32	26.51	26.42
15	333.3	30.72	31.77	31.33	31.29	26.69	1558.4	5.86	0.262E+08	0.01201	27.60	21.86	23.96	24.18	24.35	24.26
16	363.3	31.10	32.14	31.58	31.60	27.17	1574.7	5.79	0.271E+08	0.01311	28.23	22.35	25.18	25.06	25.24	25.15
17	383.3	31.44	32.37	31.78	31.84	27.49	1585.0	5.75	0.277E+08	0.01384	28.08	22.75	25.88	25.51	25.65	25.58
18	403.3	31.85	32.86	32.21	32.28	27.81	1595.4	5.71	0.283E+08	0.01456	27.48	21.97	25.18	24.80	24.95	24.88
19	423.3	32.29	33.28	32.81	32.80	28.13	1606.0	5.67	0.290E+08	0.01529	26.65	21.54	23.66	23.74	23.88	23.81
20	443.3	32.42	33.41	32.82	32.87	28.45	1616.7	5.63	0.296E+08	0.01603	27.89	22.34	25.36	25.08	25.23	25.16
21	463.3	32.78	33.75	33.21	33.24	28.77	1627.5	5.59	0.303E+08	0.01676	27.64	22.22	24.92	24.78	24.93	24.85
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	31.64	32.64	32.09	32.11	27.62	1589.4	5.73	0.280E+08	0.01414	27.66	22.14	24.87	24.73	24.88	24.81

UPWARD INCLINATION _____ 6 - 1500

INPUT ELECTRIC POWER = 2234.8 W   HEAT RATE GAINED BY WATER = 2233.1 W   HEAT BALANCE ERROR = 0.08%
MASS FLOW RATE = 39.1700 G/S   PRESSURE DROP= 1.5289MMH20   FRICTION FACTOR = 0.028437   FREM = 42.7015
REM = 1501.6   GRM = 0.51629E+08   UPSTREAM BULK TEMPERATURE = 22.31DEG C   DOWNSTREAM BULK TEMPERATURE = 35.97DEG C
PRM = 5.541   RAM = 0.28609E+09   INLET BULK TEMPERATURE = 22.32DEG C   OUTLET BULK TEMPERATURE = 35.96DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	30.28	30.68	30.48	30.48	22.48	1294.7	6.52	0.308E+08	0.00021	23.91	22.76	23.32	23.32	23.33	23.32
4	15.5	30.77	31.88	30.99	31.16	22.77	1303.1	6.47	0.316E+08	0.00060	23.30	20.47	22.68	22.23	22.28	22.25
5	25.5	31.44	32.46	32.09	32.02	23.06	1311.5	6.43	0.323E+08	0.00099	22.24	19.83	20.63	20.80	20.83	20.82
6	45.5	31.37	32.40	31.71	31.80	23.64	1328.8	6.34	0.339E+08	0.00178	24.09	21.24	23.07	22.82	22.87	22.84
7	75.5	31.65	32.88	32.02	32.14	24.52	1355.5	6.20	0.364E+08	0.00296	26.04	22.20	24.74	24.34	24.43	24.39
8	105.5	31.90	33.68	32.23	32.51	25.39	1383.3	6.06	0.391E+08	0.00414	28.46	22.36	27.10	26.03	26.25	26.14
9	135.5	32.80	34.18	33.29	33.39	26.26	1412.2	5.92	0.420E+08	0.00533	28.31	23.35	26.33	25.95	26.08	26.01
10	165.2	33.04	34.70	33.88	33.88	27.13	1440.4	5.80	0.449E+08	0.00651	31.24	24.38	27.31	27.35	27.56	27.45
11	205.2	33.64	35.18	34.18	34.29	28.29	1475.2	5.65	0.487E+08	0.00810	34.39	26.72	31.28	30.66	30.91	30.79
12	245.2	35.01	36.40	35.66	35.69	29.46	1511.6	5.50	0.528E+08	0.00970	33.04	26.42	29.57	29.46	29.65	29.56
13	275.2	35.67	37.14	36.63	36.52	30.33	1540.2	5.39	0.560E+08	0.01090	34.29	26.91	29.08	29.61	29.84	29.72
14	305.2	36.36	37.77	36.91	36.99	31.20	1569.8	5.28	0.595E+08	0.01211	35.43	27.83	32.03	31.60	31.83	31.71
15	333.3	37.56	38.96	38.40	38.33	32.02	1597.8	5.18	0.629E+08	0.01326	32.91	26.31	28.60	28.92	29.11	29.01
16	363.3	38.18	39.67	38.88	38.90	32.89	1625.2	5.08	0.664E+08	0.01448	34.41	26.88	30.42	30.30	30.54	30.42
17	383.3	38.77	40.08	39.20	39.31	33.47	1644.0	5.01	0.688E+08	0.01530	34.36	27.52	31.75	31.14	31.34	31.24
18	403.3	39.43	40.81	39.86	39.99	34.06	1663.2	4.94	0.713E+08	0.01613	33.76	26.88	31.27	30.58	30.79	30.69
19	423.3	40.08	41.50	40.79	40.79	34.64	1682.9	4.88	0.738E+08	0.01697	33.30	26.42	29.45	29.46	29.65	29.56
20	443.3	40.36	41.67	40.83	40.92	35.22	1703.1	4.81	0.765E+08	0.01780	35.23	28.08	32.26	31.75	31.96	31.85
21	463.3	41.23	42.41	41.85	41.83	35.80	1723.7	4.74	0.793E+08	0.01865	33.33	27.38	29.90	29.98	30.12	30.05
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	39.07	40.45	39.66	39.71	33.72	1652.7	4.98	0.699E+08	0.01566	34.00	27.01	30.63	30.36	30.57	30.46

UPWARD INCLINATION _____ 7 - 1500

INPUT ELECTRIC POWER = 3356.9 W   HEAT RATE GAINED BY WATER = 3352.8 W   HEAT BALANCE ERROR = 0.12%
MASS FLOW RATE = 34.6100 G/S   PRESSURE DROP= 1.9709MMH20   FRICTION FACTOR = 0.046843   FREM = 70.4180
REM = 1503.3   GRM = 0.11455E+09   UPSTREAM BULK TEMPERATURE = 23.56DEG C   DOWNSTREAM BULK TEMPERATURE = 46.76DEG C
PRM = 4.815   RAM = 0.55155E+09   INLET BULK TEMPERATURE = 23.58DEG C   OUTLET BULK TEMPERATURE = 46.76DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	34.78	35.65	35.21	35.21	23.85	1179.5	6.30	0.518E+08	0.00024	25.55	23.66	24.57	24.57	24.59	24.58
4	15.5	35.02	36.71	35.35	35.61	24.34	1192.9	6.23	0.539E+08	0.00069	26.12	22.55	25.34	24.76	24.84	24.80
5	25.5	35.90	37.35	36.79	36.71	24.84	1206.6	6.15	0.562E+08	0.00113	25.19	22.26	23.30	23.46	23.51	23.49
6	45.5	35.71	37.27	36.24	36.37	25.83	1234.9	5.99	0.609E+08	0.00202	28.12	24.29	26.69	26.37	26.45	26.41
7	75.5	36.12	37.80	36.60	36.78	27.31	1277.5	5.77	0.683E+08	0.00337	31.45	26.41	29.81	29.25	29.37	29.31
8	105.5	36.53	38.94	36.95	37.34	28.80	1317.2	5.58	0.757E+08	0.00472	35.67	27.22	33.87	32.31	32.66	32.48
9	135.5	38.18	40.04	38.98	39.04	30.28	1359.4	5.40	0.839E+08	0.00607	34.82	28.19	31.63	31.39	31.57	31.48
10	165.2	39.51	41.25	40.30	40.34	31.75	1404.0	5.21	0.928E+08	0.00743	35.31	28.85	32.05	31.90	32.07	31.98
11	205.2	40.65	42.74	41.08	41.39	33.73	1459.9	4.98	0.105E+09	0.00928	39.41	30.28	37.08	35.61	35.96	35.78
12	245.2	43.55	44.80	44.08	44.13	35.70	1520.0	4.75	0.118E+09	0.01117	34.62	29.83	32.39	32.22	32.31	32.26
13	275.2	45.34	46.88	46.35	46.23	37.19	1566.8	4.59	0.129E+09	0.01259	33.18	27.92	29.53	29.92	30.04	29.98
14	305.2	46.09	47.75	46.63	46.77	38.67	1611.1	4.45	0.141E+09	0.01400	36.37	29.72	33.89	33.29	33.47	33.38
15	333.3	47.48	49.17	48.48	48.40	40.06	1654.9	4.32	0.152E+09	0.01532	36.28	29.52	31.96	32.25	32.43	32.34
16	363.3	48.33	50.18	49.07	49.16	41.55	1704.4	4.19	0.165E+09	0.01674	39.53	31.08	35.66	35.23	35.48	35.35
17	383.3	49.61	50.92	49.78	50.02	42.54	1735.3	4.11	0.174E+09	0.01769	37.83	31.92	36.96	35.75	35.92	35.84
18	403.3	50.93	52.39	51.18	51.42	43.52	1765.5	4.03	0.183E+09	0.01865	36.08	30.14	34.90	33.84	34.01	33.92
19	423.3	52.09	53.73	52.93	52.92	44.51	1796.9	3.95	0.192E+09	0.01961	35.20	28.95	31.68	31.73	31.88	31.80
20	443.3	52.71	54.29	53.40	53.45	45.50	1829.3	3.88	0.202E+09	0.02057	36.93	30.28	33.72	33.50	33.66	33.58
21	463.3	53.72	55.47	54.24	54.42	46.49	1863.0	3.80	0.213E+09	0.02154	36.77	29.60	34.29	33.53	33.74	33.63
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	50.19	51.78	50.81	50.90	42.95	1747.7	4.08	0.178E+09	0.01810	36.97	30.32	34.15	33.72	33.90	33.81

Appendix F

Experimental Data for $\alpha = -10^\circ$

DOWNWARD INCLINATION _____ 1 - 500

INPUT ELECTRIC POWER = 151.4 W   HEAT RATE GAINED BY WATER = 145.9 W   HEAT BALANCE ERROR = 3.60%
MASS FLOW RATE = 14.7500 G/S   PRESSURE DROP= 0.2478MMH20   FRICTION FACTOR = 0.032556   FREM = 16.3407
REM = 501.9   GRM = 0.22419E+07   UPSTREAM BULK TEMPERATURE = 22.59DEG C   DOWNSTREAM BULK TEMPERATURE = 24.97DEG C
PRM = 6.315   RAM = 0.14157E+08   INLET BULK TEMPERATURE = 22.60DEG C   OUTLET BULK TEMPERATURE = 24.96DEG C

STATION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.39	23.36	23.38	23.38	22.63	489.1	6.50	0.204E+07	0.00057	15.86	16.63	16.24	16.24	16.24	16.24
4	15.5	23.54	23.58	23.54	23.55	22.68	489.7	6.49	0.205E+07	0.00160	14.12	13.45	14.12	13.95	13.95	13.95
5	25.5	23.62	23.71	23.67	23.67	22.73	490.2	6.48	0.206E+07	0.00264	13.57	12.43	12.86	12.91	12.93	12.92
6	45.5	23.77	23.87	23.79	23.80	22.83	491.3	6.47	0.207E+07	0.00471	12.96	11.71	12.65	12.47	12.49	12.48
7	75.5	23.87	23.99	23.92	23.93	22.98	493.0	6.44	0.210E+07	0.00782	13.64	12.07	12.89	12.85	12.87	12.86
8	105.5	23.98	24.09	23.99	24.01	23.13	494.6	6.42	0.213E+07	0.01093	14.41	12.74	14.13	13.82	13.85	13.84
9	135.5	24.06	24.20	24.17	24.15	23.28	496.3	6.39	0.215E+07	0.01405	15.61	13.22	13.76	14.03	14.09	14.06
10	165.2	24.25	24.35	24.30	24.30	23.43	498.0	6.37	0.218E+07	0.01713	14.88	13.19	14.06	14.02	14.04	14.03
11	205.2	24.38	24.59	24.56	24.52	23.63	500.3	6.34	0.221E+07	0.02129	16.36	12.78	13.16	13.73	13.86	13.80
12	245.2	24.76	24.88	24.78	24.80	23.84	502.5	6.31	0.225E+07	0.02545	13.21	11.64	12.85	12.61	12.64	12.63
13	275.2	24.75	24.97	24.92	24.89	23.99	504.3	6.28	0.228E+07	0.02858	15.99	12.36	12.98	13.45	13.58	13.51
14	305.2	24.99	25.17	25.12	25.10	24.14	506.0	6.26	0.231E+07	0.03170	14.28	11.82	12.43	12.68	12.74	12.71
15	333.3	25.04	25.15	25.12	25.11	24.28	507.7	6.24	0.234E+07	0.03463	16.07	14.00	14.47	14.71	14.75	14.73
16	363.3	25.28	25.39	25.35	25.34	24.43	509.4	6.21	0.236E+07	0.03776	14.36	12.63	13.25	13.35	13.37	13.36
17	383.3	25.38	25.47	25.44	25.43	24.53	510.6	6.20	0.238E+07	0.03985	14.38	12.96	13.35	13.49	13.51	13.50
18	403.3	25.44	25.58	25.52	25.51	24.63	511.8	6.18	0.240E+07	0.04194	15.09	12.85	13.71	13.79	13.84	13.82
19	423.3	25.59	25.75	25.68	25.67	24.73	513.0	6.16	0.242E+07	0.04403	14.24	11.94	12.86	12.93	12.98	12.95
20	443.3	25.70	25.83	25.76	25.76	24.84	514.2	6.15	0.244E+07	0.04613	14.09	12.21	13.08	13.08	13.12	13.10
21	463.3	25.93	25.94	26.01	25.97	24.94	515.4	6.13	0.246E+07	0.04822	12.26	12.10	11.33	11.74	11.75	11.75
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.40	25.53	25.48	25.47	24.58	511.1	6.19	0.239E+07	0.04073	14.71	12.77	13.45	13.56	13.59	13.58

DOWNWARD INCLINATION _____ 2 - 500

INPUT ELECTRIC POWER = 231.6 W   HEAT RATE GAINED BY WATER = 227.7 W   HEAT BALANCE ERROR = 1.70%
MASS FLOW RATE = 14.4943 G/S   PRESSURE DROP= 0.2537MMH20   FRICTION FACTOR = 0.034515   FREM = 17.2811
REM = 500.7   GRM = 0.36922E+07   UPSTREAM BULK TEMPERATURE = 22.56DEG C   DOWNSTREAM BULK TEMPERATURE = 26.32DEG C
PRM = 6.211   RAM = 0.22931E+08   INLET BULK TEMPERATURE = 22.56DEG C   OUTLET BULK TEMPERATURE = 26.32DEG C

STATION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.75	23.75	23.75	23.75	22.61	480.4	6.50	0.318E+07	0.00058	16.54	16.62	16.58	16.58	16.58	16.58
4	15.5	23.93	24.03	23.95	23.97	22.69	481.3	6.49	0.320E+07	0.00163	15.33	14.15	15.00	14.85	14.87	14.86
5	25.5	24.09	24.23	24.14	24.15	22.77	482.1	6.48	0.322E+07	0.00269	14.33	12.98	13.78	13.70	13.72	13.71
6	45.5	24.22	24.40	24.29	24.30	22.93	483.8	6.45	0.326E+07	0.00480	14.73	12.89	13.88	13.82	13.85	13.83
7	75.5	24.43	24.63	24.48	24.50	23.17	486.4	6.41	0.333E+07	0.00796	15.06	13.00	14.43	14.19	14.23	14.21
8	105.5	24.59	24.87	24.69	24.71	23.41	489.1	6.37	0.339E+07	0.01113	16.05	12.98	14.79	14.57	14.65	14.61
9	135.5	24.81	25.09	24.98	24.96	23.65	491.7	6.34	0.346E+07	0.01431	16.25	13.11	14.28	14.40	14.48	14.44
10	165.2	25.08	25.36	25.19	25.21	23.89	494.4	6.30	0.353E+07	0.01745	15.82	12.87	14.48	14.34	14.41	14.38
11	205.2	25.35	25.67	25.56	25.54	24.21	498.0	6.25	0.362E+07	0.02169	16.50	12.92	13.95	14.21	14.33	14.27
12	245.2	25.81	26.02	25.87	25.89	24.53	501.7	6.20	0.372E+07	0.02594	14.73	12.65	14.07	13.84	13.88	13.86
13	275.2	25.95	26.23	26.15	26.12	24.77	504.5	6.16	0.379E+07	0.02914	16.06	12.97	13.63	13.98	14.07	14.03
14	305.2	26.22	26.48	26.40	26.38	25.01	507.3	6.12	0.387E+07	0.03233	15.61	12.82	13.54	13.81	13.88	13.84
15	333.3	26.37	26.60	26.54	26.51	25.23	510.0	6.09	0.394E+07	0.03533	16.59	13.87	14.47	14.78	14.85	14.81
16	363.3	26.70	26.93	26.81	26.81	25.47	512.9	6.05	0.402E+07	0.03853	15.42	13.00	14.16	14.13	14.19	14.16
17	383.3	26.86	27.05	26.95	26.95	25.63	514.8	6.02	0.407E+07	0.04067	15.42	13.37	14.36	14.34	14.38	14.36
18	403.3	26.96	27.21	27.09	27.08	25.79	516.8	6.00	0.412E+07	0.04281	16.26	13.35	14.59	14.63	14.70	14.66
19	423.3	27.15	27.43	27.34	27.31	25.95	518.7	5.97	0.418E+07	0.04495	15.78	12.80	13.66	13.89	13.98	13.93
20	443.3	27.27	27.58	27.48	27.45	26.11	520.7	5.95	0.423E+07	0.04710	16.30	12.91	13.84	14.12	14.22	14.17
21	463.3	27.53	27.76	27.75	27.69	26.28	522.7	5.92	0.429E+07	0.04924	15.08	12.74	12.83	13.30	13.37	13.33
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	26.88	27.13	27.03	27.02	25.70	515.6	6.01	0.409E+07	0.04156	15.96	13.22	14.18	14.32	14.38	14.35

DOWNWARD INCLINATION ____ 3 - 500

INPUT ELECTRIC POWER = 274.5 W HEAT RATE GAINED BY WATER = 275.8 W HEAT BALANCE ERROR =-0.49%
MASS FLOW RATE = 14.3581 G/S PRESSURE DROP= 0.2774MMH20 FRICTION FACTOR = 0.038449 FREM = 19.2185
REM = 499.8 GRM = 0.45960E+07 UPSTREAM BULK TEMPERATURE = 22.47DEG C DOWNSTREAM BULK TEMPERATURE = 27.08DEG C
PRM = 6.158 RAM = 0.28301E+08 INLET BULK TEMPERATURE = 22.48DEG C OUTLET BULK TEMPERATURE = 27.07DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.03	24.08	24.06	24.06	22.53	475.2	6.51	0.382E+07	0.00068	15.36	14.84	15.09	15.09	15.10	15.10
4	15.5	24.23	24.39	24.26	24.28	22.63	476.2	6.50	0.385E+07	0.00165	14.41	13.07	14.16	13.93	13.95	13.94
5	25.5	24.39	24.64	24.50	24.51	22.73	477.2	6.48	0.388E+07	0.00271	13.82	12.03	12.96	12.91	12.94	12.93
6	45.5	24.55	24.76	24.66	24.66	22.92	479.3	6.45	0.395E+07	0.00484	14.14	12.52	13.28	13.28	13.30	13.29
7	75.5	24.70	25.04	24.85	24.86	23.22	482.4	6.40	0.405E+07	0.00804	15.47	12.60	14.14	14.01	14.09	14.06
8	105.5	25.01	25.32	25.11	25.14	23.51	485.6	6.36	0.414E+07	0.01124	15.37	12.74	14.40	14.16	14.23	14.20
9	135.5	25.26	25.60	25.48	25.45	23.81	488.9	6.31	0.425E+07	0.01445	15.79	12.83	13.75	13.95	14.03	13.99
10	165.2	25.58	25.94	25.81	25.79	24.10	492.1	6.26	0.435E+07	0.01763	15.44	12.43	13.39	13.58	13.67	13.62
11	205.2	25.94	26.31	26.18	26.15	24.49	496.6	6.20	0.449E+07	0.02192	15.81	12.57	13.57	13.78	13.88	13.83
12	245.2	26.42	26.72	26.57	26.57	24.88	501.1	6.14	0.464E+07	0.02621	14.86	12.45	13.56	13.56	13.61	13.58
13	275.2	26.64	26.95	26.88	26.84	25.18	504.5	6.09	0.475E+07	0.02944	15.62	12.90	13.41	13.76	13.83	13.80
14	305.2	26.95	27.29	27.13	27.13	25.47	508.0	6.05	0.486E+07	0.03268	15.51	12.54	13.76	13.81	13.89	13.85
15	333.3	27.15	27.46	27.40	27.35	25.75	511.3	6.00	0.497E+07	0.03571	16.26	13.35	13.80	14.22	14.30	14.26
16	363.3	27.51	27.85	27.68	27.68	26.04	514.9	5.96	0.509E+07	0.03895	15.57	12.65	13.95	13.95	14.03	13.99
17	383.3	27.72	28.00	27.87	27.87	26.24	517.3	5.93	0.518E+07	0.04112	15.34	12.92	13.97	14.00	14.06	14.03
18	403.3	27.85	28.19	28.04	28.03	26.43	519.8	5.90	0.526E+07	0.04329	16.04	12.97	14.19	14.27	14.35	14.31
19	423.3	28.10	28.44	28.29	28.28	26.63	522.2	5.87	0.534E+07	0.04546	15.50	12.62	13.72	13.81	13.89	13.85
20	443.3	28.23	28.62	28.46	28.44	26.82	524.7	5.83	0.543E+07	0.04763	16.23	12.71	13.92	14.09	14.19	14.14
21	463.3	28.54	28.85	28.78	28.74	27.02	526.9	5.81	0.550E+07	0.04980	15.03	12.45	12.93	13.26	13.33	13.30
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	27.76	28.09	27.96	27.94	26.32	518.4	5.91	0.521E+07	0.04203	15.82	12.87	13.93	14.06	14.13	14.10

DOWNWARD INCLINATION ____ 4 - 500

INPUT ELECTRIC POWER = 320.7 W HEAT RATE GAINED BY WATER = 327.8 W HEAT BALANCE ERROR =-2.219%
MASS FLOW RATE = 14.2389 G/S PRESSURE DROP= 0.2848MMH20 FRICTION FACTOR = 0.040139 FREM = 20.1044
REM = 500.9 GRM = 0.56660E+07 UPSTREAM BULK TEMPERATURE = 22.46DEG C DOWNSTREAM BULK TEMPERATURE = 27.98DEG C
PRM = 6.087 RAM = 0.34489E+08 INLET BULK TEMPERATURE = 22.47DEG C OUTLET BULK TEMPERATURE = 27.98DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.28	24.36	24.32	24.32	22.53	471.2	6.51	0.454E+07	0.00069	15.66	14.96	15.30	15.30	15.30	15.30
4	15.5	24.53	24.81	24.62	24.64	22.65	472.4	6.49	0.459E+07	0.00166	14.55	12.67	13.93	13.74	13.77	13.75
5	25.5	24.78	25.06	24.95	24.93	22.77	473.7	6.47	0.463E+07	0.00274	13.60	11.97	12.56	12.64	12.67	12.66
6	45.5	24.95	25.21	25.11	25.09	23.00	476.1	6.44	0.472E+07	0.00488	14.09	12.39	13.01	13.10	13.12	13.11
7	75.5	25.18	25.57	25.35	25.36	23.36	479.9	6.38	0.486E+07	0.00811	15.01	12.33	13.72	13.63	13.70	13.66
8	105.5	25.45	25.88	25.64	25.65	23.71	483.7	6.33	0.501E+07	0.01134	15.64	12.60	14.14	14.05	14.13	14.09
9	135.5	25.82	26.21	26.06	26.04	24.06	487.6	6.27	0.515E+07	0.01458	15.52	12.70	13.63	13.79	13.87	13.83
10	165.2	26.17	26.61	26.40	26.40	24.41	491.5	6.22	0.530E+07	0.01779	15.51	12.37	13.70	13.73	13.82	13.78
11	205.2	26.53	27.01	26.82	26.80	24.88	496.9	6.14	0.551E+07	0.02212	16.54	12.78	14.02	14.21	14.34	14.28
12	245.2	27.15	27.50	27.33	27.33	25.35	502.4	6.07	0.572E+07	0.02646	15.15	12.64	13.76	13.77	13.82	13.80
13	275.2	27.42	27.82	27.70	27.66	25.70	506.6	6.01	0.589E+07	0.02973	15.80	12.86	13.64	13.90	13.98	13.94
14	305.2	27.81	28.25	28.08	28.06	26.05	510.8	5.96	0.606E+07	0.03300	15.46	12.39	13.38	13.56	13.65	13.61
15	333.3	28.15	28.57	28.49	28.43	26.38	514.9	5.90	0.623E+07	0.03607	15.34	12.41	12.90	13.30	13.39	13.34
16	363.3	28.59	29.04	28.86	28.84	26.74	519.3	5.85	0.641E+07	0.03936	14.60	11.75	12.80	12.91	12.99	12.95
17	383.3	28.84	29.19	29.04	29.03	26.97	522.0	5.81	0.652E+07	0.04154	14.49	12.24	13.09	13.18	13.23	13.21
18	403.3	29.01	29.43	29.24	29.23	27.21	524.5	5.78	0.663E+07	0.04373	15.06	12.19	13.29	13.38	13.46	13.42
19	423.3	29.27	29.67	29.53	29.50	27.44	527.0	5.76	0.674E+07	0.04591	14.79	12.17	12.98	13.17	13.23	13.20
20	443.3	29.41	30.00	29.70	29.70	27.68	529.5	5.73	0.685E+07	0.04810	15.61	11.65	13.38	13.36	13.51	13.43
21	463.3	29.80	30.24	30.16	30.09	27.91	532.1	5.70	0.696E+07	0.05028	14.33	11.64	12.05	12.43	12.52	12.48
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.88	29.32	29.14	29.12	27.07	522.9	5.81	0.656E+07	0.04245	14.98	12.07	13.08	13.22	13.30	13.26

DOWNWARD INCLINATION _____ 5 - 500

INPUT ELECTRIC POWER = 581.7 W HEAT RATE GAINED BY WATER = 584.5 W HEAT BALANCE ERROR =-0.48%
MASS FLOW RATE = 13.6770 G/S PRESSURE DROP= 0.3465MMH20 FRICTION FACTOR = 0.062893 FREM = 26.7908
REM = 506.5 GRM = 0.12041E+08 UPSTREAM BULK TEMPERATURE = 22.35DEG C DOWNSTREAM BULK TEMPERATURE = 32.60DEG C
PRM = 5.751 RAM = 0.69252E+08 INLET BULK TEMPERATURE = 22.36DEG C OUTLET BULK TEMPERATURE = 32.59DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	28.11	29.28	28.70	28.70	22.48	452.1	6.52	0.807E+07	0.00061	8.67	7.18	7.85	7.85	7.89	7.87
4	15.5	28.29	29.42	28.89	28.87	22.70	454.3	6.49	0.821E+07	0.00173	8.73	7.26	7.88	7.90	7.94	7.92
5	25.5	28.55	29.73	29.27	29.20	22.92	456.5	6.45	0.836E+07	0.00285	8.66	7.16	7.68	7.76	7.79	7.78
6	45.5	28.87	29.97	29.53	29.47	23.35	460.9	6.38	0.867E+07	0.00509	8.83	7.37	7.89	7.96	8.00	7.98
7	75.5	29.31	30.49	29.93	29.92	24.01	467.8	6.28	0.915E+07	0.00846	9.17	7.50	8.22	8.23	8.28	8.26
8	105.5	29.75	31.06	30.36	30.38	24.66	474.9	6.18	0.965E+07	0.01183	9.54	7.61	8.53	8.50	8.55	8.52
9	135.5	30.40	31.51	31.00	30.98	25.32	482.2	6.07	0.102E+08	0.01522	9.55	7.84	8.53	8.57	8.61	8.59
10	165.2	31.17	32.44	31.98	31.89	25.96	489.6	5.97	0.107E+08	0.01859	9.30	7.48	8.06	8.17	8.22	8.20
11	206.2	31.77	33.06	32.58	32.50	26.84	500.0	5.83	0.115E+08	0.02315	9.79	7.76	8.41	8.53	8.59	8.56
12	245.2	32.54	33.59	33.15	33.10	27.71	508.9	5.72	0.122E+08	0.02770	9.99	8.21	8.87	8.94	8.99	8.96
13	275.2	32.97	34.04	33.77	33.64	28.36	515.9	5.64	0.128E+08	0.03112	10.46	8.49	8.91	9.13	9.19	9.16
14	305.2	33.37	34.41	34.02	33.96	29.02	523.0	5.56	0.134E+08	0.03455	11.04	8.92	9.61	9.74	9.79	9.77
15	333.3	33.86	34.78	34.64	34.48	29.63	529.8	5.48	0.140E+08	0.03777	11.35	9.33	9.59	9.90	9.96	9.93
16	363.3	34.34	35.29	34.95	34.88	30.29	537.3	5.40	0.146E+08	0.04121	11.84	9.58	10.29	10.44	10.50	10.47
17	383.3	34.60	35.44	35.13	35.07	30.72	542.4	5.34	0.151E+08	0.04351	12.35	10.16	10.88	11.01	11.07	11.04
18	403.3	34.85	35.70	35.32	35.30	31.16	547.6	5.29	0.156E+08	0.04582	12.95	10.55	11.49	11.56	11.62	11.59
19	423.3	35.08	35.85	35.60	35.53	31.59	552.9	5.23	0.160E+08	0.04813	13.71	11.24	11.95	12.15	12.21	12.18
20	443.3	35.15	35.81	35.60	35.54	32.03	558.0	5.18	0.165E+08	0.05046	15.30	12.65	13.37	13.61	13.67	13.64
21	463.3	35.55	36.23	35.96	35.93	32.47	562.8	5.13	0.169E+08	0.05280	15.45	12.67	13.66	13.79	13.86	13.82
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	34.65	35.48	35.21	35.13	30.90	544.7	5.32	0.153E+08	0.04448	12.92	10.58	11.26	11.44	11.50	11.47

DOWNWARD INCLINATION _____ 6 - 500

INPUT ELECTRIC POWER = 738.1 W HEAT RATE GAINED BY WATER = 723.4 W HEAT BALANCE ERROR = 1.99%
MASS FLOW RATE = 13.1321 G/S PRESSURE DROP= 0.3716MMH20 FRICTION FACTOR = 0.061502 FREM = 30.7636
REM = 500.2 GRM = 0.16376E+08 UPSTREAM BULK TEMPERATURE = 22.23DEG C DOWNSTREAM BULK TEMPERATURE = 35.44DEG C
PRM = 5.580 RAM = 0.91377E+08 INLET BULK TEMPERATURE = 22.24DEG C OUTLET BULK TEMPERATURE = 35.43DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	31.08	32.83	31.96	31.96	22.40	433.3	6.53	0.992E+07	0.00064	6.96	5.80	6.32	6.32	6.35	6.34
4	15.5	31.27	32.83	32.09	32.07	22.68	436.0	6.49	0.102E+08	0.00180	7.03	5.95	6.42	6.43	6.45	6.44
5	25.5	31.52	33.20	32.59	32.47	22.96	438.7	6.44	0.104E+08	0.00297	7.05	5.90	6.27	6.35	6.37	6.36
6	45.5	31.87	33.41	32.80	32.72	23.52	444.3	6.36	0.109E+08	0.00530	7.22	6.10	6.50	6.56	6.58	6.57
7	75.5	32.40	33.99	33.25	33.22	24.37	452.9	6.22	0.117E+08	0.00881	7.49	6.25	6.77	6.79	6.82	6.81
8	105.5	32.88	34.57	33.71	33.72	25.21	461.8	6.09	0.125E+08	0.01234	7.83	6.41	7.07	7.06	7.10	7.08
9	135.5	33.46	34.99	34.29	34.26	26.05	471.1	5.96	0.134E+08	0.01589	8.09	6.71	7.28	7.30	7.34	7.32
10	165.2	34.54	36.23	35.62	35.50	26.89	480.6	5.83	0.143E+08	0.01941	7.82	6.40	6.85	6.94	6.98	6.96
11	205.2	35.12	36.71	36.13	36.03	28.01	491.7	5.68	0.156E+08	0.02415	8.39	6.86	7.35	7.45	7.49	7.47
12	245.2	35.98	37.30	36.73	36.68	29.14	503.4	5.54	0.167E+08	0.02891	8.69	7.30	7.84	7.89	7.92	7.90
13	275.2	36.45	37.78	37.47	37.29	29.98	512.5	5.44	0.177E+08	0.03250	9.18	7.62	7.93	8.13	8.17	8.15
14	305.2	36.84	38.11	37.61	37.54	30.83	522.0	5.33	0.188E+08	0.03609	9.86	8.14	8.74	8.83	8.87	8.85
15	333.3	37.34	38.46	38.29	38.09	31.62	531.2	5.23	0.199E+08	0.03947	10.34	8.65	8.87	9.14	9.18	9.16
16	363.3	37.82	38.97	38.54	38.47	32.46	540.3	5.13	0.209E+08	0.04312	11.02	9.07	9.71	9.83	9.88	9.85
17	383.3	38.10	39.07	38.70	38.64	33.02	546.3	5.06	0.217E+08	0.04558	11.63	9.75	10.39	10.50	10.54	10.52
18	403.3	38.34	39.29	38.91	38.86	33.59	552.4	5.00	0.224E+08	0.04805	12.39	10.32	11.06	11.16	11.21	11.18
19	423.3	38.57	39.49	39.19	39.11	34.15	558.6	4.93	0.232E+08	0.05052	13.29	11.01	11.66	11.85	11.90	11.87
20	443.3	38.59	39.47	39.15	39.09	34.71	565.0	4.87	0.240E+08	0.05301	15.15	12.34	13.24	13.42	13.49	13.46
21	463.3	39.15	40.10	39.72	39.67	35.27	571.6	4.80	0.249E+08	0.05551	15.13	12.15	13.19	13.33	13.42	13.37
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	38.13	39.12	38.80	38.71	33.26	549.0	5.04	0.220E+08	0.04663	12.30	10.19	10.82	10.98	11.03	11.01

DOWNWARD INCLINATION ____ 7 - 500

INPUT ELECTRIC POWER = 923.6 W HEAT RATE GAINED BY WATER = 911.7 W HEAT BALANCE ERROR = 1.29%
MASS FLOW RATE = 12.4500 G/S PRESSURE DROP= 0.4966MMH20 FRICTION FACTOR = 0.091363 FREM = 45.4297

REM = 497.2 GRM = 0.24046E+08 UPSTREAM BULK TEMPERATURE = 22.27DEG C DOWNSTREAM BULK TEMPERATURE = 39.82DEG C
PRM = 5.301 RAM = 0.12748E+09 INLET BULK TEMPERATURE = 22.28DEG C OUTLET BULK TEMPERATURE = 39.81DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	36.33	38.55	37.44	37.44	22.49	411.6	6.52	0.126E+08	0.00067	5.50	4.74	5.09	5.09	5.11	5.10
4	15.5	36.45	38.53	37.56	37.52	22.86	415.0	6.46	0.130E+08	0.00190	5.60	4.86	5.18	5.19	5.20	5.20
5	25.5	36.67	38.73	38.01	37.86	23.24	418.5	6.40	0.134E+08	0.00313	5.66	4.91	5.14	5.20	5.21	5.21
6	45.5	37.03	38.98	38.20	38.10	23.98	425.6	6.28	0.142E+08	0.00560	5.82	5.06	5.34	5.38	5.39	5.38
7	75.5	37.42	39.47	38.50	38.47	25.10	436.7	6.11	0.156E+08	0.00931	6.15	5.27	5.65	5.66	5.68	5.67
8	105.5	37.82	39.94	38.84	38.86	26.23	448.5	5.93	0.171E+08	0.01305	6.51	5.50	5.98	5.98	6.00	5.99
9	135.5	38.32	40.32	39.42	39.37	27.35	459.9	5.77	0.186E+08	0.01681	6.86	5.81	6.24	6.26	6.29	6.27
10	165.2	39.60	41.75	40.98	40.83	28.46	470.5	5.63	0.201E+08	0.02052	6.74	5.65	6.00	6.07	6.10	6.09
11	205.2	40.31	42.26	41.42	41.35	29.95	485.6	5.44	0.223E+08	0.02556	7.23	6.08	6.53	6.57	6.59	6.58
12	245.2	40.93	42.57	41.96	41.86	31.45	501.7	5.25	0.247E+08	0.03062	7.87	6.71	7.10	7.17	7.19	7.18
13	275.2	41.33	42.97	42.62	42.39	32.57	513.3	5.12	0.266E+08	0.03447	8.50	7.16	7.40	7.58	7.61	7.60
14	305.2	41.76	43.26	42.60	42.55	33.69	524.8	4.99	0.284E+08	0.03836	9.20	7.75	8.33	8.37	8.40	8.39
15	333.3	42.27	43.72	43.49	43.24	34.74	536.0	4.86	0.303E+08	0.04205	9.83	8.24	8.45	8.70	8.75	8.72
16	363.3	42.81	44.27	43.79	43.66	35.86	548.6	4.73	0.325E+08	0.04601	10.62	8.78	9.31	9.46	9.50	9.48
17	383.3	43.15	44.33	43.81	43.78	36.61	557.3	4.65	0.340E+08	0.04868	11.25	9.54	10.23	10.28	10.31	10.30
18	403.3	43.34	44.52	44.01	43.97	37.36	565.4	4.57	0.355E+08	0.05131	12.29	10.26	11.06	11.12	11.17	11.14
19	423.3	43.55	44.66	44.31	44.21	38.11	573.4	4.50	0.371E+08	0.05391	13.50	11.20	11.84	12.04	12.10	12.07
20	443.3	43.54	44.49	44.09	44.05	38.85	581.6	4.44	0.386E+08	0.05653	15.65	13.02	14.00	14.10	14.17	14.13
21	463.3	43.98	45.12	44.62	44.59	39.60	590.0	4.37	0.403E+08	0.05915	16.73	13.28	14.58	14.69	14.79	14.74
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	43.11	44.33	43.92	43.82	36.92	560.4	4.63	0.347E+08	0.04975	12.19	10.17	10.81	10.95	11.00	10.97

DOWNWARD INCLINATION ____ 1 - 1000

INPUT ELECTRIC POWER = 148.5 W HEAT RATE GAINED BY WATER = 148.2 W HEAT BALANCE ERROR = 0.20%
MASS FLOW RATE = 29.7685 G/S PRESSURE DROP= 0.5477MMH20 FRICTION FACTOR = 0.017666 FREM = 17.6223

REM = 997.5 GRM = 0.21519E+07 UPSTREAM BULK TEMPERATURE = 22.50DEG C DOWNSTREAM BULK TEMPERATURE = 23.69DEG C
PRM = 6.423 RAM = 0.13822E+08 INLET BULK TEMPERATURE = 22.50DEG C OUTLET BULK TEMPERATURE = 23.69DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.14	23.11	23.13	23.13	22.52	984.8	6.51	0.205E+07	0.00028	19.69	20.92	20.28	20.28	20.29	20.29
4	15.5	23.32	23.30	23.32	23.31	22.54	985.3	6.51	0.206E+07	0.00079	15.92	16.24	15.92	16.00	16.00	16.00
5	25.5	23.40	23.46	23.43	23.43	22.57	985.9	6.51	0.206E+07	0.00131	14.76	13.85	14.41	14.35	14.36	14.35
6	45.5	23.52	23.56	23.51	23.52	22.62	987.0	6.50	0.207E+07	0.00233	13.77	13.12	13.84	13.64	13.64	13.64
7	75.5	23.62	23.71	23.62	23.64	22.69	988.6	6.49	0.208E+07	0.00387	13.32	12.17	13.40	13.05	13.07	13.06
8	105.5	23.67	23.78	23.66	23.69	22.77	990.3	6.47	0.209E+07	0.00541	13.76	12.26	13.93	13.43	13.47	13.45
9	135.5	23.73	23.87	23.80	23.80	22.85	992.0	6.46	0.211E+07	0.00695	14.04	12.10	12.90	12.95	12.99	12.97
10	165.2	23.86	23.96	23.91	23.91	22.92	993.6	6.45	0.212E+07	0.00848	13.17	11.85	12.56	12.52	12.54	12.53
11	205.2	23.93	24.08	24.05	24.03	23.02	995.9	6.43	0.214E+07	0.01053	13.61	11.65	11.98	12.26	12.31	12.28
12	245.2	24.12	24.18	24.14	24.14	23.12	998.1	6.42	0.216E+07	0.01259	12.46	11.68	12.19	12.13	12.13	12.13
13	275.2	24.08	24.22	24.19	24.17	23.20	999.8	6.41	0.217E+07	0.01413	14.07	12.16	12.43	12.73	12.77	12.75
14	305.2	24.21	24.33	24.27	24.27	23.28	1001.5	6.39	0.218E+07	0.01568	13.28	11.78	12.38	12.43	12.45	12.44
15	333.3	24.15	24.26	24.26	24.23	23.35	1003.1	6.38	0.220E+07	0.01712	15.50	13.60	13.60	14.03	14.07	14.05
16	363.3	24.27	24.42	24.31	24.33	23.42	1004.9	6.37	0.221E+07	0.01867	14.54	12.44	13.96	13.68	13.72	13.70
17	383.3	24.34	24.43	24.35	24.37	23.47	1006.0	6.36	0.222E+07	0.01970	14.24	12.97	14.06	13.81	13.83	13.82
18	403.3	24.31	24.45	24.40	24.39	23.53	1007.2	6.36	0.223E+07	0.02073	15.68	13.30	14.15	14.27	14.32	14.30
19	423.3	24.41	24.58	24.47	24.48	23.58	1008.3	6.35	0.224E+07	0.02176	14.76	12.36	13.83	13.64	13.69	13.66
20	443.3	24.43	24.59	24.53	24.52	23.63	1009.5	6.34	0.225E+07	0.02279	15.38	12.85	13.74	13.87	13.93	13.90
21	463.3	24.66	24.64	24.77	24.71	23.68	1010.6	6.33	0.226E+07	0.02382	12.54	12.82	11.27	11.93	11.98	11.96
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.32	24.45	24.39	24.39	23.50	1006.5	6.36	0.222E+07	0.02013	15.02	12.92	13.89	13.88	13.93	13.91

DOWNWARD INCLINATION _____ 2 - 1000

INPUT ELECTRIC POWER = 301.4 W HEAT RATE GAINED BY WATER = 294.2 W HEAT BALANCE ERROR = 2.40%
MASS FLOW RATE = 29.1899 G/S PRESSURE DROP= 0.5693MMH20 FRICTION FACTOR = 0.019097 FREM = 19.0452
REM = 997.3 GRM = 0.45868E+07 UPSTREAM BULK TEMPERATURE = 22.75DEG C DOWNSTREAM BULK TEMPERATURE = 25.17DEG C
PRM = 6.287 RAM = 0.28837E+08 INLET BULK TEMPERATURE = 22.75DEG C OUTLET BULK TEMPERATURE = 25.16DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.92	23.89	23.91	23.91	22.78	971.3	6.47	0.416E+07	0.00029	21.52	22.15	21.83	21.83	21.83	21.83
4	15.5	24.53	24.59	24.48	24.52	22.83	972.4	6.46	0.418E+07	0.00081	14.44	13.99	14.92	14.56	14.57	14.56
5	25.5	24.70	24.89	24.73	24.76	22.88	973.5	6.46	0.420E+07	0.00133	13.53	12.23	13.32	13.08	13.10	13.09
6	45.5	24.78	24.88	24.77	24.80	22.99	975.7	6.44	0.423E+07	0.00238	13.71	13.00	13.76	13.55	13.56	13.55
7	75.5	24.82	25.07	24.85	24.89	23.14	979.1	6.42	0.429E+07	0.00395	14.65	12.71	14.39	13.99	14.04	14.01
8	105.5	24.90	25.20	25.00	25.02	23.29	982.5	6.39	0.434E+07	0.00553	15.32	12.85	14.41	14.19	14.25	14.22
9	135.5	25.09	25.37	25.20	25.22	23.45	985.9	6.37	0.440E+07	0.00710	14.91	12.75	14.02	13.88	13.92	13.90
10	165.2	25.19	25.53	25.36	25.36	23.60	989.3	6.34	0.445E+07	0.00866	15.39	12.74	13.92	13.93	13.99	13.96
11	205.2	25.35	25.70	25.59	25.56	23.81	993.9	6.31	0.453E+07	0.01076	15.84	12.94	13.73	13.98	14.06	14.02
12	245.2	25.59	25.83	25.70	25.71	24.01	998.5	6.28	0.461E+07	0.01287	15.54	13.49	14.48	14.46	14.50	14.48
13	275.2	25.61	25.89	25.82	25.78	24.17	1002.1	6.25	0.467E+07	0.01445	16.96	14.21	14.83	15.14	15.21	15.17
14	305.2	25.77	26.03	25.90	25.90	24.32	1005.6	6.23	0.473E+07	0.01603	16.88	14.29	15.51	15.50	15.55	15.52
15	333.3	25.82	26.09	26.04	26.00	24.47	1008.9	6.21	0.478E+07	0.01751	18.14	15.03	15.57	15.99	16.07	16.03
16	363.3	25.97	26.28	26.13	26.13	24.62	1012.5	6.18	0.484E+07	0.01909	18.08	14.70	16.17	16.19	16.28	16.23
17	383.3	26.08	26.29	26.17	26.17	24.72	1014.9	6.17	0.488E+07	0.02015	18.09	15.66	16.94	16.86	16.91	16.88
18	403.3	26.11	26.39	26.28	26.26	24.83	1017.4	6.15	0.492E+07	0.02120	19.02	15.61	16.87	17.01	17.09	17.05
19	423.3	26.23	26.51	26.38	26.37	24.93	1019.8	6.13	0.497E+07	0.02226	18.81	15.50	16.85	16.92	17.00	16.96
20	443.3	26.26	26.56	26.44	26.42	25.03	1022.2	6.12	0.501E+07	0.02332	19.92	15.98	17.39	17.56	17.67	17.61
21	463.3	26.51	26.69	26.71	26.65	25.14	1024.7	6.10	0.505E+07	0.02438	17.70	15.73	15.53	16.08	16.13	16.10
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	26.08	26.35	26.24	26.23	24.77	1016.0	6.16	0.490E+07	0.02059	18.67	15.41	16.63	16.76	16.84	16.80

DOWNWARD INCLINATION _____ 3 - 1000

INPUT ELECTRIC POWER = 468.2 W HEAT RATE GAINED BY WATER = 460.1 W HEAT BALANCE ERROR = 1.73%
MASS FLOW RATE = 28.7560 G/S PRESSURE DROP= 0.5532MMH20 FRICTION FACTOR = 0.019118 FREM = 19.1340
REM = 1000.8 GRM = 0.76621E+07 UPSTREAM BULK TEMPERATURE = 22.85DEG C DOWNSTREAM BULK TEMPERATURE = 26.68DEG C
PRM = 6.159 RAM = 0.47193E+08 INLET BULK TEMPERATURE = 22.85DEG C OUTLET BULK TEMPERATURE = 26.68DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.95	24.95	24.95	24.95	22.90	959.3	6.45	0.657E+07	0.00029	18.71	18.70	18.71	18.71	18.71	18.71
4	15.5	25.31	25.48	25.31	25.35	22.98	961.1	6.44	0.662E+07	0.00082	16.50	15.34	16.50	16.19	16.21	16.20
5	25.5	25.52	25.80	25.67	25.66	23.06	962.8	6.43	0.666E+07	0.00136	15.58	14.02	14.72	14.74	14.76	14.75
6	45.5	25.65	25.88	25.72	25.74	23.22	966.3	6.40	0.675E+07	0.00242	15.84	14.43	15.36	15.23	15.25	15.24
7	75.5	25.82	26.18	25.91	25.95	23.47	971.6	6.36	0.689E+07	0.00402	16.34	14.13	15.73	15.43	15.48	15.46
8	105.5	25.96	26.46	26.14	26.18	23.71	977.0	6.33	0.703E+07	0.00562	17.09	13.94	15.78	15.56	15.65	15.61
9	135.5	26.29	26.71	26.48	26.49	23.96	982.5	6.29	0.717E+07	0.00722	16.40	13.91	15.18	15.12	15.17	15.14
10	165.2	26.42	26.95	26.71	26.70	24.20	987.9	6.25	0.732E+07	0.00880	17.27	13.94	15.27	15.35	15.43	15.39
11	205.2	26.67	27.18	26.96	26.94	24.53	995.3	6.20	0.751E+07	0.01094	17.89	14.43	15.71	15.84	15.93	15.89
12	245.2	27.06	27.53	27.27	27.28	24.85	1002.9	6.15	0.772E+07	0.01309	17.31	14.28	15.82	15.73	15.81	15.77
13	275.2	27.17	27.68	27.50	27.46	25.10	1008.6	6.11	0.787E+07	0.01470	18.43	14.82	15.92	16.17	16.27	16.22
14	305.2	27.39	27.86	27.66	27.64	25.34	1014.4	6.07	0.803E+07	0.01631	18.64	15.20	16.45	16.60	16.69	16.64
15	333.3	27.63	28.10	27.99	27.92	25.57	1019.9	6.03	0.818E+07	0.01782	18.60	15.11	15.81	16.23	16.33	16.28
16	363.3	27.84	28.35	28.10	28.10	25.82	1025.8	5.99	0.835E+07	0.01944	18.85	15.08	16.73	16.74	16.85	16.79
17	383.3	28.00	28.45	28.23	28.23	25.98	1029.8	5.97	0.846E+07	0.02052	18.85	15.42	16.94	16.95	17.04	17.00
18	403.3	28.14	28.61	28.40	28.39	26.15	1033.8	5.94	0.857E+07	0.02160	19.15	15.44	16.87	16.98	17.08	17.03
19	423.3	28.32	28.83	28.60	28.59	26.31	1037.9	5.92	0.869E+07	0.02268	18.91	15.12	16.63	16.71	16.82	16.77
20	443.3	28.40	28.93	28.74	28.70	26.47	1042.0	5.89	0.880E+07	0.02376	19.77	15.50	16.77	17.07	17.20	17.13
21	463.3	28.65	29.17	29.01	28.96	26.64	1046.1	5.86	0.892E+07	0.02484	18.91	15.03	16.05	16.39	16.51	16.45
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.05	28.54	28.34	28.32	26.05	1031.5	5.96	0.851E+07	0.02097	19.02	15.28	16.62	16.78	16.89	16.83

DOWNWARD INCLINATION _____ 4 - 1000

INPUT ELECTRIC POWER = 662.8 W HEAT RATE GAINED BY WATER = 640.6 W HEAT BALANCE ERROR = 3.35%
MASS FLOW RATE = 28.3221 G/S PRESSURE DROP= 0.5522MMH20 FRICTION FACTOR = 0.019669 FREM = 19.6967
REM = 1001.4 GRM = 0.11272E+08 UPSTREAM BULK TEMPERATURE = 22.73DEG C DOWNSTREAM BULK TEMPERATURE = 28.15DEG C
PRM = 6.052 RAM = 0.68223E+08 INLET BULK TEMPERATURE = 22.74DEG C OUTLET BULK TEMPERATURE = 28.15DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.56	25.70	25.63	25.63	22.80	942.8	6.47	0.908E+07	0.00030	19.37	18.41	18.88	18.88	18.88	18.88
4	15.5	26.00	26.38	26.06	26.12	22.92	945.2	6.45	0.917E+07	0.00084	17.36	15.45	17.05	16.69	16.73	16.71
5	25.5	26.32	26.76	26.55	26.55	23.03	947.7	6.43	0.925E+07	0.00138	16.24	14.33	15.17	15.20	15.23	15.21
6	45.5	26.46	26.89	26.59	26.63	23.26	952.6	6.40	0.943E+07	0.00246	16.70	14.72	16.06	15.85	15.88	15.87
7	75.5	26.70	27.24	26.88	26.93	23.61	960.0	6.34	0.970E+07	0.00408	17.24	14.70	16.29	16.08	16.13	16.10
8	105.5	26.96	27.69	27.20	27.26	23.95	967.5	6.29	0.998E+07	0.00570	17.73	14.26	16.42	16.11	16.21	16.16
9	135.5	27.38	28.06	27.71	27.71	24.30	975.2	6.23	0.103E+08	0.00733	17.29	14.21	15.63	15.62	15.69	15.66
10	165.2	27.59	28.37	28.05	28.02	24.64	982.9	6.18	0.106E+08	0.00895	18.09	14.29	15.61	15.79	15.90	15.84
11	205.2	27.89	28.71	28.36	28.33	25.11	993.5	6.11	0.110E+08	0.01113	19.07	14.75	16.34	16.48	16.62	16.55
12	245.2	28.45	29.15	28.81	28.81	25.57	1004.4	6.03	0.114E+08	0.01331	18.41	14.83	16.38	16.41	16.50	16.45
13	275.2	28.68	29.41	29.18	29.11	25.91	1012.6	5.98	0.117E+08	0.01495	19.21	15.20	16.25	16.60	16.73	16.67
14	305.2	28.96	29.70	29.40	29.37	26.26	1021.0	5.92	0.120E+08	0.01660	19.66	15.40	16.88	17.07	17.21	17.14
15	333.3	29.38	30.13	29.94	29.85	26.58	1029.0	5.87	0.124E+08	0.01814	18.96	14.94	15.81	16.25	16.38	16.32
16	363.3	29.71	30.52	30.15	30.13	26.93	1037.4	5.82	0.127E+08	0.01979	19.06	14.74	16.46	16.54	16.68	16.61
17	383.3	29.96	30.68	30.33	30.32	27.16	1042.2	5.79	0.129E+08	0.02089	18.91	15.06	16.73	16.74	16.85	16.80
18	403.3	30.16	30.92	30.56	30.55	27.39	1047.1	5.76	0.131E+08	0.02199	19.12	15.00	16.69	16.75	16.88	16.81
19	423.3	30.45	31.21	30.90	30.86	27.62	1052.1	5.73	0.133E+08	0.02309	18.73	14.76	16.12	16.31	16.43	16.37
20	443.3	30.59	31.41	31.08	31.04	27.85	1057.0	5.70	0.135E+08	0.02419	19.29	14.87	16.40	16.59	16.74	16.67
21	463.3	31.23	32.31	31.53	31.65	28.08	1062.1	5.67	0.138E+08	0.02529	16.79	12.50	15.33	14.81	14.98	14.90
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	30.04	30.81	30.49	30.46	27.26	1044.1	5.78	0.130E+08	0.02135	19.01	14.89	16.37	16.53	16.66	16.60

DOWNWARD INCLINATION _____ 5 - 1000

INPUT ELECTRIC POWER = 889.5 W HEAT RATE GAINED BY WATER = 876.1 W HEAT BALANCE ERROR = 1.51%
MASS FLOW RATE = 27.7435 G/S PRESSURE DROP= 0.6111MMH20 FRICTION FACTOR = 0.022679 FREM = 22.7802
REM = 1004.5 GRM = 0.16716E+08 UPSTREAM BULK TEMPERATURE = 22.65DEG C DOWNSTREAM BULK TEMPERATURE = 30.22DEG C
PRM = 5.895 RAM = 0.98540E+08 INLET BULK TEMPERATURE = 22.66DEG C OUTLET BULK TEMPERATURE = 30.22DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.70	27.10	26.90	26.90	22.75	922.5	6.48	0.124E+08	0.00030	18.52	16.80	17.62	17.62	17.64	17.63
4	15.5	27.18	27.97	27.40	27.49	22.91	925.8	6.45	0.125E+08	0.00085	17.11	14.45	16.27	15.97	16.03	16.00
5	25.5	27.64	28.44	28.02	28.03	23.07	929.1	6.43	0.127E+08	0.00140	15.99	13.61	14.77	14.74	14.78	14.76
6	45.5	27.75	28.51	28.07	28.10	23.39	935.9	6.38	0.130E+08	0.00251	16.77	14.26	15.61	15.51	15.56	15.54
7	75.5	28.15	29.05	28.50	28.55	23.88	946.1	6.30	0.136E+08	0.00417	17.08	14.11	15.77	15.61	15.68	15.65
8	105.5	28.47	29.62	28.91	28.98	24.36	956.6	6.22	0.141E+08	0.00583	17.74	13.85	16.03	15.79	15.91	15.85
9	135.5	29.08	30.06	29.52	29.55	24.84	967.3	6.15	0.147E+08	0.00750	17.17	13.96	15.56	15.48	15.56	15.52
10	165.2	29.34	30.54	30.02	29.98	25.32	978.2	6.07	0.153E+08	0.00915	18.11	13.92	15.49	15.62	15.75	15.68
11	205.2	29.74	30.94	30.43	30.38	25.97	993.2	5.97	0.161E+08	0.01138	19.26	14.59	16.27	16.43	16.60	16.52
12	245.2	30.59	31.72	31.24	31.20	26.61	1008.7	5.87	0.170E+08	0.01363	18.21	14.20	15.65	15.80	15.93	15.87
13	275.2	31.07	32.25	31.87	31.77	27.10	1019.6	5.80	0.176E+08	0.01531	18.20	14.04	15.17	15.50	15.65	15.58
14	305.2	31.47	32.76	32.18	32.15	27.58	1029.7	5.74	0.182E+08	0.01699	18.58	13.97	15.74	15.84	16.00	15.92
15	333.3	32.11	33.44	33.08	32.93	28.03	1039.3	5.68	0.188E+08	0.01857	17.73	13.35	14.31	14.75	14.92	14.84
16	363.3	32.55	33.92	33.38	33.31	28.52	1049.7	5.62	0.194E+08	0.02026	17.88	13.35	14.85	15.06	15.23	15.15
17	383.3	32.92	34.08	33.59	33.55	28.84	1056.8	5.58	0.198E+08	0.02138	17.65	13.75	15.17	15.31	15.44	15.37
18	403.3	33.22	34.40	33.87	33.84	29.16	1064.0	5.54	0.203E+08	0.02251	17.74	13.75	15.31	15.40	15.53	15.46
19	423.3	33.49	34.70	34.28	34.19	29.48	1071.3	5.50	0.207E+08	0.02364	17.97	13.80	15.02	15.31	15.45	15.38
20	443.3	33.63	34.82	34.37	34.30	29.81	1078.7	5.46	0.212E+08	0.02477	18.80	14.35	15.78	16.02	16.18	16.10
21	463.3	34.04	35.25	34.90	34.77	30.13	1086.2	5.42	0.217E+08	0.02590	18.38	14.03	15.08	15.49	15.64	15.57
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	32.99	34.23	33.76	33.68	28.97	1060.0	5.56	0.200E+08	0.02186	17.96	13.72	15.07	15.31	15.46	15.38

DOWNWARD INCLINATION _____ 6 - 1000

INPUT ELECTRIC POWER = 1176.2 W HEAT RATE GAINED BY WATER = 1132.0 W HEAT BALANCE ERROR = 3.76%
MASS FLOW RATE = 26.8034 G/S PRESSURE DROP= 0.7871MMH20 FRICTION FACTOR = 0.031282 FREM = 31.3479
REM = 1002.1 GRM = 0.24083E+08 UPSTREAM BULK TEMPERATURE = 22.88DEG C DOWNSTREAM BULK TEMPERATURE = 33.00DEG C
PRM = 5.693 RAM = 0.13710E+09 INLET BULK TEMPERATURE = 22.89DEG C OUTLET BULK TEMPERATURE = 32.99DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	29.72	31.29	30.51	30.51	23.00	896.3	6.44	0.163E+08	0.00031	14.05	11.40	12.59	12.59	12.66	12.62
4	15.5	30.00	31.63	30.66	30.74	23.22	900.6	6.40	0.166E+08	0.00088	13.93	11.23	12.69	12.56	12.63	12.60
5	25.5	30.45	32.04	31.34	31.29	23.44	905.0	6.37	0.169E+08	0.00146	13.45	10.96	11.93	12.01	12.07	12.04
6	45.5	30.52	32.07	31.32	31.31	23.87	913.8	6.30	0.175E+08	0.00260	14.16	11.49	12.65	12.67	12.74	12.70
7	75.5	31.01	32.66	31.80	31.82	24.51	927.4	6.20	0.185E+08	0.00432	14.49	11.55	12.92	12.89	12.97	12.93
8	105.5	31.48	33.40	32.31	32.38	25.16	941.5	6.10	0.195E+08	0.00605	14.86	11.41	13.14	13.02	13.14	13.08
9	135.5	32.01	33.77	32.95	32.92	25.81	955.9	5.99	0.205E+08	0.00778	15.12	11.79	13.13	13.19	13.29	13.24
10	165.2	32.87	34.95	34.11	34.01	26.45	970.6	5.89	0.216E+08	0.00950	14.59	11.02	12.23	12.39	12.52	12.45
11	205.2	33.42	35.52	34.51	34.49	27.31	989.3	5.77	0.231E+08	0.01182	15.30	11.39	12.98	13.02	13.17	13.09
12	245.2	34.43	36.26	35.47	35.41	28.17	1006.9	5.66	0.245E+08	0.01414	14.92	11.53	12.79	12.90	13.01	12.95
13	275.2	34.95	36.83	36.24	36.06	28.82	1020.6	5.58	0.256E+08	0.01589	15.21	11.63	12.56	12.86	12.99	12.93
14	305.2	35.27	37.10	36.38	36.28	29.46	1034.6	5.50	0.268E+08	0.01764	16.02	12.19	13.46	13.65	13.78	13.72
15	333.3	36.03	37.79	37.34	37.13	30.07	1048.1	5.42	0.279E+08	0.01929	15.58	12.04	12.78	13.17	13.30	13.23
16	363.3	36.46	38.27	37.59	37.48	30.72	1062.9	5.34	0.292E+08	0.02106	16.17	12.28	13.51	13.73	13.87	13.80
17	383.3	36.75	38.36	37.75	37.65	31.15	1073.0	5.29	0.301E+08	0.02222	16.54	12.85	14.04	14.25	14.37	14.31
18	403.3	37.02	38.65	37.99	37.91	31.58	1083.2	5.23	0.310E+08	0.02340	17.03	13.10	14.46	14.63	14.76	14.70
19	423.3	37.32	38.84	38.35	38.22	32.01	1093.2	5.18	0.319E+08	0.02458	17.44	13.54	14.59	14.91	15.04	14.98
20	443.3	37.36	38.82	38.33	38.21	32.44	1102.3	5.13	0.327E+08	0.02578	18.84	14.49	15.70	16.03	16.18	16.10
21	463.3	37.91	39.41	38.76	38.71	32.87	1111.7	5.08	0.336E+08	0.02698	18.32	14.13	15.67	15.81	15.95	15.88
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	36.82	38.46	37.89	37.76	31.33	1077.1	5.27	0.305E+08	0.02272	16.93	13.06	14.18	14.45	14.59	14.52

DOWNWARD INCLINATION _____ 1 - 1500

INPUT ELECTRIC POWER = 165.2 W HEAT RATE GAINED BY WATER = 162.5 W HEAT BALANCE ERROR = 1.63%
MASS FLOW RATE = 45.2450 G/S PRESSURE DROP= 0.8155MMH20 FRICTION FACTOR = 0.011389 FREM = 17.0979
REM = 1501.3 GRM = 0.22748E+07 UPSTREAM BULK TEMPERATURE = 22.22DEG C DOWNSTREAM BULK TEMPERATURE = 23.08DEG C
PRM = 6.493 RAM = 0.14771E+08 INLET BULK TEMPERATURE = 22.22DEG C OUTLET BULK TEMPERATURE = 23.08DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	22.84	22.80	22.82	22.82	22.23	1487.5	6.56	0.220E+07	0.00019	22.43	23.97	23.18	23.18	23.19	23.18
4	15.5	22.99	23.00	22.96	22.98	22.25	1488.1	6.56	0.220E+07	0.00052	18.46	18.25	19.18	18.76	18.77	18.77
5	25.5	23.07	23.13	23.09	23.10	22.27	1488.7	6.55	0.220E+07	0.00086	16.88	15.80	16.50	16.41	16.42	16.42
6	45.5	23.21	23.25	23.23	23.23	22.31	1489.9	6.55	0.221E+07	0.00153	15.08	14.36	14.68	14.70	14.70	14.70
7	75.5	23.26	23.35	23.25	23.28	22.36	1491.7	6.54	0.222E+07	0.00255	15.09	13.76	15.22	14.80	14.82	14.81
8	105.5	23.28	23.39	23.32	23.33	22.42	1493.5	6.53	0.223E+07	0.00356	15.77	13.99	14.99	14.91	14.94	14.92
9	135.5	23.36	23.48	23.41	23.42	22.47	1495.3	6.52	0.224E+07	0.00457	15.21	13.50	14.41	14.36	14.38	14.37
10	165.2	23.28	23.41	23.43	23.38	22.53	1497.1	6.51	0.225E+07	0.00557	18.09	15.41	15.03	15.80	15.89	15.85
11	205.2	23.43	23.64	23.61	23.57	22.60	1499.5	6.50	0.226E+07	0.00692	16.37	13.07	13.46	13.98	14.09	14.04
12	245.2	23.67	23.74	23.69	23.70	22.67	1501.9	6.49	0.228E+07	0.00827	13.58	12.76	13.33	13.25	13.25	13.25
13	275.2	23.66	23.77	23.72	23.72	22.73	1503.7	6.48	0.229E+07	0.00929	14.54	13.02	13.69	13.71	13.73	13.72
14	305.2	23.70	23.85	23.80	23.79	22.78	1505.6	6.47	0.230E+07	0.01030	14.72	12.72	13.35	13.50	13.53	13.52
15	333.3	23.73	23.84	23.81	23.80	22.83	1507.3	6.46	0.231E+07	0.01125	15.18	13.50	13.88	14.08	14.11	14.09
16	363.3	23.83	23.94	23.89	23.89	22.89	1509.1	6.46	0.232E+07	0.01227	14.45	12.86	13.57	13.59	13.62	13.60
17	383.3	23.84	23.95	23.91	23.90	22.93	1510.4	6.45	0.233E+07	0.01294	14.84	13.25	13.82	13.91	13.94	13.92
18	403.3	23.81	23.95	23.89	23.89	22.96	1511.6	6.44	0.233E+07	0.01362	16.04	13.76	14.55	14.68	14.73	14.70
19	423.3	23.85	23.99	23.94	23.93	23.00	1512.8	6.44	0.234E+07	0.01430	15.85	13.71	14.47	14.58	14.62	14.60
20	443.3	23.90	24.02	23.96	23.96	23.04	1514.1	6.43	0.235E+07	0.01497	15.77	13.71	14.61	14.64	14.67	14.65
21	463.3	24.13	24.06	24.21	24.15	23.07	1515.3	6.43	0.236E+07	0.01565	12.83	13.66	11.89	12.52	12.57	12.55
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	23.83	23.95	23.90	23.89	22.94	1510.9	6.45	0.233E+07	0.01322	15.35	13.46	14.15	14.25	14.28	14.26

DOWNWARD INCLINATION _____ 2 - 1500

INPUT ELECTRIC POWER = 310.7 W HEAT RATE GAINED BY WATER = 302.3 W HEAT BALANCE ERROR = 2.70%
MASS FLOW RATE = 44.5220 G/S PRESSURE DROP= 0.8076MMH20 FRICTION FACTOR = 0.011646 FREM = 17.5397
REM = 1506.1 GRM = 0.45456E+07 UPSTREAM BULK TEMPERATURE = 22.71DEG C DOWNSTREAM BULK TEMPERATURE = 24.33DEG C
PRM = 6.356 RAM = 0.28893E+08 INLET BULK TEMPERATURE = 22.71DEG C OUTLET BULK TEMPERATURE = 24.33DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.84	23.81	23.82	23.82	22.73	1479.7	6.48	0.426E+07	0.00019	22.70	23.39	23.04	23.04	23.04	23.04
4	15.5	24.12	24.14	24.09	24.11	22.76	1480.8	6.48	0.427E+07	0.00053	18.59	18.29	18.97	18.70	18.71	18.70
5	25.5	24.37	24.45	24.39	24.40	22.80	1482.0	6.47	0.428E+07	0.00087	16.05	15.25	15.79	15.72	15.72	15.72
6	45.5	24.44	24.51	24.46	24.47	22.87	1484.2	6.46	0.431E+07	0.00156	16.01	15.32	15.80	15.73	15.73	15.73
7	75.5	24.54	24.71	24.57	24.60	22.97	1487.7	6.44	0.434E+07	0.00259	16.07	14.49	15.79	15.51	15.54	15.52
8	105.5	24.59	24.84	24.63	24.67	23.07	1491.1	6.43	0.438E+07	0.00362	16.63	14.26	16.15	15.74	15.80	15.77
9	135.5	24.76	24.98	24.86	24.87	23.18	1494.6	6.41	0.442E+07	0.00465	15.93	13.96	14.94	14.91	14.95	14.93
10	165.2	24.64	24.94	24.86	24.82	23.28	1498.0	6.39	0.446E+07	0.00567	18.55	15.18	15.97	16.32	16.42	16.37
11	205.2	24.91	25.23	25.09	25.08	23.42	1502.7	6.37	0.451E+07	0.00705	16.92	13.93	15.08	15.18	15.25	15.22
12	245.2	25.20	25.38	25.26	25.27	23.56	1507.4	6.35	0.456E+07	0.00843	15.33	13.80	14.82	14.67	14.69	14.68
13	275.2	25.19	25.44	25.34	25.33	23.66	1510.9	6.33	0.460E+07	0.00946	16.44	14.12	14.97	15.08	15.13	15.10
14	305.2	25.24	25.50	25.40	25.38	23.76	1514.5	6.32	0.464E+07	0.01049	17.06	14.49	15.44	15.55	15.61	15.58
15	333.3	25.37	25.59	25.54	25.51	23.86	1517.8	6.30	0.468E+07	0.01146	16.69	14.54	15.03	15.28	15.32	15.30
16	363.3	25.42	25.67	25.52	25.53	23.97	1521.4	6.29	0.472E+07	0.01250	17.35	14.76	16.24	16.09	16.14	16.12
17	383.3	25.46	25.69	25.58	25.58	24.04	1523.8	6.27	0.474E+07	0.01319	17.66	15.17	16.28	16.30	16.34	16.32
18	403.3	25.44	25.72	25.57	25.58	24.10	1526.2	6.26	0.477E+07	0.01388	18.87	15.59	17.11	17.09	17.17	17.13
19	423.3	25.56	25.83	25.73	25.72	24.17	1528.6	6.25	0.480E+07	0.01457	18.17	15.15	16.12	16.32	16.39	16.36
20	443.3	25.56	25.86	25.73	25.72	24.24	1531.0	6.24	0.482E+07	0.01526	19.16	15.59	16.86	17.03	17.12	17.07
21	463.3	25.81	25.94	26.01	25.94	24.31	1533.5	6.23	0.485E+07	0.01595	16.76	15.46	14.84	15.44	15.47	15.46
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.47	25.73	25.61	25.61	24.06	1524.8	6.27	0.475E+07	0.01348	17.98	15.13	16.27	16.35	16.42	16.38

DOWNWARD INCLINATION _____ 3 - 1500

INPUT ELECTRIC POWER = 487.1 W HEAT RATE GAINED BY WATER = 492.4 W HEAT BALANCE ERROR =-1.08%
MASS FLOW RATE = 43.7986 G/S PRESSURE DROP= 0.8351MMH20 FRICTION FACTOR = 0.012442 FREM = 18.7126
REM = 1504.0 GRM = 0.78183E+07 UPSTREAM BULK TEMPERATURE = 22.83DEG C DOWNSTREAM BULK TEMPERATURE = 25.53DEG C
PRM = 6.252 RAM = 0.48877E+08 INLET BULK TEMPERATURE = 22.84DEG C OUTLET BULK TEMPERATURE = 25.53DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.70	24.67	24.69	24.69	22.87	1460.2	6.46	0.702E+07	0.00019	22.45	22.79	22.62	22.62	22.62	22.62
4	15.5	25.03	25.20	25.03	25.07	22.93	1462.1	6.45	0.705E+07	0.00054	19.53	18.05	19.53	19.14	19.16	19.15
5	25.5	25.33	25.58	25.45	25.45	22.98	1463.9	6.44	0.709E+07	0.00089	17.50	15.83	16.68	16.65	16.67	16.66
6	45.5	25.39	25.63	25.47	25.49	23.10	1467.7	6.42	0.715E+07	0.00159	17.89	16.21	17.32	17.16	17.18	17.17
7	75.5	25.54	25.85	25.60	25.65	23.27	1473.3	6.40	0.725E+07	0.00264	18.10	15.92	17.62	17.27	17.32	17.30
8	105.5	25.65	26.04	25.75	25.80	23.44	1479.0	6.37	0.736E+07	0.00368	18.59	15.78	17.77	17.41	17.48	17.45
9	135.5	25.88	26.24	26.01	26.03	23.61	1484.8	6.34	0.746E+07	0.00473	18.14	15.64	17.14	16.97	17.02	16.99
10	165.2	25.72	26.19	26.01	25.98	23.78	1490.5	6.31	0.757E+07	0.00577	21.15	17.01	18.45	18.65	18.77	18.71
11	205.2	26.00	26.48	26.29	26.27	24.01	1498.3	6.28	0.771E+07	0.00718	20.68	16.61	18.00	18.21	18.32	18.26
12	245.2	26.40	26.78	26.54	26.56	24.24	1506.2	6.24	0.786E+07	0.00858	19.04	16.17	17.81	17.65	17.71	17.68
13	275.2	26.45	26.90	26.72	26.69	24.42	1512.1	6.21	0.797E+07	0.00963	20.16	16.51	17.81	17.98	18.07	18.03
14	305.2	26.55	27.04	26.82	26.81	24.59	1518.1	6.19	0.808E+07	0.01069	20.82	16.67	18.30	18.41	18.52	18.47
15	333.3	26.82	27.32	27.15	27.11	24.75	1523.8	6.16	0.819E+07	0.01168	19.78	15.92	17.03	17.33	17.44	17.38
16	363.3	26.92	27.40	27.17	27.17	24.92	1529.9	6.13	0.831E+07	0.01273	20.44	16.50	18.17	18.22	18.32	18.27
17	383.3	27.03	27.50	27.23	27.24	25.04	1534.0	6.12	0.838E+07	0.01344	20.55	16.62	18.65	18.51	18.62	18.57
18	403.3	27.15	27.60	27.37	27.37	25.15	1538.1	6.10	0.846E+07	0.01414	20.43	16.68	18.44	18.40	18.49	18.45
19	423.3	27.26	27.74	27.56	27.53	25.27	1542.2	6.08	0.854E+07	0.01485	20.47	16.54	17.81	18.05	18.16	18.10
20	443.3	27.36	27.86	27.62	27.61	25.38	1546.4	6.06	0.862E+07	0.01556	20.67	16.49	18.26	18.30	18.42	18.36
21	463.3	27.67	28.01	27.94	27.89	25.49	1550.5	6.04	0.870E+07	0.01626	18.81	16.21	16.70	17.05	17.10	17.08
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	27.09	27.57	27.35	27.34	25.08	1535.7	6.11	0.842E+07	0.01373	20.39	16.46	18.06	18.13	18.24	18.19

DOWNWARD INCLINATION _____ 4 - 1500

INPUT ELECTRIC POWER = 695.2 W HEAT RATE GAINED BY WATER = 689.0 W HEAT BALANCE ERROR = 0.89%
MASS FLOW RATE = 43.0754 G/S PRESSURE DROP= 0.8928MMH20 FRICTION FACTOR = 0.013750 FREM = 20.6597
REM = 1502.5 GRM = 0.11565E+08 UPSTREAM BULK TEMPERATURE = 22.94DEG C DOWNSTREAM BULK TEMPERATURE = 26.78DEG C
PRM = 6.144 RAM = 0.71065E+08 INLET BULK TEMPERATURE = 22.95DEG C OUTLET BULK TEMPERATURE = 26.78DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.48	25.45	25.46	25.46	22.99	1440.1	6.44	0.992E+07	0.00020	23.15	23.37	23.26	23.26	23.26	23.26
4	15.5	26.24	26.54	26.24	26.32	23.07	1442.7	6.43	0.999E+07	0.00055	18.14	16.57	18.14	17.72	17.75	17.73
5	25.5	26.54	26.87	26.72	26.71	23.16	1445.3	6.41	0.101E+08	0.00090	16.98	15.47	16.13	16.16	16.18	16.17
6	45.5	26.60	26.96	26.67	26.72	23.32	1450.6	6.39	0.102E+08	0.00162	17.52	15.84	17.13	16.88	16.91	16.89
7	75.5	26.70	27.18	26.83	26.89	23.56	1458.6	6.35	0.104E+06	0.00268	18.29	15.86	17.59	17.29	17.33	17.31
8	105.5	26.85	27.53	27.01	27.10	23.81	1466.7	6.31	0.106E+08	0.00375	18.88	15.44	17.94	17.45	17.55	17.50
9	135.5	27.24	27.77	27.49	27.50	24.06	1474.9	6.27	0.108E+08	0.00482	17.99	15.43	16.71	16.66	16.71	16.69
10	165.2	26.95	27.70	27.44	27.38	24.30	1483.1	6.23	0.110E+08	0.00588	21.63	16.84	18.25	18.59	18.74	18.67
11	205.2	27.45	28.13	27.77	27.78	24.62	1494.3	6.18	0.113E+08	0.00731	20.28	16.35	18.18	18.14	18.25	18.20
12	245.2	27.81	28.45	28.11	28.12	24.96	1505.6	6.13	0.116E+08	0.00874	19.99	16.34	18.11	18.05	18.14	18.09
13	275.2	27.90	28.57	28.34	28.29	25.19	1514.2	6.09	0.119E+08	0.00981	21.17	16.95	18.19	18.50	18.62	:18.56
14	305.2	28.06	28.75	28.42	28.41	25.44	1523.0	6.06	0.121E+08	0.01089	21.79	17.26	19.17	19.22	19.36	19.28
15	333.3	28.43	29.13	28.91	28.84	25.67	1531.2	6.02	0.124E+08	0.01190	20.67	16.51	17.65	18.00	18.12	18.06
16	363.3	28.59	29.30	28.97	28.96	25.91	1540.1	5.98	0.126E+08	0.01298	21.30	16.89	18.69	18.77	18.89	18.83
17	383.3	28.76	29.41	29.04	29.06	26.08	1546.2	5.95	0.128E+08	0.01370	21.29	17.12	19.25	19.12	19.23	19.17
18	403.3	28.87	29.57	29.16	29.19	26.24	1552.2	5.93	0.129E+08	0.01442	21.73	17.14	19.54	19.35	19.49	19.42
19	423.3	28.99	29.72	29.41	29.39	26.40	1558.3	5.90	0.131E+08	0.01514	22.02	17.18	18.94	19.12	19.27	19.20
20	443.3	29.07	29.83	29.47	29.46	26.57	1564.4	5.87	0.133E+08	0.01587	22.75	17.47	19.62	19.69	19.86	19.78
21	463.3	29.49	30.06	29.76	29.77	26.73	1570.6	5.85	0.135E+08	0.01659	20.65	17.11	18.79	18.75	18.83	18.79
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	28.79	29.49	29.16	29.15	26.15	1548.7	5.94	0.128E+08	0.01400	21.63	17.05	18.95	19.01	19.15	19.08

DOWNWARD INCLINATION _____ 5 - 1500

INPUT ELECTRIC POWER = 960.1 W HEAT RATE GAINED BY WATER = 955.0 W HEAT BALANCE ERROR = 0.53%
MASS FLOW RATE = 42.7138 G/S PRESSURE DROP= 0.9539MMH20 FRICTION FACTOR = 0.014938 FREM = 22.4811
REM = 1505.0 GRM = 0.16602E+08 UPSTREAM BULK TEMPERATURE = 22.61DEG C DOWNSTREAM BULK TEMPERATURE = 27.97DEG C
PRM = 6.076 RAM = 0.10087E+09 INLET BULK TEMPERATURE = 22.62DEG C OUTLET BULK TEMPERATURE = 27.97DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	26.39	26.43	26.41	26.41	22.68	1418.1	6.49	0.134E+08	0.00020	21.48	21.26	21.37	21.37	21.37	21.37
4	15.5	26.93	27.38	26.99	27.07	22.79	1421.7	6.47	0.135E+08	0.00055	19.26	17.38	19.01	18.63	18.66	18.65
5	25.5	27.37	27.94	27.60	27.63	22.91	1425.3	6.45	0.137E+08	0.00091	17.88	15.83	16.97	16.88	16.91	16.89
6	45.5	27.41	27.95	27.57	27.63	23.14	1432.6	6.42	0.139E+08	0.00163	18.63	16.54	17.98	17.75	17.78	17.76
7	75.5	27.73	28.46	27.92	28.01	23.48	1443.6	6.36	0.143E+08	0.00270	18.72	15.97	17.93	17.58	17.64	17.61
8	105.5	27.97	28.92	28.24	28.34	23.82	1454.8	6.31	0.147E+08	0.00378	19.19	15.59	18.02	17.60	17.70	17.65
9	135.5	28.50	29.28	28.80	28.84	24.16	1466.2	6.25	0.151E+08	0.00486	18.33	15.54	17.15	16.99	17.05	17.02
10	165.2	28.06	29.15	28.73	28.67	24.50	1477.6	6.20	0.156E+08	0.00593	22.33	17.08	18.80	19.07	19.25	19.16
11	205.2	28.70	29.72	29.12	29.16	24.96	1493.3	6.13	0.162E+08	0.00738	21.18	16.68	19.08	18.87	19.01	18.94
12	245.2	29.26	30.18	29.68	29.70	25.42	1509.3	6.06	0.168E+08	0.00882	20.62	16.63	18.59	18.50	18.61	18.55
13	275.2	29.46	30.47	30.13	30.06	25.76	1521.6	6.00	0.172E+08	0.00991	21.40	16.81	18.10	18.46	18.60	18.53
14	305.2	29.68	30.66	30.16	30.16	26.10	1534.0	5.95	0.177E+08	0.01100	22.07	17.36	19.50	19.47	19.61	19.54
15	333.3	30.27	31.24	30.97	30.86	26.42	1545.8	5.90	0.182E+08	0.01203	20.54	16.39	17.39	17.80	17.93	17.86
16	363.3	30.46	31.55	31.02	31.01	26.76	1558.7	5.84	0.187E+08	0.01312	21.35	16.49	18.57	18.59	18.74	18.67
17	383.3	30.72	31.66	31.19	31.19	26.99	1566.4	5.81	0.190E+08	0.01385	21.20	16.90	18.80	18.80	18.92	18.86
18	403.3	30.92	31.93	31.43	31.43	27.22	1573.7	5.78	0.193E+08	0.01458	21.33	16.75	18.74	18.75	18.89	18.82
19	423.3	31.14	32.21	31.78	31.73	27.45	1581.0	5.75	0.196E+08	0.01530	21.34	16.55	18.23	18.43	18.59	18.51
20	443.3	31.24	32.34	31.86	31.83	27.68	1588.4	5.73	0.200E+08	0.01603	22.12	16.91	18.82	18.99	19.17	19.08
21	463.3	31.99	32.95	32.76	32.62	27.90	1595.8	5.70	0.203E+08	0.01676	19.29	15.63	16.21	16.72	16.83	16.78
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	30.79	31.82	31.37	31.34	27.09	1569.0	5.80	0.191E+08	0.01415	21.31	16.66	18.42	18.56	18.71	18.63

DOWNWARD INCLINATION _____ 6 - 1500

INPUT ELECTRIC POWER = 1323.7 W   HEAT RATE GAINED BY WATER = 1306.5 W   HEAT BALANCE ERROR = 1.30%
MASS FLOW RATE = 41.9906 G/S   PRESSURE DROP= 1.0387MMH20   FRICTION FACTOR = 0.016830   FREM = 25.2742
REM = 1501.8   GRM = 0.23911E+08   UPSTREAM BULK TEMPERATURE = 22.19DEG C   DOWNSTREAM BULK TEMPERATURE = 29.65DEG C
PRM = 5.976   RAM = 0.14289E+09   INLET BULK TEMPERATURE = 22.20DEG C   OUTLET BULK TEMPERATURE = 29.65DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	27.17	27.49	27.33	27.33	22.29	1382.2	6.55	0.177E+08	0.00020	22.37	20.99	21.66	21.66	21.67	21.66
4	15.5	28.06	29.00	28.26	28.40	22.46	1387.0	6.53	0.180E+08	0.00056	19.43	16.66	18.79	18.35	18.42	18.38
5	25.5	28.63	29.62	29.16	29.14	22.61	1391.9	6.50	0.182E+08	0.00093	18.11	15.55	16.66	16.70	16.75	16.72
6	45.5	28.65	29.60	29.02	29.07	22.93	1401.7	6.45	0.187E+08	0.00166	19.06	16.32	17.88	17.73	17.79	17.76
7	75.5	29.09	30.21	29.45	29.55	23.40	1416.7	6.37	0.195E+08	0.00275	19.14	15.99	18.00	17.70	17.78	17.74
8	105.5	29.47	31.08	29.99	30.13	23.88	1432.0	6.30	0.202E+08	0.00385	19.44	15.11	17.79	17.39	17.53	17.46
9	135.5	30.12	31.42	30.69	30.73	24.35	1447.7	6.22	0.210E+08	0.00495	18.86	15.37	17.14	17.04	17.13	17.08
10	165.2	29.64	31.36	30.66	30.58	24.83	1463.5	6.15	0.219E+08	0.00604	22.53	16.63	18.60	18.87	19.09	18.98
11	205.2	30.46	31.97	31.10	31.16	25.46	1485.4	6.06	0.230E+08	0.00751	21.68	16.64	19.22	19.02	19.19	19.11
12	245.2	31.26	32.69	31.91	31.95	26.10	1507.9	5.95	0.242E+08	0.00899	20.96	16.41	18.60	18.50	18.64	18.57
13	275.2	31.57	33.15	32.62	32.49	26.57	1525.3	5.87	0.252E+08	0.01010	21.61	16.45	17.87	18.26	18.45	18.36
14	305.2	32.20	33.82	33.21	33.11	27.05	1541.7	5.80	0.261E+08	0.01122	20.97	15.94	17.52	17.82	17.99	17.90
15	333.3	32.86	34.61	34.06	33.90	27.50	1555.8	5.75	0.270E+08	0.01226	20.11	15.16	16.44	16.85	17.04	16.95
16	363.3	33.28	35.09	34.33	34.26	27.97	1571.0	5.69	0.279E+08	0.01337	20.31	15.13	16.95	17.14	17.34	17.24
17	383.3	33.68	35.30	34.51	34.50	28.29	1581.3	5.65	0.285E+08	0.01412	19.98	15.37	17.31	17.34	17.49	17.42
18	403.3	33.98	35.70	34.88	34.86	28.61	1591.8	5.61	0.291E+08	0.01486	20.02	15.18	17.17	17.22	17.38	17.30
19	423.3	34.30	35.99	35.32	35.23	28.92	1602.4	5.57	0.298E+08	0.01560	20.00	15.22	16.83	17.05	17.22	17.14
20	443.3	34.45	36.14	35.43	35.37	29.24	1613.2	5.53	0.304E+08	0.01635	20.64	15.57	17.36	17.55	17.73	17.64
21	463.3	35.11	36.87	35.99	35.99	29.56	1624.1	5.49	0.311E+08	0.01710	19.36	14.69	16.70	16.71	16.87	16.79
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	33.76	35.47	34.75	34.68	28.42	1585.9	5.63	0.288E+08	0.01443	20.18	15.27	17.01	17.19	17.37	17.28

Appendix G

Experimental Data for $\alpha = -20°$

DOWNWARD INCLINATION ____ 1 - 500

INPUT ELECTRIC POWER = 104.2 W HEAT RATE GAINED BY WATER = 100.8 W HEAT BALANCE ERROR = 3.29%
MASS FLOW RATE = 14.7500 G/S PRESSURE DROP= 0.2222MMH20 FRICTION FACTOR = 0.029192 FREM = 14.6370
REM = 501.4 GRM = 0.15426E+07 UPSTREAM BULK TEMPERATURE = 22.92DEG C DOWNSTREAM BULK TEMPERATURE = 24.56DEG C
PRM = 6.322 RAM = 0.97521E+07 INLET BULK TEMPERATURE = 22.92DEG C OUTLET BULK TEMPERATURE = 24.55DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.48	23.44	23.46	23.46	22.94	492.5	6.45	0.144E+07	0.00067	15.59	16.68	16.12	16.12	16.13	16.12
4	15.5	23.65	23.69	23.65	23.66	22.97	492.9	6.44	0.145E+07	0.00161	12.43	11.66	12.43	12.23	12.24	12.23
5	25.5	23.73	23.82	23.78	23.78	23.01	493.3	6.44	0.145E+07	0.00264	11.57	10.39	10.82	10.88	10.90	10.89
6	45.5	23.85	23.92	23.87	23.88	23.08	494.0	6.43	0.146E+07	0.00471	10.86	9.93	10.54	10.46	10.47	10.46
7	75.5	23.90	23.96	23.90	23.91	23.18	495.2	6.41	0.147E+07	0.00782	11.71	10.81	11.77	11.50	11.52	11.51
8	105.5	23.92	24.00	23.94	23.95	23.29	496.4	6.39	0.149E+07	0.01094	13.28	11.75	12.93	12.70	12.72	12.71
9	135.5	23.98	24.03	24.00	24.00	23.39	497.5	6.38	0.150E+07	0.01405	14.32	13.05	13.82	13.74	13.75	13.74
10	165.2	24.03	24.19	24.13	24.12	23.49	498.7	6.36	0.151E+07	0.01713	15.78	12.13	13.23	13.47	13.59	13.53
11	205.2	24.21	24.36	24.33	24.31	23.63	500.3	6.34	0.153E+07	0.02129	14.59	11.53	12.00	12.42	12.53	12.48
12	245.2	24.45	24.54	24.47	24.49	23.77	501.8	6.32	0.155E+07	0.02545	12.42	10.88	12.00	11.79	11.82	11.81
13	275.2	24.52	24.63	24.56	24.57	23.88	503.0	6.30	0.156E+07	0.02857	12.99	11.09	12.33	12.15	12.19	12.17
14	305.2	24.63	24.75	24.70	24.69	23.98	504.2	6.28	0.157E+07	0.03169	13.05	11.00	11.78	11.86	11.90	11.88
15	333.3	24.65	24.73	24.67	24.68	24.08	505.3	6.27	0.159E+07	0.03462	14.83	12.92	14.14	13.97	14.01	13.99
16	363.3	24.83	24.92	24.87	24.87	24.19	506.6	6.25	0.160E+07	0.03774	12.99	11.43	12.24	12.20	12.23	12.21
17	383.3	24.93	24.99	24.94	24.95	24.26	507.4	6.24	0.161E+07	0.03983	12.44	11.40	12.26	12.07	12.09	12.08
18	403.3	24.99	25.10	25.04	25.04	24.32	508.2	6.23	0.162E+07	0.04191	12.64	10.81	11.68	11.67	11.70	11.69
19	423.3	25.06	25.16	25.17	25.14	24.39	509.0	6.22	0.163E+07	0.04400	12.68	10.91	10.78	11.24	11.29	11.26
20	443.3	25.16	25.24	25.17	25.19	24.46	509.8	6.21	0.164E+07	0.04608	12.02	10.85	11.84	11.62	11.64	11.63
21	463.3	25.36	25.25	25.42	25.36	24.53	510.6	6.20	0.165E+07	0.04817	10.10	11.76	9.48	10.12	10.20	10.16
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.94	25.02	24.98	24.98	24.28	507.7	6.24	0.161E+07	0.04070	12.93	11.39	12.16	12.13	12.16	12.14

DOWNWARD INCLINATION ____ 2 - 500

INPUT ELECTRIC POWER = 151.4 W HEAT RATE GAINED BY WATER = 145.0 W HEAT BALANCE ERROR = 4.20%
MASS FLOW RATE = 14.7500 G/S PRESSURE DROP= 0.2254MMH20 FRICTION FACTOR = 0.029608 FREM = 14.7528
REM = 498.3 GRM = 0.21696E+07 UPSTREAM BULK TEMPERATURE = 22.28DEG C DOWNSTREAM BULK TEMPERATURE = 24.64DEG C
PRM = 6.366 RAM = 0.13812E+08 INLET BULK TEMPERATURE = 22.28DEG C OUTLET BULK TEMPERATURE = 24.63DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.03	23.00	23.01	23.01	22.31	485.7	6.55	0.197E+07	0.00057	16.74	17.66	17.19	17.19	17.20	17.19
4	15.5	23.18	23.19	23.18	23.18	22.36	486.3	6.54	0.198E+07	0.00160	14.76	14.57	14.76	14.71	14.71	14.71
5	25.5	23.27	23.38	23.29	23.30	22.41	486.8	6.53	0.199E+07	0.00264	14.13	12.52	13.81	13.54	13.57	13.56
6	45.5	23.40	23.50	23.43	23.44	22.51	487.9	6.52	0.201E+07	0.00471	13.56	12.18	13.21	13.02	13.04	13.03
7	75.5	23.57	23.71	23.59	23.61	22.66	489.5	6.49	0.203E+07	0.00782	13.36	11.54	13.04	12.71	12.75	12.73
8	105.5	23.70	23.89	23.77	23.78	22.81	491.1	6.47	0.206E+07	0.01092	13.68	11.22	12.64	12.48	12.54	12.51
9	135.5	23.87	24.03	23.94	23.95	22.96	492.8	6.44	0.208E+07	0.01404	13.37	11.27	12.32	12.28	12.32	12.30
10	165.2	24.03	24.19	24.07	24.09	23.11	494.4	6.42	0.211E+07	0.01712	13.20	11.23	12.56	12.35	12.39	12.37
11	205.2	24.21	24.39	24.33	24.32	23.31	496.6	6.39	0.214E+07	0.02127	13.45	11.21	11.82	12.02	12.07	12.05
12	245.2	24.53	24.66	24.56	24.58	23.51	498.9	6.36	0.218E+07	0.02543	11.83	10.56	11.56	11.36	11.38	11.37
13	275.2	24.58	24.72	24.70	24.67	23.66	500.6	6.33	0.221E+07	0.02855	13.16	11.44	11.66	11.94	11.98	11.96
14	305.2	24.77	24.94	24.89	24.87	23.81	502.3	6.31	0.223E+07	0.03168	12.67	10.70	11.20	11.40	11.44	11.42
15	333.3	24.81	24.95	24.92	24.90	23.95	503.9	6.29	0.226E+07	0.03461	14.04	12.09	12.43	12.71	12.75	12.73
16	363.3	25.05	25.17	25.09	25.10	24.10	505.6	6.26	0.229E+07	0.03773	12.71	11.33	12.18	12.08	12.10	12.09
17	383.3	25.12	25.24	25.19	25.19	24.20	506.8	6.25	0.231E+07	0.03982	13.11	11.61	12.24	12.28	12.30	12.29
18	403.3	25.18	25.35	25.29	25.28	24.30	507.9	6.23	0.233E+07	0.04191	13.71	11.51	12.19	12.35	12.40	12.37
19	423.3	25.33	25.53	25.42	25.43	24.41	509.1	6.22	0.234E+07	0.04400	12.97	10.75	11.83	11.79	11.85	11.82
20	443.3	25.41	25.60	25.54	25.52	24.51	510.3	6.20	0.236E+07	0.04609	13.26	10.99	11.68	11.85	11.90	11.87
21	463.3	25.67	25.68	25.81	25.74	24.61	511.5	6.18	0.238E+07	0.04818	11.30	11.23	10.01	10.60	10.64	10.62
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.15	25.31	25.24	26.24	24.25	507.3	6.24	0.231E+07	0.04069	13.30	11.38	12.09	12.18	12.22	12.20

DOWNWARD INCLINATION _____ 3 - 500

INPUT ELECTRIC POWER = 187.6 W | HEAT RATE GAINED BY WATER = 191.7 W | HEAT BALANCE ERROR =-2.21%
MASS FLOW RATE = 14.7500 G/S | PRESSURE DROP= 0.2283MMH20 | FRICTION FACTOR = 0.029997 | FREM = 14.9845

REM = 499.5 | GRM = 0.28942E+07 | UPSTREAM BULK TEMPERATURE = 22.01DEG C | DOWNSTREAM BULK TEMPERATURE = 25.13DEG C
PRM = 6.348 | RAM = 0.18373E+08 | INLET BULK TEMPERATURE = 22.02DEG C | OUTLET BULK TEMPERATURE = 25.12DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.17	23.22	23.20	23.20	22.06	483.0	6.59	0.255E+07	0.00057	14.32	13.74	14.02	14.02	14.02	14.02
4	15.5	23.37	23.53	23.40	23.43	22.12	483.7	6.58	0.257E+07	0.00160	12.77	11.38	12.49	12.26	12.29	12.27
5	25.5	23.51	23.68	23.62	23.61	22.18	484.4	6.57	0.258E+07	0.00264	12.05	10.72	11.17	11.26	11.28	11.27
6	45.5	23.66	23.87	23.73	23.75	22.32	485.8	6.55	0.261E+07	0.00471	11.97	10.33	11.30	11.19	11.23	11.21
7	75.5	23.79	23.99	23.87	23.88	22.52	487.9	6.51	0.265E+07	0.00781	12.58	10.88	11.85	11.76	11.79	11.77
8	105.5	23.92	24.17	24.02	24.03	22.72	490.1	6.48	0.270E+07	0.01092	13.29	11.00	12.26	12.15	12.21	12.18
9	135.5	24.09	24.31	24.25	24.23	22.91	492.3	6.45	0.274E+07	0.01403	13.61	11.43	11.97	12.19	12.25	12.22
10	165.2	24.28	24.52	24.41	24.40	23.11	494.4	6.42	0.279E+07	0.01712	13.71	11.33	12.31	12.36	12.42	12.39
11	205.2	24.49	24.78	24.70	24.67	23.38	497.4	6.38	0.285E+07	0.02128	14.36	11.38	12.09	12.39	12.48	12.44
12	245.2	24.87	25.06	24.98	24.97	23.64	500.3	6.34	0.291E+07	0.02544	13.04	11.36	11.96	12.05	12.08	12.06
13	275.2	24.97	25.22	25.15	25.12	23.84	502.6	6.31	0.296E+07	0.02857	14.13	11.56	12.22	12.46	12.53	12.50
14	305.2	25.24	25.50	25.40	25.38	24.04	504.9	6.27	0.301E+07	0.03169	13.28	10.91	11.77	11.87	11.93	11.90
15	333.3	25.34	25.59	25.54	25.50	24.23	507.0	6.24	0.305E+07	0.03463	14.28	11.66	12.16	12.49	12.57	12.53
16	363.3	25.64	25.87	25.77	25.76	24.42	509.3	6.21	0.310E+07	0.03776	13.12	11.05	11.86	11.93	11.97	11.95
17	383.3	25.74	25.98	25.86	25.86	24.56	510.9	6.19	0.314E+07	0.03986	13.47	11.23	12.23	12.24	12.29	12.27
18	403.3	25.83	26.08	25.97	25.96	24.69	512.5	6.17	0.317E+07	0.04195	13.96	11.43	12.47	12.52	12.58	12.55
19	423.3	25.98	26.20	26.10	26.09	24.82	514.0	6.15	0.321E+07	0.04404	13.79	11.58	12.47	12.53	12.58	12.56
20	443.3	26.03	26.31	26.21	26.19	24.96	515.6	6.13	0.324E+07	0.04614	14.76	11.77	12.66	12.88	12.96	12.92
21	463.3	26.35	26.49	26.48	26.45	25.09	517.2	6.11	0.328E+07	0.04824	12.64	11.38	11.40	11.68	11.71	11.69
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	25.76	26.00	25.91	25.89	24.61	511.6	6.18	0.315E+07	0.04073	13.90	11.45	12.31	12.43	12.49	12.46

DOWNWARD INCLINATION _____ 4 - 500

INPUT ELECTRIC POWER = 219.7 W | HEAT RATE GAINED BY WATER = 226.2 W | HEAT BALANCE ERROR =-2.96%
MASS FLOW RATE = 14.5794 G/S | PRESSURE DROP= 0.2279MMH20 | FRICTION FACTOR = 0.030635 | FREM = 15.3616

REM = 501.4 | GRM = 0.36120E+07 | UPSTREAM BULK TEMPERATURE = 22.39DEG C | DOWNSTREAM BULK TEMPERATURE = 26.11DEG C
PRM = 6.241 | RAM = 0.22541E+08 | INLET BULK TEMPERATURE = 22.40DEG C | OUTLET BULK TEMPERATURE = 26.11DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.00	24.20	24.10	24.10	22.44	481.5	6.53	0.311E+07	0.00058	12.07	10.75	11.37	11.37	11.39	11.38
4	15.5	24.15	24.39	24.23	24.25	22.52	482.3	6.51	0.313E+07	0.00162	11.60	10.08	11.04	10.91	10.94	10.93
5	25.5	24.28	24.56	24.45	24.44	22.60	483.2	6.50	0.315E+07	0.00267	11.19	9.62	10.20	10.27	10.30	10.29
6	45.5	24.44	24.71	24.57	24.57	22.76	484.9	6.48	0.319E+07	0.00477	11.21	9.67	10.38	10.38	10.41	10.40
7	75.5	24.59	24.88	24.71	24.72	22.99	487.4	6.44	0.326E+07	0.00791	11.79	10.02	11.02	10.93	10.96	10.94
8	105.5	24.73	25.12	24.94	24.93	23.23	490.0	6.40	0.332E+07	0.01106	12.59	9.98	11.03	11.08	11.16	11.12
9	135.5	24.98	25.26	25.17	25.15	23.47	492.6	6.36	0.339E+07	0.01422	12.45	10.51	11.07	11.23	11.28	11.26
10	165.2	25.25	25.64	25.47	25.46	23.70	495.2	6.33	0.345E+07	0.01734	12.18	9.74	10.64	10.73	10.80	10.76
11	205.2	25.55	25.95	25.84	25.80	24.02	498.8	6.28	0.354E+07	0.02156	12.31	9.75	10.32	10.59	10.68	10.64
12	245.2	25.92	26.25	26.10	26.09	24.34	502.4	6.23	0.364E+07	0.02578	11.86	9.85	10.70	10.73	10.78	10.75
13	275.2	26.08	26.42	26.35	26.30	24.57	505.2	6.19	0.371E+07	0.02895	12.45	10.18	10.58	10.88	10.95	10.92
14	305.2	26.36	26.71	26.54	26.54	24.81	508.0	6.15	0.378E+07	0.03213	12.15	9.92	10.85	10.89	10.94	10.91
15	333.3	26.46	26.79	26.68	26.65	25.03	510.6	6.12	0.385E+07	0.03510	13.21	10.70	11.42	11.62	11.69	11.66
16	363.3	26.73	27.04	26.95	26.91	25.27	513.4	6.08	0.393E+07	0.03829	12.91	10.63	11.20	11.43	11.49	11.46
17	383.3	26.89	27.13	27.00	27.01	25.43	515.4	6.05	0.398E+07	0.04041	12.89	11.04	11.92	11.91	11.94	11.93
18	403.3	26.96	27.29	27.12	27.12	25.59	517.3	6.03	0.403E+07	0.04254	13.73	11.01	12.28	12.25	12.33	12.29
19	423.3	27.12	27.40	27.31	27.28	25.75	519.2	6.00	0.408E+07	0.04466	13.64	11.34	12.02	12.20	12.25	12.22
20	443.3	27.19	27.49	27.37	27.35	25.91	521.2	5.98	0.413E+07	0.04679	14.62	11.82	12.84	12.95	13.03	12.99
21	463.3	27.41	27.70	27.63	27.59	26.06	523.1	5.95	0.419E+07	0.04893	13.88	11.47	11.94	12.24	12.31	12.28
AVERAGE VALUES THROUGH STATIONS 15 TO 20:																
	391.6	26.89	27.19	27.07	27.05	25.50	516.2	6.04	0.400E+07	0.04130	13.50	11.09	11.95	12.06	12.12	12.09

DOWNWARD INCLINATION _____ 5 - 500

INPUT ELECTRIC POWER = 320.7 W   HEAT RATE GAINED BY WATER = 317.3 W   HEAT BALANCE ERROR = 1.06%
MASS FLOW RATE = 14.2389 G/S   PRESSURE DROP= 0.2899MMH20   FRICTION FACTOR = 0.040851   FREM = 20.4714
REM = 501.1   GRM = 0.54945E+07   UPSTREAM BULK TEMPERATURE = 22.57DEG C   DOWNSTREAM BULK TEMPERATURE = 27.92DEG C
PRM = 6.084   RAM = 0.33427E+08   INLET BULK TEMPERATURE = 22.58DEG C   OUTLET BULK TEMPERATURE = 27.91DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.78	26.32	26.06	26.05	22.64	472.3	6.50	0.444E+07	0.00069	8.44	7.20	7.77	7.77	7.80	7.78
4	15.5	25.91	26.49	26.24	26.22	22.75	473.5	6.48	0.448E+07	0.00166	8.39	7.10	7.59	7.64	7.67	7.65
5	25.5	26.10	26.65	26.47	26.42	22.87	474.7	6.46	0.452E+07	0.00274	8.19	7.00	7.35	7.45	7.47	7.46
6	45.5	26.29	26.83	26.62	26.59	23.10	477.1	6.42	0.461E+07	0.00488	8.28	7.08	7.52	7.58	7.60	7.59
7	75.5	26.51	27.07	26.80	26.80	23.44	480.8	6.37	0.474E+07	0.00811	8.61	7.28	7.86	7.87	7.90	7.89
8	105.5	26.71	27.36	27.01	27.02	23.78	484.5	6.32	0.487E+07	0.01134	9.01	7.38	8.18	8.15	8.19	8.17
9	135.5	26.96	27.55	27.29	27.27	24.12	488.3	6.26	0.501E+07	0.01458	9.28	7.70	8.33	8.37	8.41	8.39
10	165.2	27.42	28.12	27.83	27.80	24.46	492.1	6.21	0.515E+07	0.01779	8.91	7.21	7.82	7.90	7.94	7.92
11	205.2	27.78	28.46	28.25	28.19	24.91	497.3	6.14	0.535E+07	0.02212	9.18	7.43	7.90	8.05	8.10	8.08
12	245.2	28.23	28.76	28.53	28.51	25.37	502.6	6.06	0.555E+07	0.02646	9.20	7.76	8.33	8.37	8.40	8.39
13	275.2	28.40	28.96	28.84	28.76	25.71	506.6	6.01	0.571E+07	0.02973	9.78	8.09	8.39	8.62	8.66	8.64
14	305.2	28.65	29.20	29.07	29.00	26.05	510.8	5.96	0.587E+07	0.03300	10.11	8.34	8.72	8.92	8.97	8.95
15	333.3	28.88	29.35	29.30	29.21	26.37	514.7	5.91	0.602E+07	0.03607	10.47	8.81	8.98	9.26	9.31	9.29
16	363.3	29.21	29.71	29.53	29.50	26.71	518.9	5.85	0.619E+07	0.03935	10.51	8.74	9.31	9.42	9.47	9.45
17	383.3	29.35	29.78	29.63	29.59	26.94	521.6	5.82	0.630E+07	0.04154	10.90	9.24	9.75	9.87	9.91	9.89
18	403.3	29.48	29.93	29.75	29.73	27.17	524.0	5.79	0.640E+07	0.04372	11.30	9.47	10.15	10.23	10.27	10.25
19	423.3	29.64	30.03	29.92	29.88	27.39	526.4	5.76	0.650E+07	0.04591	11.68	9.94	10.37	10.55	10.59	10.57
20	443.3	29.66	30.08	29.92	29.90	27.62	528.9	5.73	0.660E+07	0.04809	12.81	10.63	11.37	11.50	11.55	11.52
21	463.3	29.91	30.26	30.18	30.14	27.85	531.4	5.70	0.671E+07	0.05028	12.68	10.83	11.20	11.44	11.48	11.46
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	29.37	29.82	29.67	29.63	27.03	522.4	5.81	0.634E+07	0.04245	11.28	9.47	9.99	10.14	10.18	10.16

DOWNWARD INCLINATION _____ 6 - 500

INPUT ELECTRIC POWER = 474.8 W   HEAT RATE GAINED BY WATER = 460.3 W   HEAT BALANCE ERROR = 3.04%
MASS FLOW RATE = 13.8983 G/S   PRESSURE DROP= 0.4876MMH20   FRICTION FACTOR = 0.072108   FREM = 36.0714
REM = 500.2   GRM = 0.86092E+07   UPSTREAM BULK TEMPERATURE = 22.22DEG C   DOWNSTREAM BULK TEMPERATURE = 30.17DEG C
PRM = 5.934   RAM = 0.51086E+08   INLET BULK TEMPERATURE = 22.23DEG C   OUTLET BULK TEMPERATURE = 30.15DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	28.61	29.62	29.11	29.11	22.32	457.8	6.55	0.627E+07	0.00060	6.11	5.27	5.66	5.66	5.68	5.67
4	15.5	28.73	29.67	29.22	29.21	22.49	459.5	6.52	0.636E+07	0.00170	6.17	5.36	5.71	5.72	5.74	5.73
5	25.5	28.85	29.84	29.49	29.42	22.66	461.2	6.49	0.645E+07	0.00280	6.21	5.35	5.63	5.69	5.71	5.70
6	45.5	29.09	29.97	29.58	29.56	23.00	464.7	6.44	0.663E+07	0.00500	6.30	5.51	5.83	5.86	5.87	5.86
7	75.5	29.31	30.27	29.79	29.79	23.51	470.0	6.36	0.691E+07	0.00831	6.60	5.67	6.11	6.10	6.12	6.11
8	105.5	29.47	30.49	29.97	29.97	24.01	475.4	6.28	0.721E+07	0.01163	7.02	5.92	6.44	6.43	6.45	6.44
9	135.5	29.92	30.78	30.39	30.37	24.52	481.0	6.20	0.751E+07	0.01495	7.09	6.11	6.52	6.54	6.56	6.55
10	165.2	30.53	31.55	31.17	31.10	25.02	486.6	6.12	0.783E+07	0.01825	6.94	5.86	6.22	6.29	6.31	6.30
11	205.2	30.96	31.95	31.60	31.53	25.70	494.4	6.01	0.827E+07	0.02271	7.25	6.11	6.46	6.55	6.57	6.56
12	245.2	31.40	32.19	31.86	31.83	26.37	502.4	5.91	0.874E+07	0.02719	7.59	6.55	6.95	6.99	7.01	7.00
13	275.2	31.55	32.36	32.20	32.08	26.88	508.6	5.83	0.910E+07	0.03055	8.16	6.94	7.15	7.32	7.35	7.34
14	305.2	31.86	32.62	32.34	32.29	27.39	513.8	5.76	0.943E+07	0.03391	8.50	7.27	7.67	7.75	7.78	7.77
15	333.3	32.08	32.75	32.69	32.55	27.86	518.8	5.70	0.974E+07	0.03706	9.01	7.78	7.87	8.10	8.13	8.11
16	363.3	32.36	33.09	32.81	32.77	28.37	524.3	5.64	0.101E+08	0.04043	9.51	8.04	8.54	8.63	8.66	8.64
17	383.3	32.50	33.10	32.87	32.83	28.71	528.0	5.60	0.103E+08	0.04268	9.99	8.63	9.12	9.19	9.22	9.20
18	403.3	32.60	33.19	32.94	32.92	29.05	531.8	5.55	0.106E+08	0.04493	10.65	9.13	9.72	9.78	9.81	9.79
19	423.3	32.71	33.28	33.10	33.04	29.39	535.6	5.51	0.108E+08	0.04718	11.39	9.73	10.20	10.35	10.38	10.36
20	443.3	32.65	33.24	33.02	32.98	29.72	539.4	5.47	0.111E+08	0.04944	12.93	10.75	11.49	11.61	11.66	11.64
21	463.3	32.89	33.49	33.30	33.24	30.06	543.4	5.43	0.113E+08	0.05170	13.37	11.01	11.68	11.87	11.94	11.90
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	32.48	33.11	32.90	32.85	28.85	529.6	5.58	0.104E+08	0.04362	10.58	9.01	9.49	9.61	9.64	9.63

DOWNWARD INCLINATION _____ 1 - 1000

INPUT ELECTRIC POWER = 114.8 W HEAT RATE GAINED BY WATER = 119.1 W HEAT BALANCE ERROR =-3.77%
MASS FLOW RATE = 29.6962 G/S PRESSURE DROP= 0.4881MMH20 FRICTION FACTOR = 0.015821 FREM = 15.8098
REM = 999.3 GRM = 0.17568E+07 UPSTREAM BULK TEMPERATURE = 22.81DEG C DOWNSTREAM BULK TEMPERATURE = 23.77DEG C
PRM = 6.393 RAM = 0.11231E+08 INLET BULK TEMPERATURE = 22.81DEG C OUTLET BULK TEMPERATURE = 23.77DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.31	23.33	23.32	23.32	22.82	988.9	6.47	0.169E+07	0.00028	20.17	19.39	19.77	19.77	19.78	19.78
4	15.5	23.54	23.64	23.59	23.59	22.84	989.4	6.46	0.169E+07	0.00080	14.19	12.43	13.15	13.20	13.23	13.21
5	25.5	23.71	23.76	23.73	23.73	22.86	989.8	6.46	0.170E+07	0.00131	11.72	11.00	11.41	11.38	11.39	11.38
6	45.5	23.82	23.90	23.87	23.87	22.90	990.7	6.45	0.170E+07	0.00234	10.76	9.98	10.19	10.27	10.28	10.28
7	75.5	23.82	23.88	23.78	23.82	22.96	992.1	6.44	0.171E+07	0.00388	11.62	10.86	12.07	11.63	11.66	11.65
8	105.5	23.78	23.86	23.71	23.77	23.02	993.5	6.43	0.172E+07	0.00543	13.12	11.84	14.39	13.35	13.43	13.39
9	135.5	23.75	23.81	23.75	23.77	23.08	994.8	6.43	0.173E+07	0.00697	14.81	13.65	14.96	14.57	14.59	14.58
10	165.2	23.75	23.85	23.79	23.80	23.14	996.2	6.42	0.174E+07	0.00850	16.44	14.03	15.32	15.23	15.28	15.25
11	205.2	23.79	23.94	23.91	23.89	23.23	998.0	6.40	0.175E+07	0.01066	17.59	13.85	14.43	14.95	15.08	15.01
12	245.2	24.03	24.10	24.05	24.06	23.31	999.8	6.39	0.176E+07	0.01263	13.71	12.57	13.32	13.22	13.23	13.22
13	275.2	23.97	24.13	24.06	24.05	23.37	1001.2	6.38	0.177E+07	0.01417	16.63	13.02	14.50	14.55	14.66	14.61
14	305.2	24.07	24.24	24.19	24.17	23.43	1002.6	6.37	0.178E+07	0.01572	15.61	12.25	13.07	13.39	13.50	13.45
15	333.3	24.06	24.23	24.17	24.16	23.49	1003.9	6.36	0.179E+07	0.01717	17.32	13.41	14.50	14.81	14.94	14.87
16	363.3	24.27	24.36	24.37	24.34	23.55	1005.3	6.35	0.180E+07	0.01872	13.72	12.23	12.18	12.54	12.58	12.56
17	383.3	24.31	24.48	24.38	24.39	23.59	1006.2	6.34	0.180E+07	0.01975	13.72	11.12	12.56	12.42	12.49	12.45
18	403.3	24.37	24.48	24.43	24.43	23.63	1007.1	6.34	0.181E+07	0.02078	13.45	11.67	12.49	12.50	12.53	12.51
19	423.3	24.44	24.55	24.50	24.50	23.67	1008.0	6.33	0.181E+07	0.02182	12.92	11.34	12.03	12.05	12.08	12.07
20	443.3	24.49	24.56	24.50	24.51	23.71	1009.0	6.33	0.182E+07	0.02285	12.84	11.72	12.66	12.45	12.47	12.46
21	463.3	24.61	24.58	24.69	24.64	23.75	1009.9	6.32	0.183E+07	0.02388	11.65	11.97	10.62	11.18	11.21	11.20
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.32	24.44	24.39	24.39	23.61	1006.6	6.34	0.180E+07	0.02018	14.00	11.92	12.74	12.80	12.85	12.82

DOWNWARD INCLINATION _____ 2 - 1000

INPUT ELECTRIC POWER = 148.5 W HEAT RATE GAINED BY WATER = 144.5 W HEAT BALANCE ERROR = 2.69%
MASS FLOW RATE = 29.6962 G/S PRESSURE DROP= 0.5163MMH20 FRICTION FACTOR = 0.016733 FREM = 16.7395
REM = 1000.4 GRM = 0.21393E+07 UPSTREAM BULK TEMPERATURE = 22.75DEG C DOWNSTREAM BULK TEMPERATURE = 23.92DEG C
PRM = 6.386 RAM = 0.13661E+08 INLET BULK TEMPERATURE = 22.75DEG C OUTLET BULK TEMPERATURE = 23.91DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.37	23.33	23.35	23.35	22.76	987.8	6.48	0.204E+07	0.00028	20.06	21.32	20.67	20.67	20.68	20.68
4	15.5	23.59	23.58	23.59	23.59	22.79	988.3	6.47	0.205E+07	0.00080	14.99	15.22	14.99	15.05	15.05	15.05
5	25.5	23.68	23.79	23.73	23.73	22.81	988.9	6.47	0.205E+07	0.00131	13.94	12.37	13.18	13.14	13.17	13.15
6	45.5	23.82	23.87	23.82	23.83	22.86	990.0	6.46	0.206E+07	0.00234	12.57	12.01	12.63	12.45	12.46	12.46
7	75.5	23.93	23.99	23.92	23.94	22.94	991.6	6.45	0.207E+07	0.00388	12.19	11.49	12.24	12.03	12.04	12.04
8	105.5	23.95	24.06	23.99	24.00	23.01	993.2	6.44	0.208E+07	0.00543	12.90	11.54	12.31	12.25	12.27	12.26
9	135.5	24.03	24.15	24.08	24.09	23.09	994.9	6.42	0.210E+07	0.00697	12.74	11.38	12.11	12.06	12.08	12.07
10	165.2	24.08	24.24	24.19	24.17	23.16	996.5	6.41	0.211E+07	0.00850	13.08	11.14	11.76	11.90	11.94	11.92
11	205.2	24.21	24.36	24.33	24.31	23.26	998.7	6.40	0.213E+07	0.01066	12.69	10.94	11.22	11.48	11.52	11.50
12	245.2	24.39	24.46	24.39	24.41	23.36	1001.0	6.38	0.214E+07	0.01263	11.65	10.94	11.70	11.48	11.49	11.49
13	275.2	24.33	24.50	24.42	24.42	23.43	1002.6	6.37	0.216E+07	0.01417	13.46	11.35	12.23	12.27	12.32	12.30
14	305.2	24.43	24.58	24.50	24.50	23.51	1004.3	6.36	0.217E+07	0.01572	13.07	11.27	12.16	12.13	12.16	12.15
15	333.3	24.40	24.51	24.48	24.47	23.58	1005.9	6.35	0.218E+07	0.01717	14.73	12.96	13.37	13.58	13.61	13.59
16	363.3	24.52	24.64	24.53	24.56	23.65	1007.6	6.34	0.220E+07	0.01872	13.82	12.19	13.67	13.30	13.34	13.32
17	383.3	24.54	24.62	24.58	24.58	23.70	1008.7	6.33	0.221E+07	0.01976	14.41	13.06	13.77	13.74	13.75	13.74
18	403.3	24.54	24.68	24.59	24.60	23.75	1009.9	6.32	0.221E+07	0.02079	15.31	12.99	14.29	14.17	14.22	14.20
19	423.3	24.61	24.74	24.67	24.67	23.80	1011.0	6.31	0.222E+07	0.02182	14.92	12.78	13.92	13.84	13.89	13.86
20	443.3	24.60	24.73	24.67	24.67	23.85	1012.1	6.30	0.223E+07	0.02286	16.10	13.71	14.77	14.79	14.84	14.81
21	463.3	24.83	24.79	24.91	24.86	23.90	1013.3	6.30	0.224E+07	0.02389	12.94	13.61	11.88	12.54	12.58	12.56
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.53	24.65	24.59	24.59	23.72	1009.2	6.32	0.221E+07	0.02019	14.88	12.95	13.96	13.90	13.94	13.92

DOWNWARD INCLINATION ____ 3 - 1000

INPUT ELECTRIC POWER = 215.8 W HEAT RATE GAINED BY WATER = 209.2 W HEAT BALANCE ERROR = 3.06%
MASS FLOW RATE = 29.4070 G/S PRESSURE DROP= 0.5233MMH20 FRICTION FACTOR = 0.017297 FREM = 17.2496
REM = 997.3 GRM = 0.31747E+07 UPSTREAM BULK TEMPERATURE = 22.78DEG C DOWNSTREAM BULK TEMPERATURE = 24.48DEG C
PRM = 6.339 RAM = 0.20124E+08 INLET BULK TEMPERATURE = 22.78DEG C OUTLET BULK TEMPERATURE = 24.48DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.67	23.64	23.65	23.65	22.80	978.9	6.47	0.296E+07	0.00029	20.02	20.83	20.42	20.42	20.42	20.42
4	15.5	24.04	24.06	24.01	24.03	22.84	979.7	6.46	0.297E+07	0.00081	14.55	14.30	14.89	14.65	14.66	14.65
5	25.5	24.12	24.26	24.14	24.17	22.87	980.5	6.46	0.298E+07	0.00132	13.99	12.60	13.72	13.48	13.51	13.50
6	45.5	24.33	24.40	24.32	24.34	22.94	982.1	6.45	0.300E+07	0.00236	12.62	12.00	12.67	12.48	12.49	12.48
7	75.5	24.37	24.52	24.37	24.41	23.05	984.5	6.43	0.303E+07	0.00392	13.24	11.94	13.25	12.89	12.92	12.91
8	105.5	24.42	24.62	24.47	24.49	23.16	986.8	6.41	0.305E+07	0.00548	13.86	11.99	13.38	13.11	13.15	13.13
9	135.5	24.54	24.73	24.61	24.62	23.27	989.3	6.40	0.308E+07	0.00705	13.79	11.94	13.00	12.90	12.94	12.92
10	165.2	24.61	24.86	24.75	24.74	23.38	991.6	6.38	0.311E+07	0.00859	14.16	11.81	12.76	12.82	12.87	12.84
11	205.2	24.77	25.03	24.96	24.92	23.52	994.9	6.36	0.315E+07	0.01068	14.02	11.57	12.23	12.45	12.51	12.48
12	245.2	24.95	25.13	25.00	25.02	23.67	998.1	6.33	0.318E+07	0.01276	13.61	11.93	13.05	12.88	12.91	12.89
13	275.2	24.97	25.16	25.12	25.09	23.78	1000.6	6.32	0.321E+07	0.01433	14.62	12.57	13.00	13.25	13.30	13.27
14	305.2	25.05	25.28	25.17	25.17	23.89	1003.1	6.30	0.324E+07	0.01589	15.04	12.53	13.57	13.62	13.68	13.65
15	333.3	25.09	25.31	25.20	25.20	23.99	1005.4	6.28	0.327E+07	0.01736	15.80	13.14	14.35	14.35	14.41	14.38
16	363.3	25.19	25.42	25.26	25.29	24.10	1007.9	6.26	0.330E+07	0.01893	15.90	13.17	14.94	14.67	14.74	14.70
17	383.3	25.26	25.44	25.36	25.36	24.17	1009.6	6.25	0.332E+07	0.01997	15.91	13.71	14.66	14.70	14.74	14.72
18	403.3	25.30	25.47	25.38	25.38	24.24	1011.3	6.24	0.334E+07	0.02102	16.52	14.24	15.33	15.31	15.36	15.33
19	423.3	25.36	25.58	25.48	25.48	24.32	1012.9	6.23	0.336E+07	0.02206	16.63	13.74	14.94	14.99	15.06	15.03
20	443.3	25.41	25.60	25.48	25.50	24.39	1014.6	6.22	0.338E+07	0.02311	16.95	14.33	15.92	15.72	15.78	15.75
21	463.3	25.64	25.68	25.75	25.71	24.46	1016.3	6.21	0.340E+07	0.02416	14.70	14.28	13.45	13.95	13.97	13.96
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.27	25.47	25.36	25.37	24.20	1010.3	6.25	0.333E+07	0.02041	16.29	13.72	15.02	14.96	15.01	14.98

DOWNWARD INCLINATION ____ 4 - 1000

INPUT ELECTRIC POWER = 300.1 W HEAT RATE GAINED BY WATER = 304.4 W HEAT BALANCE ERROR =-1.45%
MASS FLOW RATE = 29.1899 G/S PRESSURE DROP= 0.5359MMH20 FRICTION FACTOR = 0.017977 FREM = 17.9790
REM = 1000.1 GRM = 0.47942E+07 UPSTREAM BULK TEMPERATURE = 22.83DEG C DOWNSTREAM BULK TEMPERATURE = 25.33DEG C
PRM = 6.267 RAM = 0.30045E+08 INLET BULK TEMPERATURE = 22.84DEG C OUTLET BULK TEMPERATURE = 25.33DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.20	24.20	24.20	24.20	22.87	973.1	6.46	0.434E+07	0.00029	19.05	19.09	19.07	19.07	19.07	19.07
4	15.5	24.56	24.70	24.62	24.62	22.92	974.3	6.45	0.436E+07	0.00081	15.48	14.27	14.97	14.91	14.92	14.92
5	25.5	24.78	25.00	24.92	24.91	22.97	975.4	6.44	0.438E+07	0.00133	14.06	12.52	13.04	13.14	13.16	13.15
6	45.5	24.92	25.10	24.99	25.00	23.08	977.7	6.43	0.441E+07	0.00238	13.81	12.57	13.26	13.21	13.22	13.22
7	75.5	25.04	25.21	25.07	25.10	23.24	981.2	6.40	0.447E+07	0.00395	14.10	12.87	13.87	13.66	13.68	13.67
8	105.5	25.09	25.37	25.16	25.20	23.40	984.7	6.38	0.453E+07	0.00553	14.98	12.85	14.36	14.09	14.14	14.12
9	135.5	25.21	25.48	25.37	25.36	23.56	988.3	6.35	0.459E+07	0.00710	15.39	13.16	14.03	14.11	14.15	14.13
10	165.2	25.36	25.69	25.50	25.52	23.72	991.8	6.33	0.465E+07	0.00866	15.40	12.82	14.19	14.09	14.15	14.12
11	205.2	25.44	25.81	25.68	25.65	23.93	996.6	6.29	0.473E+07	0.01077	16.79	13.46	14.50	14.72	14.81	14.76
12	245.2	25.76	25.97	25.82	25.84	24.14	1001.5	6.26	0.482E+07	0.01287	15.69	13.87	15.12	14.92	14.95	14.94
13	275.2	25.69	26.03	25.96	25.91	24.30	1005.1	6.23	0.488E+07	0.01445	18.17	14.64	15.27	15.73	15.84	15.78
14	305.2	25.91	26.26	26.10	26.09	24.46	1008.6	6.21	0.494E+07	0.01603	17.45	14.08	15.48	15.53	15.62	15.58
15	333.3	26.07	26.40	26.29	26.26	24.61	1012.3	6.18	0.501E+07	0.01751	17.38	14.13	15.07	15.33	15.41	15.37
16	363.3	26.28	26.59	26.44	26.44	24.77	1016.0	6.16	0.507E+07	0.01910	16.74	13.88	15.12	15.15	15.22	15.18
17	383.3	26.38	26.68	26.56	26.54	24.88	1018.5	6.14	0.511E+07	0.02016	16.78	14.02	15.04	15.16	15.22	15.19
18	403.3	26.45	26.73	26.61	26.60	24.98	1021.1	6.13	0.516E+07	0.02121	17.24	14.47	15.52	15.62	15.69	15.66
19	423.3	26.62	26.90	26.75	26.75	25.09	1023.6	6.11	0.520E+07	0.02227	16.51	13.98	15.26	15.20	15.25	15.23
20	443.3	26.62	26.98	26.80	26.80	25.20	1026.1	6.09	0.525E+07	0.02333	17.68	14.13	15.72	15.71	15.81	15.76
21	463.3	26.91	27.09	27.07	27.04	25.30	1028.7	6.07	0.530E+07	0.02439	15.73	14.11	14.27	14.57	14.59	14.58
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	26.40	26.71	26.57	26.57	24.92	1019.6	6.13	0.513E+07	0.02060	17.06	14.10	15.29	15.36	15.43	15.40

DOWNWARD INCLINATION _____ 5 - 1000

INPUT ELECTRIC POWER = 451.0 W HEAT RATE GAINED BY WATER = 447.1 W HEAT BALANCE ERROR = 0.86%
MASS FLOW RATE = 28.7560 G/S PRESSURE DROP= 0.5705MMH20 FRICTION FACTOR = 0.019716 FREM = 19.6475
REM = 996.5 GRM = 0.73328E+07 UPSTREAM BULK TEMPERATURE = 22.72DEG C DOWNSTREAM BULK TEMPERATURE = 26.44DEG C
PRM = 6.189 RAM = 0.45380E+08 INLET BULK TEMPERATURE = 22.72DEG C OUTLET BULK TEMPERATURE = 26.44DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.84	24.84	24.84	24.84	22.76	956.5	6.48	0.632E+07	0.00029	18.00	17.99	17.99	17.99	17.99	17.99
4	15.5	25.28	25.54	25.36	25.38	22.84	958.2	6.46	0.636E+07	0.00082	15.33	13.85	14.82	14.69	14.71	14.70
5	25.5	25.58	25.96	25.75	25.76	22.92	959.9	6.45	0.640E+07	0.00135	14.05	12.27	13.19	13.15	13.18	13.16
6	45.5	25.76	26.11	25.89	25.91	23.08	963.3	6.43	0.648E+07	0.00242	13.93	12.33	13.28	13.18	13.21	13.19
7	75.5	26.01	26.46	26.16	26.20	23.32	968.4	6.39	0.661E+07	0.00401	13.85	11.86	13.13	12.95	12.99	12.97
8	105.5	26.18	26.74	26.37	26.41	23.56	973.6	6.35	0.674E+07	0.00561	14.21	11.70	13.27	13.04	13.11	13.08
9	135.5	26.46	26.91	26.65	26.67	23.80	978.8	6.31	0.688E+07	0.00721	13.97	11.97	13.05	12.97	13.01	12.99
10	165.2	26.58	27.14	26.88	26.87	24.03	984.1	6.28	0.701E+07	0.00880	14.57	11.96	13.08	13.11	13.17	13.14
11	205.2	26.78	27.43	27.13	27.12	24.35	991.3	6.23	0.720E+07	0.01094	15.31	12.07	13.37	13.43	13.53	13.48
12	245.2	27.15	27.70	27.47	27.44	24.67	998.5	6.18	0.738E+07	0.01308	14.98	12.25	13.27	13.37	13.44	13.41
13	275.2	27.31	27.93	27.72	27.67	24.90	1004.0	6.14	0.753E+07	0.01469	15.43	12.28	13.17	13.42	13.51	13.47
14	305.2	27.56	28.16	27.92	27.89	25.14	1009.6	6.10	0.768E+07	0.01630	15.35	12.28	13.37	13.51	13.60	13.55
15	333.3	27.85	28.40	28.27	28.20	25.36	1014.9	6.06	0.782E+07	0.01781	14.94	12.20	12.79	13.10	13.18	13.14
16	363.3	28.04	28.68	28.44	28.40	25.60	1020.6	6.03	0.797E+07	0.01943	15.23	12.04	13.09	13.27	13.36	13.31
17	383.3	28.20	28.76	28.54	28.51	25.76	1024.4	6.00	0.807E+07	0.02051	15.20	12.35	13.34	13.48	13.56	13.52
18	403.3	28.28	28.89	28.71	28.65	25.92	1028.3	5.98	0.818E+07	0.02159	15.72	12.46	13.27	13.58	13.68	13.63
19	423.3	28.44	29.05	28.85	28.80	26.08	1032.2	5.95	0.828E+07	0.02266	15.72	12.46	13.35	13.62	13.72	13.67
20	443.3	28.45	29.10	28.88	28.83	26.24	1036.1	5.93	0.839E+07	0.02375	16.70	12.94	13.99	14.28	14.41	14.34
21	463.3	28.82	29.40	29.29	29.20	26.40	1040.1	5.90	0.850E+07	0.02483	15.29	12.32	12.80	13.21	13.30	13.26
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	28.21	28.82	28.61	28.56	25.83	1026.1	5.99	0.812E+07	0.02096	15.59	12.41	13.30	13.55	13.65	13.60

DOWNWARD INCLINATION _____ 6 - 1000

INPUT ELECTRIC POWER = 657.8 W HEAT RATE GAINED BY WATER = 629.2 W HEAT BALANCE ERROR = 4.35%
MASS FLOW RATE = 28.3221 G/S PRESSURE DROP= 0.8184MMH20 FRICTION FACTOR = 0.029152 FREM = 29.1449
REM = 999.8 GRM = 0.11009E+08 UPSTREAM BULK TEMPERATURE = 22.71DEG C DOWNSTREAM BULK TEMPERATURE = 28.03DEG C
PRM = 6.064 RAM = 0.66756E+08 INLET BULK TEMPERATURE = 22.71DEG C OUTLET BULK TEMPERATURE = 28.03DEG C

STA-TION NO.	Z CM	-WALL TEMPERATURE (DEG C)- A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	27.09	27.97	27.53	27.53	22.78	942.3	6.47	0.890E+07	0.00030	12.19	10.12	11.06	11.06	11.10	11.08
4	15.5	27.35	28.22	27.71	27.74	22.89	944.7	6.46	0.898E+07	0.00084	11.78	9.85	10.90	10.82	10.86	10.84
5	25.5	27.59	28.52	28.19	28.12	23.00	947.1	6.44	0.907E+07	0.00138	11.45	9.51	10.13	10.26	10.31	10.28
6	45.5	27.72	28.57	28.18	28.16	23.23	951.9	6.40	0.924E+07	0.00246	11.68	9.83	10.59	10.63	10.67	10.65
7	75.5	27.95	28.82	28.36	28.38	23.57	959.2	6.35	0.950E+07	0.00408	11.96	9.98	10.94	10.91	10.95	10.93
8	105.5	28.13	29.15	28.57	28.61	23.91	966.6	6.29	0.977E+07	0.00570	12.41	10.00	11.24	11.16	11.22	11.19
9	135.5	28.50	29.36	28.94	28.93	24.25	974.1	6.24	0.100E+08	0.00733	12.32	10.25	11.17	11.18	11.23	11.20
10	165.2	28.64	29.88	29.40	29.33	24.59	981.7	6.19	0.103E+08	0.00895	12.90	9.89	10.87	11.03	11.13	11.08
11	205.2	29.26	30.38	29.93	29.87	25.04	992.0	6.12	0.107E+08	0.01113	12.38	9.78	10.70	10.81	10.89	10.85
12	245.2	29.51	30.57	30.12	30.08	25.49	1002.6	6.04	0.111E+08	0.01331	13.00	10.28	11.27	11.38	11.46	11.42
13	275.2	29.79	30.83	30.52	30.42	25.83	1010.7	5.99	0.114E+08	0.01495	13.18	10.44	11.12	11.38	11.47	11.42
14	305.2	30.02	31.05	30.66	30.60	26.17	1019.0	5.94	0.118E+08	0.01660	13.56	10.69	11.61	11.78	11.87	11.83
15	333.3	30.44	31.33	31.16	31.02	26.49	1026.8	5.89	0.121E+08	0.01814	13.21	10.77	11.16	11.50	11.57	11.54
16	363.3	30.60	31.61	31.21	31.16	26.83	1035.3	5.83	0.124E+08	0.01979	13.81	10.90	11.88	12.03	12.12	12.07
17	383.3	30.77	31.64	31.27	31.24	27.06	1040.1	5.80	0.126E+08	0.02089	14.02	11.37	12.34	12.45	12.52	12.48
18	403.3	30.89	31.79	31.46	31.40	27.29	1044.9	5.77	0.128E+08	0.02199	14.43	11.55	12.46	12.64	12.73	12.68
19	423.3	31.06	31.88	31.61	31.54	27.51	1049.7	5.75	0.130E+08	0.02308	14.65	11.91	12.70	12.91	12.99	12.95
20	443.3	31.02	31.86	31.53	31.48	27.74	1054.6	5.72	0.132E+08	0.02418	15.86	12.61	13.72	13.88	13.98	13.93
21	463.3	31.23	32.08	31.75	31.71	27.97	1059.5	5.69	0.134E+08	0.02528	15.90	12.62	13.70	13.89	13.98	13.93
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	30.80	31.68	31.37	31.31	27.15	1041.9	5.79	0.127E+08	0.02135	14.33	11.52	12.38	12.57	12.65	12.61

DOWNWARD INCLINATION _____ 1 - 1500

INPUT ELECTRIC POWER = 132.7 W HEAT RATE GAINED BY WATER = 130.1 W HEAT BALANCE ERROR = 1.92%
MASS FLOW RATE = 44.8834 G/S PRESSURE DROP= 0.7399MMH20 FRICTION FACTOR = 0.010499 FREM = 15.8009

REM = 1505.0 GRM = 0.18935E+07 UPSTREAM BULK TEMPERATURE = 22.78DEG C DOWNSTREAM BULK TEMPERATURE = 23.47DEG C
PRM = 6.419 RAM = 0.12153E+08 INLET BULK TEMPERATURE = 22.78DEG C OUTLET BULK TEMPERATURE = 23.47DEG C

STA-	Z	-WALL TEMPERATURE (DEG C)-				TB	RE	PR	GR	Z+	NUSSELT NUMBER					
TION	CM	A	B	C	AVER-	(C)					A	B	C	AVERAGE		
NO.					AGE									T	H	T+H
3	5.5	23.26	23.25	23.25	23.25	22.79	1493.7	6.47	0.184E+07	0.00019	23.16	23.59	23.37	23.37	23.37	23.37
4	15.5	23.48	23.53	23.48	23.49	22.80	1494.2	6.47	0.184E+07	0.00053	15.90	14.97	15.90	15.66	15.67	15.66
5	25.5	23.65	23.71	23.65	23.66	22.82	1494.7	6.47	0.185E+07	0.00087	12.98	12.18	13.07	12.82	12.83	12.82
6	45.5	23.77	23.81	23.76	23.78	22.85	1495.6	6.46	0.185E+07	0.00155	11.77	11.23	11.83	11.66	11.67	11.67
7	75.5	23.84	23.90	23.84	23.86	22.89	1497.1	6.46	0.186E+07	0.00257	11.38	10.70	11.43	11.22	11.23	11.23
8	105.5	23.86	23.95	23.88	23.89	22.93	1498.6	6.45	0.186E+07	0.00359	11.68	10.73	11.47	11.33	11.34	11.33
9	135.5	23.87	23.95	23.86	23.88	22.98	1500.1	6.44	0.187E+07	0.00461	12.23	11.16	12.32	11.98	12.01	11.99
10	165.2	23.83	23.96	23.91	23.90	23.02	1501.5	6.43	0.188E+07	0.00562	13.40	11.53	12.29	12.34	12.38	12.36
11	205.2	23.90	24.08	24.03	24.01	23.08	1503.5	6.43	0.189E+07	0.00699	13.22	10.83	11.48	11.69	11.75	11.72
12	245.2	24.03	24.10	24.03	24.05	23.14	1505.5	6.42	0.190E+07	0.00835	12.16	11.33	12.26	11.99	12.00	12.00
13	275.2	23.99	24.10	24.03	24.04	23.19	1507.0	6.41	0.190E+07	0.00937	13.40	11.80	12.89	12.72	12.75	12.73
14	305.2	24.07	24.19	24.13	24.13	23.23	1508.5	6.40	0.191E+07	0.01040	12.95	11.35	11.98	12.04	12.07	12.05
15	333.3	24.01	24.15	24.09	24.08	23.27	1509.9	6.40	0.192E+07	0.01135	14.76	12.41	13.25	13.37	13.42	13.39
16	363.3	24.16	24.25	24.20	24.20	23.32	1511.4	6.39	0.192E+07	0.01238	12.81	11.61	12.31	12.24	12.26	12.25
17	383.3	24.17	24.26	24.19	24.20	23.35	1512.4	6.38	0.193E+07	0.01306	13.07	11.87	12.90	12.67	12.69	12.68
18	403.3	24.14	24.23	24.17	24.18	23.37	1513.4	6.38	0.193E+07	0.01374	14.08	12.69	13.56	13.46	13.48	13.47
19	423.3	24.19	24.30	24.24	24.24	23.40	1514.4	6.37	0.194E+07	0.01442	13.80	12.16	12.90	12.92	12.94	12.93
20	443.3	24.18	24.31	24.24	24.24	23.43	1515.4	6.37	0.194E+07	0.01511	14.59	12.42	13.37	13.40	13.44	13.42
21	463.3	24.41	24.32	24.49	24.43	23.46	1516.4	6.37	0.195E+07	0.01579	11.46	12.60	10.53	11.22	11.28	11.25
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.14	24.25	24.19	24.19	23.36	1512.8	6.38	0.193E+07	0.01334	13.85	12.19	13.06	13.01	13.04	13.02

DOWNWARD INCLINATION _____ 2 - 1500

INPUT ELECTRIC POWER = 161.8 W HEAT RATE GAINED BY WATER = 156.1 W HEAT BALANCE ERROR = 3.51%
MASS FLOW RATE = 45.2450 G/S PRESSURE DROP= 0.7663MMH20 FRICTION FACTOR = 0.010701 FREM = 16.0880

REM = 1503.5 GRM = 0.21979E+07 UPSTREAM BULK TEMPERATURE = 22.31DEG C DOWNSTREAM BULK TEMPERATURE = 23.13DEG C
PRM = 6.483 RAM = 0.14248E+08 INLET BULK TEMPERATURE = 22.31DEG C OUTLET BULK TEMPERATURE = 23.13DEG C

STA-	Z	-WALL TEMPERATURE (DEG C)-				TB	RE	PR	GR	Z+	NUSSELT NUMBER					
TION	CM	A	B	C	AVER-	(C)					A	B	C	AVERAGE		
NO.					AGE									T	H	T+H
3	5.5	22.87	22.83	22.85	22.85	22.32	1490.2	6.55	0.213E+07	0.00019	23.70	25.49	24.56	24.56	24.58	24.57
4	15.5	23.15	23.14	23.10	23.12	22.33	1490.8	6.54	0.213E+07	0.00052	15.93	16.27	17.08	16.57	16.59	16.58
5	25.5	23.29	23.32	23.26	23.28	22.35	1491.3	6.54	0.213E+07	0.00086	13.83	13.44	14.37	13.99	14.00	14.00
6	45.5	23.43	23.42	23.37	23.40	22.39	1492.5	6.54	0.214E+07	0.00153	12.49	12.62	13.25	12.89	12.90	12.89
7	75.5	23.43	23.54	23.42	23.45	22.44	1494.2	6.53	0.215E+07	0.00255	13.20	11.82	13.28	12.86	12.90	12.88
8	105.5	23.47	23.61	23.49	23.52	22.49	1496.0	6.52	0.216E+07	0.00356	13.30	11.66	13.07	12.74	12.78	12.76
9	135.5	23.50	23.64	23.55	23.56	22.54	1497.7	6.51	0.217E+07	0.00457	13.60	11.86	12.94	12.80	12.83	12.82
10	165.2	23.42	23.55	23.54	23.51	22.60	1499.4	6.50	0.218E+07	0.00557	15.94	13.74	13.82	14.27	14.33	14.30
11	205.2	23.60	23.75	23.69	23.68	22.67	1501.8	6.49	0.219E+07	0.00692	14.05	12.06	12.74	12.86	12.90	12.88
12	245.2	23.70	23.82	23.80	23.78	22.74	1504.1	6.48	0.220E+07	0.00828	13.56	12.06	12.25	12.50	12.53	12.52
13	275.2	23.77	23.88	23.83	23.83	22.79	1505.9	6.47	0.221E+07	0.00929	13.28	11.95	12.54	12.56	12.58	12.57
14	305.2	23.82	23.96	23.88	23.89	22.84	1507.6	6.46	0.222E+07	0.01030	13.41	11.66	12.54	12.51	12.54	12.52
15	333.3	23.81	23.87	23.84	23.84	22.89	1509.3	6.46	0.223E+07	0.01125	14.19	13.38	13.78	13.78	13.78	13.78
16	363.3	23.86	23.97	23.92	23.91	22.95	1511.0	6.45	0.224E+07	0.01227	14.33	12.71	13.43	13.45	13.47	13.46
17	383.3	23.89	23.95	23.91	23.91	22.98	1512.2	6.44	0.225E+07	0.01294	14.25	13.47	14.08	13.96	13.97	13.97
18	403.3	23.81	23.95	23.89	23.89	23.02	1513.4	6.44	0.225E+07	0.01362	16.47	13.98	14.84	14.98	15.03	15.01
19	423.3	23.85	24.02	23.96	23.95	23.05	1514.6	6.43	0.226E+07	0.01430	16.22	13.50	14.28	14.51	14.57	14.54
20	443.3	23.90	24.05	23.99	23.98	23.09	1515.8	6.42	0.227E+07	0.01497	16.11	13.48	14.39	14.54	14.60	14.57
21	463.3	24.13	24.06	24.24	24.17	23.12	1517.0	6.42	0.227E+07	0.01565	12.94	13.82	11.64	12.44	12.51	12.48
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	23.85	23.97	23.92	23.91	23.00	1512.7	6.44	0.225E+07	0.01323	15.26	13.42	14.13	14.20	14.24	14.22

DOWNWARD INCLINATION _____ 3 - 1500

INPUT ELECTRIC POWER = 236.5 W　　HEAT RATE GAINED BY WATER = 236.1 W　　HEAT BALANCE ERROR = 0.15%
MASS FLOW RATE = 44.6665 G/S　　PRESSURE DROP= 0.7737MMH20　　FRICTION FACTOR = 0.011085　　FREM = 16.6808
REM = 1504.9　　GRM = 0.34986E+07　　UPSTREAM BULK TEMPERATURE = 22.71DEG C　　DOWNSTREAM BULK TEMPERATURE = 23.97DEG C
PRM = 6.385　　RAM = 0.22338E+08　　INLET BULK TEMPERATURE = 22.71DEG C　　OUTLET BULK TEMPERATURE = 23.97DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.59	23.58	23.59	23.59	22.72	1484.3	6.48	0.332E+07	0.00019	22.75	22.92	22.84	22.84	22.84	22.84
4	15.5	23.84	23.89	23.84	23.85	22.75	1485.2	6.48	0.333E+07	0.00053	18.02	17.28	18.02	17.83	17.84	17.83
5	25.5	24.01	24.09	24.06	24.06	22.78	1486.1	6.47	0.334E+07	0.00087	15.97	14.97	15.33	15.39	15.40	15.40
6	45.5	24.16	24.23	24.15	24.18	22.83	1487.9	6.47	0.335E+07	0.00156	14.81	14.06	14.88	14.65	14.66	14.65
7	75.5	24.26	24.38	24.26	24.29	22.91	1490.6	6.45	0.338E+07	0.00258	14.60	13.44	14.62	14.30	14.32	14.31
8	105.5	24.31	24.51	24.33	24.37	22.99	1493.2	6.44	0.340E+07	0.00361	14.94	13.02	14.75	14.32	14.36	14.34
9	135.5	24.37	24.54	24.45	24.45	23.07	1495.9	6.43	0.342E+07	0.00464	15.20	13.45	14.35	14.31	14.34	14.32
10	165.2	24.25	24.47	24.44	24.40	23.15	1498.6	6.41	0.345E+07	0.00565	17.96	15.00	15.32	15.82	15.90	15.86
11	205.2	24.43	24.64	24.59	24.56	23.26	1502.2	6.40	0.348E+07	0.00702	16.79	14.26	14.86	15.14	15.19	15.16
12	245.2	24.64	24.82	24.73	24.73	23.37	1505.9	6.38	0.351E+07	0.00840	15.43	13.52	14.51	14.46	14.49	14.48
13	275.2	24.66	24.89	24.75	24.76	23.45	1508.6	6.37	0.353E+07	0.00942	16.21	13.70	15.08	14.96	15.02	14.99
14	305.2	24.74	24.97	24.89	24.87	23.53	1511.3	6.35	0.355E+07	0.01045	16.30	13.67	14.46	14.66	14.72	14.69
15	333.3	24.81	25.04	24.95	24.94	23.61	1513.9	6.34	0.358E+07	0.01142	16.30	13.76	14.61	14.76	14.82	14.79
16	363.3	24.91	25.11	25.01	25.01	23.69	1516.7	6.33	0.360E+07	0.01245	16.02	13.78	14.86	14.84	14.88	14.86
17	383.3	24.96	25.16	25.06	25.05	23.74	1518.5	6.32	0.362E+07	0.01314	16.17	13.87	15.01	14.97	15.02	14.99
18	403.3	24.93	25.16	25.07	25.06	23.79	1520.4	6.31	0.363E+07	0.01382	17.30	14.44	15.42	15.58	15.64	15.61
19	423.3	25.03	25.25	25.17	25.15	23.85	1522.3	6.30	0.365E+07	0.01461	16.68	14.06	14.86	15.06	15.12	15.09
20	443.3	25.11	25.29	25.20	25.20	23.90	1524.1	6.30	0.366E+07	0.01520	16.35	14.14	15.15	15.16	15.20	15.18
21	463.3	25.36	25.36	25.47	25.42	23.96	1526.0	6.29	0.368E+07	0.01588	13.97	13.99	12.96	13.45	13.47	13.46
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	24.96	25.17	25.08	25.07	23.76	1519.3	6.32	0.362E+07	0.01342	16.47	14.01	14.99	15.06	15.11	15.09

DOWNWARD INCLINATION _____ 4 - 1500

INPUT ELECTRIC POWER = 310.7 W　　HEAT RATE GAINED BY WATER = 308.1 W　　HEAT BALANCE ERROR = 0.83%
MASS FLOW RATE = 44.5220 G/S　　PRESSURE DROP= 0.8145MMH20　　FRICTION FACTOR = 0.011745　　FREM = 17.6710
REM = 1504.6　　GRM = 0.46172E+07　　UPSTREAM BULK TEMPERATURE = 22.65DEG C　　DOWNSTREAM BULK TEMPERATURE = 24.31DEG C
PRM = 6.363　　RAM = 0.29380E+08　　INLET BULK TEMPERATURE = 22.65DEG C　　OUTLET BULK TEMPERATURE = 24.30DEG C

STA-TION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVER-AGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	23.89	23.81	23.85	23.85	22.67	1477.8	6.49	0.432E+07	0.00019	20.98	22.61	21.77	21.77	21.78	21.77
4	15.5	24.15	24.17	24.12	24.14	22.70	1478.9	6.49	0.433E+07	0.00053	17.82	17.56	18.17	17.92	17.93	17.93
5	25.5	24.39	24.48	24.42	24.43	22.74	1480.1	6.48	0.434E+07	0.00087	15.53	14.79	15.28	15.21	15.22	15.22
6	45.5	24.50	24.54	24.49	24.50	22.81	1482.4	6.47	0.437E+07	0.00156	15.24	14.86	15.30	15.17	15.17	15.17
7	75.5	24.59	24.77	24.59	24.64	22.91	1485.9	6.45	0.441E+07	0.00259	15.31	13.89	15.31	14.93	14.96	14.94
8	105.5	24.67	24.92	24.72	24.76	23.02	1489.4	6.44	0.445E+07	0.00362	15.56	13.50	15.14	14.79	14.84	14.82
9	135.5	24.84	25.07	24.92	24.94	23.13	1492.9	6.42	0.449E+07	0.00465	14.98	13.25	14.33	14.20	14.22	14.21
10	165.2	24.64	24.97	24.91	24.86	23.23	1496.4	6.40	0.453E+07	0.00567	18.26	14.80	15.27	15.79	15.90	15.84
11	205.2	24.94	25.25	25.12	25.11	23.37	1501.1	6.38	0.458E+07	0.00705	16.44	13.65	14.73	14.82	14.89	14.85
12	245.2	25.23	25.44	25.31	25.32	23.51	1505.9	6.36	0.463E+07	0.00843	14.98	13.35	14.28	14.20	14.22	14.21
13	275.2	25.26	25.53	25.37	25.38	23.62	1509.5	6.34	0.467E+07	0.00946	15.76	13.46	14.66	14.59	14.64	14.61
14	305.2	25.30	25.59	25.45	25.45	23.73	1513.1	6.32	0.471E+07	0.01049	16.34	13.80	14.87	14.92	14.97	14.94
15	333.3	25.43	25.68	25.56	25.56	23.83	1516.5	6.31	0.475E+07	0.01146	16.03	13.86	14.75	14.81	14.85	14.83
16	363.3	25.50	25.78	25.63	25.63	23.93	1520.2	6.29	0.479E+07	0.01250	16.35	13.85	15.12	15.06	15.11	15.08
17	383.3	25.54	25.81	25.64	25.66	24.00	1522.6	6.28	0.482E+07	0.01319	16.63	14.21	15.69	15.50	15.55	15.53
18	403.3	25.52	25.80	25.66	25.66	24.07	1525.1	6.27	0.485E+07	0.01388	17.69	14.82	16.16	16.15	16.21	16.18
19	423.3	25.59	25.89	25.76	25.75	24.14	1527.5	6.26	0.488E+07	0.01457	17.77	14.67	15.84	15.96	16.03	15.99
20	443.3	25.61	25.94	25.76	25.77	24.21	1530.0	6.25	0.491E+07	0.01526	18.34	14.84	16.55	16.48	16.57	16.52
21	463.3	25.81	26.00	26.01	25.96	24.28	1532.5	6.24	0.493E+07	0.01595	16.77	14.97	14.88	15.34	15.37	15.36
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	25.53	25.82	25.67	25.67	24.03	1523.6	6.28	0.483E+07	0.01347	17.13	14.38	15.68	15.66	15.72	15.69

DOWNWARD INCLINATION _____ 5 - 1500

INPUT ELECTRIC POWER = 482.9 W HEAT RATE GAINED BY WATER = 483.9 W HEAT BALANCE ERROR =-0.20%
MASS FLOW RATE = 43.7986 G/S PRESSURE DROP= 0.8457MMH20 FRICTION FACTOR = 0.012599 FREM = 18.9424
REM = 1503.5 GRM = 0.76736E+07 UPSTREAM BULK TEMPERATURE = 22.84DEG C DOWNSTREAM BULK TEMPERATURE = 25.49DEG C
PRM = 6.254 RAM = 0.47990E+08 INLET BULK TEMPERATURE = 22.85DEG C OUTLET BULK TEMPERATURE = 25.49DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	24.70	24.67	24.69	24.69	22.88	1460.5	6.46	0.690E+07	0.00019	22.16	22.50	22.33	22.33	22.33	22.33
4	15.5	25.17	25.37	25.19	25.23	22.93	1462.3	6.45	0.693E+07	0.00054	18.07	16.57	17.85	17.57	17.59	17.58
5	25.5	25.52	25.77	25.64	25.64	22.99	1464.2	6.44	0.697E+07	0.00089	15.94	14.52	15.24	15.21	15.23	15.22
6	45.5	25.62	25.85	25.69	25.71	23.10	1467.8	6.42	0.703E+07	0.00159	16.04	14.67	15.58	15.45	15.47	15.46
7	75.5	25.79	26.10	25.82	25.88	23.27	1473.4	6.40	0.713E+07	0.00264	16.03	14.27	15.81	15.45	15.48	15.47
8	105.5	25.87	26.35	25.95	26.03	23.44	1479.0	6.37	0.723E+07	0.00368	16.58	13.86	16.09	15.58	15.66	15.62
9	135.5	26.10	26.49	26.20	26.25	23.61	1484.6	6.34	0.733E+07	0.00473	16.20	14.01	15.55	15.28	15.33	15.30
10	165.2	25.75	26.31	26.12	26.07	23.78	1490.3	6.32	0.743E+07	0.00577	20.42	15.94	17.20	17.55	17.69	17.62
11	205.2	26.16	26.70	26.40	26.42	24.00	1497.9	6.28	0.757E+07	0.00718	18.64	14.91	16.78	16.67	16.78	16.72
12	245.2	26.59	27.00	26.77	26.78	24.23	1505.6	6.24	0.771E+07	0.00858	17.05	14.52	15.85	15.77	15.82	15.79
13	275.2	26.67	27.17	26.94	26.93	24.40	1511.5	6.22	0.782E+07	0.00963	17.71	14.49	15.83	15.89	15.97	15.93
14	305.2	26.78	27.29	27.08	27.06	24.57	1517.4	6.19	0.793E+07	0.01069	18.19	14.74	16.03	16.16	16.25	16.20
15	333.3	27.10	27.63	27.43	27.40	24.72	1522.9	6.17	0.803E+07	0.01168	16.96	13.86	14.86	15.06	15.14	15.10
16	363.3	27.20	27.73	27.48	27.47	24.89	1528.9	6.14	0.814E+07	0.01273	17.43	14.15	15.54	15.58	15.66	15.62
17	383.3	27.33	27.83	27.53	27.56	25.01	1532.9	6.12	0.822E+07	0.01344	17.27	14.21	15.90	15.74	15.82	15.78
18	403.3	27.43	27.94	27.68	27.68	25.12	1537.0	6.10	0.829E+07	0.01414	17.37	14.25	15.72	15.68	15.76	15.72
19	423.3	27.54	28.07	27.87	27.84	25.23	1541.0	6.09	0.837E+07	0.01485	17.40	14.14	15.23	15.41	15.50	15.46
20	443.3	27.61	28.17	27.90	27.89	25.35	1545.1	6.07	0.845E+07	0.01555	17.73	14.23	15.72	15.75	15.85	15.80
21	463.3	27.89	28.33	28.17	28.14	25.46	1549.2	6.06	0.853E+07	0.01626	16.50	13.97	14.82	14.98	15.03	15.00
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	27.37	27.90	27.65	27.64	25.05	1534.6	6.11	0.825E+07	0.01373	17.36	14.14	15.49	15.54	15.62	15.58

DOWNWARD INCLINATION _____ 6 - 1500

INPUT ELECTRIC POWER = 695.2 W HEAT RATE GAINED BY WATER = 673.7 W HEAT BALANCE ERROR = 3.09%
MASS FLOW RATE = 43.0754 G/S PRESSURE DROP= 1.0115MMH20 FRICTION FACTOR = 0.015578 FREM = 23.3386
REM = 1498.2 GRM = 0.11191E+08 UPSTREAM BULK TEMPERATURE = 22.86DEG C DOWNSTREAM BULK TEMPERATURE = 26.61DEG C
PRM = 6.164 RAM = 0.68983E+08 INLET BULK TEMPERATURE = 22.87DEG C OUTLET BULK TEMPERATURE = 26.61DEG C

STATION NO.	Z CM	WALL TEMPERATURE (DEG C) A	B	C	AVERAGE	TB (C)	RE	PR	GR	Z+	NUSSELT NUMBER A	B	C	AVERAGE T	H	T+H
3	5.5	25.48	25.48	25.48	25.48	22.91	1437.4	6.45	0.963E+07	0.00020	21.90	21.86	21.88	21.88	21.88	21.88
4	15.5	26.16	26.49	26.24	26.28	22.99	1440.0	6.44	0.970E+07	0.00055	17.72	16.07	17.27	17.06	17.08	17.07
5	25.5	26.57	27.04	26.80	26.80	23.07	1442.5	6.43	0.976E+07	0.00090	16.06	14.16	15.06	15.05	15.08	15.07
6	45.5	26.68	27.11	26.84	26.87	23.23	1447.7	6.40	0.989E+07	0.00161	16.26	14.46	15.55	15.43	15.46	15.44
7	75.5	26.95	27.54	27.08	27.16	23.47	1455.5	6.36	0.101E+08	0.00268	16.11	13.77	15.55	15.19	15.24	15.22
8	105.5	27.18	27.92	27.40	27.47	23.71	1463.3	6.33	0.103E+08	0.00375	16.14	13.33	15.20	14.90	14.97	14.93
9	135.5	27.49	28.11	27.76	27.78	23.95	1471.3	6.29	0.105E+08	0.00482	15.81	13.49	14.69	14.62	14.67	14.65
10	165.2	26.92	27.81	27.52	27.44	24.18	1479.3	6.25	0.107E+08	0.00588	20.50	15.45	16.80	17.20	17.38	17.29
11	205.2	27.56	28.32	27.91	27.93	24.50	1490.1	6.20	0.110E+08	0.00731	18.33	14.67	16.43	16.36	16.46	16.41
12	245.2	28.15	28.81	28.47	28.48	24.82	1501.2	6.15	0.113E+08	0.00874	16.84	14.02	15.33	15.31	15.38	15.35
13	275.2	28.29	29.07	28.79	28.73	25.06	1509.6	6.11	0.115E+08	0.00981	17.35	13.95	15.01	15.24	15.33	15.28
14	305.2	28.48	29.28	28.90	28.89	25.30	1518.0	6.07	0.117E+08	0.01089	17.57	14.04	15.55	15.58	15.68	15.63
15	333.3	28.99	29.85	29.57	29.50	25.53	1526.0	6.04	0.119E+08	0.01190	16.13	12.91	13.80	14.07	14.16	14.12
16	363.3	29.21	30.13	29.73	29.70	25.77	1534.7	6.00	0.122E+08	0.01298	16.22	12.79	14.10	14.20	14.30	14.25
17	383.3	29.40	30.23	29.80	29.81	25.92	1540.5	5.98	0.123E+08	0.01370	16.06	12.97	14.42	14.39	14.47	14.43
18	403.3	29.54	30.41	30.00	29.99	26.08	1546.4	5.95	0.125E+08	0.01442	16.14	12.89	14.25	14.29	14.38	14.34
19	423.3	29.66	30.56	30.23	30.17	26.24	1552.3	5.93	0.127E+08	0.01514	16.31	12.92	14.00	14.20	14.31	14.25
20	443.3	29.75	30.68	30.29	30.25	26.40	1558.3	5.90	0.128E+08	0.01586	16.67	13.05	14.35	14.50	14.61	14.55
21	463.3	30.31	31.22	30.77	30.77	26.56	1564.3	5.88	0.130E+08	0.01658	14.90	11.98	13.24	13.26	13.34	13.30
AVERAGE VALUES THROUGH STATIONS 15 TO 20:	391.6	29.43	30.31	29.94	29.90	25.99	1543.1	5.97	0.124E+08	0.01400	16.26	12.92	14.15	14.27	14.37	14.32