COMBINED FREE AND FORCED CONVECTION DURING LAMINAR FLOW THROUGH HELICALLY COILED CIRCULAR TUBES OF SUBSTANTIAL PITCH

by

David Steven Austen

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ABSTRACT

The pressure drop and heat transfer performance in helically coiled circular tubes has been thoroughly investigated for selected coil geometries in laminar water flow. Two coils of close pitch were compared with two coils of substantial pitch. The investigation covered isothermal flow, the Neumann boundary condition via resistance heating, and the Dirichlet boundary condition via condensing steam. For each tested coil, the heated section was preceded by a one dimensional hydrodynamic entry section with a tangent connection at the point of incidence with the coil. No conclusive results were produced under the Dirichlet boundary condition due to equipment limitations. A fifth coil was investigated isothermally only, as discussed herein.

Pressure drop measurements under isothermal conditions were performed to verify the modified Dean number as a correlation parameter and the results compared favourably with other experimental correlations. Further pressure drop results are reported for heat addition and showed a free convective effect for the high pitched coils, as discussed herein.

Heat transfer measurements were taken at a number of stations along the lengths of the coils and evaluated locally and as fully developed. The fully developed Nusselt number results are studied thoroughly with respect to the laminar flow regime and compared favourably with correlations found in the literature. In a particular flow range, it was found that there is a substantial effect on the Nusselt number based on the coil pitch angle and the coil axis orientation. A postulated geometric continuum map was given initial substantiation, and recommendations are made for further investigations. No correlations were developed, however, the modified Dean number was initially substantiated as a substitutive modification for existing correlations, under their respective restrictions.

DEDICATION

"He is a poor disciple who does not excel his master."

Leonardo da Vinci

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K. Majury	many extension cords
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H. Weiss	paperwork & administration
A. McKay W. Bourbonnaise	electrical test equipment
D. Mathew	clay and information

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NOMENCLATURE

English Symbols

Ac	flow cross sectional area	[m^2]
As	flow contact surface area	[m^2]
cp	specific heat capacity	[J/kg•K]
D	coil diameter (centre-centre)	[m]
Dc	coil diameter of curvature	[m]
d or di	tube inner diameter	[m]
h	coil pitch (centre-centre)	[m]
hi	tube inner film coefficient	[$W/m^2 \cdot K$]
I	electrical current	[ampere]
k	fluid thermal conductivity	[W/m•K]
ks	tube thermal conductivity	[W/m•K]
L	length of tube coiled	[m]
$\dot{m}$	mass flow rate	[kg/s]
p	static pressure	[mm]
R	electrical resistance	[ohms]
Qe	heat added electrically	[W]
Qf	heat absorbed by the fluid	[W]
T	temperature	[°C]
Tb	bulk fluid temperature	[°C]
Tba	bulk average of fluid	[°C]
Tbi	bulk inlet of fluid	[°C]

Tbo	bulk outlet of fluid	[°C]
Tbx	bulk of fluid at position x	[°C]
Twa	wall inner average	[°C]
Twi	wall inner temperature	[°C]
Two	wall outer temperature	[°C]
u	fluid mean velocity (1-d)	[m/s]
V	voltage drop across coil	[volts]
x	distance from upper coil end	[m]

Greek Symbols

α	thermal diffusivity	[m^2/s]
β	coeff. of thermal expansion	[1/ K]
β	pitch angle	[degrees]
Δ	change of a property or a measured quantity	
μ	dynamic viscosity	[kg/ms]
ν	kinematic viscosity	[m /s]
ρ	density	[kg/m]
ρ_e	electrical resistivity	[cm /cm]
σ	standard deviation	

Non-Dimensional Parameters

D/d	diametral ratio
Dc/d	diametral ratio

Dn	Dean's number, $Dn=Re\sqrt{d/D}$
Dn*	modified Dean's number, $Dn^*=Re\sqrt{d/Dc}$
fc	friction factor: curved (eqn 3.3)
fs	friction factor: straight, $fs=16/Re$
Gr	Grashof number, $Gr=\frac{g\beta d_i^3(T_{wi}-T_{bx})}{\nu^2}$
Gz	Graetz number, $Gz=\pi/4 RePr(d/L)$
h/d	pitch ratio
L/d	length ratio
Nu	Fully Developed Nusselt No., $Nu=hd/k$
Nux	Local Nusselt No.
Pr	Overall Prandtl No., $Pr=\mu cp/k$
Prx	Local Prandtl No.
Ra	Rayleigh No., $Ra=GrPr$
Re	Reynolds No., $Re=ud/\nu$
Rex	Local Reynolds No.
x/d	axial position from upper inlet

Definitions

AMTD	arithmetic mean temperature difference
LMTD	logarithmic mean temperature difference
transide	(tran-sīd') v. to undergo a change of state eg. "straight tube flow transides around a Reynolds number of 2300"---see transition.

Chapter 1

INTRODUCTION

During any convective heat transfer process, the actual heat transfer passage can provide a wide variety of effects to the process based on the interaction of geometric parameters alone. This is completely aside from the flow parameters and the boundary conditions, and is exemplified by the helically coiled tube. Although its main attribute is its compactness, it is used in a variety of applications ranging from stagnant batch heating to dynamic distillation processes and has almost limitless utility as a method of experimental and analytical modelling.

1.1 Geometry of Coiled Tube Helices

In a coiled tube helix, there are two governing geometric parameters: the diametral ratio (D/d) and the pitch ratio (h/d). The coil diameter D and pitch h are non-dimensionalized in terms of d, the inner tube diameter for circular tubes and the hydraulic diameter for non-circular tubes. Figure 1.1 illustrates the geometry of helically coiled tubes. Most coils used as heat exchangers

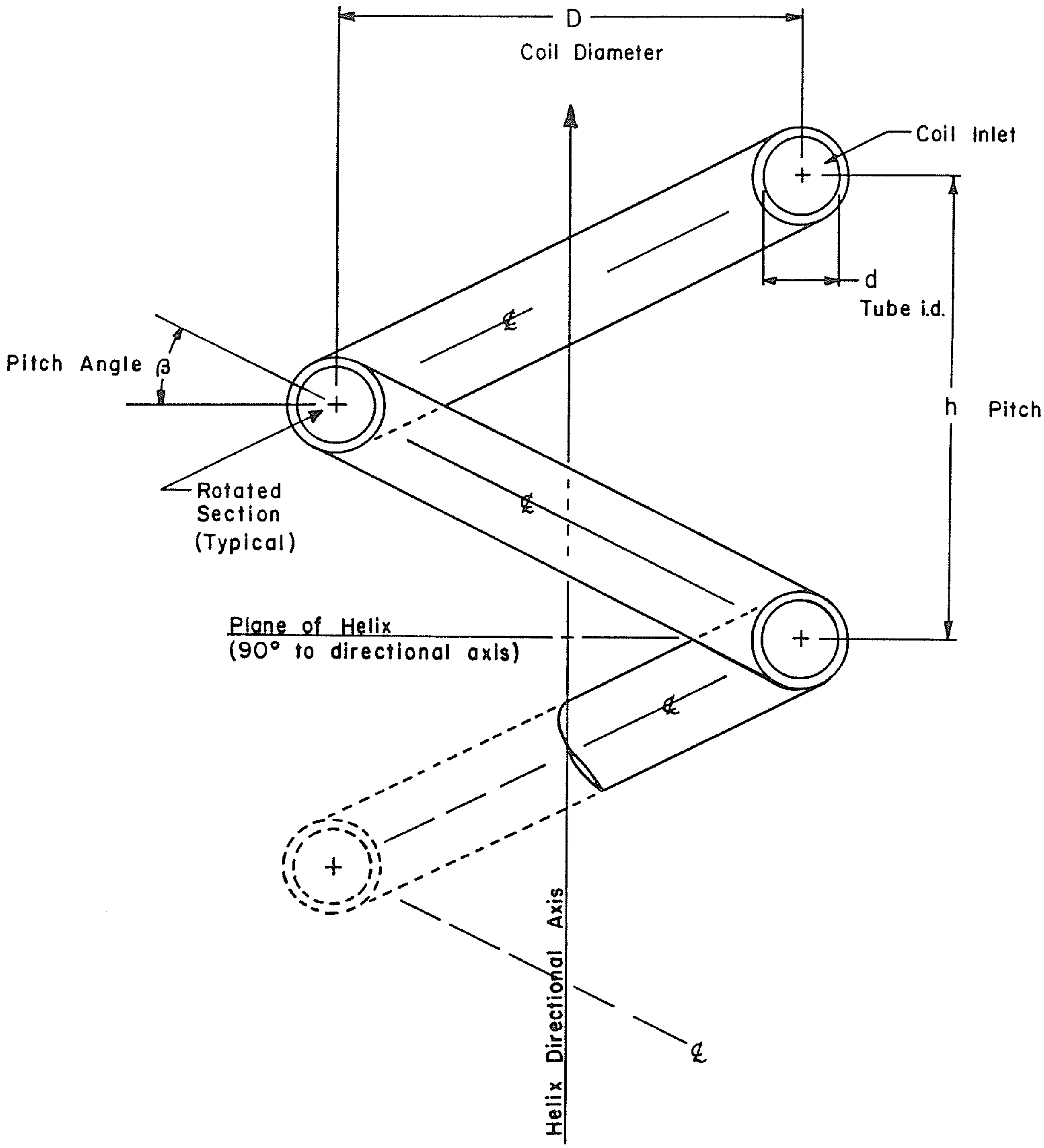


Figure 1.1: Parametric Definition of a Helically Coiled Tube

are closely pitched at $1<(h/d)<5$ for compactness and have a diametral ratio suited to the specific application. In cross-flow or in-line tube banks, externally and internally finned tubes have augmented heat transfer rates in a variety of domestic, commercial, and industrial applications. Work in this area is also progressing on the use of twisted tubes of non-circular cross-section (ovoid and rectangular for example). This is still essentially a helically coiled tube, but of zero diametral ratio and moderate to extreme pitch. Generally, when either the coil diameter or the coil pitch are taken to infinity, a straight tube will be produced as shown in Figure 1.2. Also, if the diametral ratio is reduced to zero for a tube of circular cross-section, a straight tube is again produced whereas a tube of non-circular cross-section will form a twisted tube, as illustrated in Figure 1.2 f.

Aside from these two examples, there are other combinations of the diametral and pitch ratios, irrespective of tube cross-sectional shape, as can be seen in Figure 1.3. Zone A represents the area for which experimental work has been done to date in closely pitched helically coiled tubes. Zone B represents single plane curved passages or pipe bends where the pitch is usually zero. Partial coils of this nature have been in general

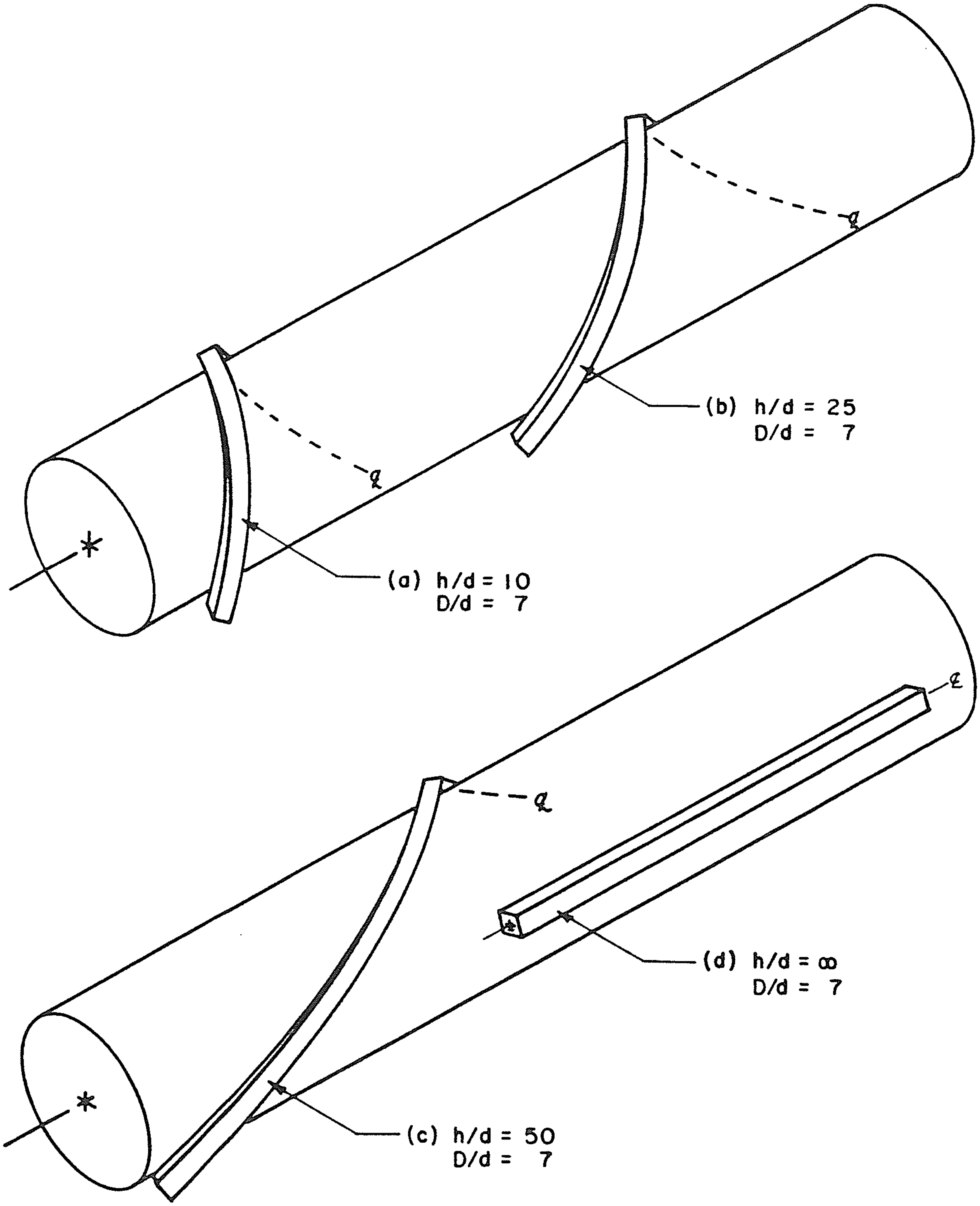


Figure 1.2: Examples of Coiled Tube Geometric Progression

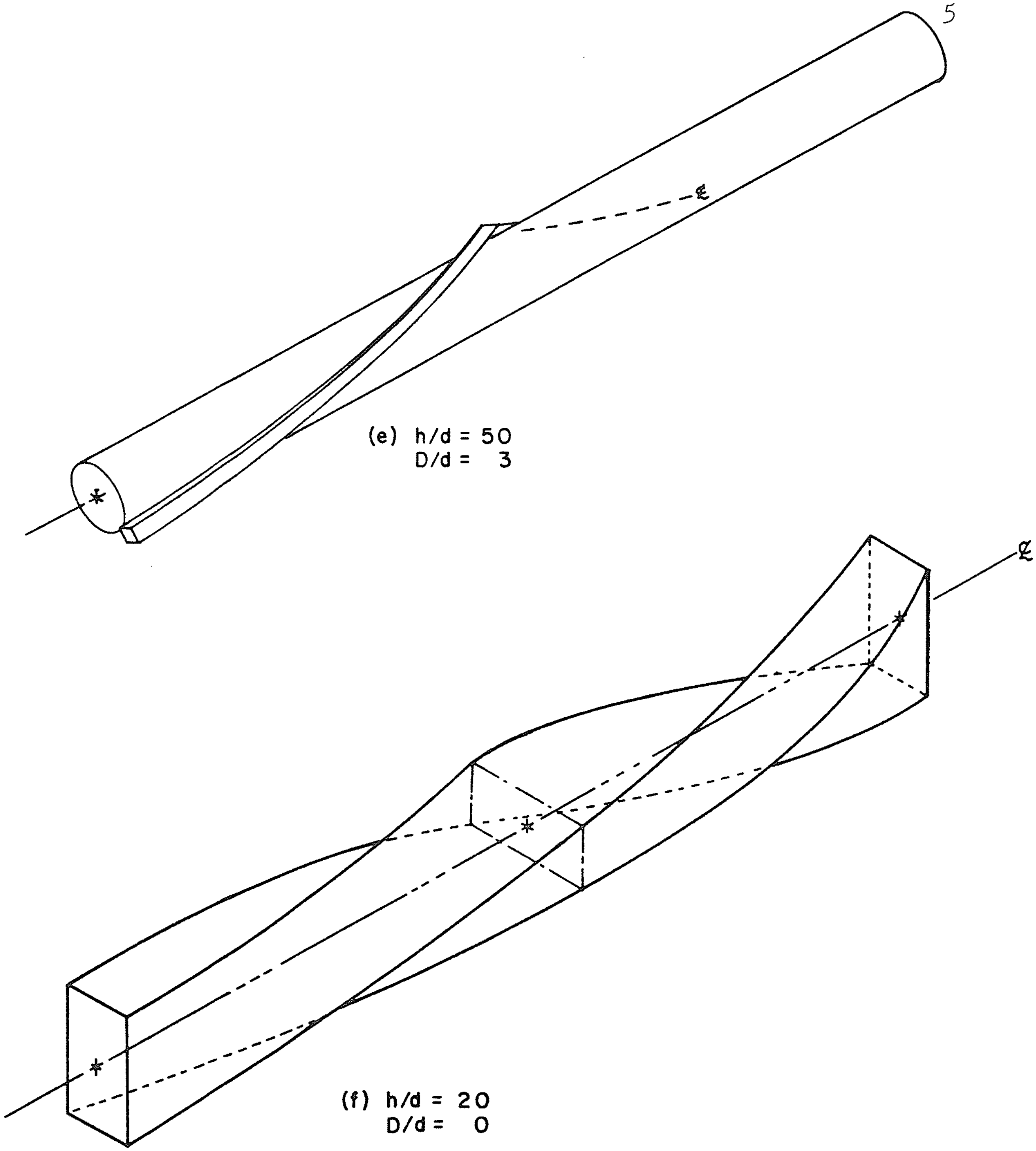


Figure 1.2 (cont'd)

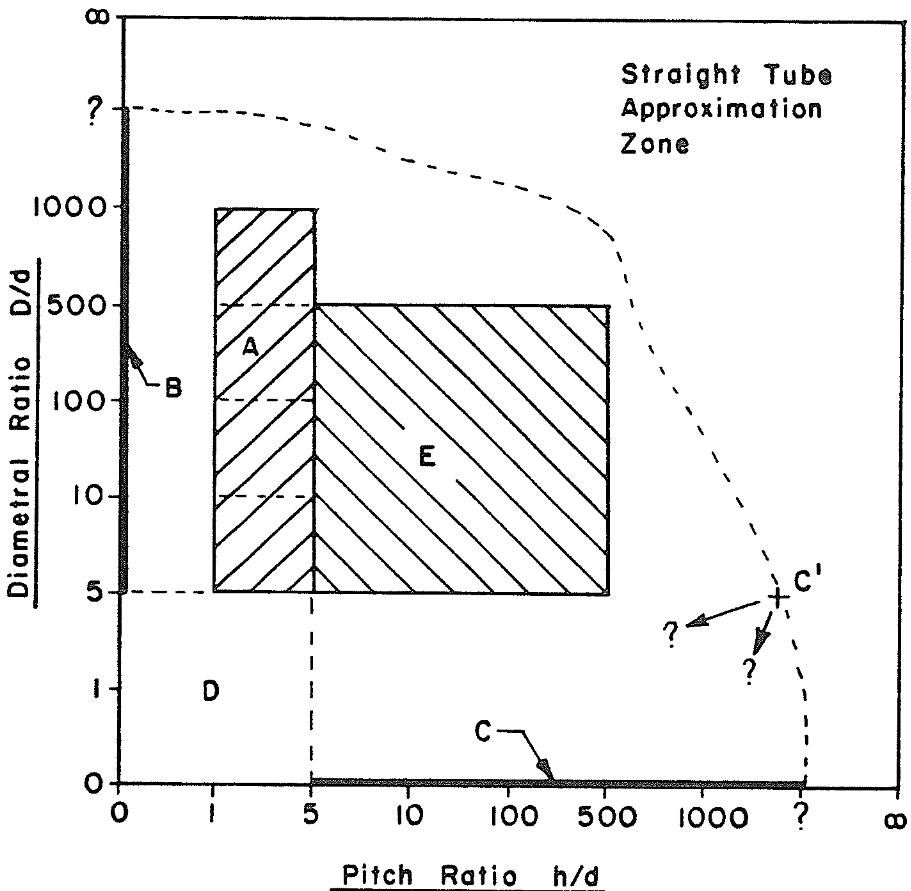


Figure 1.3: Geometric Continuum Map (I)

use for some time in many applications. Zone C represents the case of the twisted tube where the pitch has been extended to allow for further contraction of the diametral ratio below the normal mechanical limit. Zone D indicates combinations of coil geometric parameters where mechanical distortions of the tube cross-section are most likely to occur, based on material limits. This may be avoided by actual moulding of the product at high temperature, but requires special machinery and possibly special materials. Zone E covers a wide area of combination for the diametral and pitch ratios allowing for the design of a variety of applicable heat exchangers.

The broken arbitrary curve of unknown ordinate and abscissa intercepts in Figure 1.3, represents a boundary beyond which straight tube approximations will provide excellent accuracy in hydrodynamic and thermodynamic analyses. This boundary is representative of tubes of non-circular cross- section only, since a twisted tube of circular cross- section forms a straight tube. Thus, the point C' is used to denote an undetermined point of departure for tubes of circular cross-section whereby a seperate boundary begins formation. The location and shape of these boundaries can only be determined by further research in zones A,C, and E.

It is therefore necessary to cover the complete geometric range of helical coils in order to model the hydrodynamic and thermal flow fields. This also requires further research with respect to laminar/turbulent flow regimes, the possible inclusion of free convection via a Gr/Re ratio, and the extent of the entrance region.

1.2 Flow Physics

Visualization studies of isothermal flow in helical tubes from prior work and this project indicate the presence of two contra-rotating vortices within the tube flow cross- section as shown in Figure 1.4. This phenomenon is the result of centrifugal forces acting in the plane of the helix, on the central core of the flow where the shear stress is small. The core mass tends to flow in an outward spiralling (global) motion composed of an axial flow and a local cross flow until coming in contact with what has been considered to be a boundary layer of axi- tangential flow. Once in the boundary layer, the fluid particles then return to the core after following the tubewall inwards to the coil inner flow limit as shown in Figure 1.5. Although inconclusive, the present visual study tended to indicate that the fluid particles

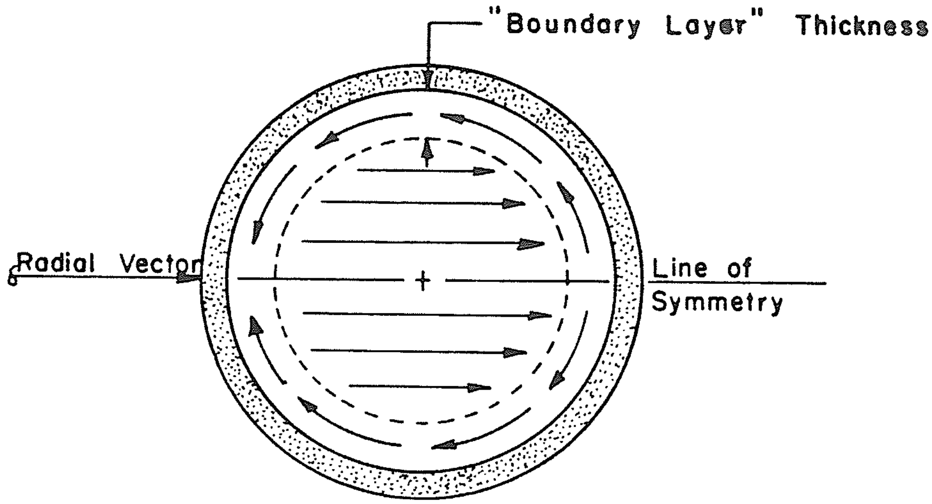


Figure 1.4: A Simplified Diagram of a Coiled Tube Secondary Flow Field

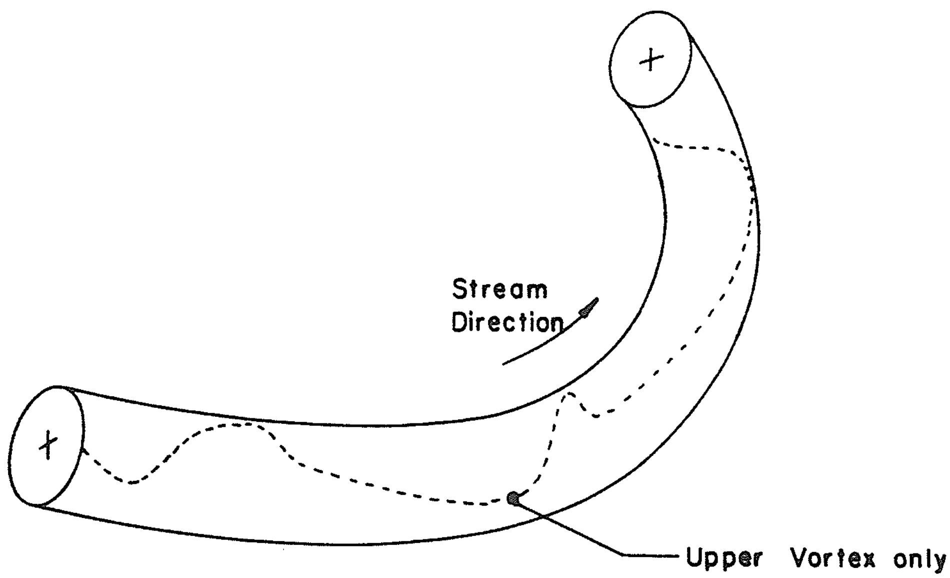


Figure 1.5: Three Dimensional Vortex Flow Filament

involved in each vortex do not cross the line of symmetry between the vortices. This phenomenon has also been noted by other researchers.

The noted line of symmetry may be modelled as a dipole vector as shown in Figure 1.6, and can be compared with previously encountered dipoles in straight tube convection. This observation immediately raises the possibility of superposition effects when heat transfer is involved in the flow inside helical tubes. For significant (Gr/Re^2) ratios it is foreseen that the secondary flow due to free convection may augment, retard, cancel, or reverse either the cross or axial core flow components of helical flow. Figure 1.7 illustrates these various effects for both vertical and horizontal axis helices, where the free convective component corresponds to the case of heating while the centrifugal component is always in the outward radial direction. The resultants of the superposition may cause unwanted flow disturbances in the case of the horizontal axis helix, but tend only to directionally rotate or shift the dipole vector in the vertical axis helix. From the two extremes above come further questions as to the intermediate effects when the helix axis direction is between the vertical and the horizontal, and the effect of the helix being top or bottom fed (vertical

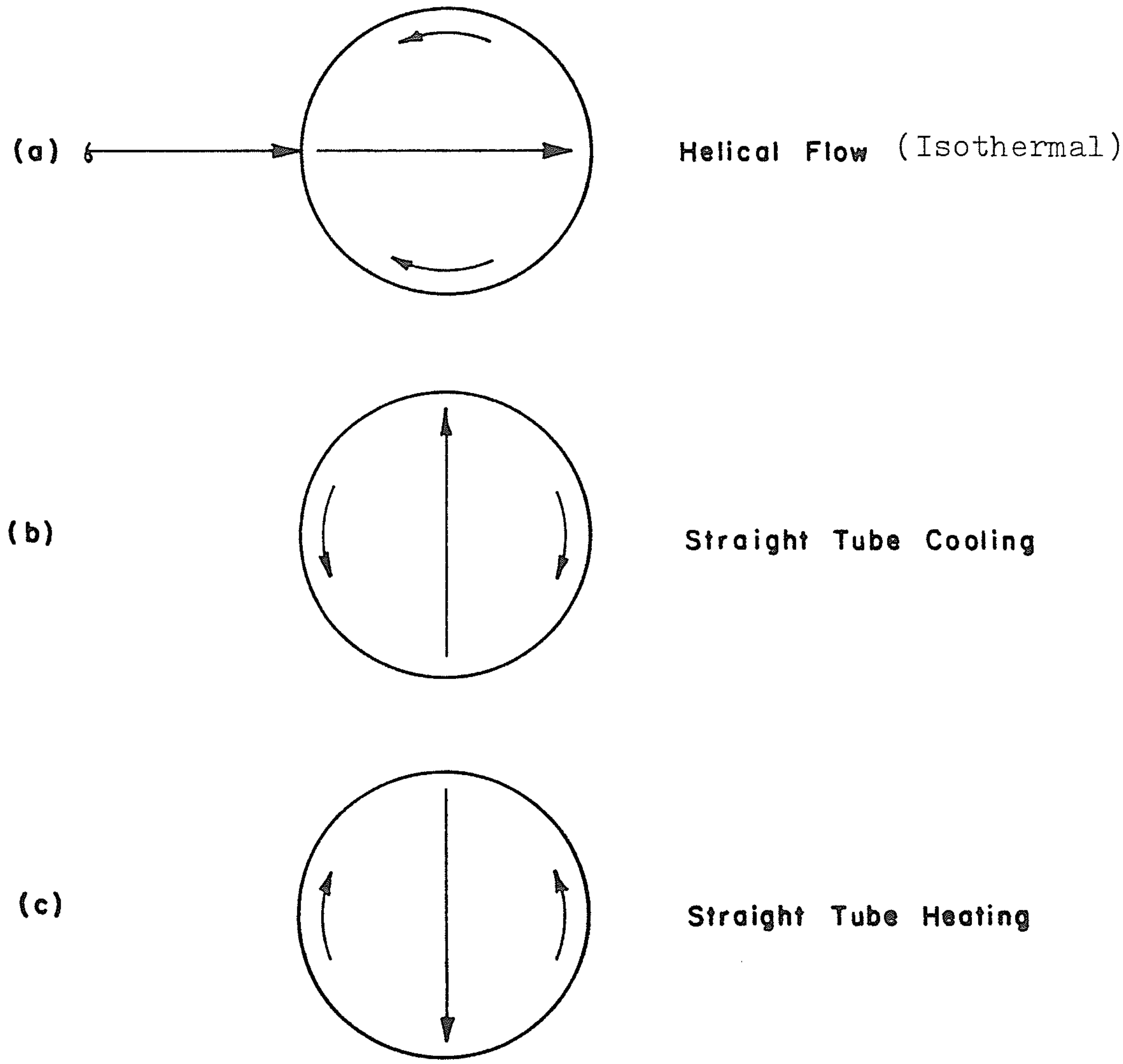


Figure 1.6: Examples of Secondary Flow Loops

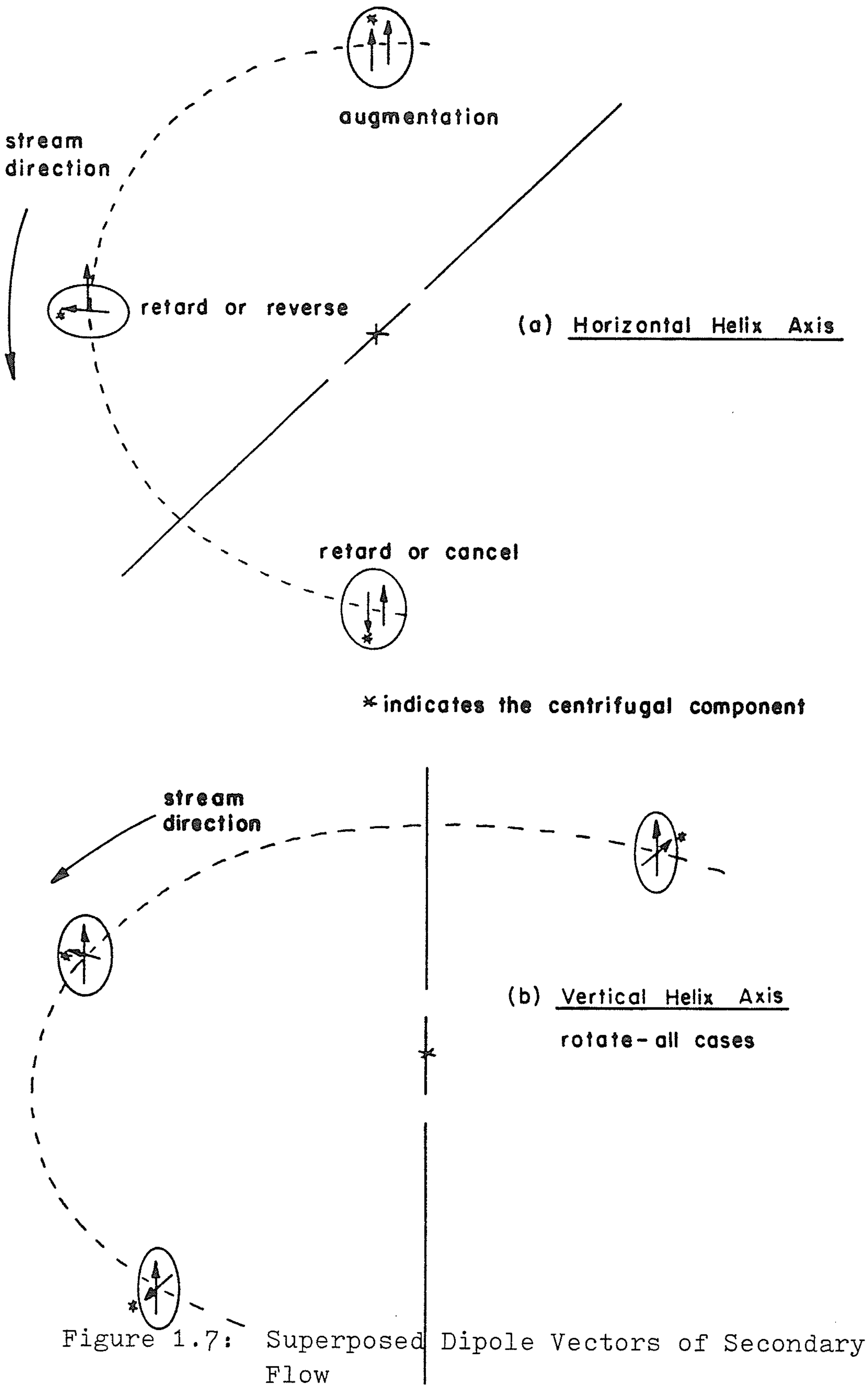


Figure 1.7: Superposed Dipole Vectors of Secondary Flow

upward axis or vertical downward axis). Also, the limit of effectivity of the (Gr/Re^2) ratio for the different helix orientations and flow directions is presently unknown.

1.3 Boundary Layer Concepts

Although the dipole model covers the fully developed flow, additional investigations are required to define the entry and exit regions of a helical geometry with respect to both geometric parameters. In a straight tube, the boundary layer grows from the tubewall to the tube centre over the entry or development length. This length is dependent on the Reynolds number associated with the flow and is influenced by the presence of heat transfer.

It is foreseen that the limitation on boundary layer thickness, as observed in a helical geometry, may vary with the diametral and pitch ratios. As $D/d \to \infty$ and/or $h/d \to \infty$, what is observed in a straight tube must be approached in a helix also. As in a straight tube, the Reynolds number in a helix is expected to affect the entry length. However, it may also affect the thickness of the boundary layer since a straight tube is defined as $Dn=0$, which may be simulated at low Reynolds numbers. The Dean number being $Re\sqrt{d/D}$ may therefore be inadequate as a correlation parameter for finite pitched helices. The exact relative effects between the two geometric parameters is still undetermined and can only be found by a comprehensive research effort in the area noted as Zone E of Figure 1.3. Inclusion of some form of the tube section chord angle may produce compatibility between circular and non-circular tube effects, but is considered an unnecessary complication at this early stage of research.

In addition, there is the relaminarization effect itself where flow in a straight tube at Re=5000 encounters a helical geometry of D/d=20 (critical Re=6000). In this instance the fully developed linear flow undergoes reversion as the twin vortices are generated. This author believes this to be due to the diversion of turbulent stream- wise energy and momentum into the secondary flow field, and the energy vector in a particular direction is reduced to a laminar magnitude. At the same time, the fully developed boundary layer is rolled back from the central stream axis to some limit based on the helix geometry and the bulk Reynolds number. The roll-back also occurs in laminar flow; and in both flow regimes some effect may exist upstream of the helix point of entry. Since the centrifugal force of the helical geometry does not maintain the vortices downstream of the coil, the vortices tend to damp out due to viscous drag, and their energy returns to augment the energy level in the primary flow direction. As this energy level accumulates past a critical point, flow begins to transide to turbulent form. The entry and exit lengths will be affected by the Reynolds and Prandtl numbers, as in a straight tube, with additional effects based on the relative significance of the Gr/Re ratio.

1.4 Heat Transfer

The Nusselt number has been shown to exceed both the constant flux (Neumann) and constant wall temperature (Dirichlet) values for a straight tube (experimentally) when encountering a helical geometry. Also, a peripheral variation in wall temperature is notable such that the point of the tubewall outermost with respect to the helix radius has the lowest temperature of the cross-section during an influx of heat, and the innermost point the highest. This phenomenon is a result of the secondary flow field as shown in Figure 1.4, with the cross- flow momentum causing a peripheral variation in the boundary layer thickness and a corresponding variation in the wall to fluid temperature gradient.

Overall, a unified analysis may reveal a widely variable continuum effect based on both geometric parameters and flow parameters. The special cases of the straight tube, the closely pitched helix, and the twisted tube provide the boundaries for such research.

1.5 Project Objective

The objective of this project is to investigate the effect of substantial coil pitch relative to that of the diametral ratio on the pressure drop and heat transfer characteristics of helically coiled tubes. For a particular diametral ratio, two test sections of significantly differing pitch were compared experimentally to confirm the effect of pitch change and to check the validity of the Dean number as a correlation parameter. This was repeated using two additional coils of a different diametral ratio, but with pitches identical to those of the first pair of helices. The two closely pitched helices are of diametral ratios 49 and 29. The test sections of significant pitch both have a pitch ratio of about 60. This allows for two comparisons at constant pitch ratio and two comparisons at constant diametral ratio. A fifth test coil of diametral ratio 4 and pitch ratio 61 was investigated isothermally only due to its length being insufficient for use with the equipment available.

Both the Neumann and the Dirichlet boundary conditions were investigated. The Dirichlet condition was applied using condensing steam at atmospheric pressure, whereas the Neumann condition was applied using tubewall resistance heating. Entry length and free convective effects are also considered.

Chapter 2

LITERATURE REVIEW

Helically coiled tubes, curved pipes, curved (open) channels, and pipe elbows have been the subjects of occasional experimental investigation beginning prior to the year 1900. Some work was published up to 1930, but most of the findings are relatively recent, dating from 1950 and thereafter.

2.1 Early Work

In 1910, Eustice [1] reported the results of his pressure drop experiments in coiled tubes and oval-section straight tubes. He noted that coiled tubes exhibited a greater pressure drop per unit length than did straight tubes, for the same flow rate and cross-sectional area. He also noted that over the straight tube laminar flow range, there appeared to be no laminar-turbulent transition in coiled tubes, whereas straight tubes exhibited a marked change as they began to transide toward turbulent flow. The results of his flow visualization experiments [2] were published the following year, and detailed diagrammatically the individual paths of coloured tracers in various sizes of curved glass tubes and sharp elbows. His results showed that a dye filament split into a number of sub-filaments during axi-tangential flow near the tubewall, and tended to reform into a single filament as the tracer re-entered the region of axial cross-flow.

Later, Dean [3],[4] produced perturbation analyses for a toroidally coiled pipe of large (D/d), but noted that the theory was quantitatively good only for $Re\sqrt{d/D} < 38$ when compared with the data of Eustice [1]. In addition, he did note that fc/fs (friction factor ratio: coiled to straight) appeared to be dependent on $Re\sqrt{d/D}$.

In 1929, White [5] tested curved pipes of D/d= 15, 50, and 2050 using oil up to Re=500 and water thereafter, with laminar flow in each test section. He noted that the resultant graph of fc/fs correlated very well with $Re\sqrt{d/D}$, which he termed Dean's number, and that:

$$fc/fs = \left\{1 - \left[1 - (11.6/Dn)^{.45} \right]^{1/.45} \right\}^{-1} \qquad (2.1)$$

where the Dean no. is given by $Dn = Re\sqrt{d/D}$ with

Reynolds no. $Re = ud/\nu$

friction factor (straight) $fs = 16/Re$

friction factor (coiled) $= fc$

Taylor [6] confirmed the correlation parameter in 1929 and experimented with flow visualization using glass helices. He noted that a turbulent entry flow relaminarized in the first turn of the coil for D/d of 18.7, and in the course of the second turn for D/d of 31.9.

Overall, the early coiled/curved tube work consistently refers to curvature in the two dimensional sense without noting any dimensional distinction. This means that it may have been acknowledged that the close pitched experiments represented three dimensional curvature, due to the minimal pitch, but this acknowledgement was never stated. The term "curvature" was always used, but without being fully defined.

2.2 Recent Experimental Studies

2.2.1 Flow Visualization

In 1964, Koutsky and Adler [7] published coiled tube data based on visualization studies directed at minimizing axial dispersion for chemical reactors. Their tests covered twenty-one coils with $6.5<(D/d)<16.8$ for both laminar and turbulent flow regimes, using flexible tubing in a tube ellipticity range of 1.094 to 2.74. The results included a good correlation for axial dispersion and nomographs relating pressure drop to dispersion for straight tubes, coiled tubes, and packed beds. Also noted is that coiled tube dispersion approximated that of straight tubes at Reynolds numbers below 300, and that increasing ellipticity produced a significant upward shift in the friction factor ratio curve. The final note was that for equal axial dispersion, the coiled tube required only about a fifth of the power consumption required by a straight tube.

In 1984, Cheng and Yuen [8] presented photographic sequences of the secondary flow field dispersement downstream of an isothermal 180 degree tube bend of D/d=10, in comparison with Dirichlet applied free convection in a horizontal straight tube. The photographs verify similar dipole effects in the secondary flow field for a curvature vector at exit consistent with the direction of buoyancy, as compared to the straight tube, under the common flow range of $100<Re<1800$. Also, for Dean numbers around 100, an extra pair of vortices appeared to be generated as part of the dispersement process, although both pairs are nearly always damped out about 50 diameters downstream of the bend exit. They do not, however, mention whether or not the flow is fully developed at the bend exit with respect to the different flow rates tested, or that the dipoles are opposite in direction (a minor point).

2.2.2 Pressure Drop During Isothermal Flow

In 1959, Ito [9] produced data for curved pipes of D/d= 648, 250, 100, 40, and 16.4 from a low Reynolds number of approximately 1500 upward through transition to turbulent flows of Reynolds number 100,000. The data was presented in various graphical formats, notably fc vs. Re and fc/fs vs. Dn for the laminar and transition regimes, and became more complex for fully turbulent flows. The results were compared with the data of White [5] and showed White's empirical formula to be in good agreement with the laminar flow data. An interesting note was that the point of transition was substantially delayed for an undisturbed flow at the inlet beyond that of a disturbed flow at the inlet, but that the fully developed turbulent friction factors were the same. Ito also produced a criterion for transition (critical) Reynolds number in curved pipes, in the form:

$$Re(crit)=20,000(d/D)^{.32} \qquad (2.2)$$

However, beyond (D/d) of 860 the critical Reynolds number coincided with that of a straight tube. Again, the term curvature was used liberally without dimensional distinction since only close pitched curved pipes were considered. Also, it is apparent that only one complete coil turn was tested for each (D/d), although no specific lengths of coil were mentioned. The entry length was considered briefly and without any detail.

In 1979, Mishra and Gupta [10],[11] collected data for laminar and turbulents flow of water and water-glycerol mixtures in sixty coils covering the ranges of $6.7<(D/d)<333$, $0<(h/d)<300$, and $150<Re<20{,}000$. A preliminary correlation for friction factor ratio for close pitch data only was obtained, but was shown to be very close to that of White [5]. Also, neither formula accounted for substantial pitch unless the coil diameter was replaced by the diameter of curvature, effectively modifying the Dean number to:

$$Dn^* = Re[(D/d)\{1+[(h/d)(1/\pi)(d/D)]^2\}]^{-1/2} \qquad (2.3)$$

This modification was first postulated in 1970 by Truesdell and Adler [26] (reviewed in 2.3.1), but had never been verified experimentally. Mishra and Gupta [10] proposed the following empirical equation:

$$(fc/fs-1) = .033(\log Dn^*)^4 \qquad (2.4)$$

This correlation agreed well with their experimental data for high and low pitch with a standard deviation of 5% and an overall deviation of ± 15%. Substitution of the modified Dean number into White's equation by this author also produced as good a correlation for high and low pitch in comparison with the correlation of Mishra and Gupta. It is noted by the present author that Mishra and Gupta 's data scatter is minimal for the glycerine-water mixtures, but somewhat larger (+10% to-20% and mostly low) for water. In producing their correlation, however, Mishra and Gupta plotted (fc/fs -1) versus Dn* on a log-log scale. In approaching a straight tube case (fc/fs=1) the ordinate becomes zero which is not plottable on log scales thus enhancing scatter of data for the low flow rates. Mishra and Gupta themselves noted that as the Reynolds number is reduced below 300 the Hagen-Poiseuille line was approached for coiled tube flow. A plot of transition Reynolds number (observed) as a function of curvature was also provided in comparison with the modified form of the equation of Ito [9], using the three dimensional sense of curvature included in Dn*. The experimental data for the covered combinations of pitch ratio and diametral ratio agreed to within ± 20% with the modified equation.

2.2.3 Heat Transfer with the Neumann Boundary Condition

In 1963, Seban and McLaughlin [12] published heat transfer and friction factor results for laminar oil flow and turbulent water flow in coils of D/d= 17 and 104. Both coils were fabricated from approximately the same length of number 321 stainless steel with the large coil consisting of one turn and the small coil of 6.5 turns. No mention was made of coil-axis orientations, except that a figure appeared to indicate a horizontal axis for the small coil and a vertical axis for the large coil. Alternating current resistance heating was employed through both the coils and their tangential entry/exit lengths of 10 to 20 tube diameters. Wall thermocouples were mounted on a seperative surface layer of mylar tape on the outer tubewall. The fluid properties were evaluated at the mean film temperature, and local film coefficients evaluated peripherally and axially using the analytical solution for uniform heat generation in a hollow externally insulated cylinder. They noted that the larger coil produced more scattered laminar friction factor data than the smaller coil, with the smaller coil consistently about 8% low with respect to the correlation of White [5]. Both isothermal and non-isothermal friction factors were shown to approach the Hagen-Poiseuille line simultaneously for Reynolds numbers below 200. This is to be expected for high Prandtl number fluids which are more resistant to free convective viscosity effects. Low Prandtl number fluids, however, would be expected to exhibit a higher friction factor when heated at low Reynolds numbers. Heat transfer results showed that the Nusselt number on the radially outer coil surface was higher than that of the radially inner coil surface, and that both values substantially exceeded those known for a straight tube. A correlation for the fully developed Nusselt number was produced as:

$$Nu = .13 \left\{ (fc/8)\ Re^2 Pr \right\}^{1/3} \qquad (2.5)$$

This correlation uses peripheral averaging and the asymptotic, fully developed Nusselt number based on the Leveque theory, but it was noted that the data scatter was markedly pronounced for the large coil compared to that of the small coil. They also noted that cyclic oscillations in the Nusselt number were apparent along the flow for some runs, but offered no explanation. In addition, the Dean was not used in conjunction with any of the results, since it was claimed that little or no effect of the coil diameter was observable, and that the tenuous theoretical application involved rendered the use of the diametral ratio as unjustifiable.

In 1965, Mori and Nakayama [13],[14] collected laminar and turbulent experimental data respectively in conjunction with a theoretical analysis of the hydrodynamic and thermal flow fields. A single turn horizontal axis coil of D/d= 40 and d= 35.6mm was heated via wire surface windings for a flow range of 1900<Re<6325 to provide corroborative data for the theoretical analysis, using air as the working fluid. In addition, the axial hydrodynamic and thermal profiles were presented from traverse data taken perpendicular to, and in the plane of the helix. The figures presented illustrated a velocity and temperature peak just outside what appeared to be the boundary layer, near the radially outer tubewall, in the plane of the helix. However, a nearly flat temperature profile was apparent from the traverse perpendicular to the helical plane. In both velocity and temperature profiles, there was a substantial portion "missing" from the shape of the axial profile in comparison to the paraboloids of revolution found in laminar straight tube flow. No experimental correlation was offered, however, the concept of treating an axi- tangential boundary layer seperately from the core region of axial cross flow was postulated and developed. No comparisons were made with data from other literature.

In 1971, Dravid et al.[15] studied heat transfer characteristics for laminar water flow in a coil of D/d= 20 for 358<Re<8944 as well as higher Prandtl number fluids, in conjunction with an analytical treatment of the development of the secondary flow field. The higher Prandtl number fluids were n-amyl acetate, n-butanol, n-amyl alcohol, and ethylene glycol. The tested copper coil was resistance wire wound with a straight unheated settling length of 50 tube diameters, and instrumented with thermocouples on the radially inner and outer coil surfaces. No pressure taps were used, and the inlet to outlet bulk temperature difference was maintained below 20 C. No mention was made of the coil axis orientation, but it was noted that the fluid properties were evaluated at the mean bulk temperature. Free convection and gravity effects were found to be negligible as were the tubewall temperature- pair differentials, although they attributed the latter due to the thick tubewall and non-uniform flux around the periphery of the tube section. The reported data showed a very short entry length for water, termed the Leveque region for comparison with the Leveque theory. The Nusselt number data proceeded to oscillate for the duration of the 560 diameter coil length (about 6 turns), and asymptotic Nusselt numbers were estimated for each run, although they give no reason for the estimate. A correlation was obtained from the estimated asymptotic

Nusselt numbers of the different flow rates of the five fluids tested, and presented as:

$$Nu=\left\{ .65\ Dn^{1/2} + .76 \right\} \quad Pr^{.175} \qquad (2.6)$$

They reported that the data agreed with eqn (2.6) within a maximum deviation of 14%, and a standard deviation of 6%. However, statistical analysis requires 99% of the data to fall within $\pm$ 2.96σ or, for this correlation, about $\pm$ 18%. They concluded by postulating the oscillatory phenomenon to be a result of a non-mixing core flow region and non-uniform convective propagation of energy.

In 1974, Singh and Bell [16] reported their heat transfer data for coils of D/d= 20.2 and 41.7, effected by direct current resistance heating. They tested water in a flow range of 700<Re<7600 and Dowtherm- G (100<Pr<200) in a flow range of 6<Re<2450. Both coils had vertical axes, were bottom-fed, and had approximately 200 tube diameters length, resulting in 1.6 and 3 turns. The internal diameter of the test sections was 12.6mm. No pressure drop data was reported and a Grashof number range of 241<Gr<922,000 was covered although no indication was given of how the fluid properties were evaluated. Selected stations were investigated using an eight point periphery, with consideration to entry length and free convective effects. The results of the peripheral examination showed that the radially inner/outer coil film coefficient differences were enhanced at high Reynolds numbers and relatively minor at low Reynolds numbers, as expected since low Reynolds number coiled tube flow phenomena must approach straight tube flow phenomena. However, it was noted that for low Reynolds numbers, the tube cross-section's bottom station had the highest film coefficient of the periphery, which indicated a free convective effect. This corresponds to a rotation of the secondary flow field dipole vector without entrance effects since the particular station was well beyond the entrance region at low Reynolds numbers. An eight point average of the peripheral film coefficients was used to evaluate the Nusselt number for an entry length comparable to published curves of Hausen and of Sieder- Tate for straight tubes. Using only Dowtherm-G data, the comparison indicated the previously noted oscillatory behaviour of the Nusselt number over the tube length. A correlation was obtained as a piece-wise product by consideration of data of minimal free convective effect seperately. The final form for the fully developed Nusselt number was:

$$Nu=\{.224+1.369(d/D)\}\{Re^{[.501+.318(d/D)]}\}\{1+4.8[1-$$

$$\exp(-.00946(Gr/Dn^2)(D/d))]\} Pr^{1/3}(\mu b/\mu w)^{.14} \quad (2.7)$$

The claimed agreement was an average absolute percentage deviation of about 12% for nearly 2000 data points. However, this could easily point to a data scatter of ± 20% since an average is typically weighted by the number of data points averaged. Also, it was claimed that the study corresponded to neither Neumann nor Dirichlet, but an intermediate, unspecified boundary condition due to the peripheral temperature gradient.

In 1978, Janssen and Hoogendoorn [17] reported their findings from laminar tests of four coils of D/d= 100, 62.5, 42, and 12 for water- glycerol mixtures in low flow ranges selected from 20<Re<4000. No mention was made of how fluid properties were evaluated or how the coils were oriented or fed. A film coefficient accuracy of 15% was noted and no friction factor data was taken. A correlation for local Nusselt number in the entry region was obtained to ± 20% as:

$$Nux=(.32+3(d/D))Re^{1/2}Pr^{1/3}(d/x)^{.14+.8(d/D)} \quad (2.8)$$

for 30<Pr<450, and for fully developed flows as:

$$Nu =.9(Re^2 Pr)^{1/6} \qquad 20<Dn<100 \quad (2.9)$$

$$Nu = .7Re^{.43} Pr^{1/6} (d/D)^{.07} \qquad 100<Dn<830 \qquad (2.10)$$

No error estimations were reported. They also conclude that the thermal entry length would be determined by a particular number of secondary flow circulations. However, they admit that this conclusion has no experimental support.

In 1979, Abul-Hamayel and Bell [18] presented results of a study of laminar water flow, and two other fluids of higher Prandtl number, for a coil with D/d= 20.2 in a flow range 30<Re<5500. Their coil consisted of 9.5 turns of number 304 stainless steel, resistance heated with a vertical coil axis, and fed at the bottom connection. The internal diameter of the tube was 12.6mm. The coil's pitch was h/d=1.4, the entry/exit lengths were unheated, and the fluid properties were evaluated at each station's local bulk temperature. The data was reduced using the method of Singh and Bell [16], but used only four peripheral points instead of eight. The analysis of the results proceeded similarly as Singh and Bell to obtain a fully developed Nusselt number correlation as:

$$Nu=\{4.36+2.84(Gr/Re^2)^{3.94}\}\{1+.0276Dn^{.75}Pr^{.197}\}\{1+ .9348(Gr/Dn^2)^{2.78}\exp(-1.33Gr/Dn^2)\}(\mu b/\mu w)^{.14} \qquad (2.11)$$

This correlation predicted the data with an average percentage deviation of about 9%, which may produce a total scatter of ±18%. An error ratio graph of their data showed that for the water data, the results were consistently zero to 15% lower than predicted for the laminar range. Also, other correlations tested using average absolute percentage deviation were found to be substantially different, the closest noted to have an average absolute percentage deviation of at least 11%, and none of the previous correlations approached the straight tube asymptotic value. They recommended further work to involve curvature ratios, horizontal helix orientation, and cooling rather than heating.

Also in 1979, Moshfeghian and Bell [19] reported the findings of experiments on four 180 degree tube bends for water, Dowtherm G, and ethylene glycol, in the flow range of $4<Re<27000$, with $D/d= 25.62$, 12.32, 7.66, and 4.84. While the results were not compared to helically coiled tube research, it was noted that the time delay in secondary flow field decay downstream of the bend produced enhanced heat transfer well beyond the exit of the tube bend. Two correlations for the decay of enhancement were developed, however, nothing was reported as to whether the bend exit flow was fully developed or not, and at what flow rates.

In 1983, Manafzadeh, Chow, and Simon [20] presented data for laminar air flow in a coil of diametral ratio 153, and for laminar water flow in a coil of diametral ratio 18.8 ($3800<Re<23,000$). The coils were preceded by straight, heated settling lengths, with the air coil axis mounted horizontally and the water coil axis mounted vertically. Fluid properties were evaluated at the local bulk temperatures. The local bulk temperatures were calculated based on the corresponding local wall temperature, heat flux, the bulk inlet temperature, and the local position. It was noted that the pitch ratio (h/d) was about 1.1, and that the investigation was primarily concerned with the entrance region and turbulent flow. Correlations were developed for the entry region oscillation wavelength, and for the Nusselt number in turbulent flow.

2.2.4 Heat Transfer with the Dirichlet Boundary Condition

In 1950, Berg and Bonilla [21] published the results of the (apparent) first heat transfer experiment for helically coiled tubes. They tested three coils of $D/d=17.21$, 6.08, and 5.3 with tube pitch ratios (h/d) of 3, 2.3, and 3 respectively, for laminar and turbulent flow.

The boundary condition was applied using atmospheric pressure steam, and the subsequent analysis involved use of the arithmetic mean temperature difference (AMTD) rather than the logarithmic mean temperature difference (LMTD). The fluid properties were evaluated at the average bulk temperature for the fluids (air, water, and an oil) that were tested. Correlations were attempted, however, it was noted that the average deviation for water was 20% and for air was 10%. No use was made of the Dean number, or the Reynolds and Prandtl numbers per-se.

In 1964, Rogers and Mayhew [22] presented results of experiments which utilized coils of D/d= 20.12 (4.5 turns), 13.3 (6.5 turns), and 10.8 (8.5 turns), with a pitch ratio (h/d) of about 4, for turbulent water flow. The coils were illustrated to have been horizontally mounted in a steam chest with a partially heated, 180 diameter tangential settling length which protruded from the coil point of incidence to the exterior of the steam chest. The flow range covered was $3000<Re<100{,}000$ for city water at mains temperature, and both friction factor and heat transfer data were analysed, with the fluid properties evaluated at both the mean bulk and mean film temperatures. The results presented agreed well with Ito [9] for the isothermal friction factors. The heat transfer results, evaluated via LMTD were about 10% low with respect to Seban and

McLaughlin [12] (Neumann boundary condition) and 10% to 20% high with respect to Kirpikov (not reviewed herein). It was noted that the validity of the mean film temperature under the Dirichlet boundary condition was tenuous, and a mean bulk based correlation for the overall average Nusselt number produced as:

$$Nu = .023 Re^{.85} Pr^{.4} (d/D)^{.1} \qquad (2.12)$$

In 1966, Kubair and Kuloor [23] reported results for horizontal axis coils of diametral ratios 27, 17.8, 13.5, and 10.3 of tight pitch with 7 to 12 turns for glycerol solutions in the flow range of $60<Re<5000$. In addition, results for two Archimedian (flat) spirals were presented, however, it is questionable as to whether fully developed flow is obtainable for a diametral ratio that changes with the axial distance from the inlet. In other words, the entire coil or spiral may be in developing flow. The fluid properties were evaluated at an unspecified bulk temperature for heat transfer coefficient calculation on an AMTD basis. A correlation was obtained for the overall Nusselt number as related to curvature and the Graetz number as:

$$Nu = [1.98 + 1.8(d/D)] Gz^{.7} \qquad (2.13)$$

They claimed an agreement of ± 5% average deviation. A graph presented indicated considerably wider scatter (± 16%) and included both helical coil and Archimedian spiral data. No mention or use was made of the Dean number.

In 1976, Oliver and Asghar [24] presented their results of tests for coils of D/d= 30.4, 26.6, 22.6, 20.1, 19.3, 15.1, 13.1, and 12.2, each at unspecified pitch with 3 to 4 turns. Two complete turns were fully insulated to allow for full development of the secondary flow field prior to heating in a constant temperature agitated water bath. Water and water-glycerol mixtures were used as a datum for tests of viscoelastic fluids, with a common flow range of approximately 25<Re<7000. Correlations were obtained for the overall Nusselt number as:

$$Nu=1.75Gz^{1/3}(1+.118Dn^{1/2})(\mu b/\mu w)^{.14} \qquad 60<Re<2000 \qquad (2.14)$$

$$Nu=1.75Gz^{1/3}(1+.360Dn^{1/4})(\mu b/\mu w)^{.14} \qquad 4<Re<60 \qquad (2.15)$$

The correlations were based upon the Graetz-Leveque solution for a straight tube, however, the curves illustrated with data suggest a scatter bandwidth of ± 20%. No distinction was made between the results for water and the results for the other Newtonian fluids. They did note, however, that both AMTD and LMTD calculated results were almost the same.

In 1978, Janssen and Hoogendoorn [17] collected Dirichlet boundary condition results in conjunction with their Neumann boundary condition investigation (reference section 2.2.3). For coils of diametral ratio 100, 41.6, and 15.4 they tested the same range of flow rates for the oils previously tested, by use of a steam jacket. Nusselt number results were produced using LMTD to an accuracy of $\pm$ 20% and were compared with:

$$Nu = (1/L) \int_0^L (\text{eqn } 2.8)\,dx \qquad (2.16)$$

They noted the comparison to be in reasonable agreement which enabled them to conclude that the choice of the two boundary conditions produced little difference with respect to the heat transfer results. However, at low Reynolds numbers they did not note that the difference should have increased toward the different asymptotic straight tube Nusselt numbers, which may have been a result of the $\pm$ 20% scatter bandwidth. Results were presented in support of the comparison, but showed distinct trends that were not parallel with the integrated correlation.

2.3 Analytical Studies

Curved passages have also been subjected to significant attention with respect to analytical and numerical treatments. These studies are covered briefly, by method, with additional depth as required. The tube section under study is to be taken as circular unless otherwise noted.

2.3.1 Perturbation

The perturbation method of Dean [3],[4] was utilized by Janssen and Hoogendoorn [17] in 1978, but it was concluded from experimental data that the method showed validity only for Dn<17 and that, in this regime, the effect of free convection was unseen.

2.3.2 Boundary Layer

In 1965 and 1966, Mori and Nakayama [13],[14],[25] presented an analysis based on seperating a boundary layer of axi-tangential flow from a core region of axial cross flow, with respect to velocity distributions used in the momentum and energy equations. Their second order approximation agreed well with their experimental heat transfer air data for $200<Dn<1000$. They also concluded that the analytical results for both Neumann and Dirichlet boundary conditions were indistinguishable, related to $Dn>200$ for experimental agreement. Their analysis, however, was criticized in 1971 by Dravid et al.[15] for integrating the energy equation over the hydrodynamic rather than the thermal boundary layer. This was noted to have produced an erroneous Prandtl number dependance.

2.3.3 Finite Difference

In 1970, Truesdell and Adler [26] solved the Navier-Stokes equations using a finite difference method employed in a toroidal (zero pitch) coordinate system. The results were within 20% of the White [5] correlation up to Dn=300, and they postulated a corrective substitution for finite pitch.

In 1971, Dravid et al.[15] solved the energy equation by an alternating-direction-implicit (ADI) finite difference method. The results were compared to the Graetz- Leveque straight tube solution, and reflected the axial oscillations in heat transfer that had been noted experimentally by themselves and others. Radial temperature profiles were also produced, but not compared with other published data.

In 1972, Patankar and Spalding [27] presented a procedure for calculation of heat, mass, and momentum transfer in three dimensional parabolic flows, which was later used in a numerical study on coiled pipes by Patankar, Pratap, and Spalding [28]. The method was applied using finite difference method, and the axial velocity profiles agreed well with most of the experimental traverses of Mori and Nakyama [13], but highlighted some significant discrepancies. Nusselt number results tended to agree with Dravid et al.[15].

In 1974, Collins and Dennis [29] solved the equations of viscous flow for steady motion in toroidal coordinates by finite difference, with friction factor results in good agreement with those of White [5] for $100<Dn<3000$. Secondary flow field contours were also presented, but not compared with the literature.

In 1975, Joseph, Smith, and Adler [30] repeated their group's previous work, but for a tube of square section. It was noted that at a low enough Dean number, the two contra- rotating vortices became four which was subsequently confirmed by flow visualization, and that the friction factor ratios agreed with White [5] only for $Dn<200$. Secondary flow field contour plots were also presented, but without comparison to the literature.

In 1979, Masliyah and Nandakumar [31] solved the

Navier-Stokes equations and the energy equation for zero pitch of coils of semi-circular cross-section, by a finite difference method, for Dn<300. Their results for Nusselt number and enhancement factor agreed with other numerical data.

In 1980, Manlapaz and Churchill [32] produced results of numerical studies which included finite pitch, and used the correlation of Mishra and Gupta [10], among others, as a basis of isothermal flow comparison. They introduced a correlation parameter (denoted the helical number) which was identical to the modified Dean number of Mishra and Gupta [10], which in turn used the finite pitch correction of Truesdell and Adler [26]. A new friction factor ratio correlation was presented and shown to agree well with the experimental data of White [5] and Ito [9] to within zero to 5%, and deviated up to -10% in comparison with Mishra and Gupta [10]. The new correlation intersected the equation of Mishra and Gupta [10] at fc/fs=6 and fc/fs=1.2, with the plot abcissa represented by the product of the modified Dean number with an algebraic relation including radius of curvature. Comparison was also made with the results of other numerical studies.

In 1981, Manlapaz and Churchill [33] extended their earlier work to heat transfer results of both Neumann and Dirichlet boundary conditions. For each boundary condition, in the ranges .1<Dn*<2000 and .005<Pr<1600, a graph of Nu vs. Dn* was produced and compared to data points of other research groups. For the Dirichlet boundary condition, five sets of points were compared, however, only the few points of Dravid et-al [15] and Mori and Nakayama [13] were experimental. These comparisons indicated the new correlation to be of the order of 10% low for a single water data point and over 15% low for a few air data points, in the range 200<Dn*<600. No other experimental data were compared under this boundary condition, although other numerical results over the total Dn* range tended to support the new correlation.

For the Neumann boundary condition, only the experimental data reviewed herein were compared. In this instance the air results are in very good agreement, but the prediction for water was up to 30% high while for some of the other test fluids of Dravid et al.[15], much worse and low. Again, the experimental comparison was limited, to the range 200<Dn*<2000 for this boundary condition, whereas the numerical comparison extended for .1<Dn*<10,000. The correlations are not reproduced here due to their cumbersome and over- complicated nature. Exclusive use of Dn* in their results did not allow conclusions to be drawn for the effect of significant pitch by itself.

Also in 1981, Murata et al.[34] presented a finite difference solution for isothermal flow in coils incorporating helix pitch in the original continuity and Navier-Stokes equations. It was noted that the analysis was for a vertical axis, bottom- fed helix, and the results were in the form of secondary flow field contour plots. The plots indicated that for large pitch angles, the location of the vortex centres shifted slightly as the dipole vector was rotated to become more aligned with the radius of curvature vector of the helix. No experimental data has been reported in the literature to verify either the phenomenon or its indicated magnitude.

Again in 1981, Prusa and Yao [35] reported numerical results of their zero pitch study involving free and forced convection, which indicated significant dipole rotation (45 degrees) for ReRa=500 and Dn=26. Their major result was a chart to indicate regions of applicability for forced, free+forced, and free convection domination. This showed for ReRa<20,000 that no free convection was significant for Dn>75. Zonal boundary equations were supplied for the range of investigation indicated.

2.3.4 Boundary Vorticity and ADI

Since 1971, Akiyama and Cheng [36],[37],[38] and

Akiyama et al.[39] have produced numerical results which utilized a boundary vorticity method, and ADI techniques. Their results appear to be limited to Dn<200 for both the developing and fully developed flow regimes of tubes of circular and rectangular cross-section. Results presented included polar plots of Nusselt number for the tube periphery, secondary flow field contours, and graphs of Nusselt number related to the Graetz number. Limited experimental results were compared, although some numerical comparisons were also made.

In 1972, Tarbell and Samuels [40] reported findings of an ADI study, but noted their friction factor ratio correlation to be limited to 20<Dn<500. Their Nusselt number correlations were also consistently low in comparison to other numerical studies; as much as 20% for low Prandtl numbers.

In 1979, Rabadi, Chow, and Simon [41] presented results of an ADI study (to increase algorithm efficiency) that had good numerical agreement, but were not compared experimentally. The flow range covered was 100<Dn<1300, for toroidal coordinates and Pr<5.

2.3.5 Secondary Stream Function with Vorticity

Since 1972, Kalb and Seader [42],[43], and Austin and

Seader [44] have presented their results which combined a stream function and vorticity in the secondary flow field, for $1<Dn<1000$. The Nusselt number results were in agreement with other numerical treatments, and also for experimental air data, but were significantly high for $Pr>1$. Axial velocity and thermal fields were illustrated using three dimensional surfaces under various conditions.

2.3.6 Boussinesq Approximation

In 1980, Chilukuri and Humphrey [45] produced results of their study on curved square ducts, which utilized the Boussinesq approximation to aid in studying the effects of buoyancy-induced recirculation. The duct modelled was a 90 degree bend at moderate Reynolds number and high Grashof number. They concluded that when buoyant forces were aligned with the secondary flow field's dipole, heat transfer was considerably enhanced.

In 1983 and 1985, Lee, Simon, and Chow [46],[47] produced nearly identical papers which reported the findings of a numerical study of curved tube buoyancy under the Boussinesq approximation. The results agreed in trend with other numerical studies, and represented an extension of the work by Prusa and Yao [35] by enlargement of the Dean-Grashof map of forced, free+forced, and free convection dominance regions. The new range was 0<Dn<150, 0<Gr<60,000 for toroidal coordinates, however, no boundary equations were provided for the region limits.

2.4 General Comments and Evaluation

With respect to the experimental heat transfer references reviewed [12] to [24], it is evident that many combinations of relevent parameters, for example Re, Pr, D/d, etcetera, have been investigated, and in different ways. Some researchers use distilled water for turbulent [12] or high Reynolds number tests only [16], [20] while others used mixtures [17], [22], or air [13]. The observed range of diametral ratio was 5.3<(D/d)<104 with tube pitches h<5d (where mentioned), except [10] which covered h>5d in a purely isothermal investigation. Most investigators declined to mention the helix orientation, feed direction, or how the entry length was attached [12] to [15], [17], [19], [21] to [24]. Some researchers heated the straight entry length in whole or in part [12], [22], while one research group allowed two coil turns to fully develop the secondary flow field prior to heating [24]. Most investigators make mention of how the fluid properties were evaluated, whereas a few do not [13], [16], [17], and the results produced generally fit correlations in bandwidths of $\pm$ 16% to $\pm$ 20%.

For the Neumann boundary condition, the Dean number is the most widely accepted correlation parameter although only one Nusselt number correlation reduces to the forced convective value of 4.36 for flows and/or geometries approaching the straight tube limit. For the Dirichlet boundary condition, it appears that the accepted parameter is the Graetz number with the Nusselt number based on either AMTD or LMTD. The Graetz number has also been utilized for analysis of the Neumann boundary condition, however, it has not appeared in the associated correlations.

Probably the most important point in respect of the experimental heat transfer investigations is that no research group has (yet) undertaken experimental work with high pitched helices. Also, no previous researchers have evolved the concept of the geometric continuum map postulated herein (Figure 1.3).

In terms of the analytical/numerical references reviewed [25] to [47], only [32], [33], and [34] include the effect of pitch. All others assume toroidal coordinates, with [26] suggesting a correction factor for finite pitch coils. The inclusion of many of the nonexperimental work reviewed herein is for the sole purpose of completeness of subject material, to emphasize some interesting results at the conceptual level, and to identify relevant correlating parameters.

An additional note is that a number of correlations, whether experimental or analytical, utilize ratios with respect to straight tube phenomena. For example, use of the friction factor ratio fc/fs where fs=16/Re (or 64/Re) or the Nusselt number ratio Nuc/Nus where Nus=4.36 (Neumann) or 3.66 (Dirichlet) is quite common---especially in numerical work. These ratios are somewhat tenuous for coiled tube flow of Re=5000 (for example: laminar for D/d<70) when fs and Nus are laminar based, yet at this Reynolds number the straight tube flow should clearly not be laminar.

Chapter 3

EXPERIMENTAL INVESTIGATION

The flow parameters in this investigation cover the laminar range from $Dn = Re\sqrt{d/D} = 20$ to the particular test section's calculated point of transition. The working fluid is distilled water, $3 < Pr < 6$, with a bulk inlet temperature of 40°C, or 20°C, and a bulk temperature rise of up to 20°C, dependent on the flowrate and the heat input.

3.1 System Design

An experimental system in the free convection lab of the University of Manitoba engineering complex has been modified to accommodate the objectives of this project by running helical coil test sections in a circuit parallel to the existing internally finned tubes experiment. Instrumentation readouts were shared as only one of the two experiments was in operation at a particular time. Figure 3.1 illustrates the shared portion of the experimental system, with both the closed circuit working

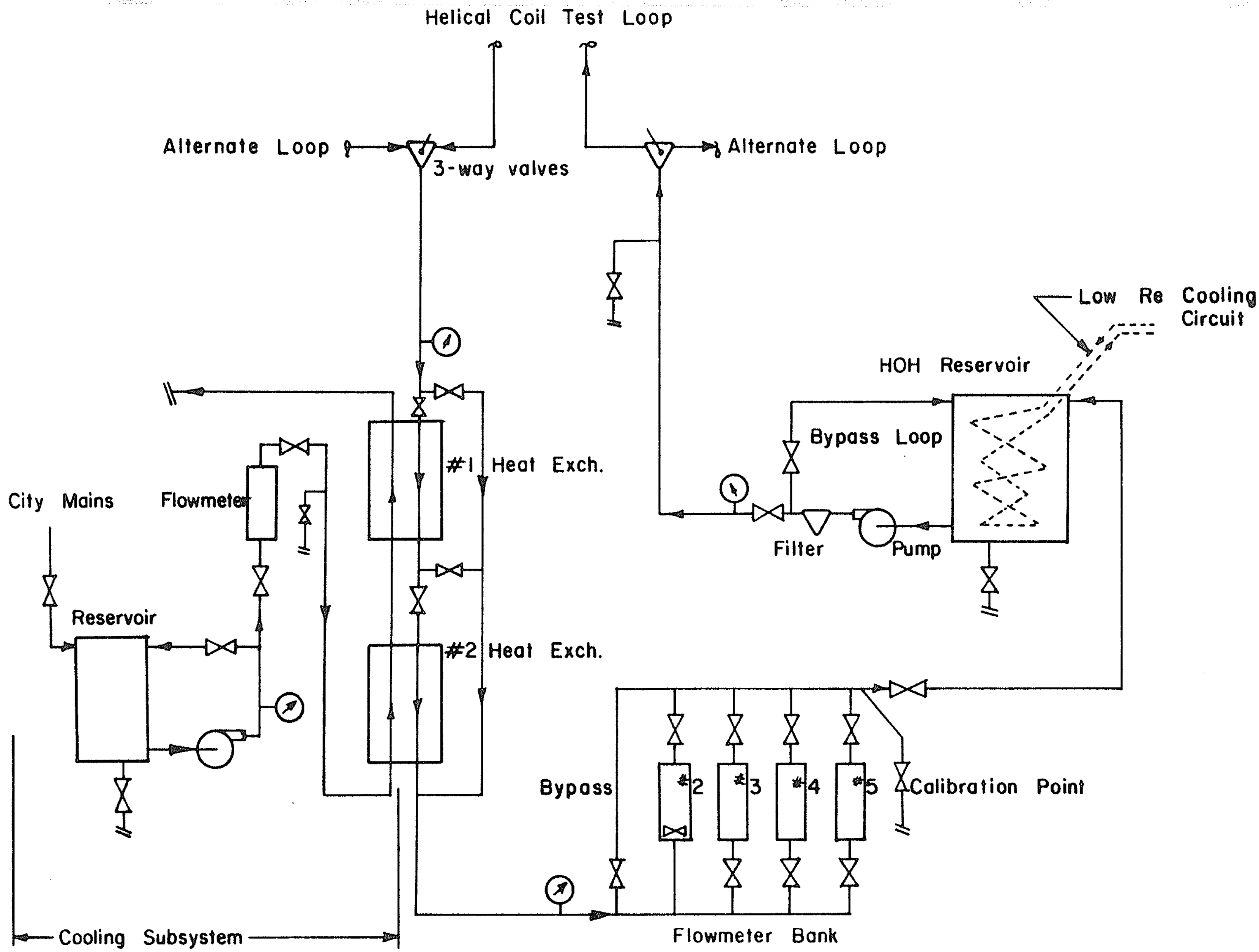


Figure 3.1: Peripheral System

fluid loop, and the open circuit cooling loop.

3.2 Test Fluid and Cooling Loops

The cooling loop provides a sink to remove heat gained by the working fluid passing through the test section connected to the test fluid circuit. A tap-fed reservoir of city water was pumped through a flowmeter, followed by two double-pipe heat exchangers before being discharged to a drain. The flow rate was controlled by two gate valves such that the flow in excess of that required for adequate cooling returns to the reservoir.

The working fluid circuit consists of an insulated reservoir of distilled water which was circulated by a centrifugal pump through a filter to the test section circuit. Choice of test section circuits was provided by two three-way ball valves, one in each of the working fluid supply and return lines. The working fluid returns via one or two flow controlled double-pipe heat exchangers and a flowmeter bank to the main reservoir, closing the circuit. Both the heat exchangers and the flowmeters may be bypassed completely, and all piping was fully insulated excepting flowmeters and line pressure gauges. All flowmeters were calibrated in-situ by timing a volume flow for the graduated markings given, and measuring the fluid temperature. The flowmeters used were calibrated at 8.3, 4.2, 17.9, 62.5 grams/second of distilled water. The flow rate to the test sections was controlled by two gate valves such that excess fluid flow was returned to the reservoir by way of a bypass line. The test fluid system was capable of providing flow rates corresponding to Reynolds numbers in excess of 12,000 for a 13 mm i.d. straight tube which was more than adequate for the present project. A note from previous research in this facility was the lower flow limit of Re=325, beyond which system pressure fluctuations negated steady flow throughout the working fluid circuit. However, installation of low capacity flow meters with integral needle valves has since eliminated this limitation when using the procedure described herein. Both the working fluid and cooling circuits were filled by pumping continuously from their respective reservoirs and drained from the noted points in Figure 3.1.

3.3 Test System

The helical coil test system, as shown in Figure 3.2, has been designed to allow for an "open-ended" versatility in that a wide range of test coil geometries can be

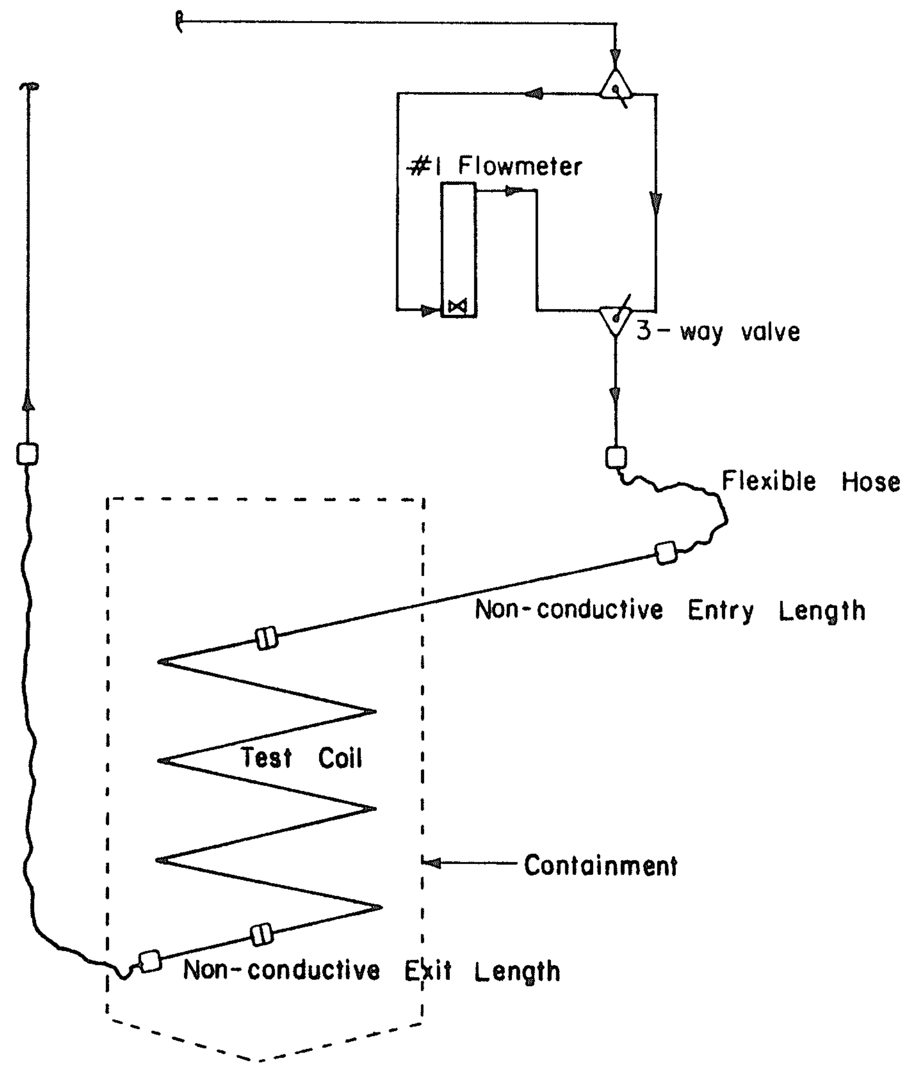


Figure 3.2: Helical Coils Test Loop

accommodated using an exacting standard.

The distilled water was supplied through a flexible plastic hose to a rigid plastic hydrodynamic entry length of the same inner diameter as the coiled tube, prior to entering the test coil. At the coil exit, the water passed through a shorter version of the entry length, followed by another flexible hose prior to entering the system return lines. The flexible hoses allow for the different angles of the entry and exit lengths due to variations in test coil geometry, and the entry/exit lengths conform to a zero degree angle of incidence requirement at connection to the test section. The test coil, exit length, and part of the entry length were mounted within a dual purpose insulated canister designed to accommodate the noted variations in coil geometry while providing a receptacle for atmospheric steam and, alternatively, a safe containment for substantial levels of resistance heating current as required. All piping, hosing, and the entry/exit lengths were fully insulated. The test coils were insulated during the Neumann boundary condition tests only.

3.3.1 Entry/Exit Lengths and Coil Connections

Due to the use of tubewall resistance heating, nonconductive entry and exit lengths were used to connect with the test coil via brass fluid fittings. The electrical connections to the coils were automotive battery cables and brass lugs mounted on the brass connector fittings using an extra nut provided with each of the fluid fittings. The entry and exit lengths were about 160 tube diameters and 60 tube diameters respectively, and connected after insertion into the particular coil end fittings. The connecting surfaces were sealed against the coil end using a film of silicon sealant. The entry length was used as a hydrodynamic settling length after measuring the inlet bulk temperature. The exit length was similarly instrumented, but of a shorter length since hydrodynamic settling is not necessary downstream of the test coil. A mixing cup was considered unnecessary downstream of the coil since the secondary flow would provide adequate mixing as it encountered a thermocouple probe inserted into the main flow stream. A pair of brass fluid fittings were silver-soldered to each test coil and remained with that coil thereafter. The fluid fittings were reamed to provide good concentricity between the coil and entry/exit lengths; and approximately three tube inner diameters of the coil protruded into the fitting at the time of soldering. This allowed the coil end to sit radially beneath the electrical lugs. Extreme care was exercised to ensure that connection of the entry and exit lengths to any test coil maintains a zero degree angle of incidence in space (colinearity) as indicated in Figure 3.3. This removed any possibility of adverse entry effects prior to the flow encountering the helical coil, except those forced upstream by the coil geometry itself.

3.3.2 Housing/Mounting Chamber

The test coil assembly was mounted inside a dual purpose insulated chamber, accommodating as wide a variety of coil geometries as possible while remaining handleable for in-situ servicing and dis-assembly. The chamber had three axial flange-connected sections with an instrumented flat lid. As shown in Figure 3.4, all sections need not be used at once unless the test coil geometry demands it. Design considerations also allowed for twenty flange bolt positions so that the access slots in the chamber sections' walls need not always be aligned. Different entry to exit length angles (in the plane of the helix) may therefore be accepted by assembling the canister sections after rotating them to suit the intended test coil. The lid of the chamber is flat and carries instrumentation as outlined in Appendix A. The overall unit is mounted on a stand for steam trap clearance, was externally insulated

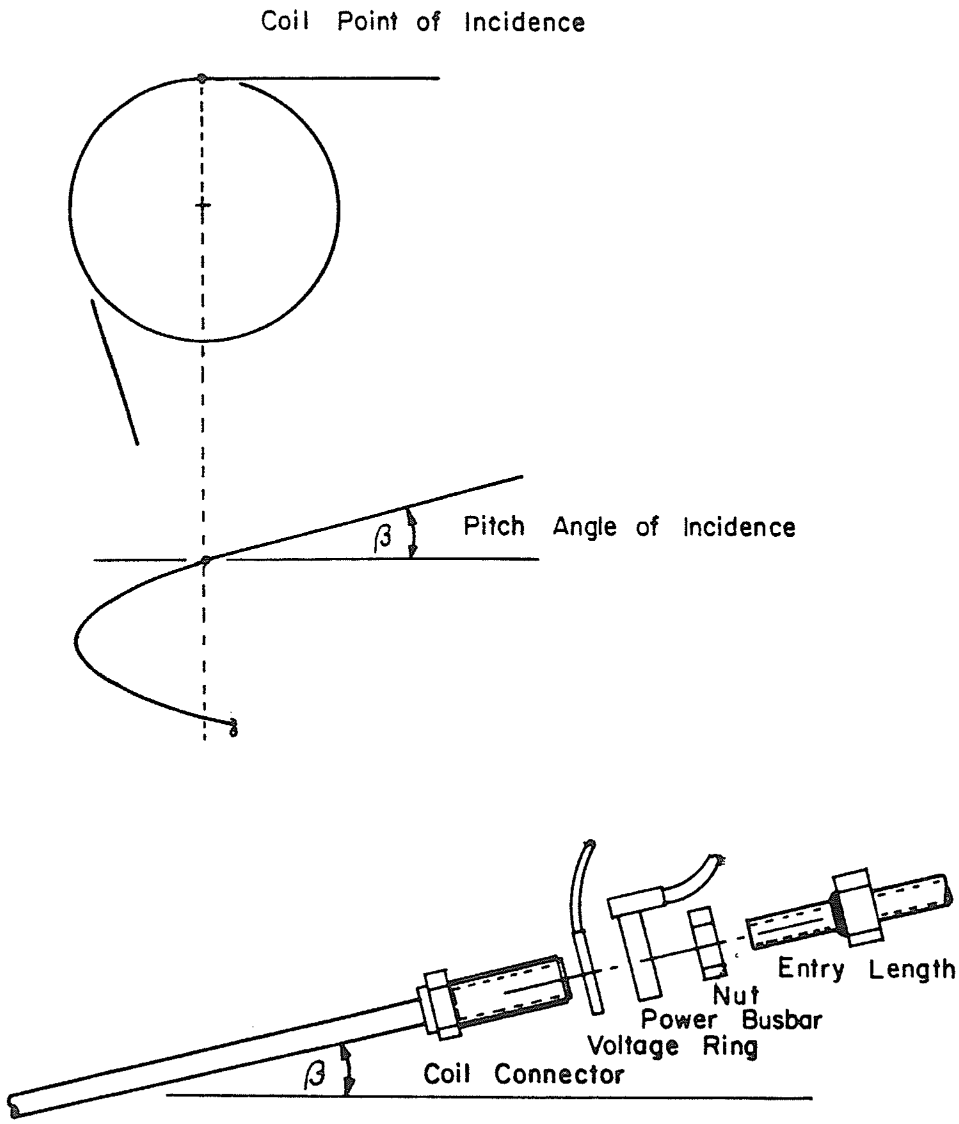


Figure 3.3: Coil Connection Details

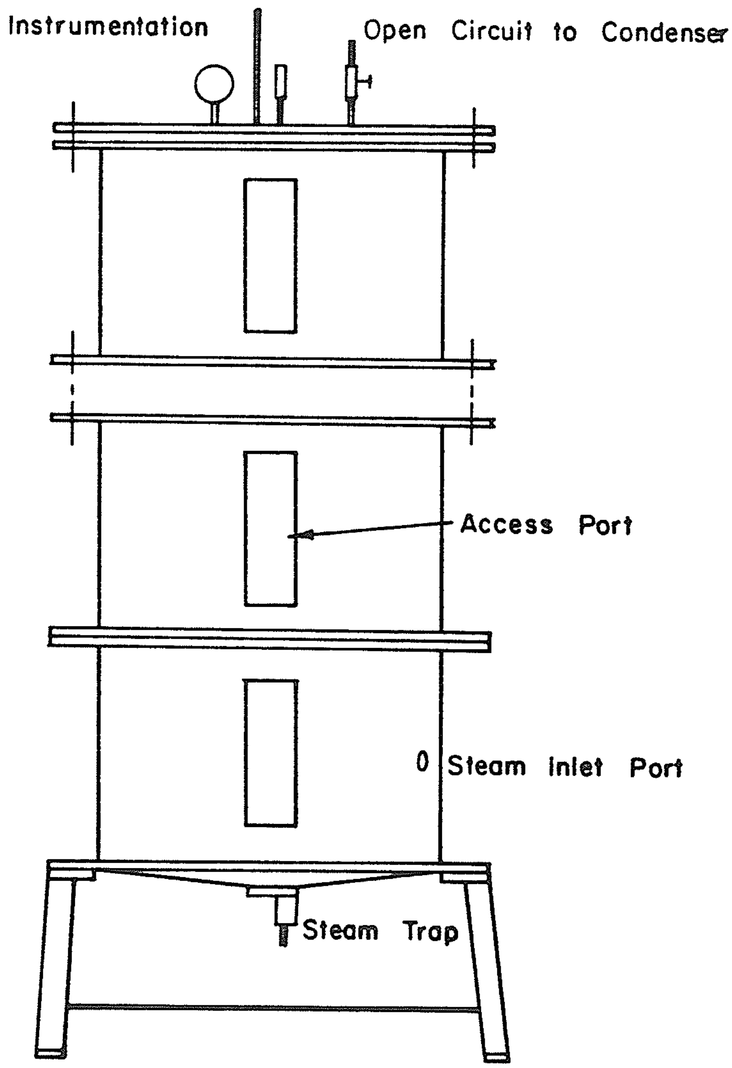


Figure 3.4: Steam Environment Chamber

for the Dirichlet boundary condition, and internally instrumented with wall mounted copper-constantan thermocouples. The instrumentation was identically mounted for interchangeability of positions as required. The sidewall access slots were closed off after installation of the test section and entry/exit length connections such that no steam leakage occurred (Dirichlet boundary condition only).

3.3.3 Coil Support

Whether the coiled tube was prior insulated (Neumann condition) or not (Dirichlet condition), the test section was mounted using a vertical rod and laboratory-standard adjustable finger-clamps, as shown in Figure 3.5. This system allows for any tube geometry since it is a building block concept in frame construction. The rod fits into holding cups at the top and bottom of the mounting canister. The top cup was welded to the underside of the canister lid while the bottom cup was tripod mounted to allow for proper condensate drainage when needed. The support rod itself is sectioned to allow for use of one, two, or three canister sections as necessary.

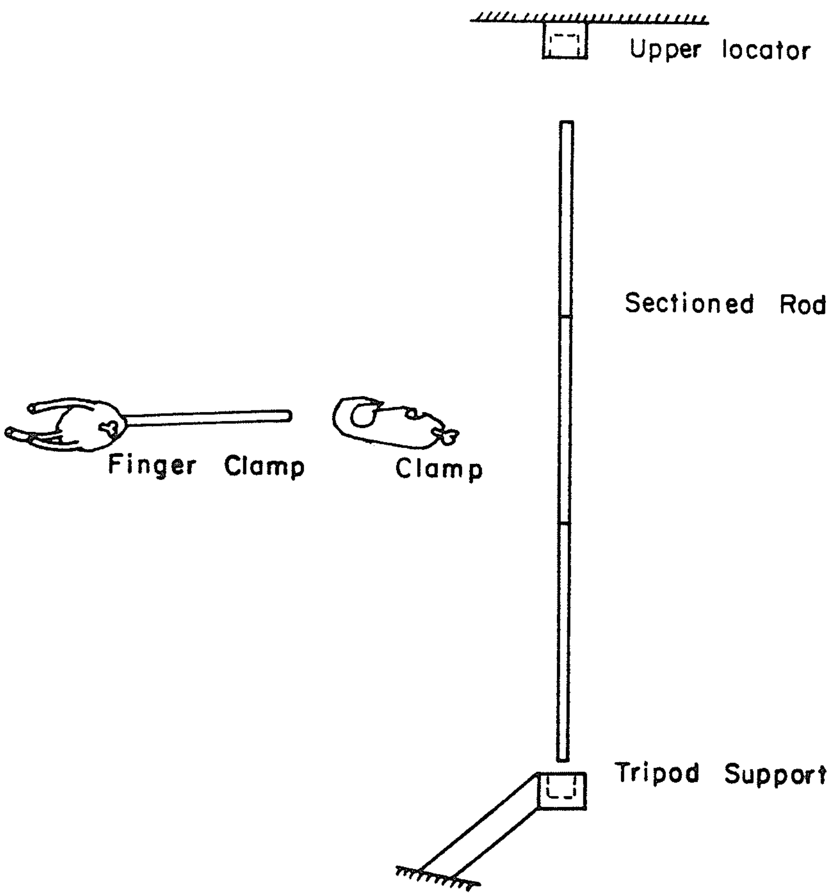


Figure 3.5: Coil Support System

3.3.4 Boundary Condition Equipment

The Neumann boundary condition was applied using direct current heating between the coil end fittings by use of a Hewlett-Packard Harrison 6260A dc power supply (0-10V, 0- 100A) and automotive battery cables. The Dirichlet boundary condition was applied by use of atmospheric steam delivered to the housing canister through a sidewall fitting. A small 3 kW electric steam generator delivered steam in an open circuit with a downstream valve set to allow only excess steam out of the canister.

3.4 Coil Manufacture

Test coils were manufactured from 6.35 mm O.D. x .889 mm wall thickness, circular section #304 stainless steel tubing. To preserve cross-sectional shape, 25 mm of one end of the length to be wound was crimped shut by use of a vise, and the tube was filled from the open end with a fine grain sand. After shock compacting and topping off with additional sand, the open end was also vise-crimped shut. It should be noted that the length to be wound included an extra 150 mm to 300 mm to account for end crimping, and short end lengths which could not wind into shape properly due to mandrel and winding tool attachment. The tube length may be wound either mechanically by lathe, or manually by hand. The manual method is preferred due to the minimal set-up and winding time, and also since there is no limitation on the size of the mandrel or the space required to perform the winding process. In either method, mechanical spring- back of the tube must be accounted for by undersizing the mandrel, allowing the coil to spring back to the desired size and shape upon release.

The simplest method of winding a coil to a specific pitch is to draw the winding path as straight lines at pitch angle, β, on a flat sheet of paper and to wrap the sheet directly on the mandrel. This works well for the manual winding method where one end of the prepared tube length is securely clamped to the end of the mandrel and the tube wound on the lines drawn, under a slight tension. At the same time, the mandrel may be rotated in the opposite direction. It is of the utmost importance to keep the tube in tension at all times during winding since a release of tension will initiate premature springback. To obtain a result within 3 to 5 tube diameters of the desired geometry, the pitch angle is drawn undersized to .8 h/d and the mandrel itself undersized to .85 D/d. For close pitched helices the underdrawn pitch angle is not critical.

However, the springback phenomenon is essentially a rotation in the plane of the helix (refer to Figure 1.1) and its error increases significantly with pitch. Dependent on the tube diameter and wall thickness, the wound product may be malleable enough to allow correction of small errors by hand. It is not recommended to attempt modification of major errors under any circumstances since this may result in significant distortion of the coil geometry or the tube cross-section.

After winding, the tube end lengths not conforming to the desired coil geometry were cut off, and the compacted sand removed by tapping the coil while rotating it about its axis. The cut coil ends were filed square to the tube centreline at the respective ends, and deburred without scarring the inner surface of the tube. The coil electrical resistance was measured prior to attachment of brass fluid connector fittings by passing a one ampere direct current through the tubewall and measuring the voltage drop across the coil. The coil and tube size were measured at the ends, and its diameter and pitch in four locations chosen at random. The described method of coil manufacture has been determined by test trials associated with the present project and may be applied successfully under similar conditions. Samples were wound manually on different mandrels to determine springback and subsequently cut down to check for distortion of the tube bore. The final four test coils were manually wound in a twenty minute concerted effort by three people. While this method has only been applied to tubes of circular cross- section, ovoid and rectanguloid sections of similar size and wall thickness are expected to be equally successful.

3.5 Instrumentation

Heat transfer and pressure drop data were obtained using thermocouples and static pressure taps attached to the test coils. The static pressure tap holes which access the fluid flow were .635 mm to .762 mm in diameter to allow proper pressure measurement from the 6.35 mm O.D. x .889 mm wall thickness tube. The holes were electrically discharge machined using a brass wire electrode approximately .695 mm diameter by 25 mm long. This ensured that no burring would occur on the hole edges inside the tube coil and negated the necessity of de-burring which was difficult for this application. Drilling of the pressure tap holes is not recommended due to the production of internal burrs and the possibility of breaking numerous drill bits. Sample holes were machined and inspected to confirm that no internal burrs were produced.

The tap holes were electrically discharge machined before installation of the tap tubes, as illustrated in Figure 3.6. To avoid tap hole blockage during silver-soldering, the holes were temporarily filled using a composite clay known as a high-fire body. This material is stable to approximately 1280°C (cone #9 on the ceramic pyrometry scale). The composition of the clay used in this project and details of the pyrometry scale are provided in Appendix B. Tests showed that silver-solder would not flow over the ceramic surface during tap tube attachment. After the pressure tap tubes were soldered in place, the ceramic was chipped out of the hole using the prior noted brass electrode wire, and the debris was flushed clear of the coil. Placement of the tap tube was attempted prior to tap hole machining during a preliminary test, but required an excessive electrode length. The electrode buckled as a slender column and arced against the tap tube wall creating a hole in the tap tube. Each pressure tap station was connected via 3.2 mm bore tygon plastic tubing to a valve-selective multi-port manifold. The manifold allows various combinations of pressure taps to be accessed for measurement of pressure differentials, with appropriate

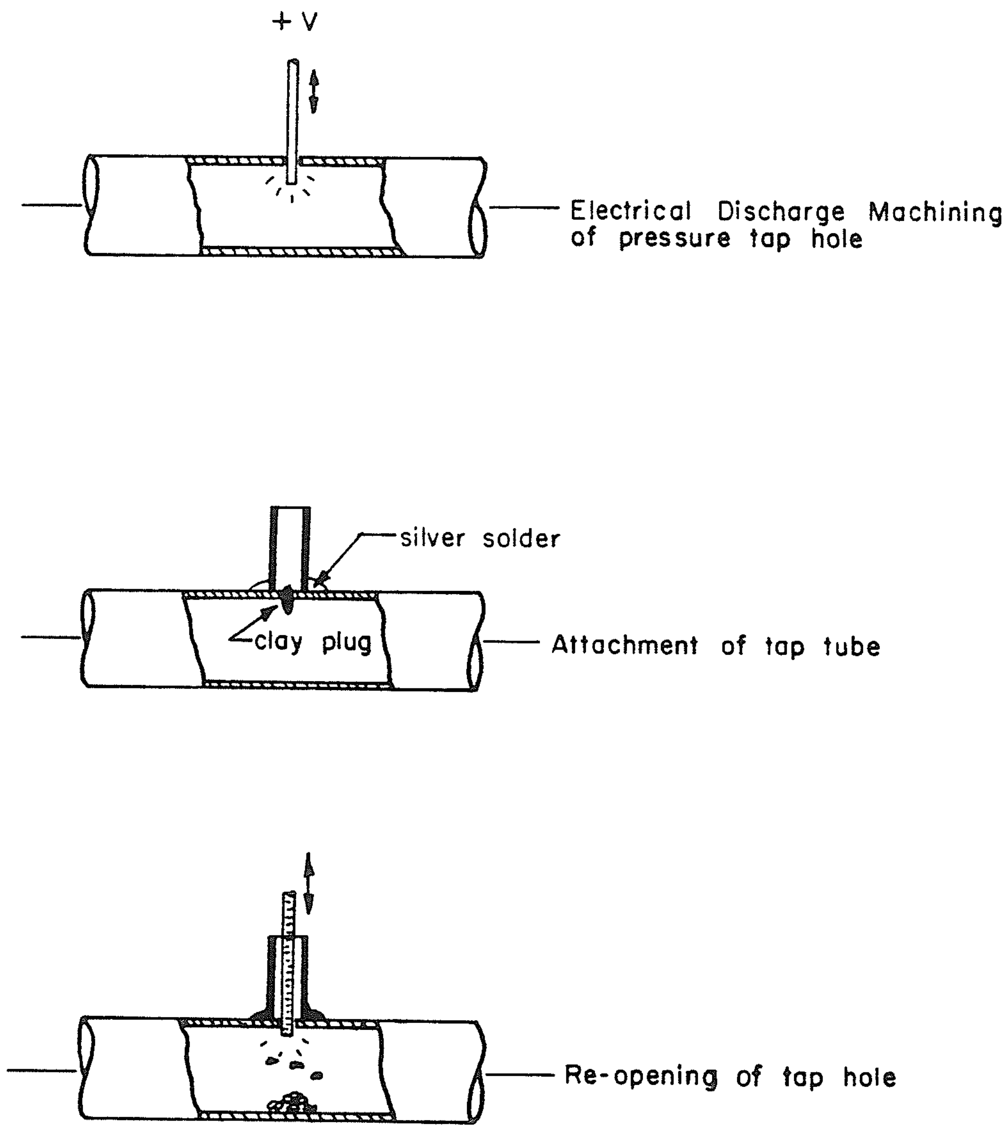


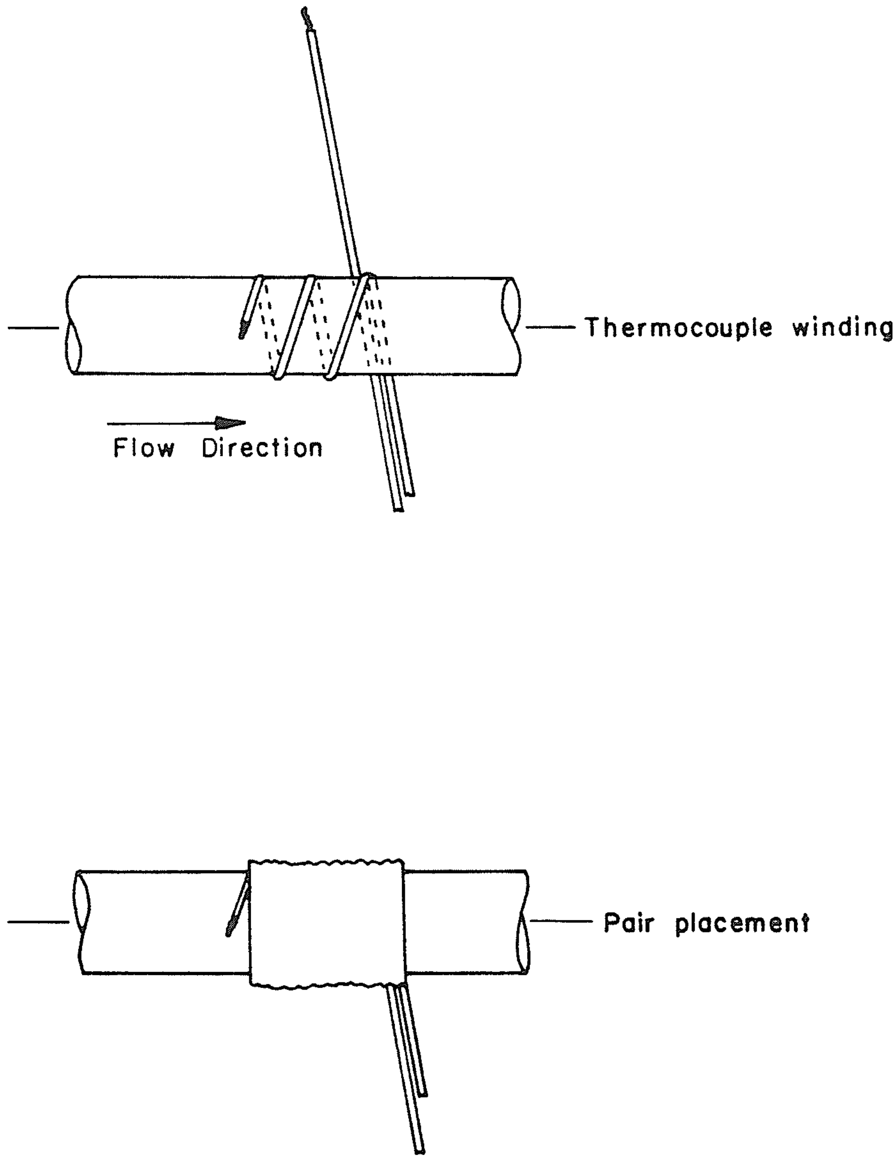
Figure 3.6: Pressure Tap Drilling Process

ends connected via the same tubing to the high and low pressure ports of a pressure transducer. The tubing was secured at the coil tap using an epoxy resin glue and was sealed at the manifold and transducer fluid fittings using silicon sealant.

The transducer used was a Rosemount 1151DP Alphaline differential pressure transmitter, electrically supplied by a Lambda LL-905 regulated dc power supply. The pressure transducer was set for calibration E (4mA to 20mA) and calibrated in-situ to read 1 to 5 volts linearly across a 250 ohm, 1/8 watt resistor for 0 to 30 inches (762 mm) of distilled water (HOH). The power supply (0 to 120V, 0 to 65 mA) was set at 24 volts with the current unlimited to allow the transducer to operate within its specifications' range while drawing what current it may require at various pressure differentials. The 1 to 5 volt transducer output was read on a Keithley 177 Microvolt digital multimeter set for the 0 to 20 vdc range.

Tubewall thermocouples were not attached directly to the tube coil surface due to interference of the resistance heating method. The tube was first wrapped in a single layer of Scotch brand electrical insulating tape, and the thermocouple bead taped to the new "tube surface", as suggested by Bergles and Rohsenow [57]. A pair of copper-constantan, 24 gauge thermocouples were mounted at each of twenty axial stations by winding approximately 120mm of each in the coil-upstream direction until the bead end came into contact with the wrapped coil. One bead made contact on the outer radial coil surface and the other bead on the opposite surface across the tube diameter. The winding negated thermocouple errors due to thermal conduction in the thermocouple leads and all thermocouples were covered by electrical tape to keep it from unwinding, as shown in Figure 3.7. The thermocouple pair was then slid over the tube coil to its selected position and taped in place ensuring initial bead contact on opposing surfaces. The unit was then fully covered with electrical tape.

The copper and constantan leads have spade lugs of their respective materials soldered in place and were connected by copper-constantan terminal blocks to two rotary selector switches. The output of the switches was connected to a Leeds Northrop digital Numatron 938 temperature readout accurate to .1 degree on the Fahrenheit scale. All thermocouples were calibrated against a precision thermometer at a number of temperatures and the corrections accessed from a data file during actual data



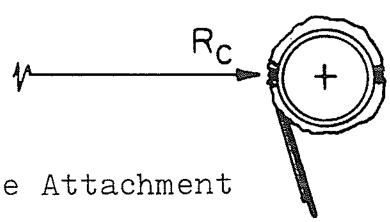


Figure 3.7: Thermocouple Attachment Process

conversion.

The test coils were fully insulated prior to thermocouple calibration and Neumann boundary condition tests using an adhesive-backed insulative tape 50 mm wide, doubly secured by duct tape. A pressure tap leak check was run between isothermal friction factor tests and the insulating of the coils. For the Dirichlet boundary condition, the coils were completely stripped of insulation, thermocouples, and electrical tape.

Detailed geometric and instrumentation data for the tested coils is supplied in Table 3.1 with an analysis of equipment specifications and associated errors affecting data conversion provided in Appendix C.

3.6 Operating Conditions

Operational conditions were determined based on calculations involving distilled water (HOH) at 40°C, passing through a .180 inch (4.57 mm) internal diameter tube. The laminar flow range of $100<Re<6000$ was selected based on Eqn (2.2) for the transition points to turbulence, and based on the chosen coil diametral ratios operating at a Dean number as low as 20. The close pitched helix range

Table 3.1: Test Section and Instrumentation Specifications

Coil Number	1	2	3	4	5
Diametral Ratio	29.	29.	49.	50.	4.
Pitch Ratio	5.	60.	5.	58.	61.
Pressure Tap Locations	5.	5.	3.	3.	1.
(x/d from upper connection)	100.	115.	167.	175.	286.
	193.	225.	321.	337.	
	287.	332.	475.	494.	
	379.	439.	529.	525.	
	472.	525.			
	521.				
Total Length of Coiled Tube,L/d	526.	530.	532.	528.	286.
Pitch Angle (degrees)	4.7	46.1	3.0	30.1	82.5
Number of Coil Turns	5.6	4.7	3.4	3.1	4.5
Entry Fitting Depth	6.8	7.1	6.5	6.6	6.3
Squareness	0.	0.	0.	0.	0.
Exit Fitting Depth	6.9	6.7	6.9	6.4	5.9
Squareness	0.	0.	0.	0.	0.
Thermocouple Locations	10.	7.	6.	6.	
(x/d from upper connection)	21.	19.	16.	16.	
	33.	29.	25.	30.	
	44.	39.	35.	43.	
	56.	46.	46.	55.	
	67.	60.	57.	69.	
	78.	88.	70.	80.	
	107.	126.	90.	91.	
	133.	147.	115.	115.	
	153.	172.	135.	138.	
	183.	206.	155.	162.	
	213.	244.	178.	179.	
	242.	274.	217.	201.	
	273.	304.	249.	224.	
	330.	333.	289.	246.	
	367.	365.	307.	297.	
	440.	406.	383.	341.	
	465.	446.	461.	424.	
	502.	496.	510.	498.	
	518.	525.	527.	524.	

Note: (1) Isothermal tests covered coils 1 to 5.

(2) Neumann boundary condition tests covered coils 1 to 4 with thermocouple stations detailed above.

(3) Dirichlet tests covered coil 2 only due to equipment limitations, and used six randomly placed wall thermocouples not detailed above.

(4) Coil 2 was shortened to L/d=335 for the Dirichlet boundary condition to allow it to fit into the steam chamber.

provides the widest field of conditions since the high pitched helices are expected to be limited somewhat closer to the straight tube laminar regime.

The tube coil electrical resistance was calculated based on resistance data for the same tube material, but different geometry, as in use in the vertical two phase flow lab (R- 325). Using the formula $R=\rho_e L/A$ yields a resistivity of:

$$\rho_e = 7.023 \times 10^{-5} \quad \Omega cm^2/cm \qquad (3.1)$$

Thus, for a 4.57 mm internal diameter tube of .889 mm wall thickness with a 2 metre length, $R=.107\Omega$. The required power input at the highest mass flow for 40°C water with a temperature increase of 10°C was 589 Watts based on $Qf=\dot{m}cp\Delta T$. At the low flow end the required input was 8 W. Using $Qe=I^2R$, the maximum required tubewall current was close to 75 amperes. Similar calculations for distilled water at 20°C showed that the maximum required current would rise to 100 amperes. For this reason, the inlet bulk temperature of the working fluid was maintained at a value near 40°C for all high input power test runs. The actual tubing used for manufacturing the test coils was number 304 stainless steel, 4.57 mm internal diameter at

.889 mm wall thickness. After manufacture, the coils were tested as outlined in Appendix D and found to have resistances between .110Ω and .116Ω for tube lengths between 2.275 m and 2.350 m. A check calculation showed that this corresponds to $\rho_e = 7.3719 \times 10^{-5}\ \Omega cm^2/cm$, which is less than 5% off the published values for number 304 stainless steel.

3.7 Operating Procedure

Test coils were tested under the isothermal, Neumann, and Dirichlet boundary conditions.

3.7.1 Isothermal Boundary Condition

Isothermal tests were conducted to evaluate the friction factor in the laminar flow regime. For each coil, the pressure drop was recorded between pressure tap pairs at various Reynolds numbers between Re=147 and Re=7000. Wider intervals of Reynolds numbers were used in the laminar regime than in the estimated zone of transition to turbulent flow (Re>3500). Inlet and outlet bulk temperatures were recorded to prove that no heat was added and to determine water properties used in calculating the mass flow, Reynolds number, and friction factor.

Individual tap-to-tap values of fc were calculated. An overall value was calculated as the average after deleting the readings for the inlet and exit of the coil, where possible.

3.7.2 Neumann Boundary Condition

Prior to running the Neumann boundary condition, the insulated coil tubewall thermocouples were calibrated in-situ against a precision thermometer at four fixed temperature levels. This was accomplished by submerging a 1500 watt heating element in the distilled water reservoir and running the working fluid system until steady state was reached. The actual temperature was read from a previously calibrated thermocouple inserted into the fluid flow. Corrective differentials for each thermocouple were determined for each temperature level between 20°C and 70°C and entered in the thermocouple calibration data file for conversion programming access. The maximum correction observed was 3.5°C at the highest calibration level, with much smaller corrections in the 20°C to 50°C range.

Each of coils 1 to 4 was tested at several Reynolds numbers covering the laminar flow regime through that particular coil's point of transition to turbulent flow.

The heat input was set to produce a 10°C to 15°C bulk temperature rise across each coil, using a bulk inlet temperature around 40°C for each flowrate. Each test run was allowed to continue until steady state was reached prior to data recording. Steady state was determined by the stability of the pressure transducer, thermocouple, and flowmeter readings. The following data was recorded on a raw data sheet and later entered into a personal computer raw data file for conversion:

1 Inlet and outlet bulk temperatures in °F

2 Tubewall temperatures in °F

3 Input current in amperes

4 Coil voltage drop in volts

5 Pressure differentials in volts

6 Flowmeter reading (sightglass graduations)

7 Miscellaneous coil identification and condition data

3.7.3 Dirichlet Boundary Condition

Prior to running the Dirichlet boundary condition, all test coils are completely stripped of insulation, thermocouples, and electrical tape; and mounted in the atmospheric steam housing chamber. Six randomly placed tubewall thermocouples were attached directly to the tube surface using electrical tape, without winding. Steam was delivered to the chamber at atmospheric pressure by a 3 kW steam generator. Condensed steam was discharged to a drain through a bottom-mounted steam trap. Each coil was tested at various Reynolds numbers using a bulk inlet temperature of about 25°C, however, results were only obtained for the shortened coil 2. The following data was recorded upon achieving steady conditions:

1 Inlet and outlet bulk temperatures in °F
2 Environmental temperatures in °F
3 Selected tubewall temperatures in °F
4 Flowmeter reading (sightglass graduations)
5 Miscellaneous coil identification and condition data

3.8 Data Conversion

Raw experimental data was converted using a specially prepared software package developed in Fortran 77 using the UCSD-p operating system as illustrated schematically in Figure 3.8. The software package was run on an IBM personal computer with serial ports linked to an Epson FX-100 dot matrix printer and a Hewlett-Packard 7475A plotter. Raw data was entered manually from the

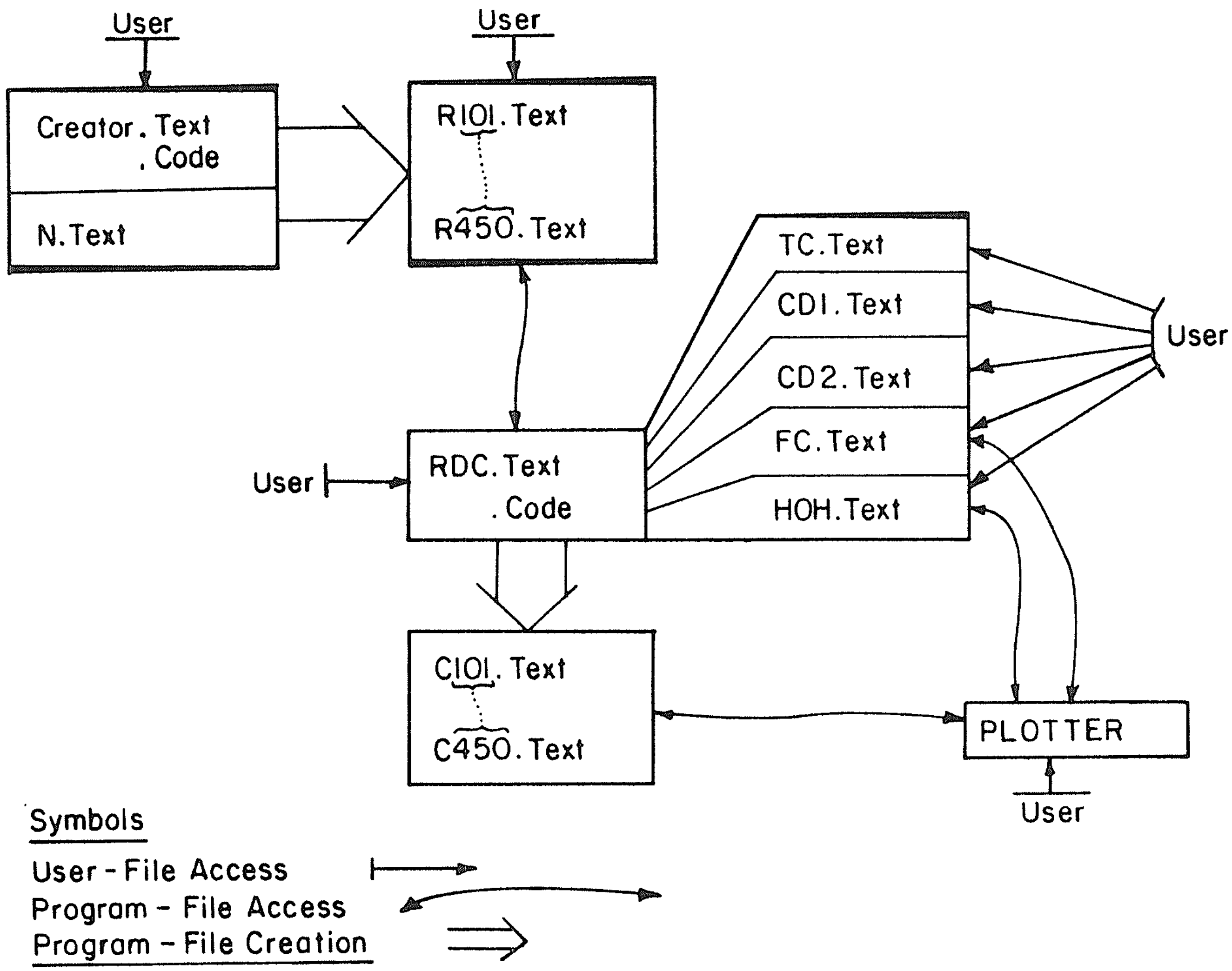


Figure 3.8: Schematic of Data Conversion Process

experimental data sheet into a unique raw data file for that particular run. The program then converted the data according to the isothermal, Neumann, or Dirichlet boundary condition noted in the raw data file, and outputs the converted data to a matchingly unique converted data file. During data conversion, the program also accessed other data files for water properties, flowmeter and thermocouple calibrations, and coil data on geometric parameters and instrumentation locations.

Raw data, converted data, and conversion programming were stored on three separate, 12.7 cm magnetic discs to maximize experimental data storage versatility. The different discs were inserted by the user when prompted by the running data conversion/plotting programs. Further software details and program listings are provided in Appendix E in a user manual format. A sample run calculation for all boundary conditions is provided in Appendix F detailing calculations common and exclusive to each of the different boundary conditions. The following briefly summarizes the data conversion process and details the general equations utilized by the software package.

1 All thermocouple readings were corrected using the thermocouple calibration data file.

2 Mass flowrate was determined using the flowmeter calibration data file (ref. 20°C), and corrected for density to the actual average bulk temperature for that particular run.

3 The station to station pressure drop determines the friction factor, fc, using:

$$u=\dot{m}/\rho Ac \quad (3.2)$$

$$fc=.5g\ (d/\Delta x)\ \Delta p/u^2 \quad (3.3)$$

Δp in mm of water

u in m/s

4 The heat power absorbed by the fluid is calculated as:

$$Qf=\dot{m}cp(Tbo-Tbi) \quad \text{Watts} \quad (3.4)$$

5 During all calculations involving water properties, a single degree increment data file is accessed, scanned, and linear interpolation employed to determine the properties between consecutive data points listed. The data points were determined by plotting published data, graphically fitting an

appropriate curve, and visually digitizing this curve in increments of 1°C.

For the Neumann boundary condition:

6 The electrical power input was calculated as:

$$Qe=VI \qquad \text{Watts} \qquad (3.5)$$

V is the measured coil voltage drop in volts

I is the current set for the test run in amps

7 The percentage heat balance was calculated as:

$$HB=(Qe-Qf)x100/Qe \qquad (3.6)$$

The observed heat balances were such that the average value was about 3.5% with over 90% of runs falling within 8%. A heat balance of less than 8% was considered acceptable.

8 The local bulk temperature at any axial position was evaluated by linear interpolation between Tbi and Tbo since it is assumed that no heat addition occured along the acrylic entry and exit lengths.

9 The thermal conductivity of number 304 stainless steel was evaluated from [57]:

$$ks = (.00445 \times Twa + 8.46) \times 1.7306 \quad W/m \cdot K \tag{3.7}$$

where Twa is the average of all inner surface thermocouple readings.

10 The coil inner tubewall surface temperature was evaluated at any axial position using the measured outer tube surface temperature and the following relation:

$$Twi = Two - .02899 \times Qe/(L \cdot ks) \tag{3.8}$$

Equation (3.8) is the solution to the classic insulated tube problem using an internal heat generation term, and simplifying for the present tube geometry. It assumes radial heat conduction only through the tubewall, uniform heat generation in the tubewall, and perfect insulation at the outer surface. Two is the average of the two measured outer surface temperatures at the axial position under consideration.

11 The local Nusselt number was calculated as:

$$Nux=(Qf/As)(d/k)/(Twi-Tbx) \quad (3.9)$$

Qf was used rather than Qe because Qf was the heat actually absorbed by the fluid whereas some of Qe was lost externally. Other local parameters such as Reynolds (Rex), Prandtl (Prx), and Grashof (Grx) numbers were calculated also at local fluid properties; with the Grashof number using the relation:

$$Grx=\frac{g\ \beta\ di^3\,(Twi-Tbx)}{\nu^2} \qquad (3.10)$$

12 xFully developed parameters were calculated as

(a) Nusselt no. (Nu): average of axial stations 3 to 18 inclusive

(b) Reynolds no.(Re): evaluated at average bulk temperature

(c) Prandtl no. (Pr): evaluated at average bulk temperature

(d) Graetz no. (Gz): using fully developed Re and Pr numbers

(e) Grashof no. (Gr): average of axial stations 3 to 18 inclusive

(f) Dn and Dn* : using fully developed Re

For the Dirichlet boundary condition:

13 The logarithmic mean temperature difference was calculated as:

$$LMTD=(Tbo-Tbi)/\log[(Tw-Tbi)/(Tw-Tbo)] \quad (3.11)$$

Tw was the average of six randomly placed outer surface tubewall thermocouples. Variation was accepted within 1°C. LMTD is used throughout industry in heat exchanger design and evaluation.

14 Fully developed parameters were calculated as:

(a) Nusselt no. (Nu): eqn (3.9) substituting LMTD in place of (Twi-Tbx)

(b) Reynolds no.(Re): evaluated at average bulk temperature

(c) Prandtl no. (Pr): evaluated at average bulk temperature

(d) Graetz no. (Gz): using fully developed Re and Pr numbers

(e) Grashof no. (Gr): eqn (3.10) substituting LMTD in place of (Twi-Tbx)

(f) Dn andDn* : using fully developed Re

A complete listing of all converted data files is provided in Appendix G.

Chapter 4

RESULTS AND DISCUSSION

In this chapter, a preliminary analysis is discussed based on the literature review of chapter 2 and some of the theoretical concepts of chapter 1. This is followed by presentation and discussion of the present results of pressure drop with and without heat transfer, and the Neumann and Dirichlet boundary condition Nusselt number. Comparisons are made with other results available in the literature when possible. The Dirichlet boundary condition data is highly limited due to technical difficulties with the available facility.

4.1 Preliminary Analysis

With respect to the coil geometries considered, and the possibility of investigating the boundaries of the geometric continuum map postulated in chapter 1, a preliminary analysis is presented as follows. Utilizing Equation (2.2) and the correction of Truesdell and Adler [26] as used by Mishra and Gupta [10], contours of constant critical Reynolds number are plotted as a map of (D/d) versus (h/d), as shown in Figure 4.1. This was done by

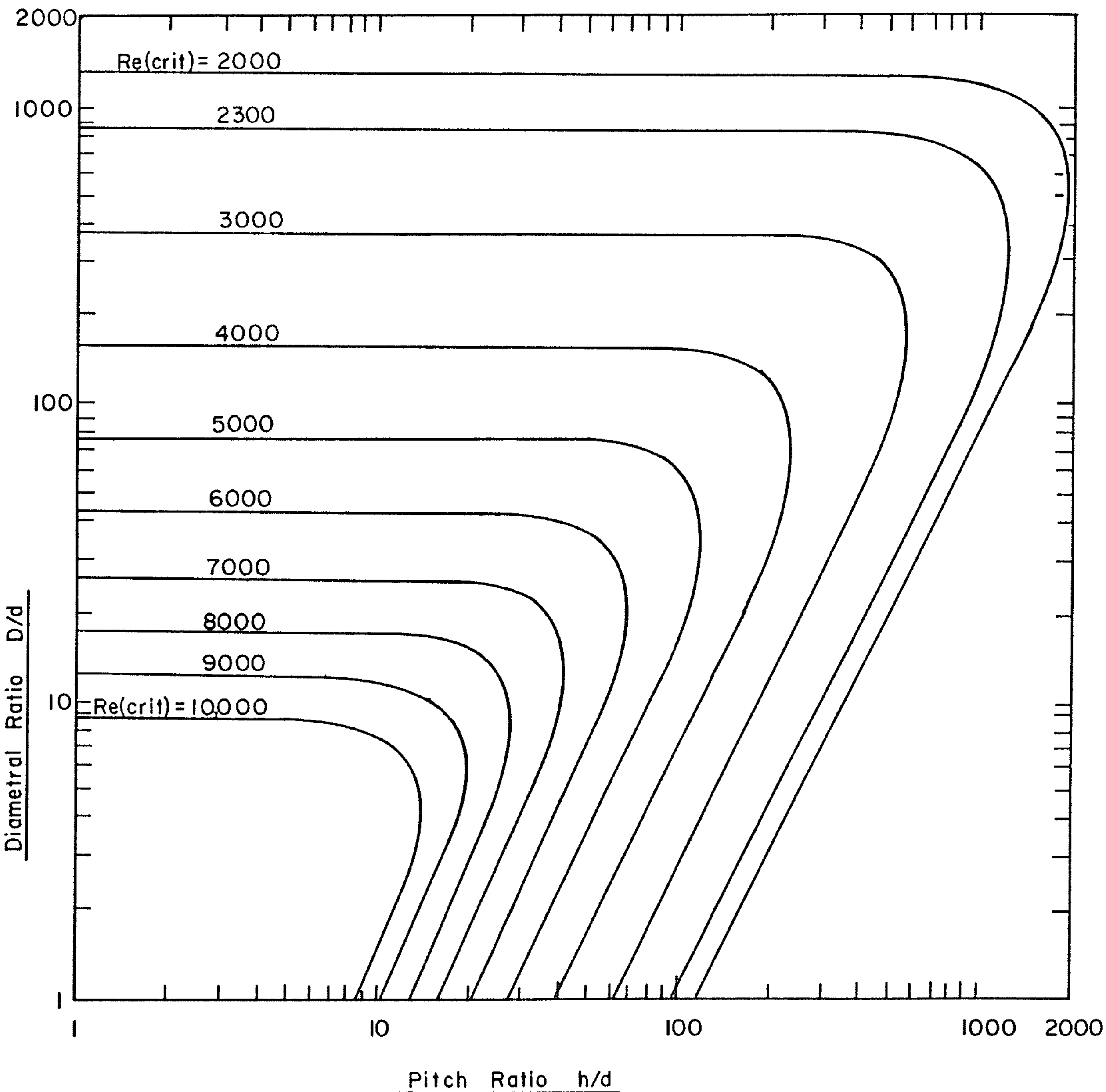
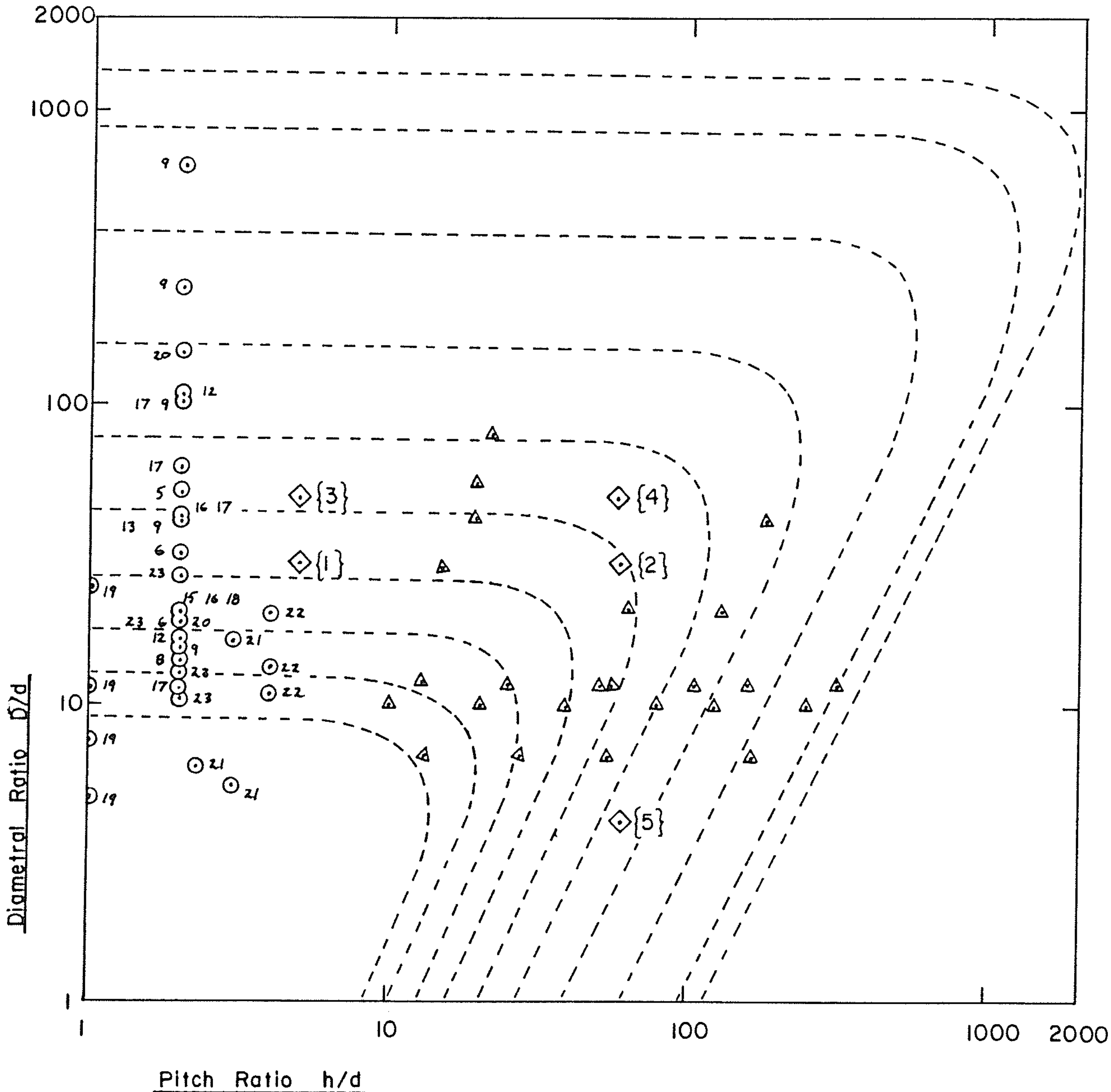


Figure 4.1: Geometric Continuum Map (II)

selecting (h/d) and calculating (D/d) for a given critical Reynolds number. This is duplicated in Figure 4.2, on which the previous experimental coils are noted with appropriate references, and the coils pertaining to this investigation (1 to 5) are also marked.

An initial consideration of Figure 4.1 is that the overall form indicates not only contours of critical Reynolds number, but contours of constant curvature or equivalent geometry. This is logical, based on Eqn (2.2) and substituting (Dc/d) for (D/d), and has been substantiated in terms of isothermal transition and pressure drop by Mishra and Gupta [10] (refer to section 2.2.2). However, it remains to be proven or disproven for heat transfer in the present investigation. From coils' 1 to 4 locations investigated in the present study, it appears that little effect of pitch is expected due to similar curvature. Therefore, if the effect of pitch is immeasurable within the limits of experimental error, the first step in non- isothermal substantiation will have been gained. This means that the modified Dean number, Dn*, will be partially accepted as an appropriate correlation parameter for helically coiled tubes, pending further research. If, however, the effect of pitch is substantial for coils 1 to 4 , an initial trend may then be



◇{no.} indicates coils investigated herein
△ Isothermal test geometries of Mishra & Gupta [10]
⊙[no.] geometry tested by reference no. cited
Note: - unspecified pitch assumed to be 2d
- points plotted are approximate

Figure 4.2: Geometric Continuum Map (II): Previous Work

established with respect to the "correct" heat transfer contour shapes to be more rigorously defined by further research. The aforegoing may not, however, apply to free convection flow regimes which are also considered. Also, an initial substantiation of the geometric continuum map of Figure 4.1 may allow this concept to be extended into the third dimension as shown in Figure 4.3, with two projected views as shown in Figure 4.4 and Figure 4.5 respectively. The inertial flow regimes are typical of the continuum effect which are postulated as due to the geometric parameters and the flow parameters of helically coiled tubes.

Another aspect of the geometric continuum map of chapter 1 is that for significant pitch and a zero diametral ratio, a rectangular/oval twisted tube or a straight circular tube phenomenon may be produced. To test this theory in light of Figure 4.1 and Figure 4.2, coil 5 of pitch ratio 61 and diametral ratio 4 was employed, but on an isothermal basis only. The latter restriction was due to the test section length (L/d=286) lacking sufficient resistance to allow application of the Neumann boundary condition, and the length being too long to fit in the available steam chamber.

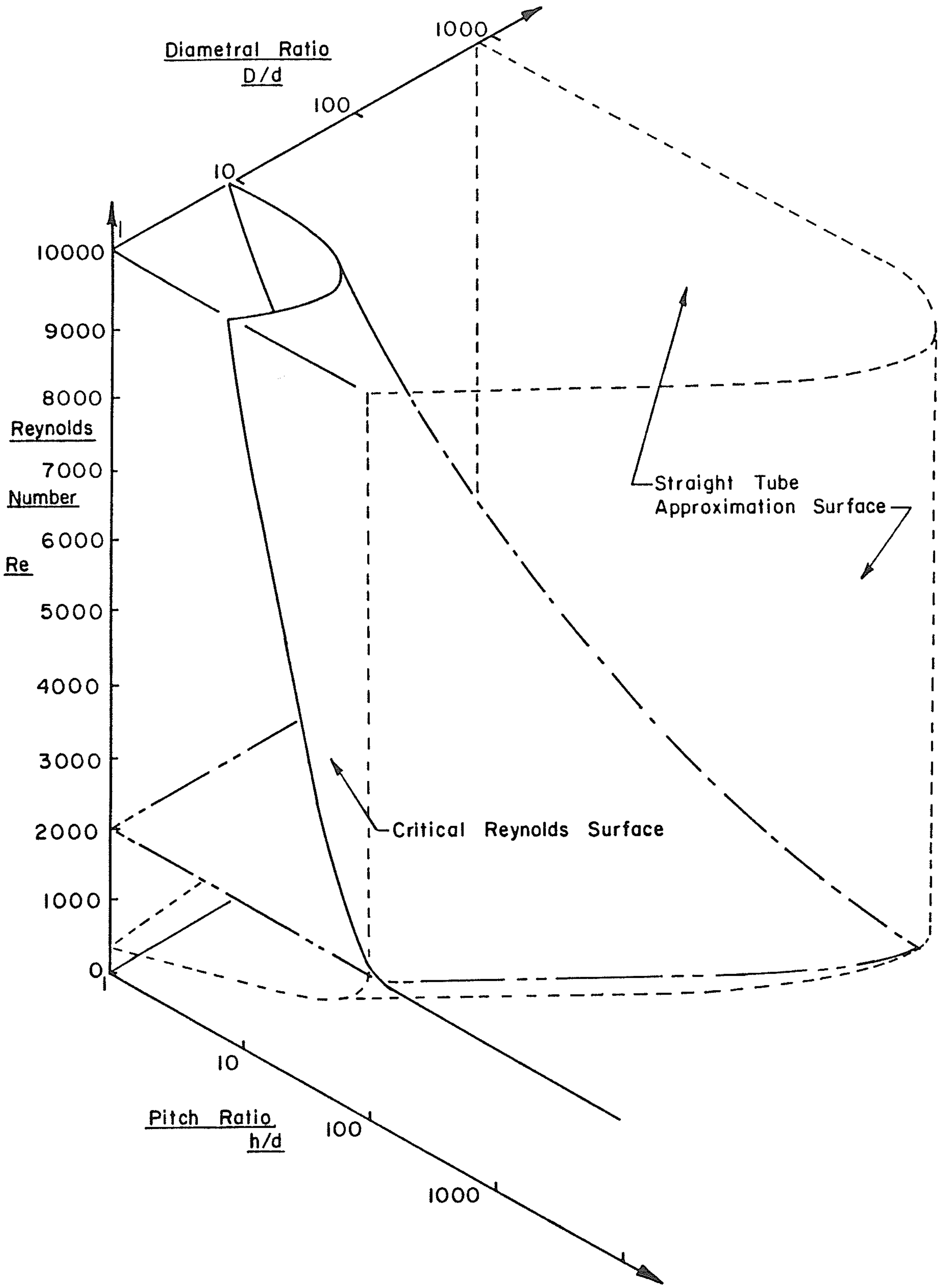


Figure 4.3: Parametric Inertial Flow Regimes

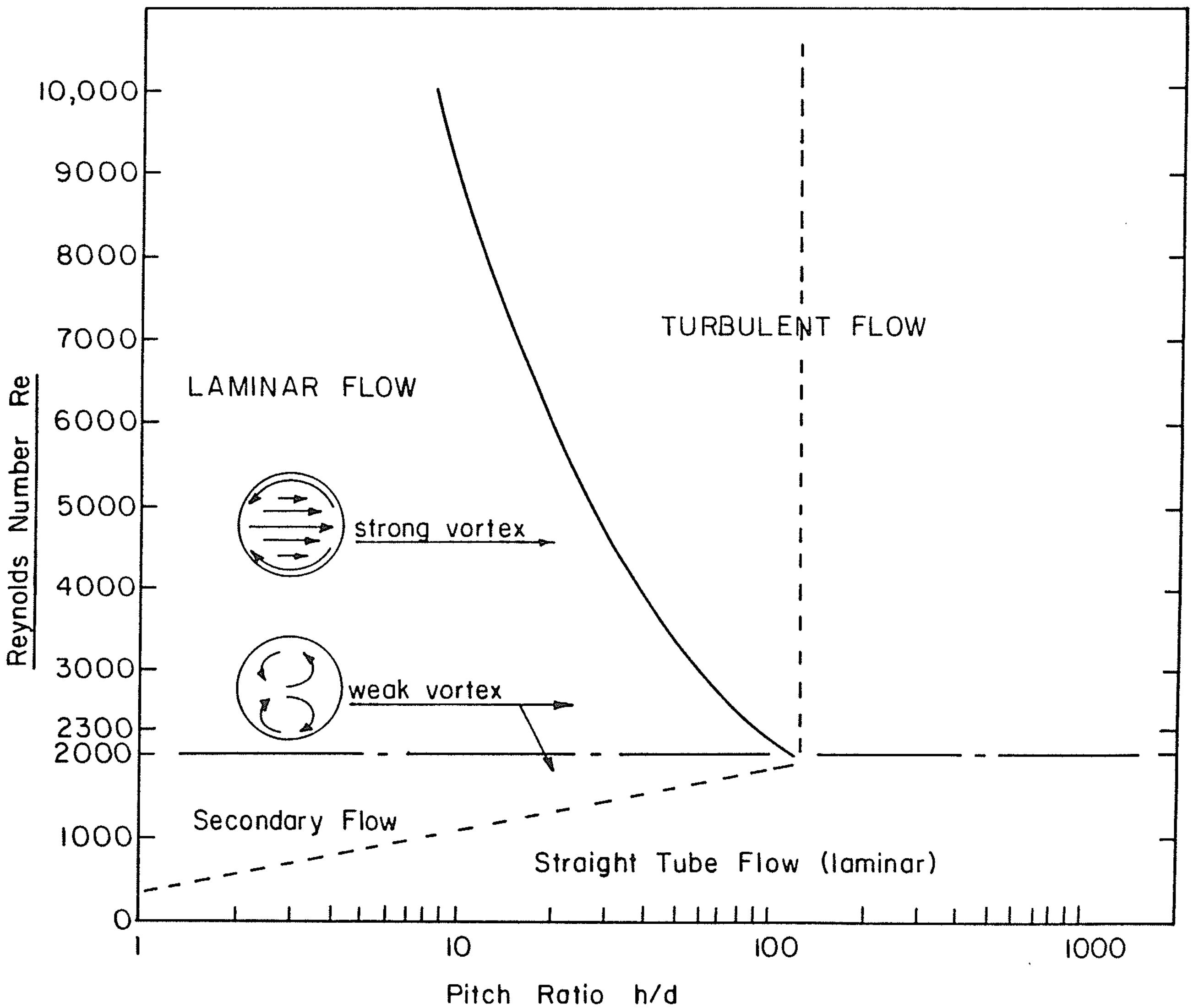


Figure 4.4: Parametric Inertial Flow Regimes: Projection 1

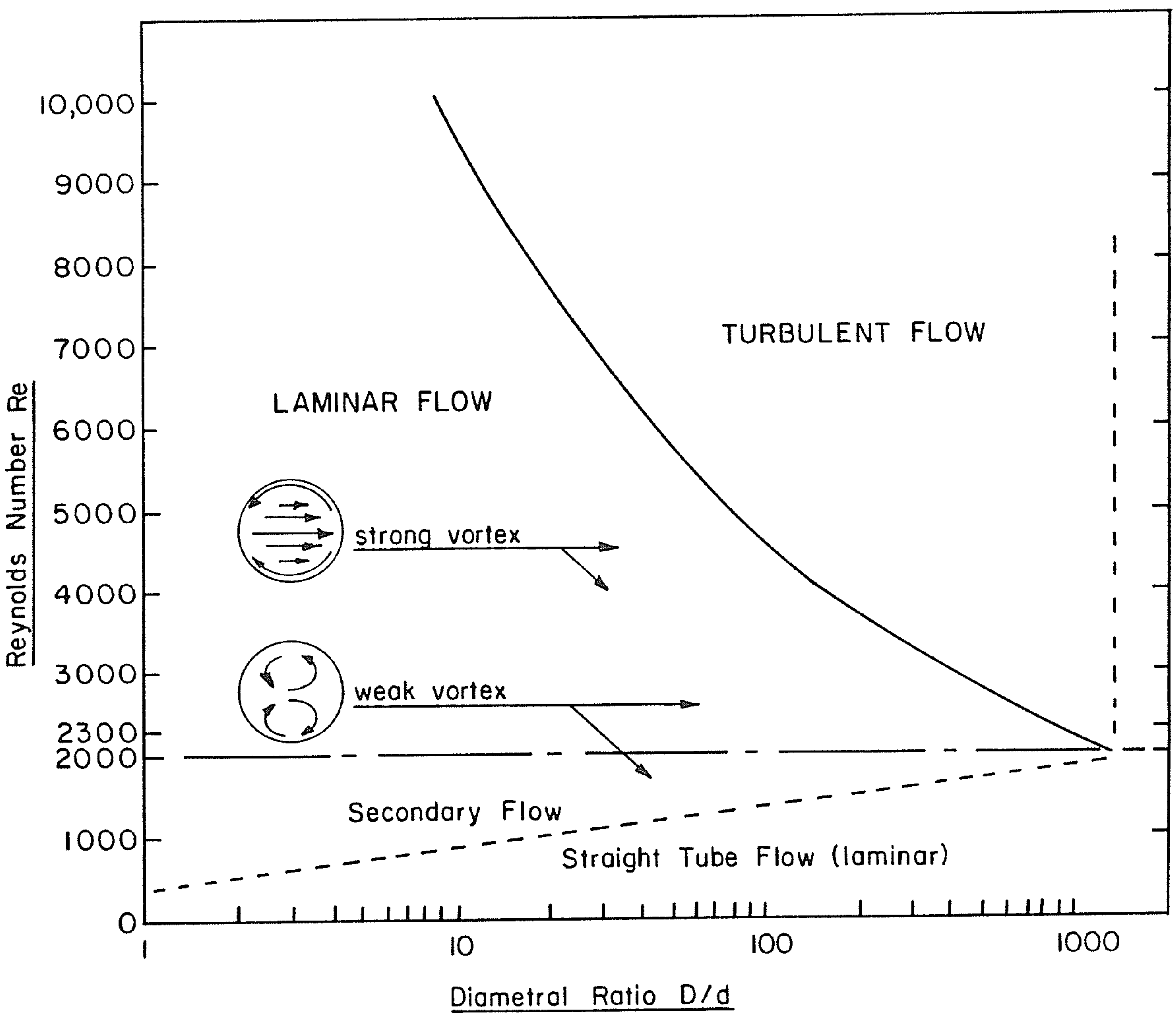


Figure 4.5: Parametric Inertial Flow Regimes: Projection 2

The five coils tested under the present study are defined parametrically in Table 4.1, and were examined in the laminar flow regime up to each test section's calculated point of transition (refer to Eqns 2.2 and 2.3).

4.2 Pressure Drop Results

This section is divided into subsections for separate examination of isothermal and non-isothermal pressure drop measurements. The experimental procedure employed was as described in chapter 3 with the friction factor calculated based on the measured mass flowrate and the tube inner diameter. The fluid properties were evaluated at the average bulk temperature. Coils 1 to 4 had one pressure tap per turn whereas coil 5 had only inlet and outlet pressure taps. For coils 1 to 4 , the first and last pressure differentials were ignored in calculating the average friction factor for the run. The majority of the friction factors were within about 5% of the average value indicating a very short entry length, always less than one coil turn if observable at all.

4.2.1 Isothermal Flow

The isothermal friction factor as a function of

Table 4.1: Test Coil Parametric and Test Data

Coil No.	D/d	h/d	Dc/d [1]	Re(cr) [2]	Dn(cr) [3]	Dn*(cr) [4]	L/d	πD/d [6]
1	29	5	29.1	6802	1263	1263	526	91.4
2	29	60	41.6	6067	1127	948	528 [5]	—
3	49	5	49.1	5755	822	822	532	154.1
4	49	58	56.0	5517	788	738	528	—
5	4	61	98.3	4608	2304	465	286	—

Notes:

1 $Dc/d = D/d \left\{ 1 + \left(\frac{h}{d} \frac{d}{\pi D} \right)^2 \right\}$ Truesdell & Adler [26]

2 $Re(cr) = 20{,}000\,[Dc/d]^{-.32}$ Ito [9] & note 1

3 $Dn\,(cr) = Re(cr)\ (D/d)^{-1/2}$

4 $Dn^*(cr) = Re\,(cr)\ (Dc/d)^{-1/2}$

5 L/d of 528 reduced to 335 for Dirichlet tests.

6 Length of one turn in "d" — not valid for high pitch.

Reynolds number is presented in Figures 4.6 to 4.10 along with the accepted straight tube laminar Hagen-Poiseuille line. As expected, all five test sections approximated straight tube flow at Reynolds numbers less than 300, irrespective of their coil geometries. This is directly attributable to the weak centrifugal force field being unable to generate significant secondary flow vortices at low Reynolds numbers. As the Reynolds number increases, it is seen from Figures 4.6 to 4.10 that the friction factor is increasingly in excess of that in straight tube laminar flow. The initiation of transition to turbulent flow, as noted by Ito [9], is usually a minor change in slope for a standard fc vs. Re plot. As shown in Figures 4.6 to 4.10, the point at which each test section begins to transide is not readily identifiable without further tests in the turbulent regime. However, transition point tests would be redundant as discussed by Ito [9] and Mishra and Gupta [10].

The friction factor ratio, fc/fs, is plotted against the Dean number for comparison with Eqn (2.1), and is presented in Figures 4.11 to 4.15. As illustrated, the data the data is usually below the correlation line, with the data of the high pitched coils being generally lower than the data of the low pitched coils. For low Dean

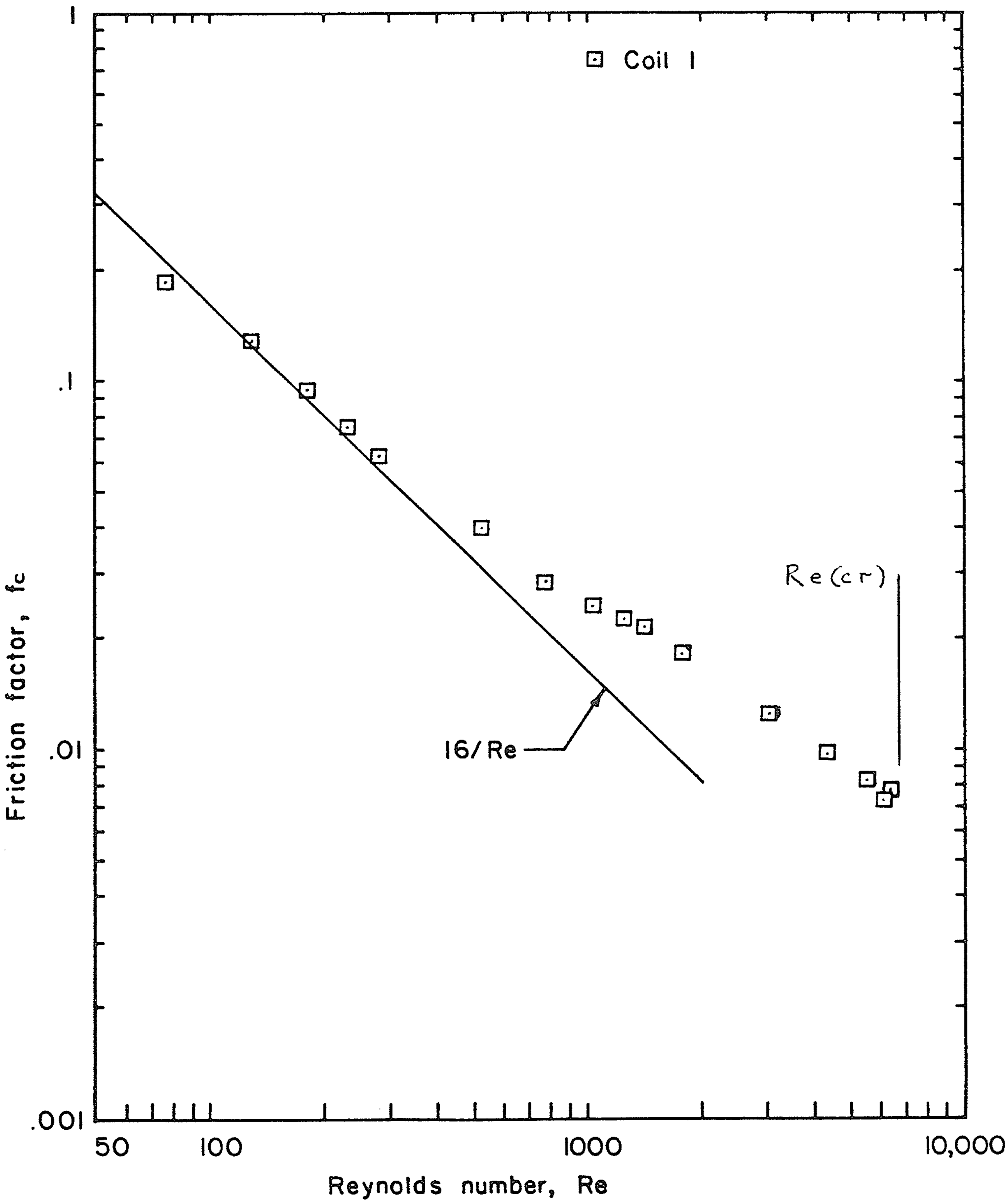


Figure 4.6: Isothermal Friction Factor: Coil No.1

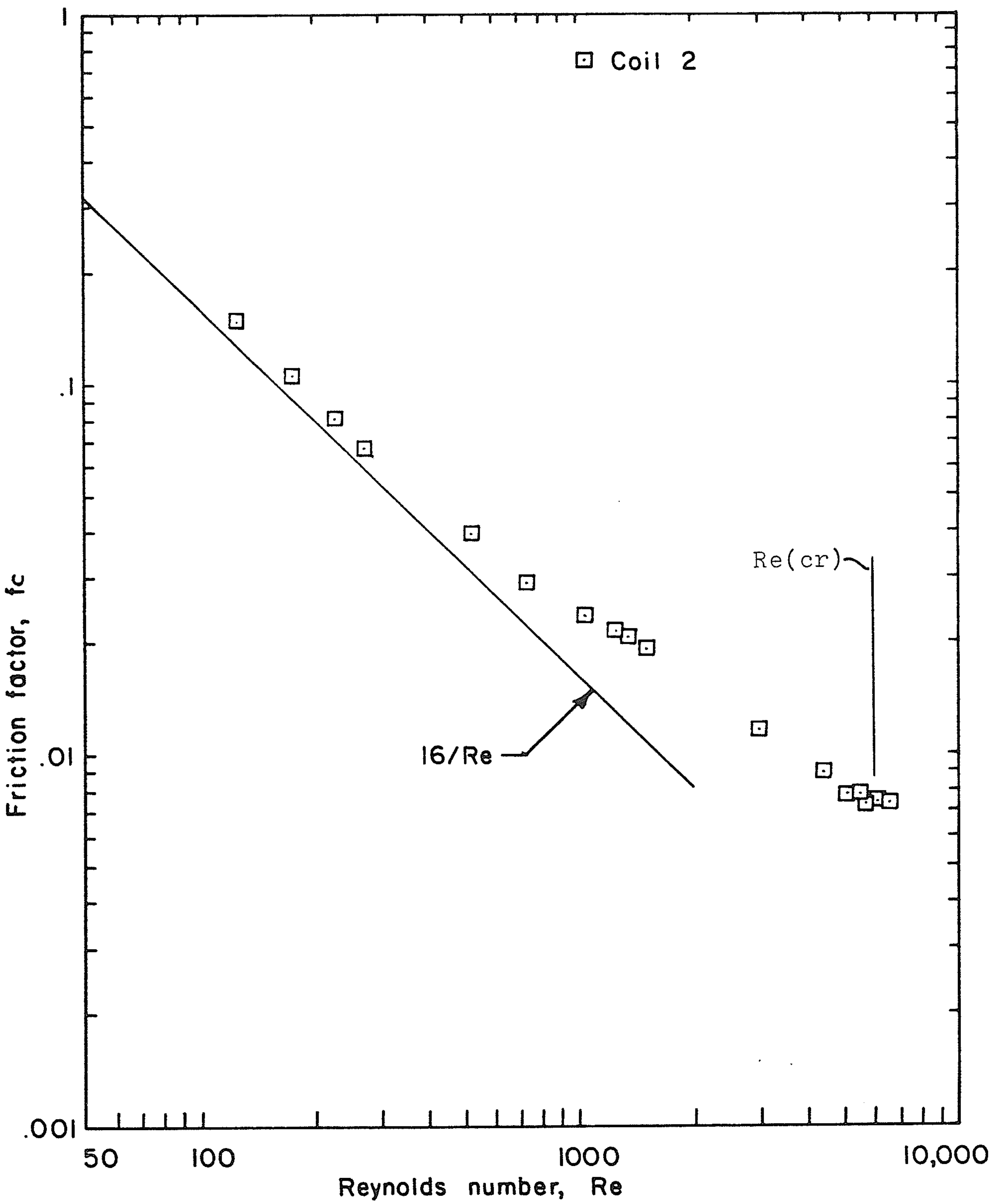


Figure 4.7: Isothermal Friction Factor: Coil No.2

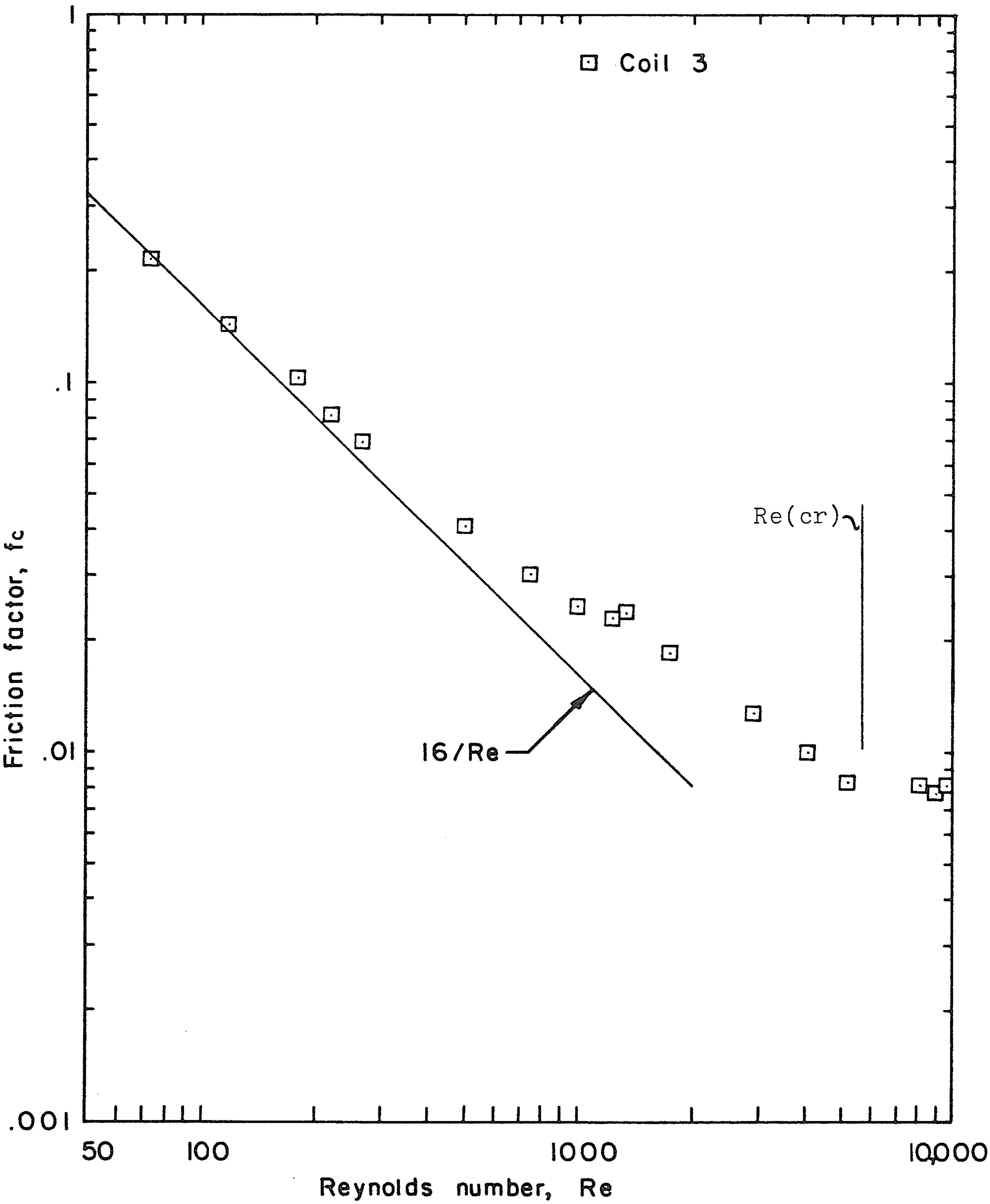


Figure 4.8: Isothermal Friction Factor: Coil No.3

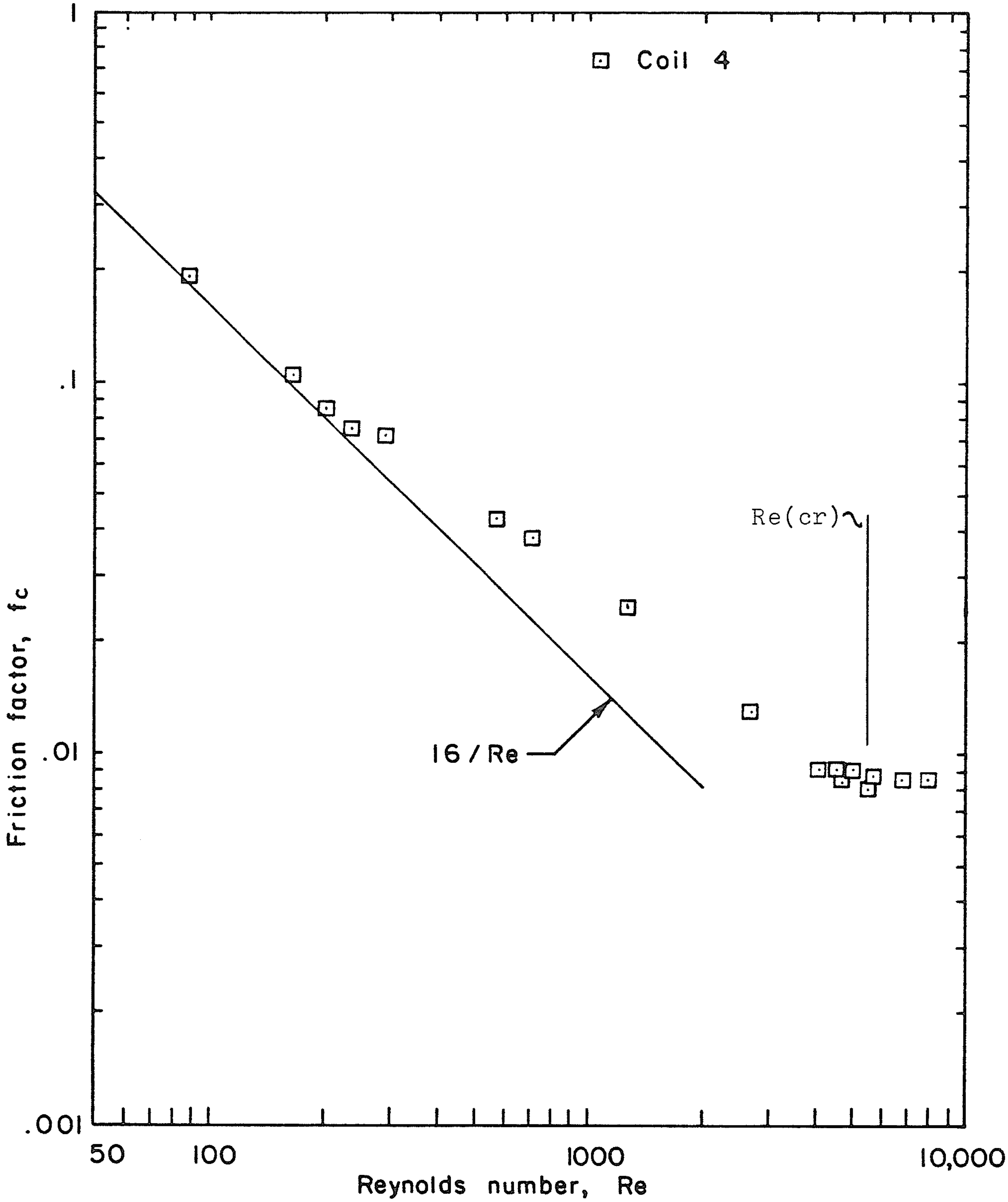


Figure 4.9: Isothermal Friction Factor: Coil No.4

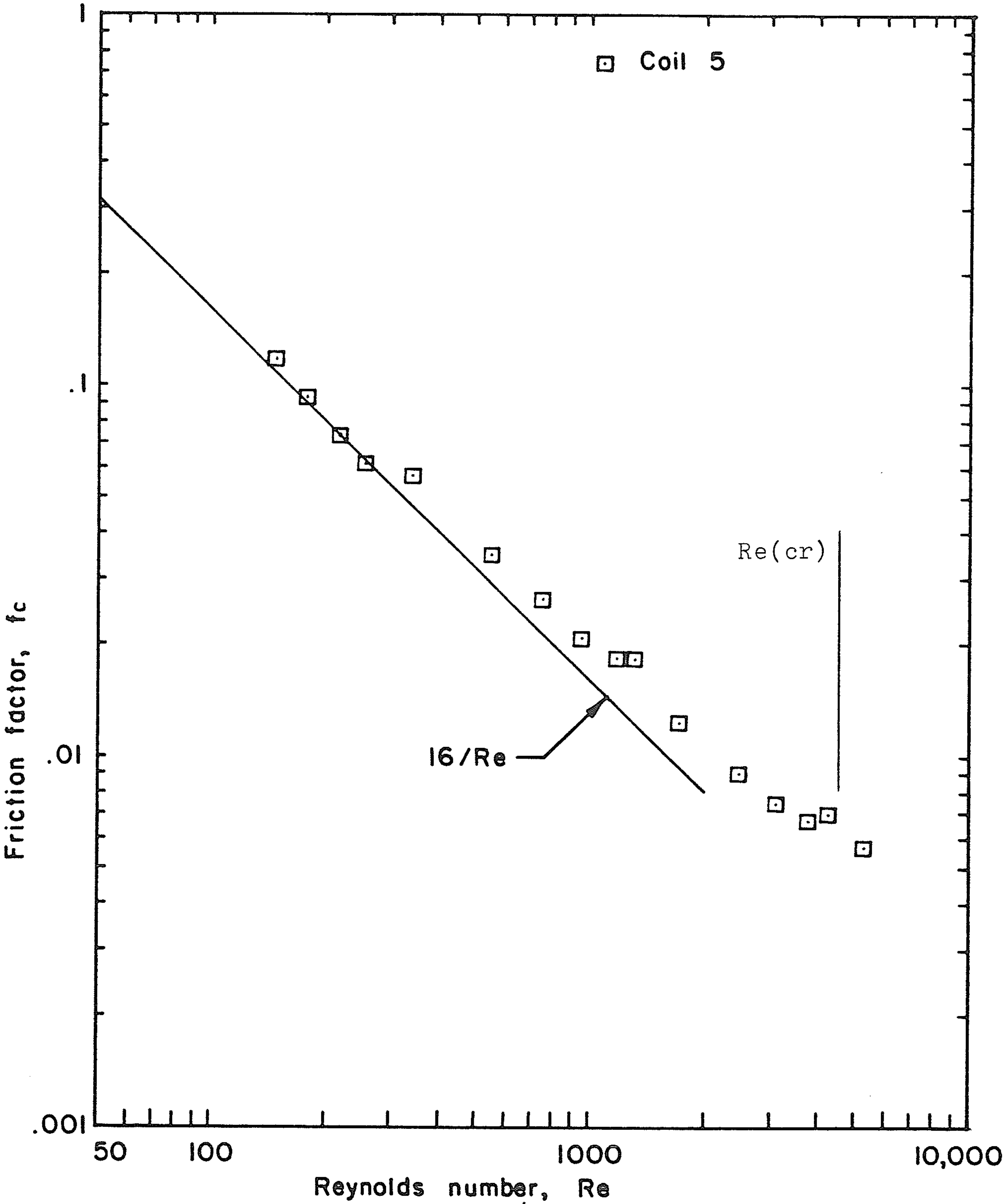


Figure 4.10: Isothermal Friction Factor: Coil No.5

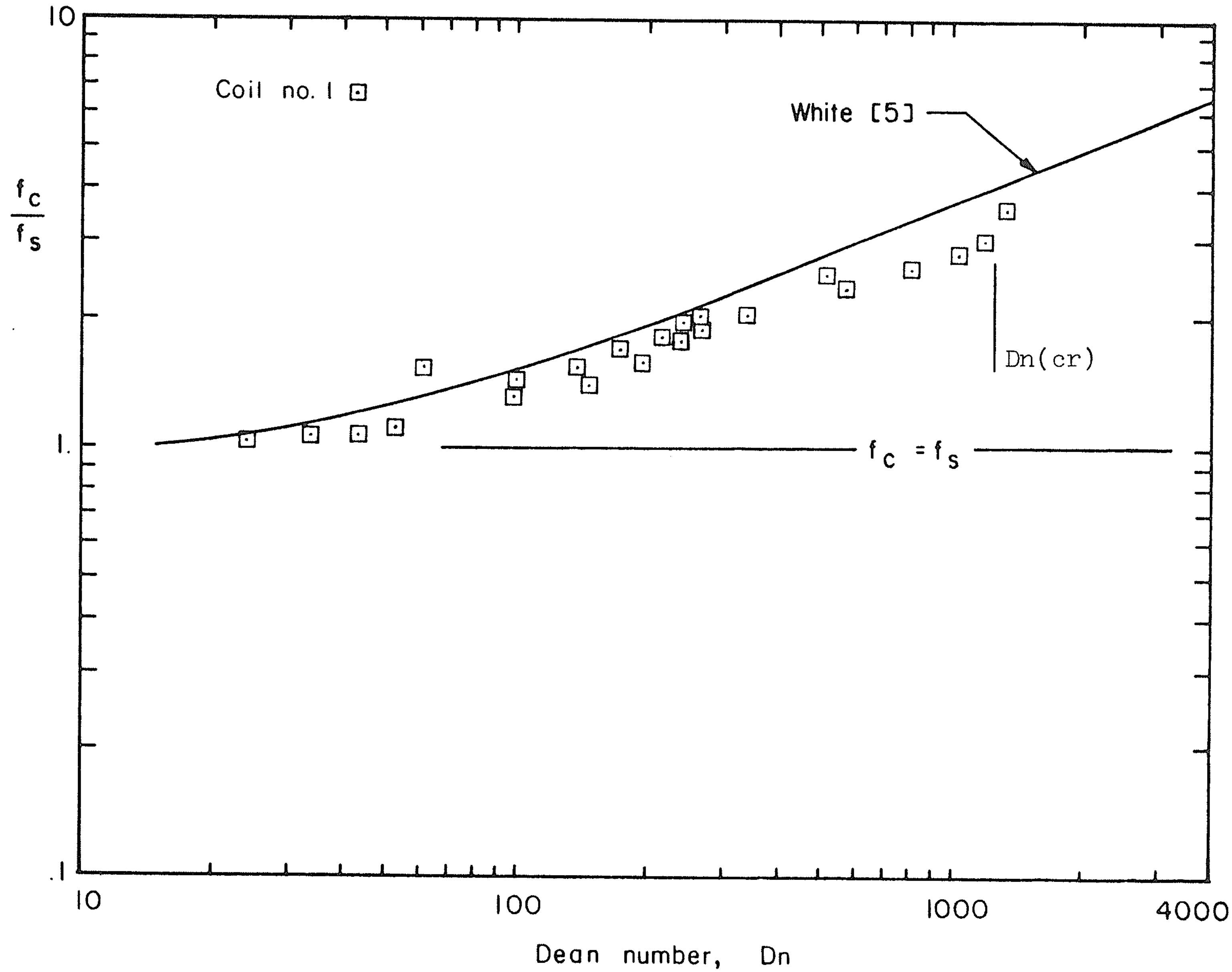


Figure 4.11: Isothermal Friction Factor Ratio: Coil No.1 Compared with White

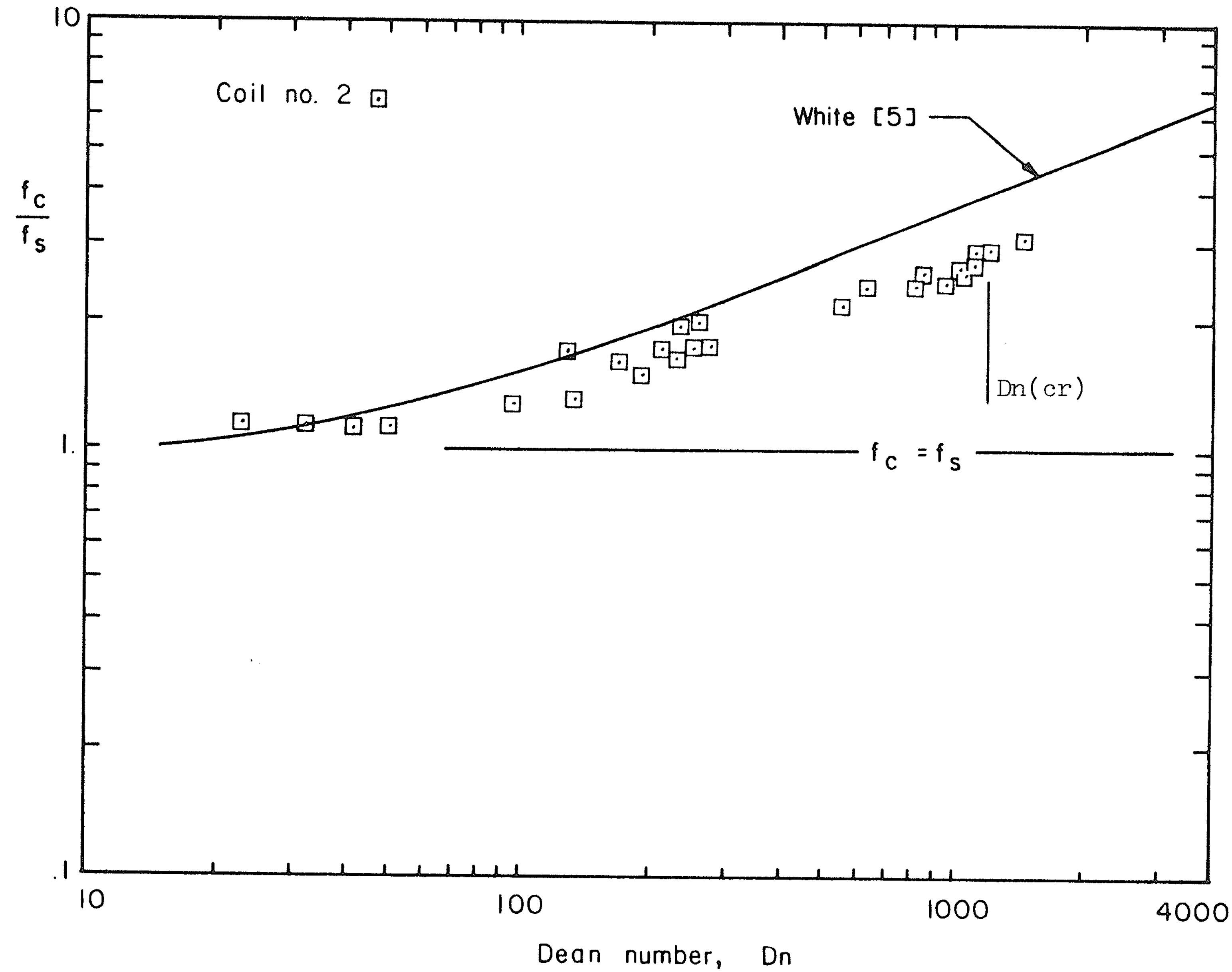


Figure 4.12: Isothermal Friction Factor Ratio: Coil No.2 Compared with White

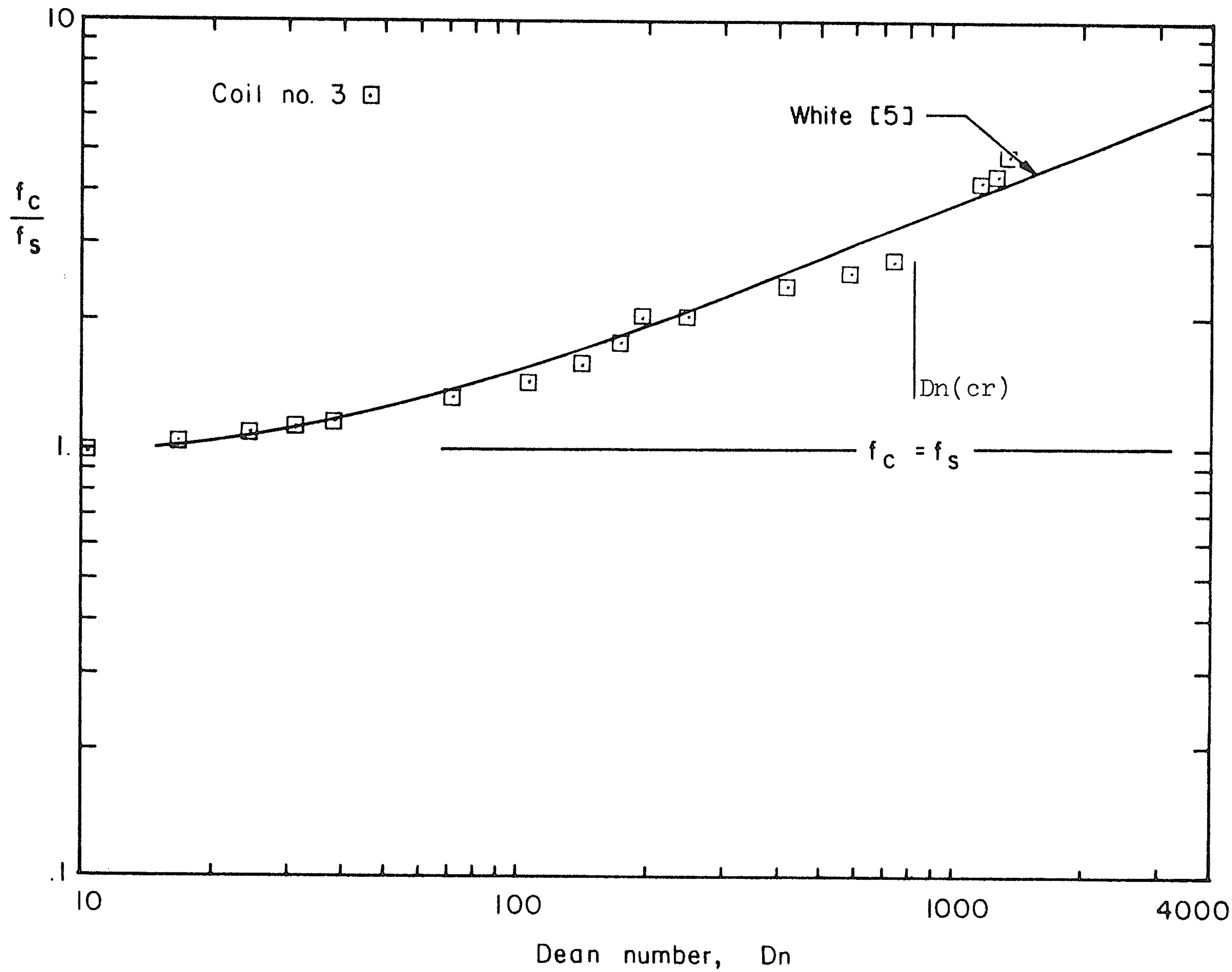


Figure 4.13: Isothermal Friction Factor Ratio: Coil No.3 Compared with White

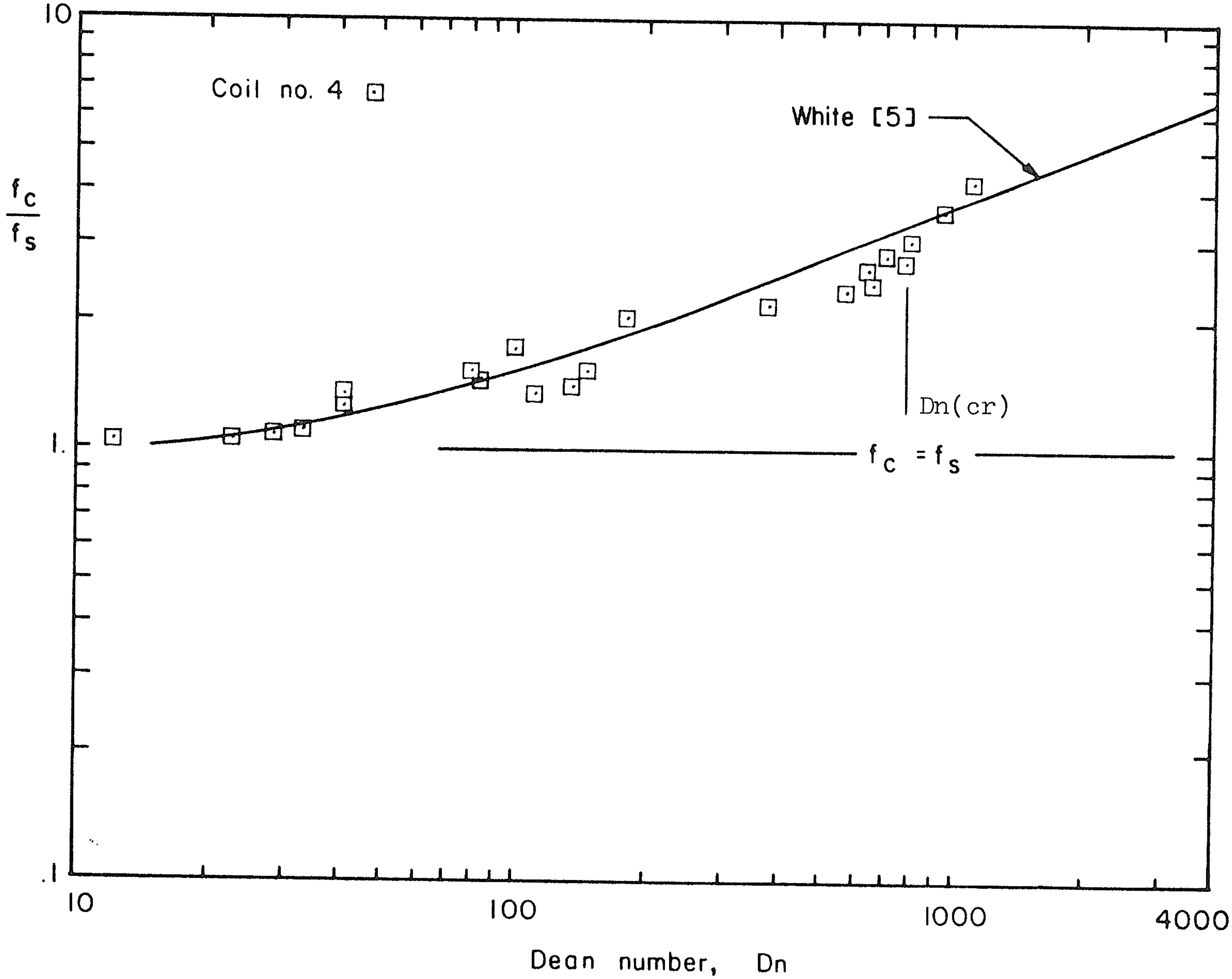


Figure 4.14: Isothermal Friction Factor Ratio: Coil No.4 Compared with White

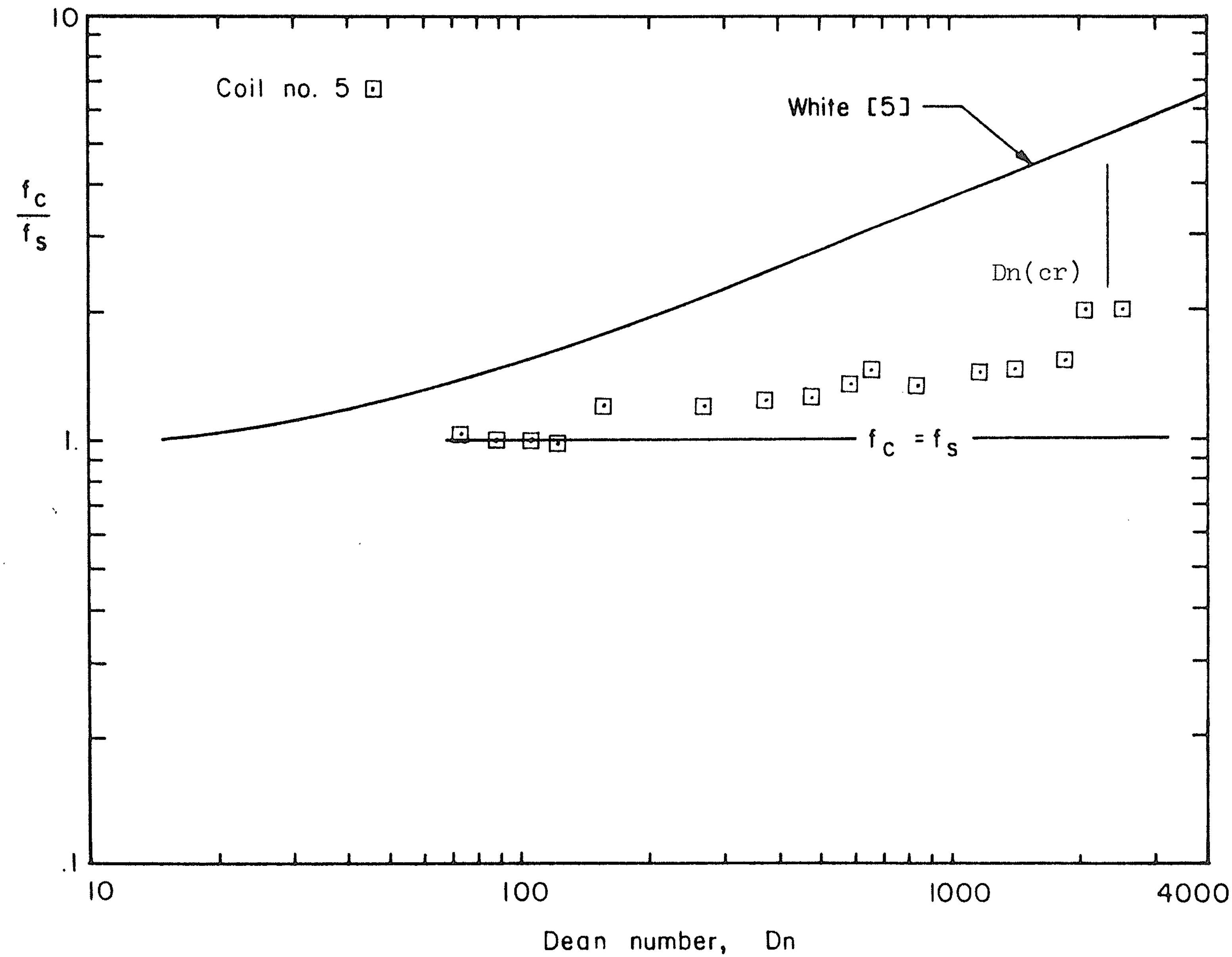


Figure 4.15: Isothermal Friction Factor Ratio: Coil No.5 Compared with White

numbers, the friction factor ratio approaches 1.0, meaning that straight tube laminar flow is being approximated due to weak secondary flow vortices. The data is presented again in Figures 4.16 to 4.20 using the modified Dean number, Dn*, for comparison with Eqn (2.4). As can be seen, the data is usually low, but generally falls in a bandwidth of +5% to -15% for coils 1 to 4 and somewhat more for coil 5 . This is an acceptable comparison since the actual water data of Mishra and Gupta falls into a scatter bandwidth of +10% to - 20%, and also due to the limited amount of data taken in this study.

It should be noted that in coiled tubes a straight tube flow approximation is generally approached for an increasing diametral ratio (D/d) or pitch ratio (h/d). However coil 5 , when compared to the other coils of high pitch, exhibits the same trend for a decreasing diametral ratio, although its three dimensional curvature parameter, (Dc/d), is seen to be double that of the other test sections, as previously noted in Table 4.1. This information, with the noted position of coil 5 in Figure 4.2, demonstrates the general validity of the modified Dean number with respect to isothermal flow. This is also confirmed by the composite friction factor plots of coils 1 to 5 in Figures 4.21 to 4.23. These figures also

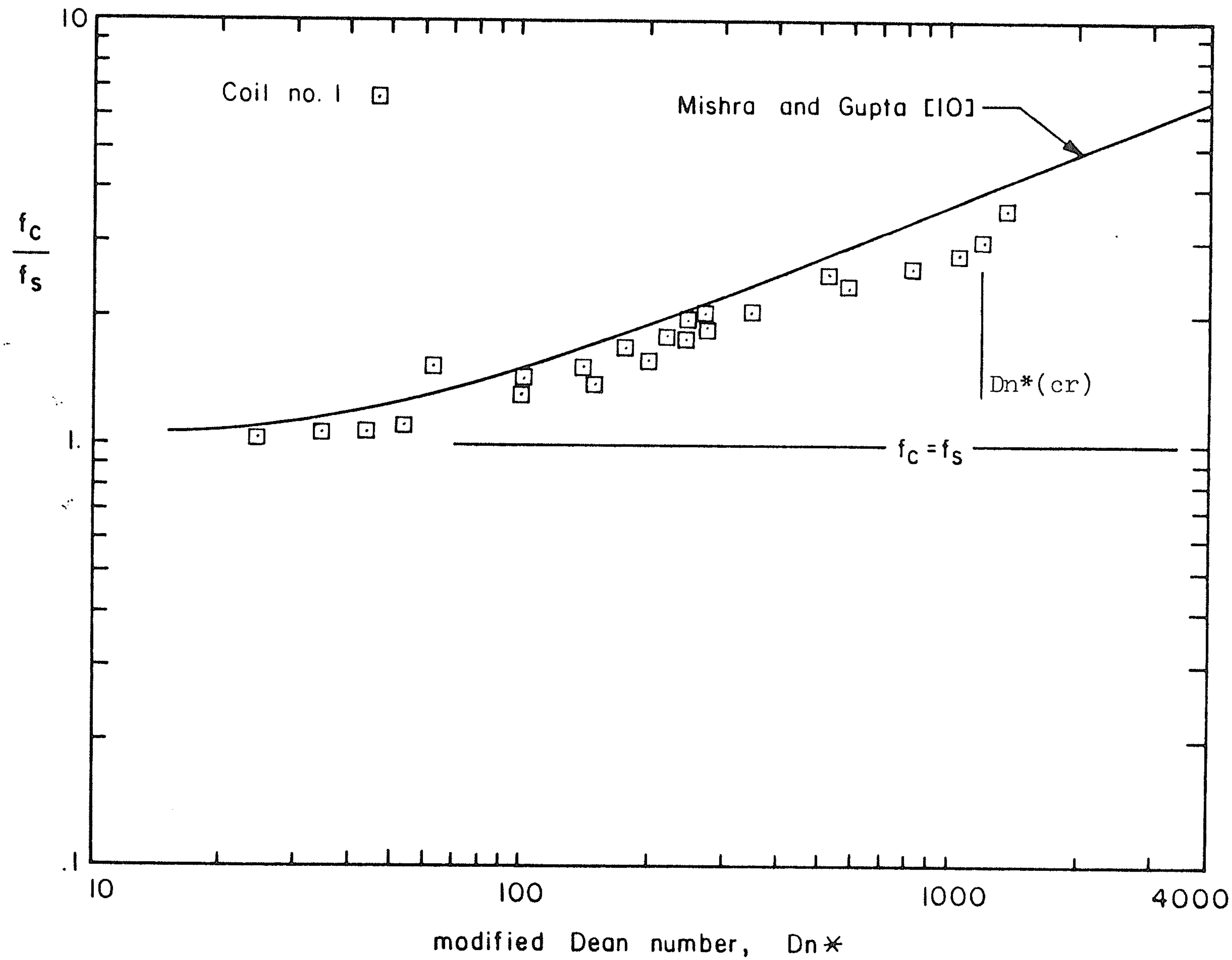


Figure 4.16: Isothermal Friction Factor Ratio: Coil No.1 Compared with Mishra and Gupta

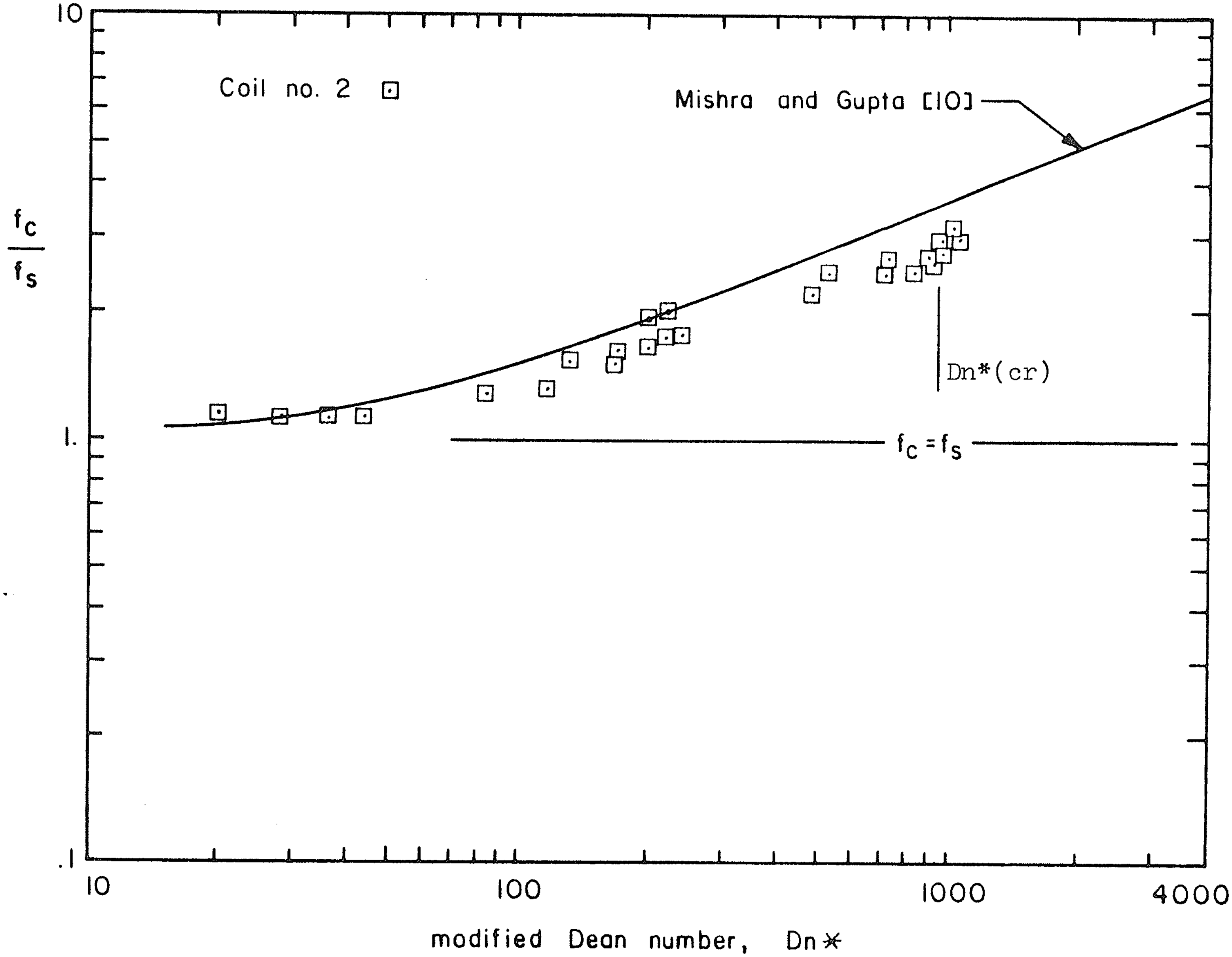


Figure 4.17: Isothermal Friction Factor Ratio: Coil No.2 Compared with Mishra and Gupta

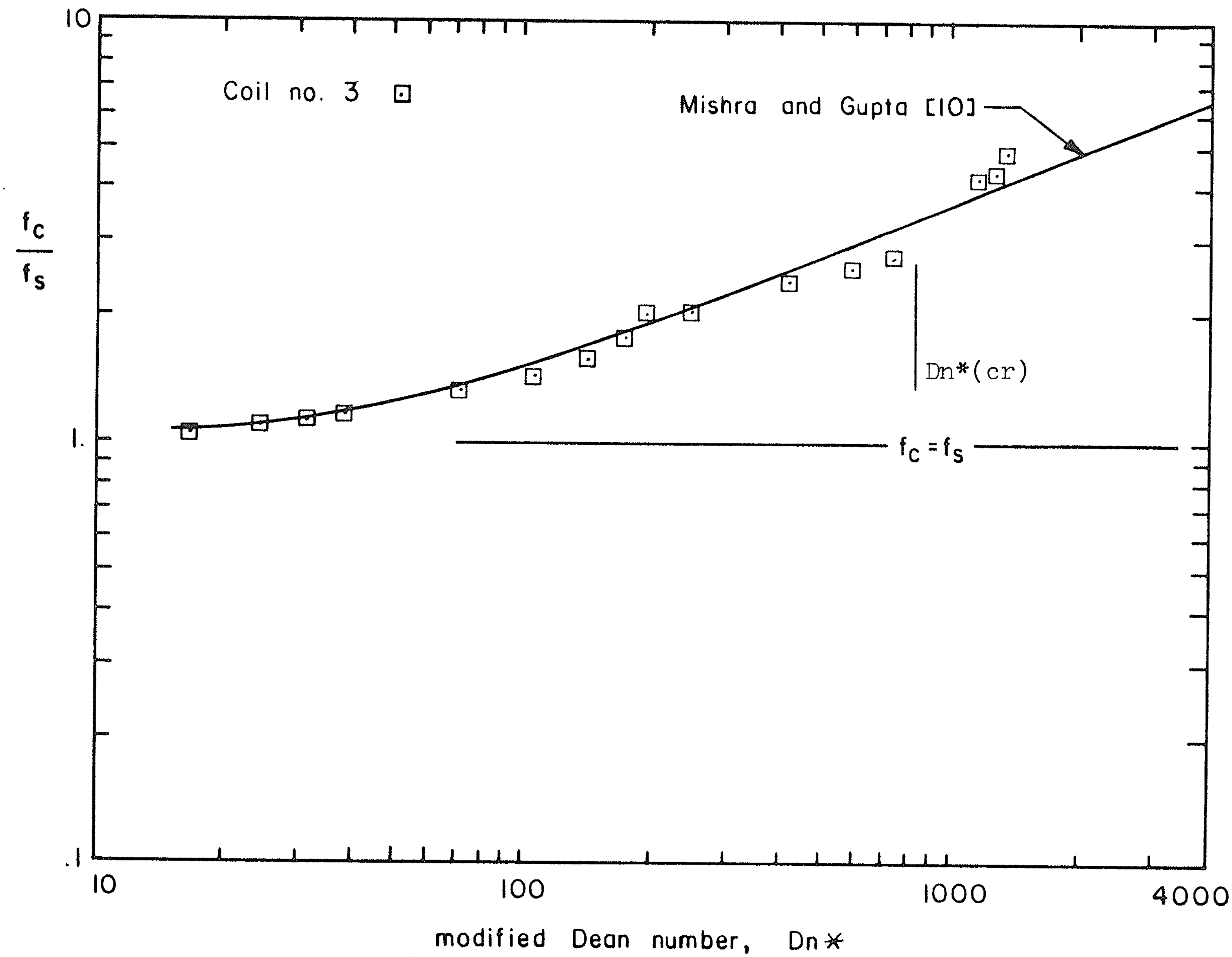


Figure 4.18: Isothermal Friction Factor Ratio: Coil No.3 Compared with Mishra and Gupta

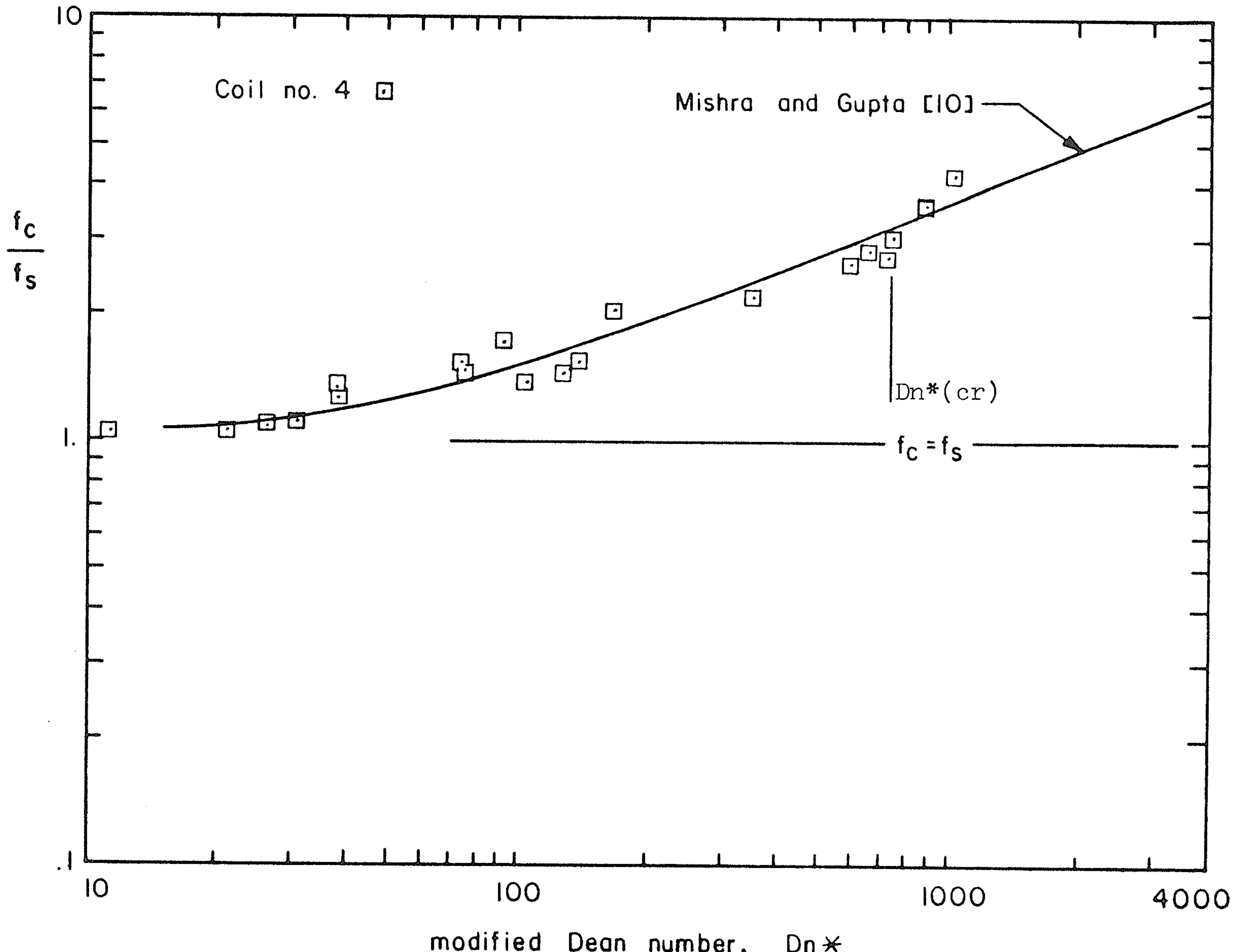


Figure 4.19: Isothermal Friction Factor Ratio: Coil No.4 Compared with Mishra and Gupta

4

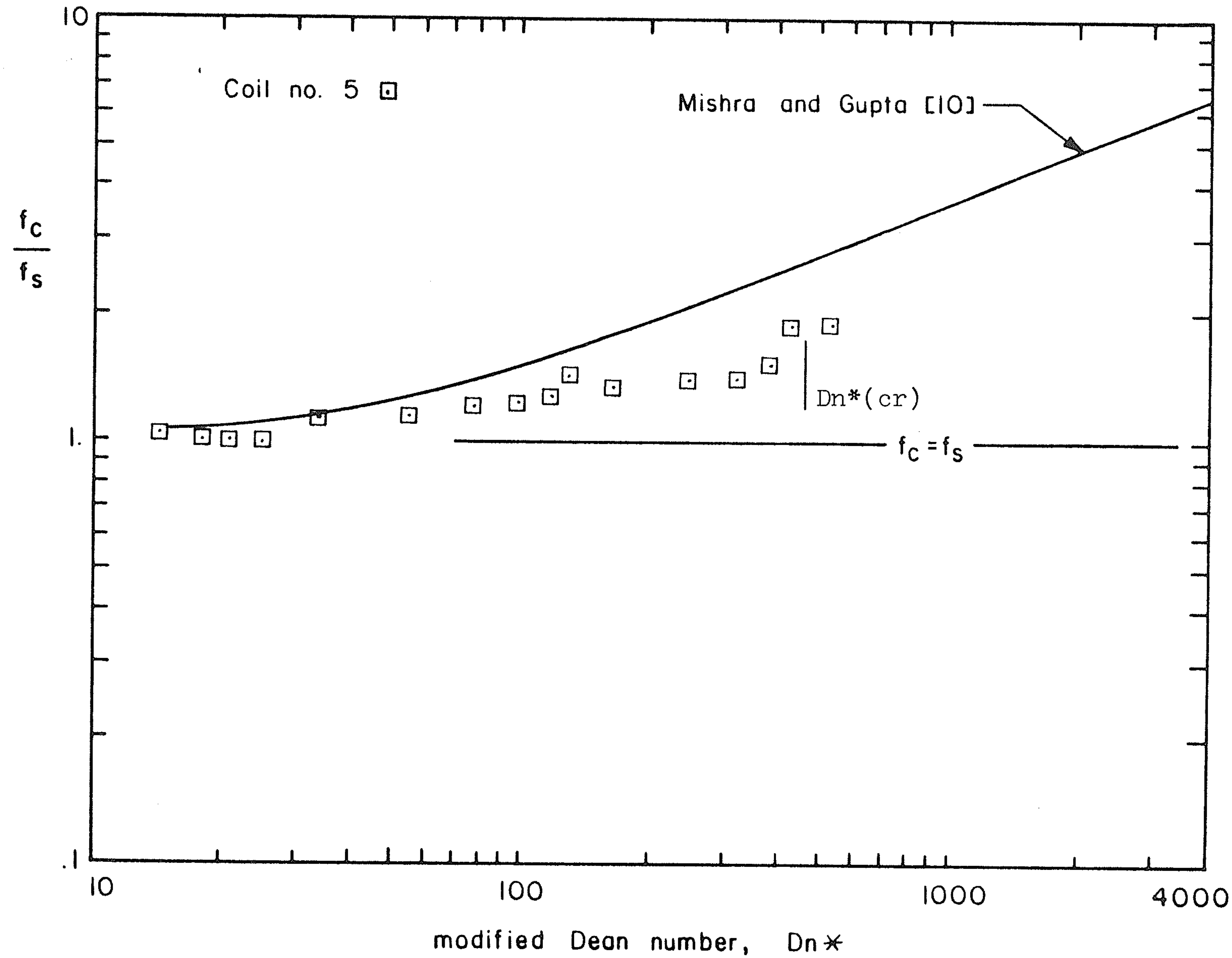


Figure 4.20: Isothermal Friction Factor Ratio: Coil No.5 Compared with Mishra and Gupta

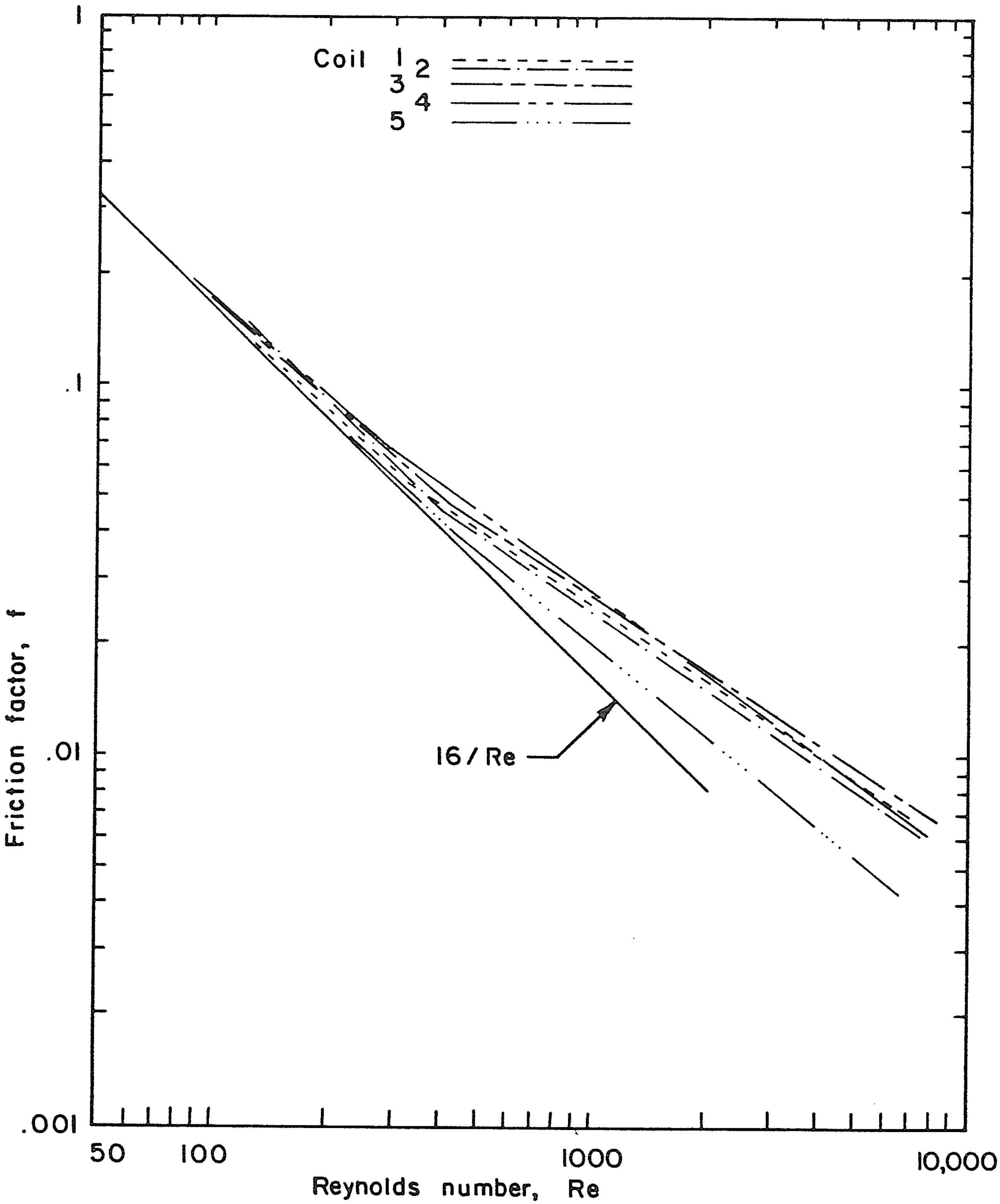


Figure 4.21: Isothermal Friction Factors of All Coils

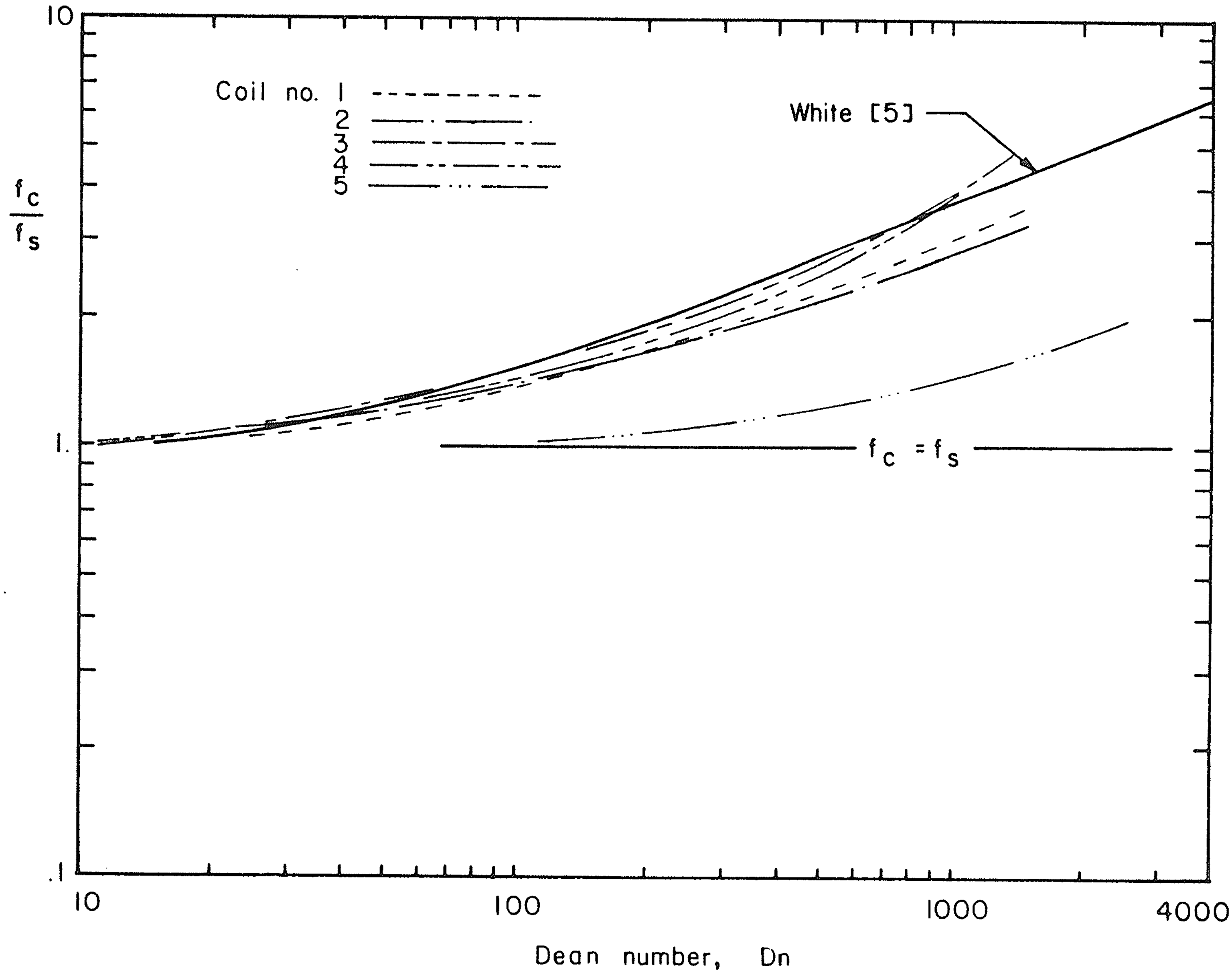


Figure 4.22: Isothermal Friction Factors of All Coils Compared with White

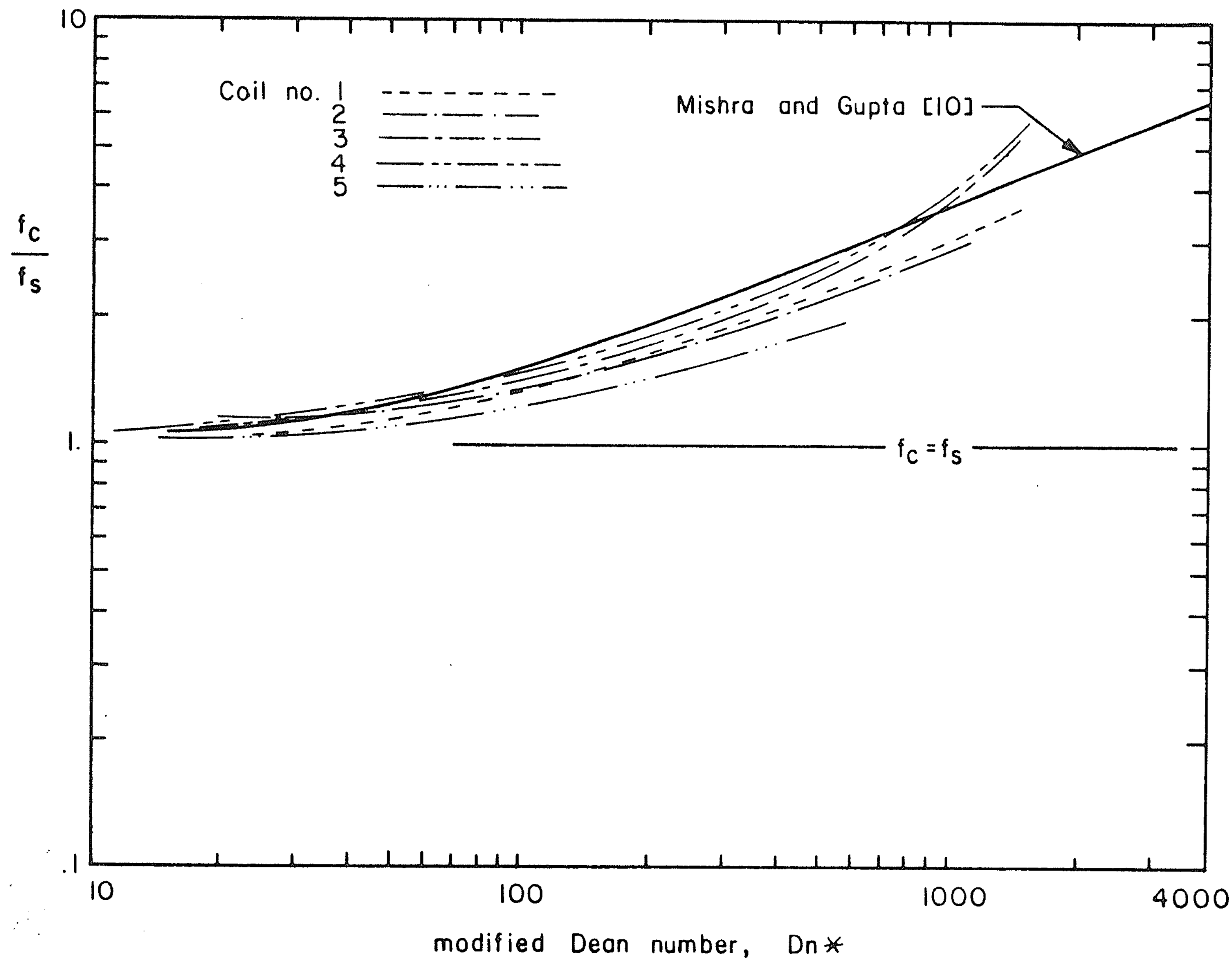


Figure 4.23: Isothermal Friction Factors of All Coils Compared with Mishra and Gupta

illustrate the close similarity of geometry for coils 1 to 4 . The data for coil 5 , however, in exhibiting a larger deviation from Eqn (2.4) than coils 1 to 4 , may be indicating that the modified Dean number alone is insufficient as a correlating parameter.

A final test of the modified Dean number is to use it as a substitute for the standard Dean number and effectively modify Equation (2.1) for direct comparison with Equation (2.4). Figure 4.24 shows that there is no appreciable difference between the modified White correlation and the correlation of Mishra and Gupta. This is not surprising since Mishra and Gupta noted that when their correlation was used with the Dean number, Dn, the result was in very close agreement with the correlation of White.

4.2.2 Neumann Boundary Condition

The isothermal and non-isothermal friction factors for coils 1 to 4 (top feeding) are compared as a function of the Reynolds number in Figures 4.25 to 4.28. Similar data for the bottom feeding runs was not taken. As can be seen in Figure 4.25 and Figure 4.27, the close pitched coils (1 and 3) exhibit no noticeable change in

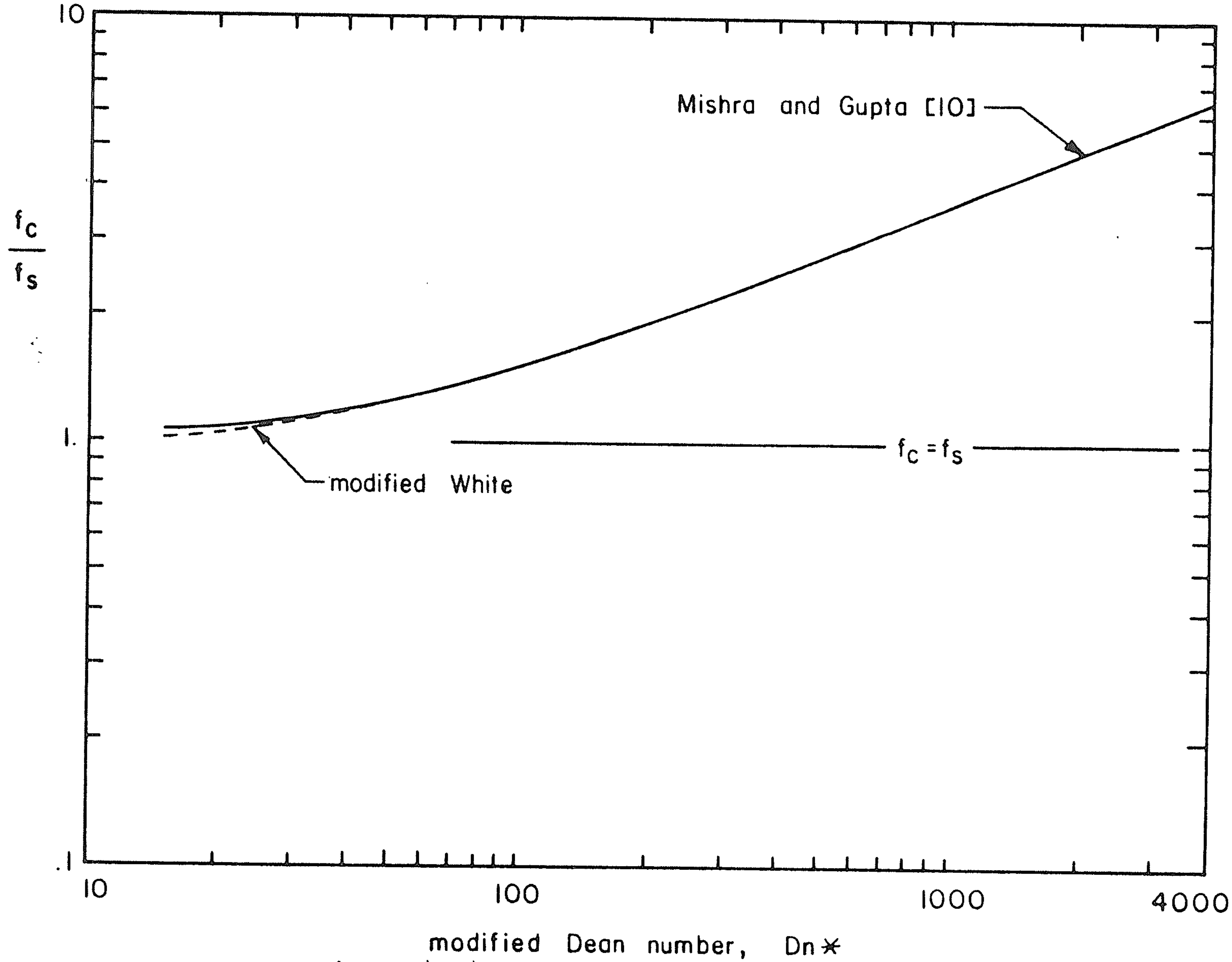


Figure 4.24: Comparison of the Modified Version of White with Mishra and Gupta

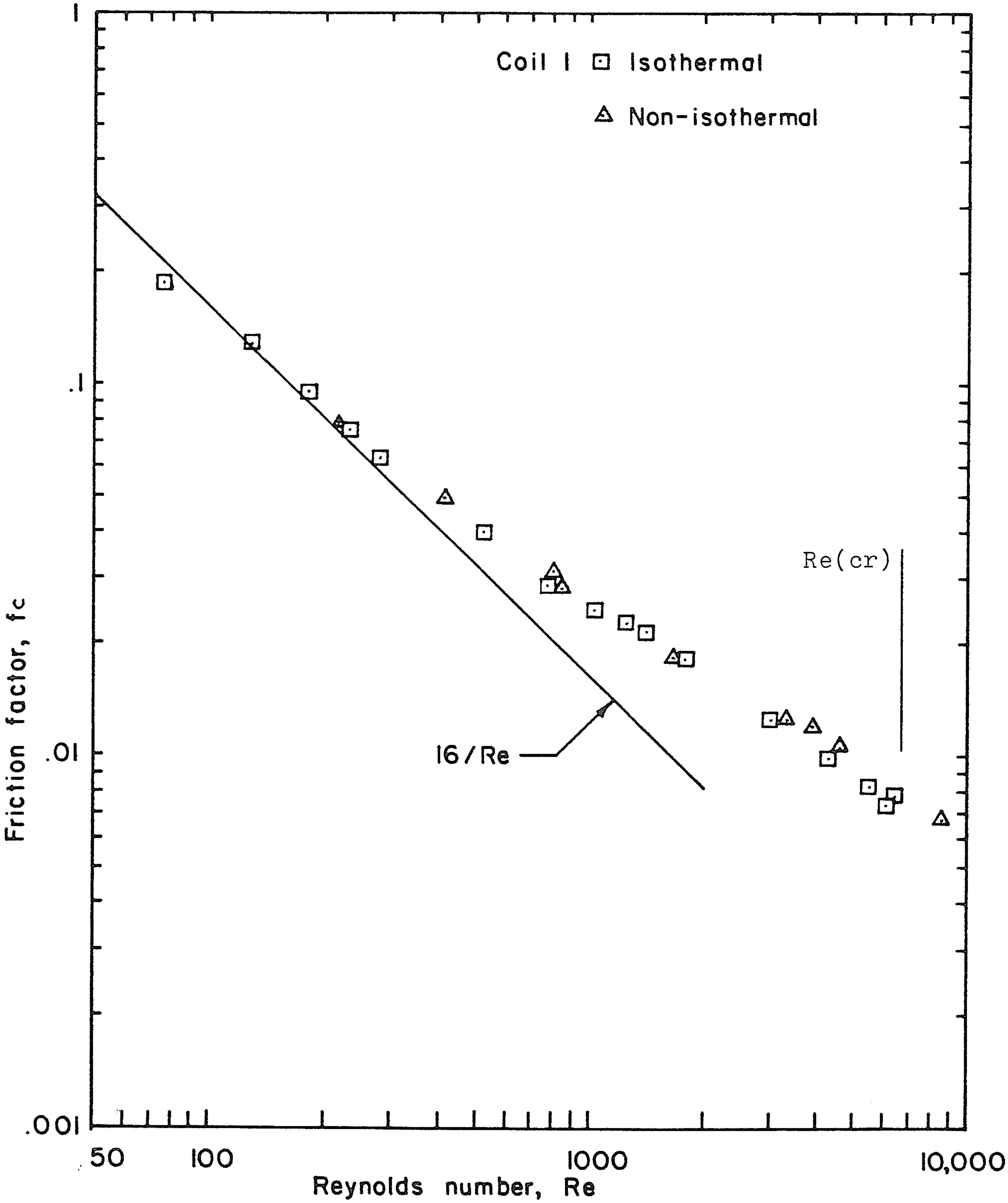


Figure 4.25: The Effect of Heating on Friction Factor: Coil No.1

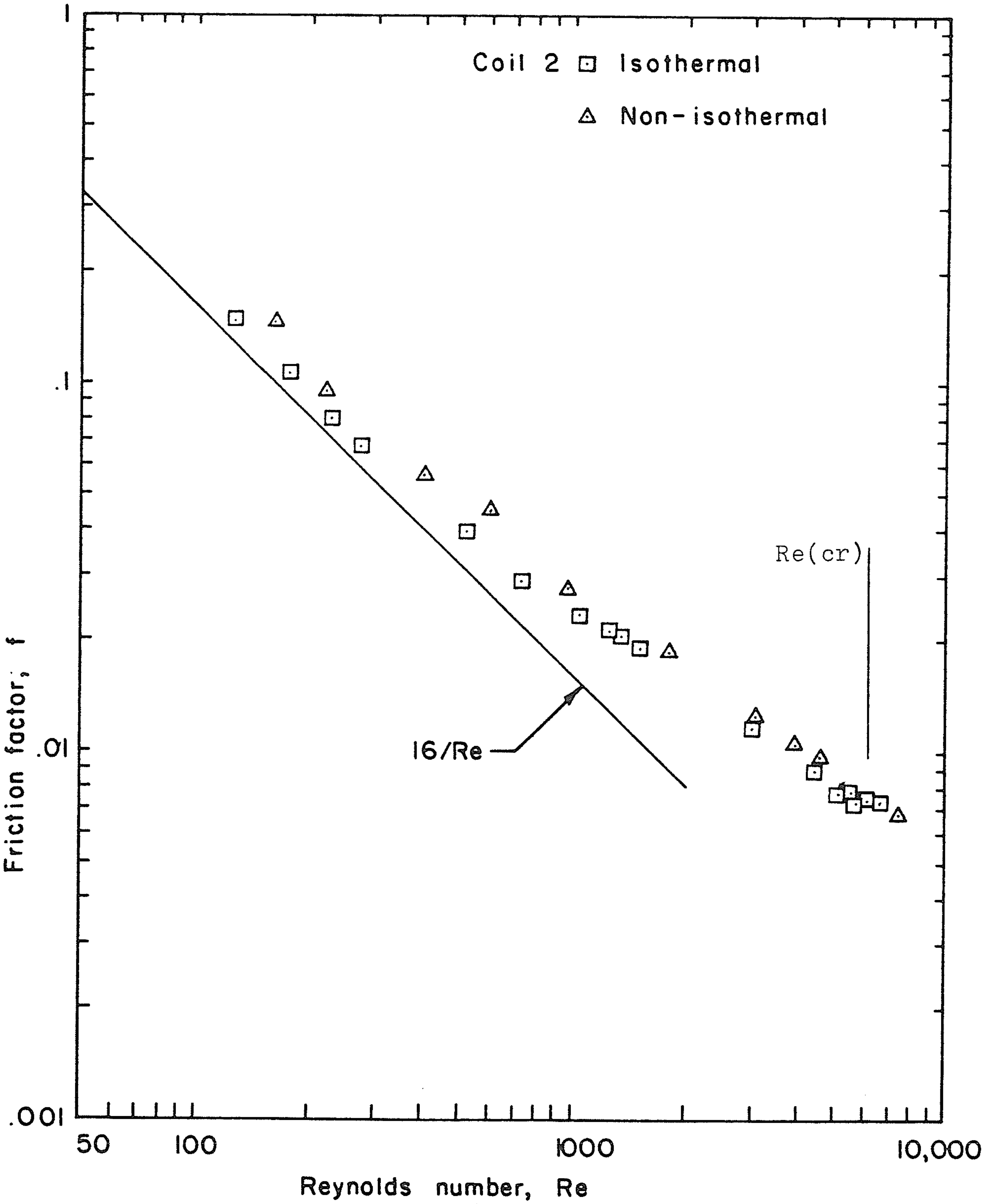


Figure 4.26: The Effect of Heating on Friction Factor: Coil No.2

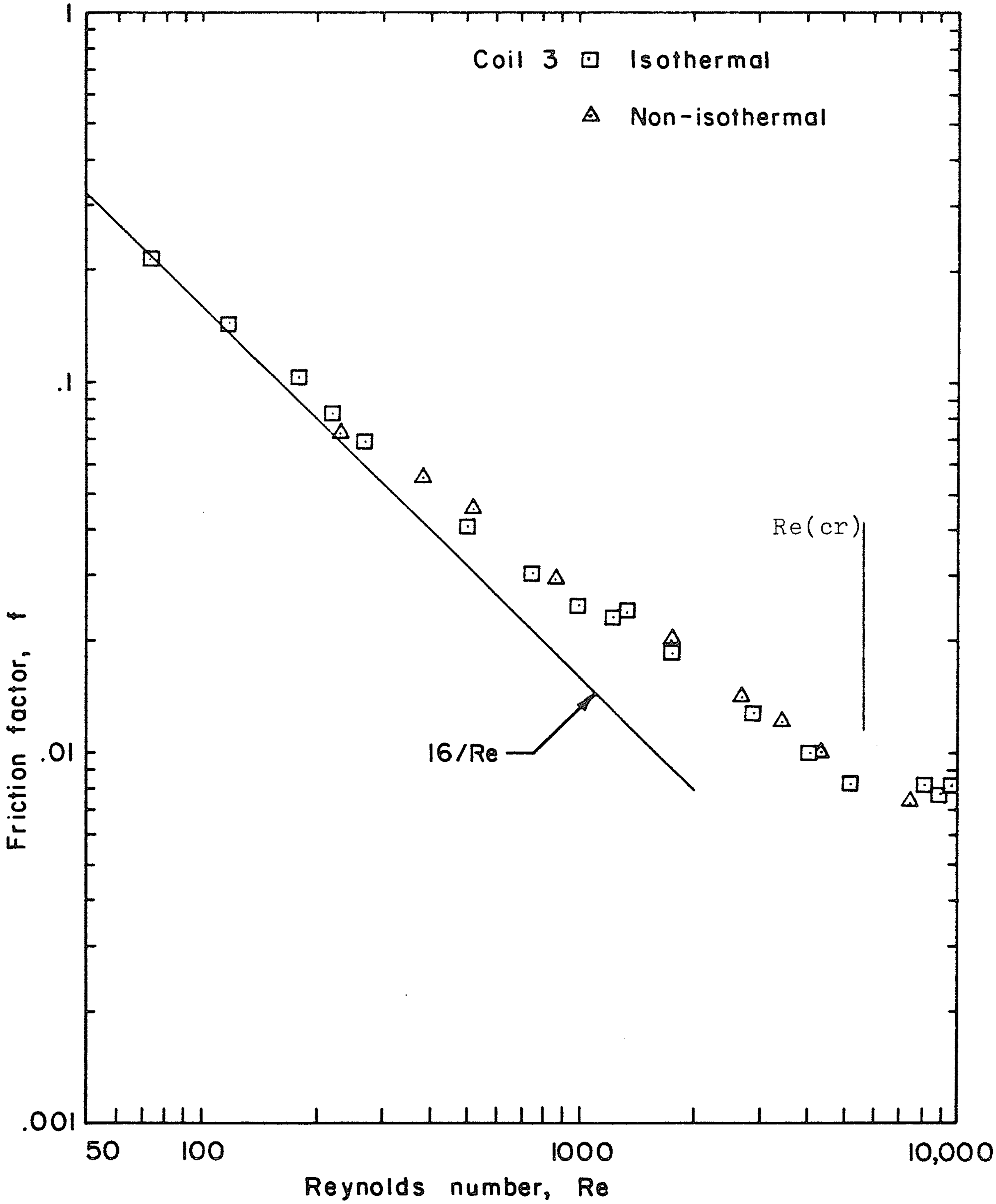


Figure 4.27: The Effect of Heating on Friction Factor: Coil No.3

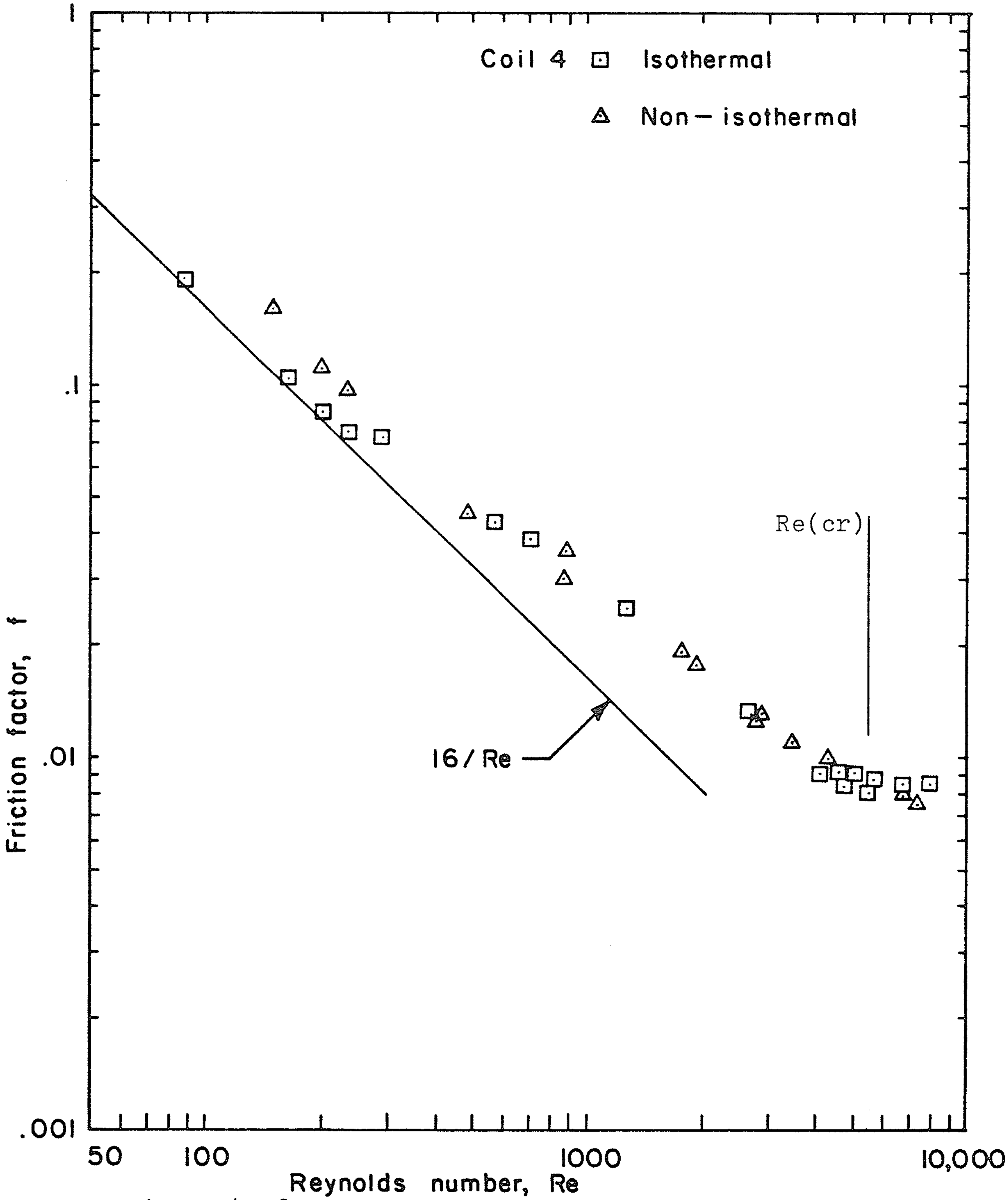


Figure 4.28: The Effect of Heating on Friction Factor: Coil No.4

friction factor during heating under this boundary condition. However, the high pitched coils (2 and 4) demonstrate that there is an effect of pitch at the lower Reynolds numbers as shown in Figure 4.26 and Figure 4.28. For coil 4 , the increased friction factor effect is evident at Reynolds numbers below 300, and is insignificant above Re=400. Coil 2 exhibits an increased friction factor at Reynolds numbers up to 600. From Table 4.1 it is seen that the three dimensional curvature parameter of coil 2 lies between that of coils 1 and 3 , thus eliminating the diametral ratio as a possible influence. Since the heat input per unit mass flow was the same for each of the four coils, the effect of heating on the friction factor is therefore directly attributable to the magnitude of the coil pitch, for a vertically oriented coil axis. The effect is most likely caused by an increase in buoyancy which, for increasing pitch in a vertical axis coil, will increasingly add to the wall shear stress and hence augment the friction factor. The heating effect on the friction factor is also seen to persist to higher Reynolds numbers for coil 2 than coil 4 . This may be attributed to coil 2 having a larger pitch angle than coil 4 , yielding a larger projection of the buoyancy vector in the upstream direction for coil 2 . It is important to note that this phenomenon is seen only at low

Reynolds numbers where, as previously noted, the secondary flow vortices are very weak, and where the flow is approximately parallelling the tube centreline ("one dimensional" flow). As the Reynolds number increases, the vortices strengthen and the centrifugal forces dominate the (now) relatively weak buoyancy forces. In the closely pitched coils, the augmented friction factor is not seen, probably due to the buoyancy vector being almost perpendicular to the flow direction, even at low Reynolds numbers. It is to be expected that no increase in friction factor will occur for a highly pitched coiled tube of horizontal axis. Since its geometric progression is towards a horizontal straight tube, the buoyancy vector will again be perpendicular to the approximate flow direction. Thus, in spite of the relatively minor changes in Dc/d amongst coils 1 to 4, coil orientation and pitch are shown to be able to augment the flow phenomena. Similar effects may be seen in the progressive inclination of a straight tube from horizontal to vertical orientation.

4.3 Heat Transfer Results (Neumann Boundary Condition)

The experimental procedure employed was as described in chapter 3 with most runs conforming approximately to:

$$Qe/\dot{m} = c_p \Delta T \doteq \text{constant}$$

This restriction was employed to limit variation of the fluid properties between different runs and coil test data, and to prevent low Reynolds number flows from boiling since most bulk inlet temperatures were near 40°C.

4.3.1 Circumferential Wall Temperature Variation

The circumferential variation of tube wall temperatures was not significant in this study due to the small tube diameter of the test sections. Herein, only the local average is reported in Appendix G based on the innermost and outermost tubewall points in the direction of the three dimensional curvature. The maximum observed variation in a thermocouple pair at any axial location was about 1°C. This was observed in the high mass flow tests and decreased to zero toward the low mass flow tests, for all coils. The parameter governing this variation is, of course, the strength of the secondary flow field vortices, which in turn is proportional to some function of the Reynolds number or mass flow rate. This variational phenomenon falls directly "in-line" with the previous results for friction factor at low Reynolds numbers.

4.3.2 Fully Developed Nusselt Number (Top Feeding)

The results for the fully developed Nusselt number in the top feeding (downward) flow direction were calculated as an average of axial stations numbered 3 to 18 since the hydrodynamic pressure drop results indicated an extremely short developing length. The results are presented as a function of the Reynolds number in Figures 4.29 to 4.32 as compared to the straight tube correlations of Sieder and Tate [58]. The Sieder and Tate curves have been calculated using the present experiment's observed ranges of Prandtl number and the viscosity ratio factor, $(\mu b/\mu w)^{.14}$, and for two different coil lengths. The observed average Prandtl number varied from 3 to 6.3 while the viscosity ratio factor varied only between 1.00 and 1.02, since the maximum wall to bulk temperature difference was 3°C. As illustrated in Figures 4.29 to 4.32, the laminar flow Nusselt number is in considerable excess with respect to both the laminar correlation of Sieder and Tate [58] and the accepted analytical laminar value of 4.36. These figures are presented to show the basic Nusselt number data, and also to illustrate that ratios of Nuc/Nus, as previously noted in chapter two, can be misleading since Nus is usually taken as 4.36. Figures 4.29 to 4.32 also indicate that, for Reynolds numbers above 5000, there may be little

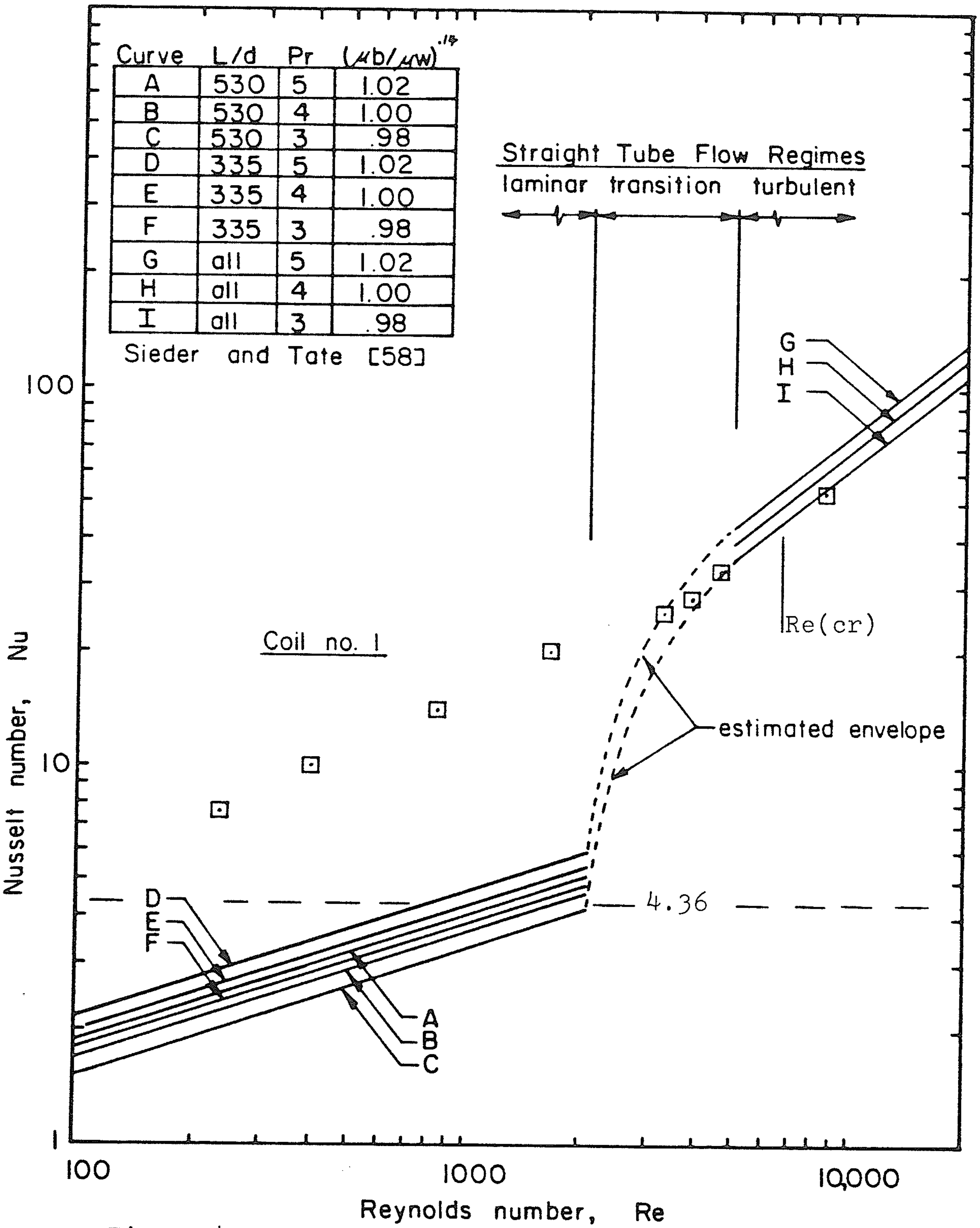


Figure 4.29: Fully Developed Nusselt Number for the Neumann Boundary Condition: Coil No.1

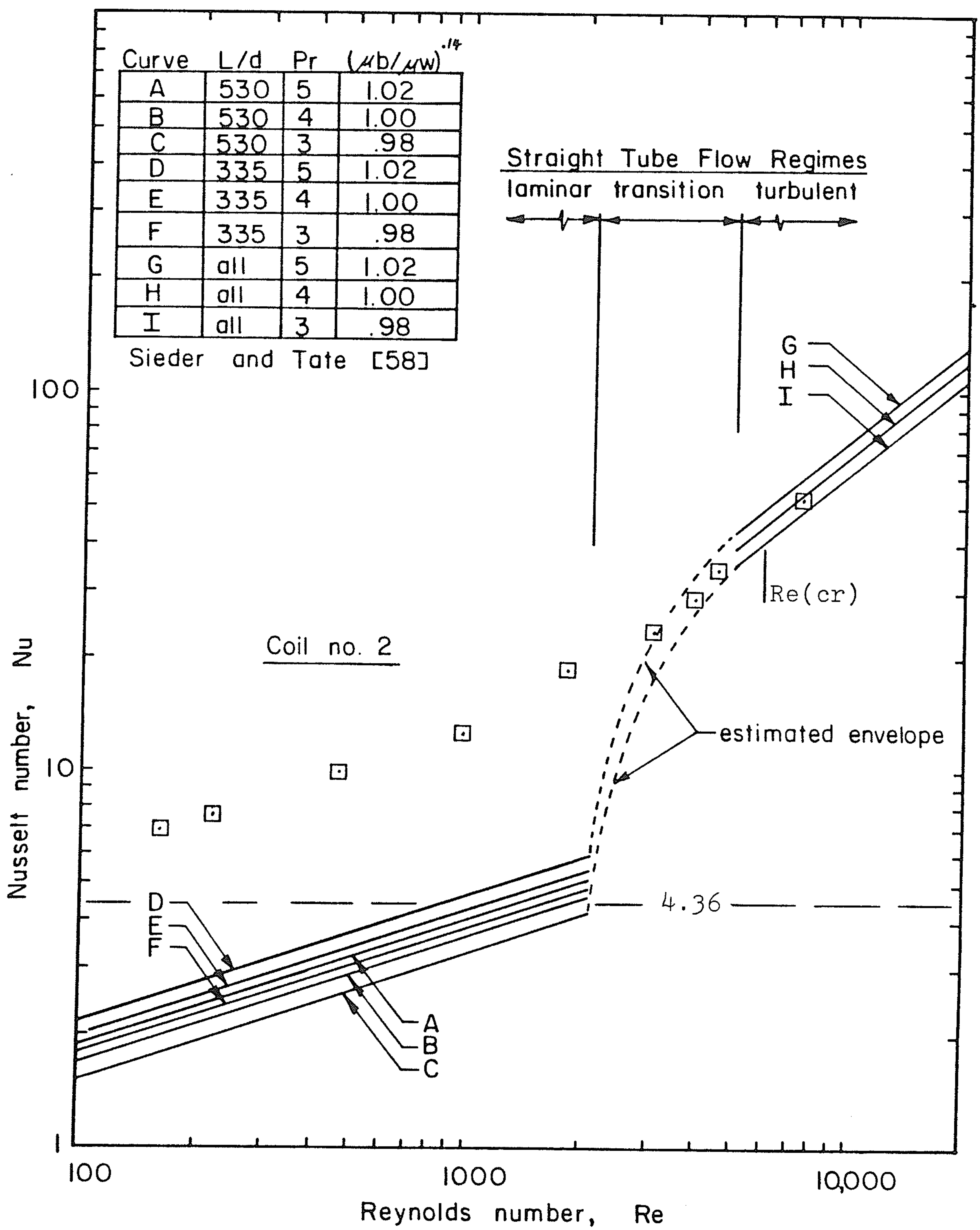


Figure 4.30: Fully Developed Nusselt Number for the Neumann Boundary Condition: Coil No.2

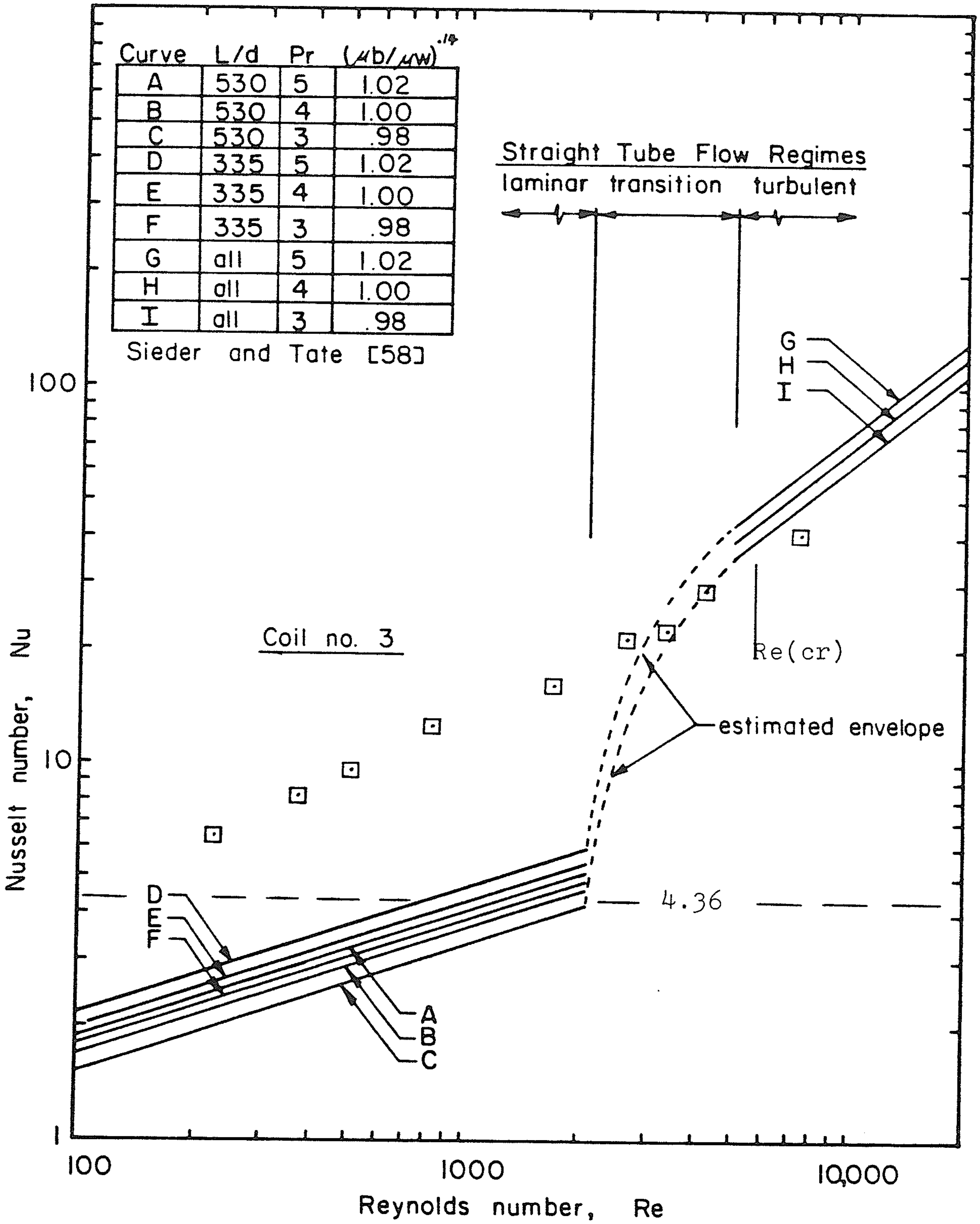


Figure 4.31: Fully Developed Nusselt Number for the Neumann Boundary Condition: Coil No.3

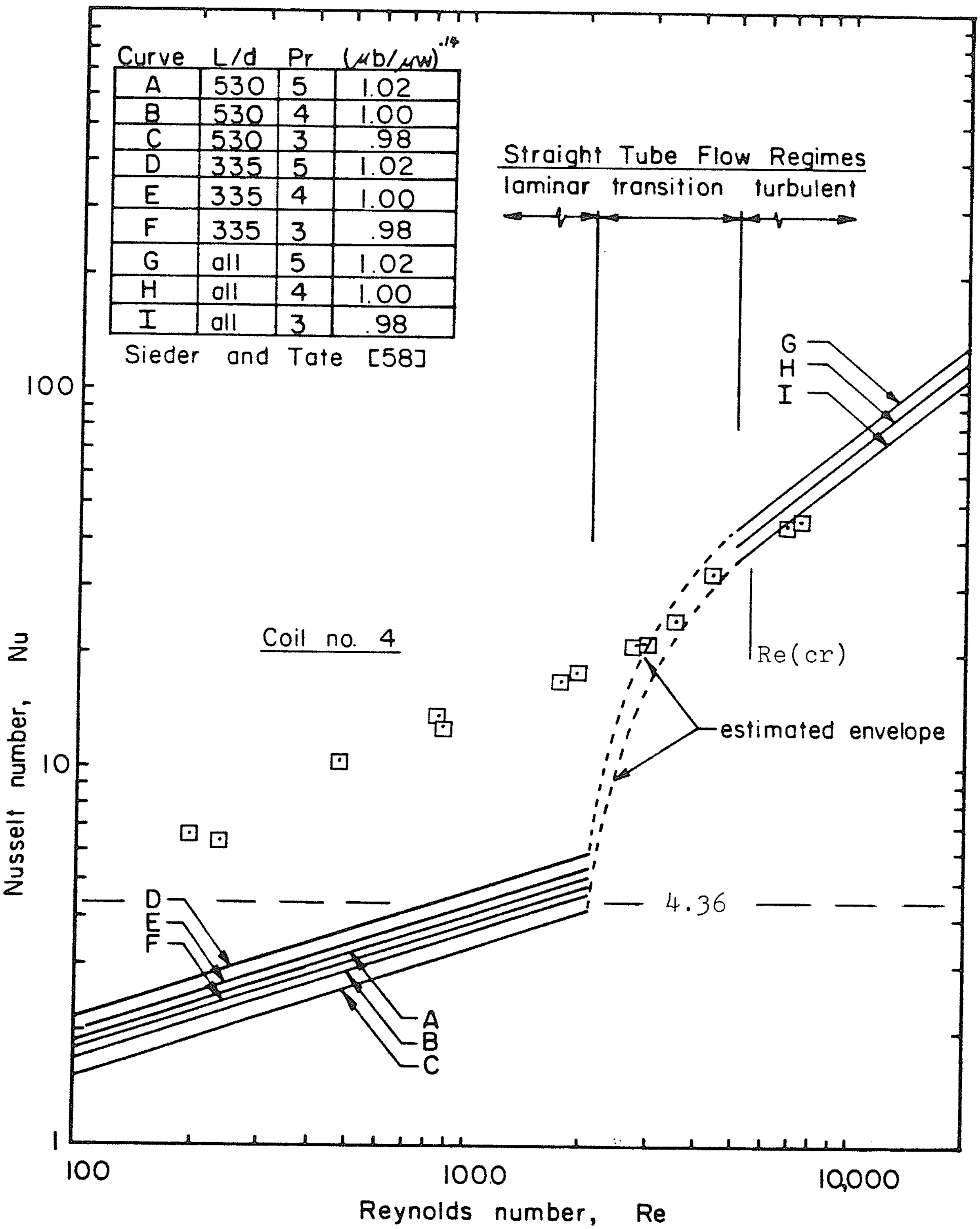


Figure 4.32: Fully Developed Nusselt Number for the Neumann Boundary Condition: Coil No.4

difference between the coiled tubes of the present study and straight tube heat transfer. This point, however, is subject to further discussion later in this subsection.

The Nusselt number results for coil pairs of constant diametral ratio are presented as a function of the Dean number in Figure 4.33 and Figure 4.34 to provide a datum prior to comparison with experimental correlations found in the literature. As can be seen, no effect of pitch is evident for coil pairs of constant diametral ratio. The results are compared with Eqn (2.6) in Figure 4.35 and Figure 4.36, after being re-formulated in such a way as to eliminate the effects of properties. The correlation is plotted along with an indicated bandwidth of ± 20%, although the estimated error in the present Nusselt numbers is only ±15% as noted in Appendix C. As illustrated in Figures 4.33 to 4.36, there appears to be little, if any, difference in Nusselt number between the high and low pitched coils at constant diametral ratio, within the limits of experimental error. This substantiates the expectations of the preliminary analysis based on Figure 4.2. In comparison with the correlation of Dravid et al. [15], the data is seen to be in good agreement at lower Dean numbers, but becoming increasingly less in agreement (on the high side) as the Dean number rises toward its

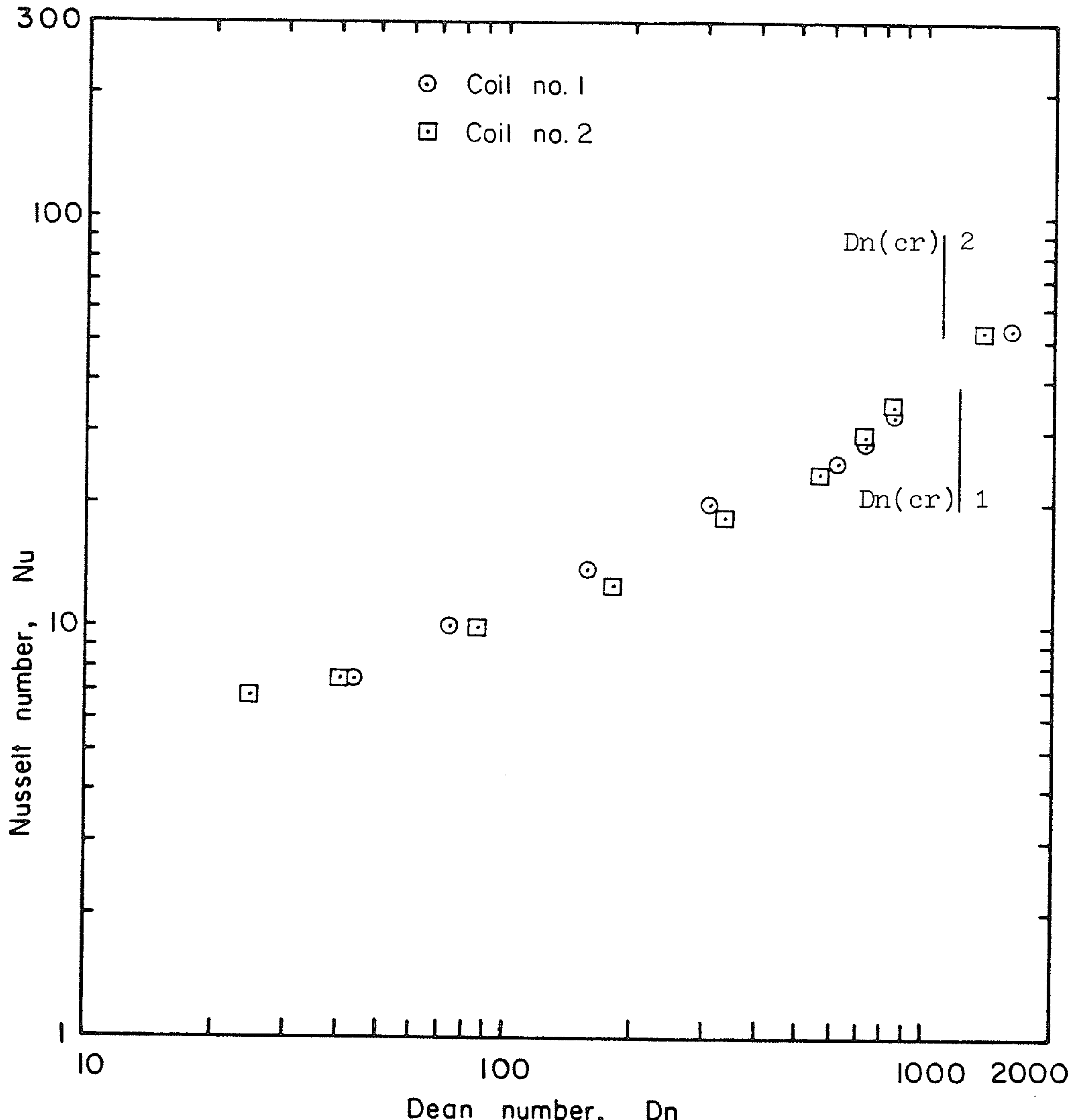


Figure 4.33: Fully Developed Nusselt Number for the Neumann Boundary Condition: Coils No.1 and No.2

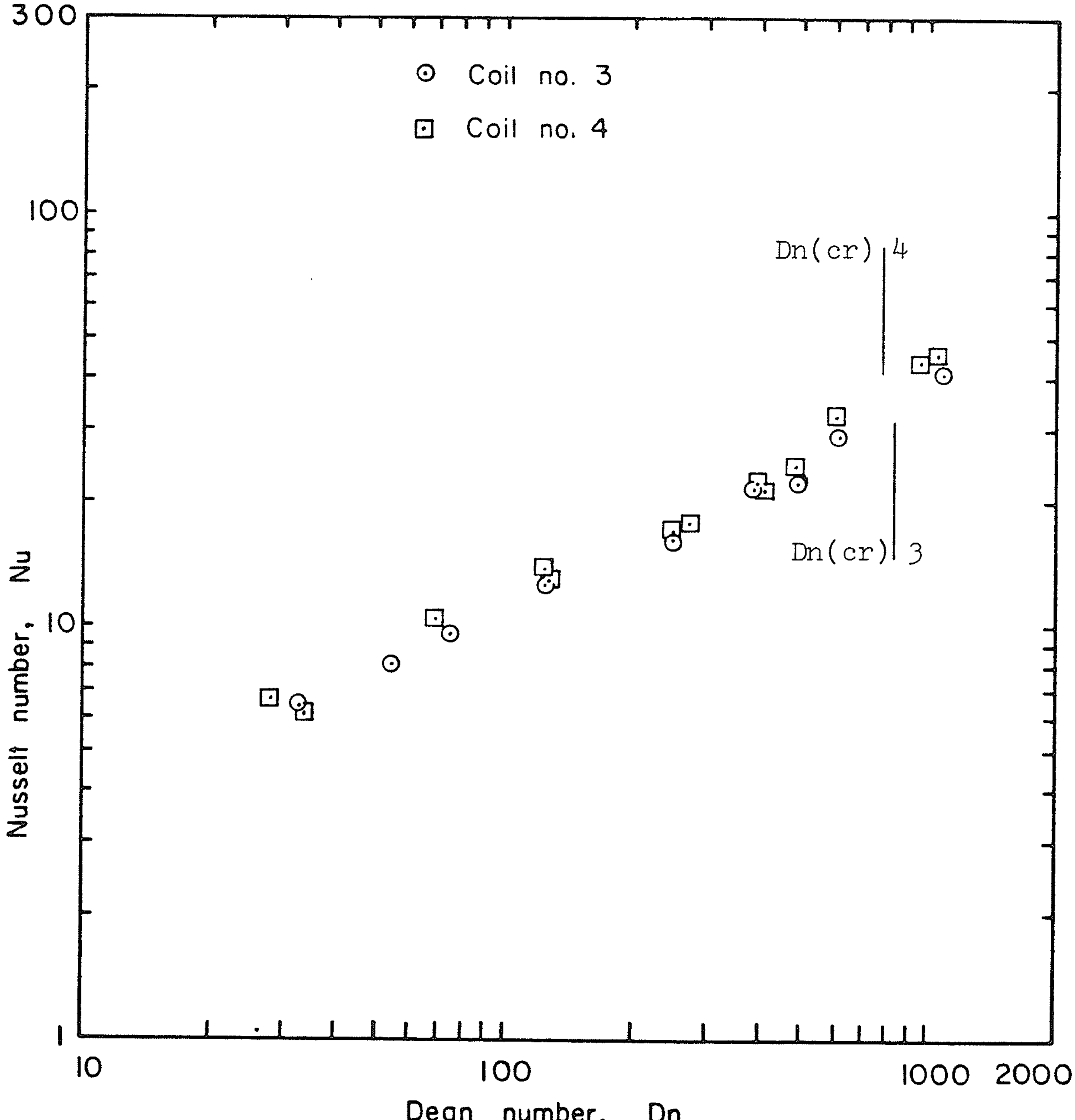


Figure 4.34: Fully Developed Nusselt Number for the Neumann Boundary Condition: Coils No.3 and No.4

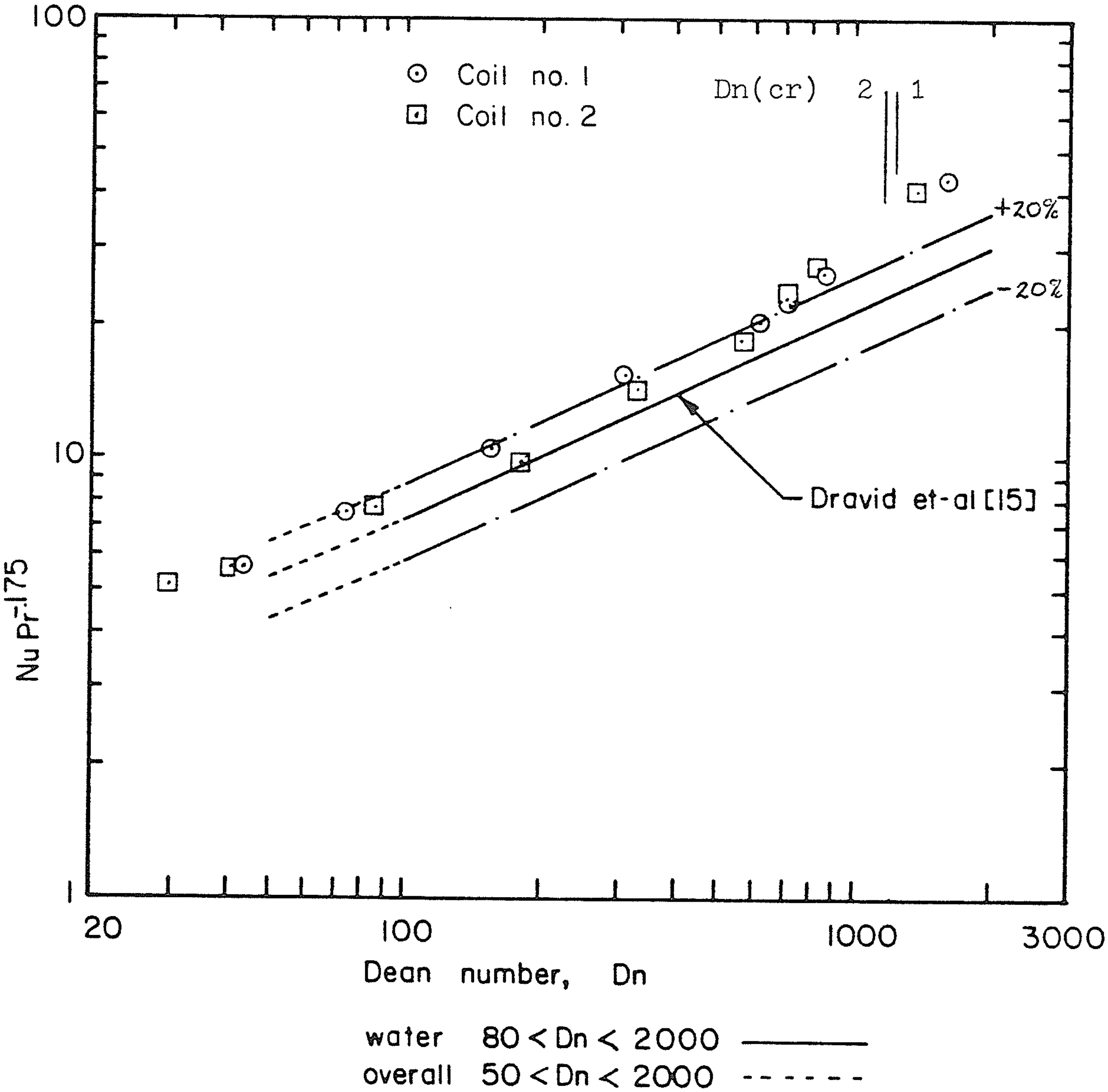


Figure 4.35: Comparison of Coils 1 and 2 with Dravid et al.

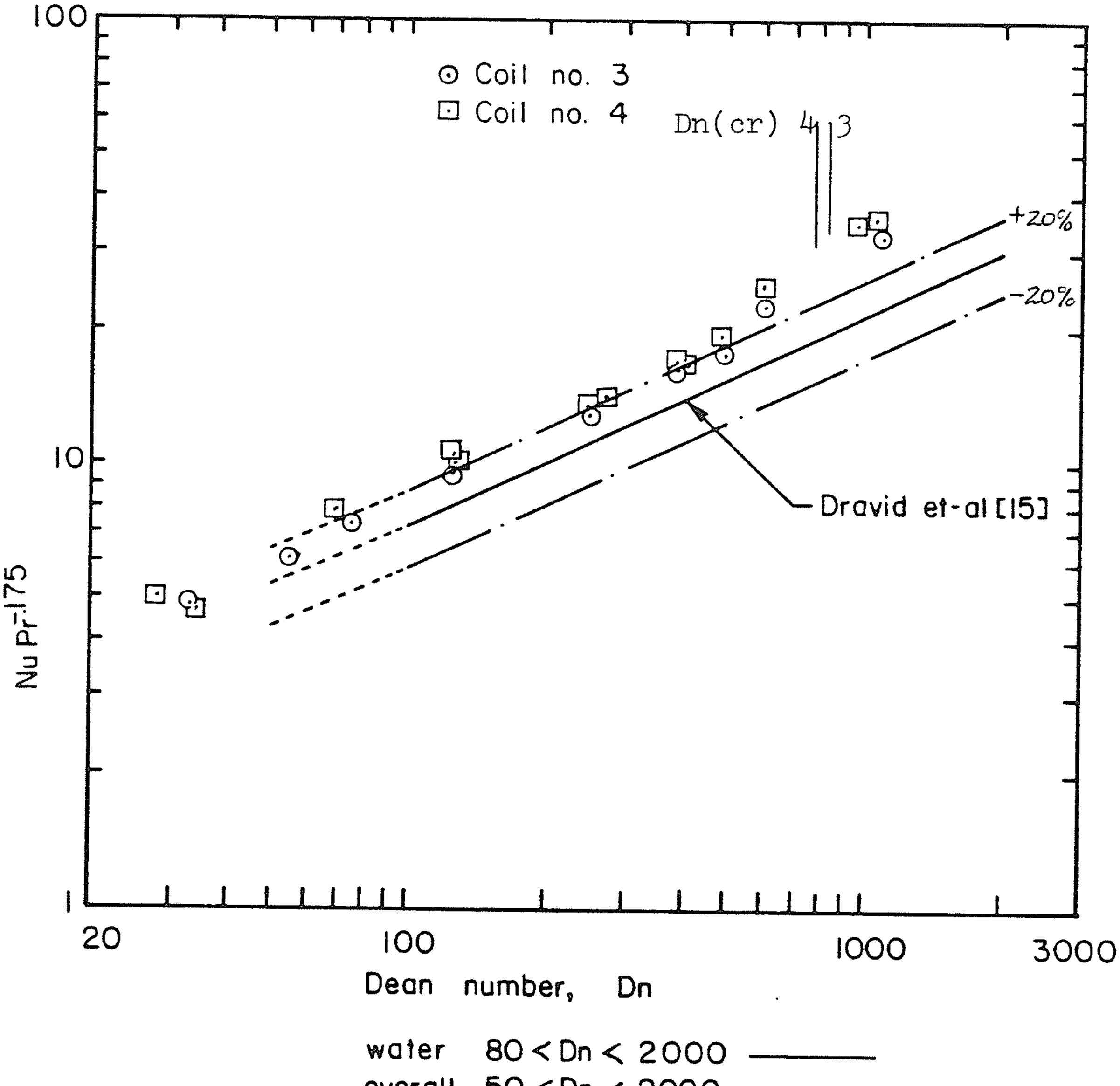


Figure 4.36: Comparison of Coils 3 and 4 with Dravid et al.

critical (transition) value. It should be noted, however, that this may be due in part to the increase in the magnitude of the thermal entry length as the Dean number increases. Since the Nusselt numbers shown are averages for the respective test sections, they may contain some bias toward the high side of the fully developed value, due to progressive inclusion of the thermal entry length. Therefore, as the Dean number increases, the thermal entry length in becoming longer causes the Nusselt number to contain a higher bias compared to the Nusselt numbers at lower values of the Dean number. This, however, is not expected to cause large discrepancies because the flow was seen to be hydrodynamically fully developed over most of the coil length.

It is also recalled from chapter 2 that the correlation of Dravid et al.[15] is based upon estimated asymptotic Nusselt numbers rather than the actual data obtained, so to eliminate the effects of the thermal entry length. In an attempt to comfirm this further, a thermocouple station near, but not at the exit of coil 1 and of coil 2 are compared with the average fully developed values of Nusselt number, under the same conditions. Nusselt number results for station 17 at x/d=440 of coil 1 and station 18 at x/d=446 of coil 2 are presented in Figure 4.37 and Figure 4.38, respectively. As can be seen, there is a significant decrease in the value of Nusselt number at lower Dean numbers, with the differential decreasing to zero as the Dean number increases toward transition. This indicates that using a particular station's Nusselt number can lead to better agreement with the asymptotic correlation of Dravid et al.[15]. Further evidence of this was found by averaging only stations in the centre third of the coil. The majority of the new averages were found to be in better agreement with Eqn (2.6) by up to 5%.

With respect to the Nusselt number data above the critical Dean numbers indicated in Figures 4.35 to 4.38, the larger deviation illustrated may be due to a different trend in the Nusselt number for turbulent or transitional flow. Overall, the data of the present experiment is seen to be in good agreement with Dravid et al.[15].

Another comparison was made with the correlation of Abul-Hamayel and Bell [18] Eqn (2.11), as demonstrated in Figure 4.39 and Figure 4.40, for the average fully developed Nusselt numbers. The correlation of Abul-Hamayel and Bell [18] has been reduced to a shorter form by deletion of all terms utilizing the ratios Gr/Dn^2 and Gr/Re^2

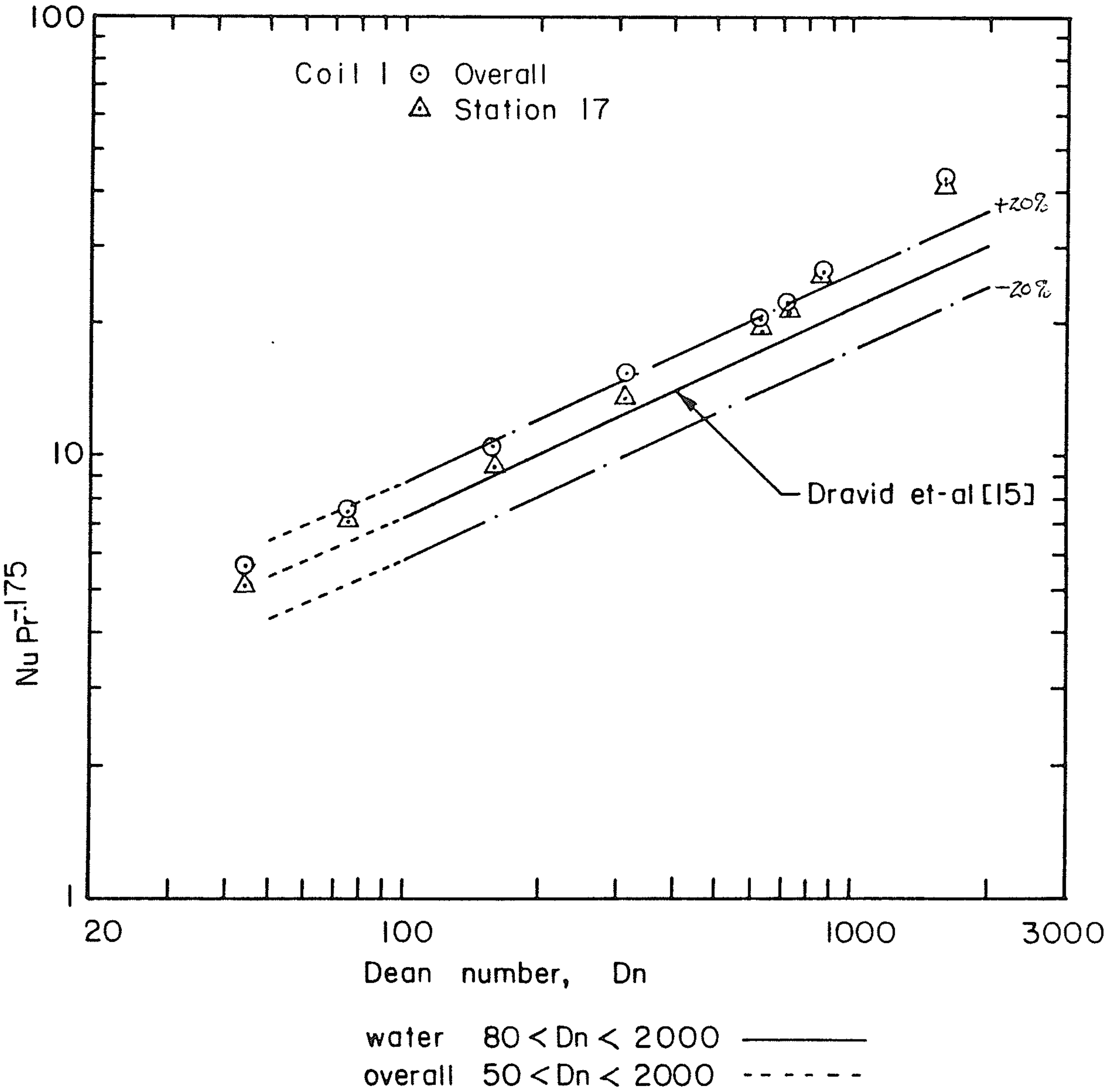


Figure 4.37: Comparison of Coil 1, Station 17 with Dravid et al.

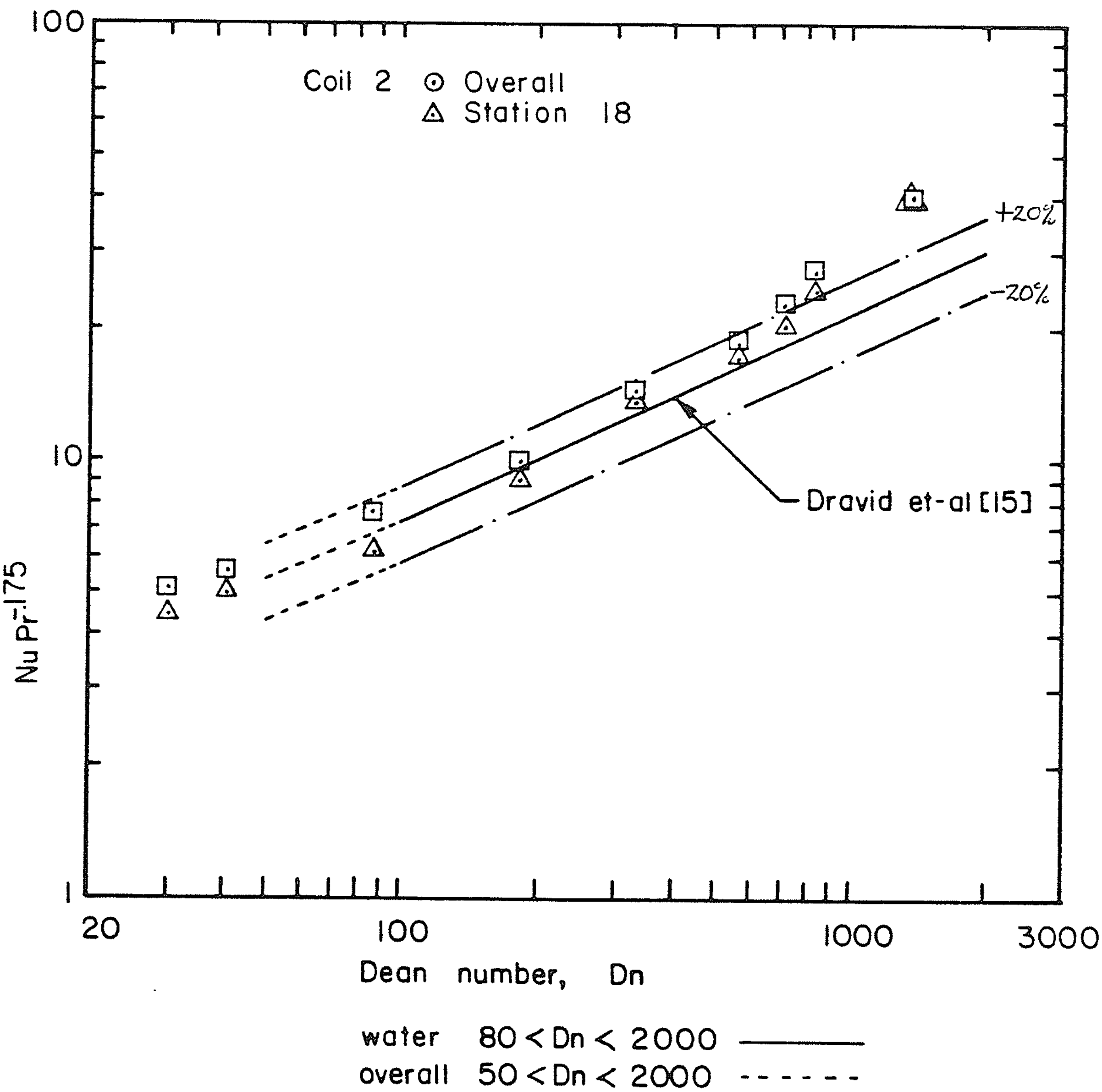


Figure 4.38: Comparison of Coil 2, Station 18 with Dravid et al.

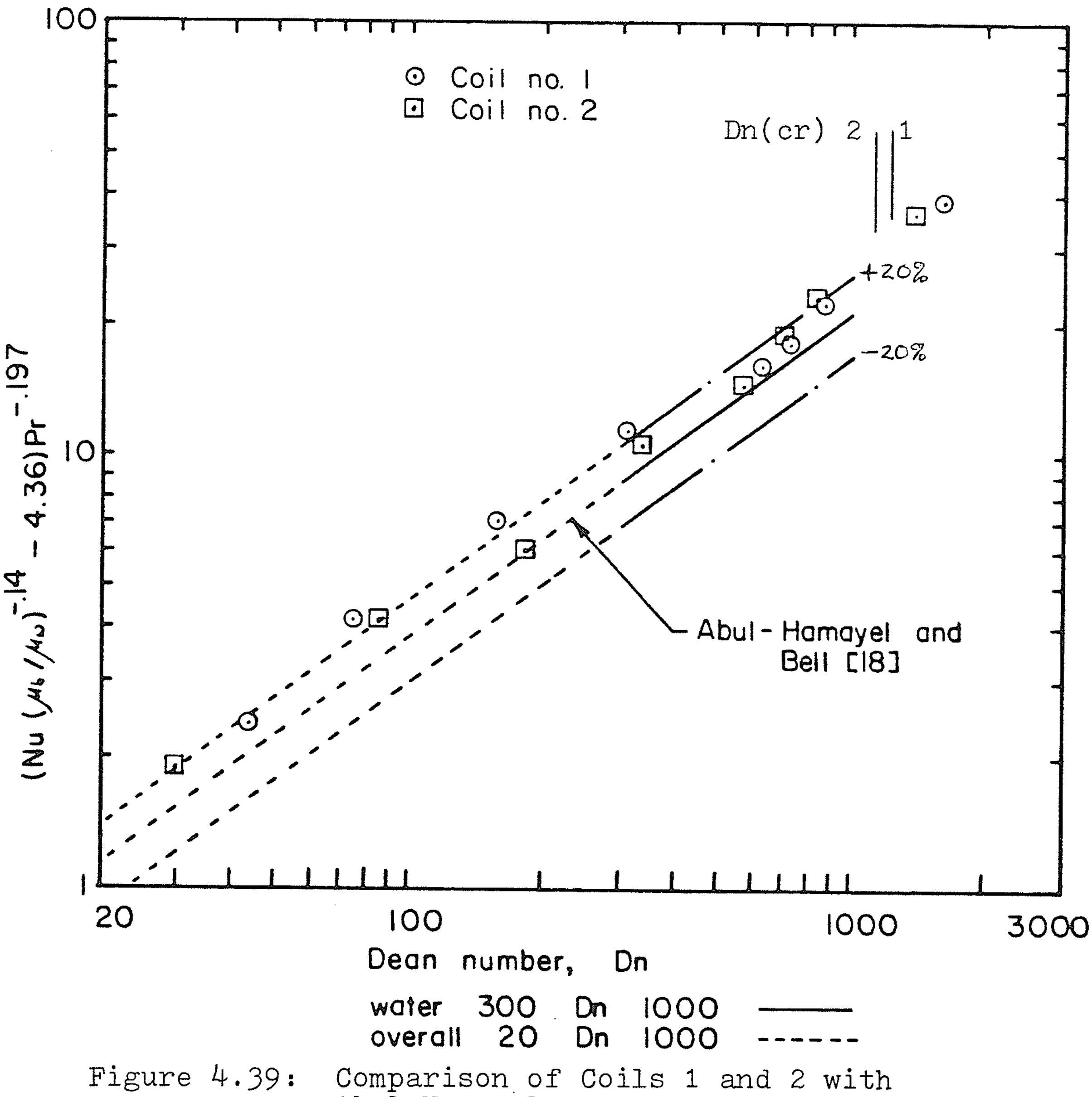


Figure 4.39: Comparison of Coils 1 and 2 with Abul-Hamayel and Bell

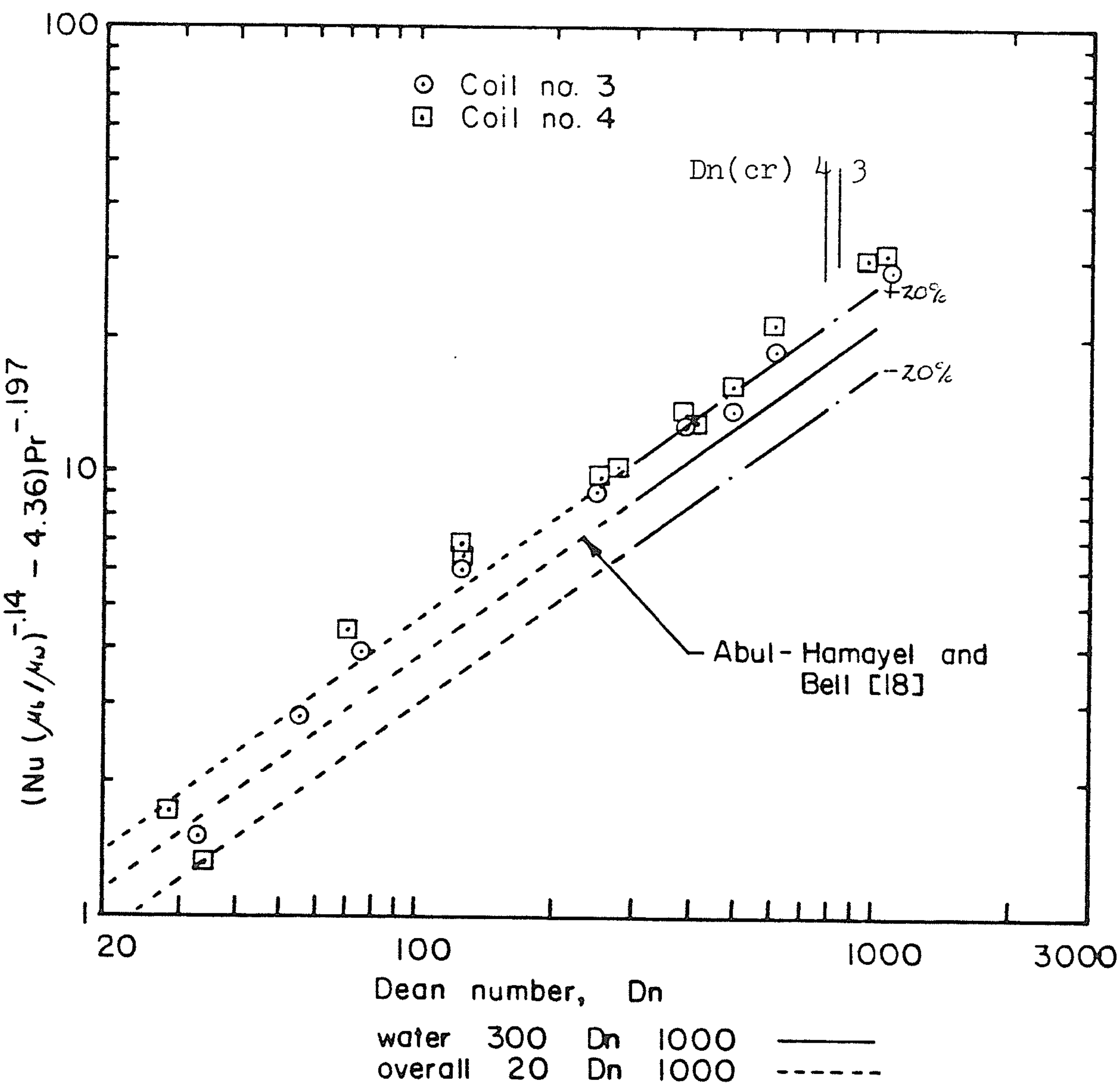


Figure 4.40: Comparison of Coils 3 and 4 with Abul-Hamayel and Bell

due to the very low magnitudes of these parameters observed in the present study. As can be seen, the agreement is similar to that with Dravid et al.[15] except that the form of the correlation of Abul- Hamayel and Bell [18] tends to excessively pronounce the data scatter at low Dean numbers. This may be due in part to the differential of 4.36 in the correlation equation, and in part to the different exponent for the Prandtl number.

The data of the present study is next compared to the only available correlation to include the influence of coil pitch. The Nusselt number results are presented as a function of the modified Dean number in Figure 4.41 and Figure 4.42, and compared with the analytical correlation of Manlapaz and Churchill [33]. Due to the excessive complexity of the correlation, an envelope bounded by the curves of Prandtl number 3 and 5 is plotted with a bandwidth +20% of the upper bound and -20% of the lower bound. As can be seen in Figure 4.41 and Figure 4.42, the agreement is very good for high Dn* and satisfactory for low Dn* for all test sections. However, the high bias found in comparison with Dravid et al.[15] would suggest that this numerical correlation contains some high bias itself, since the minor variation in Dn* for the four test sections is seen to produce negligible differences in the

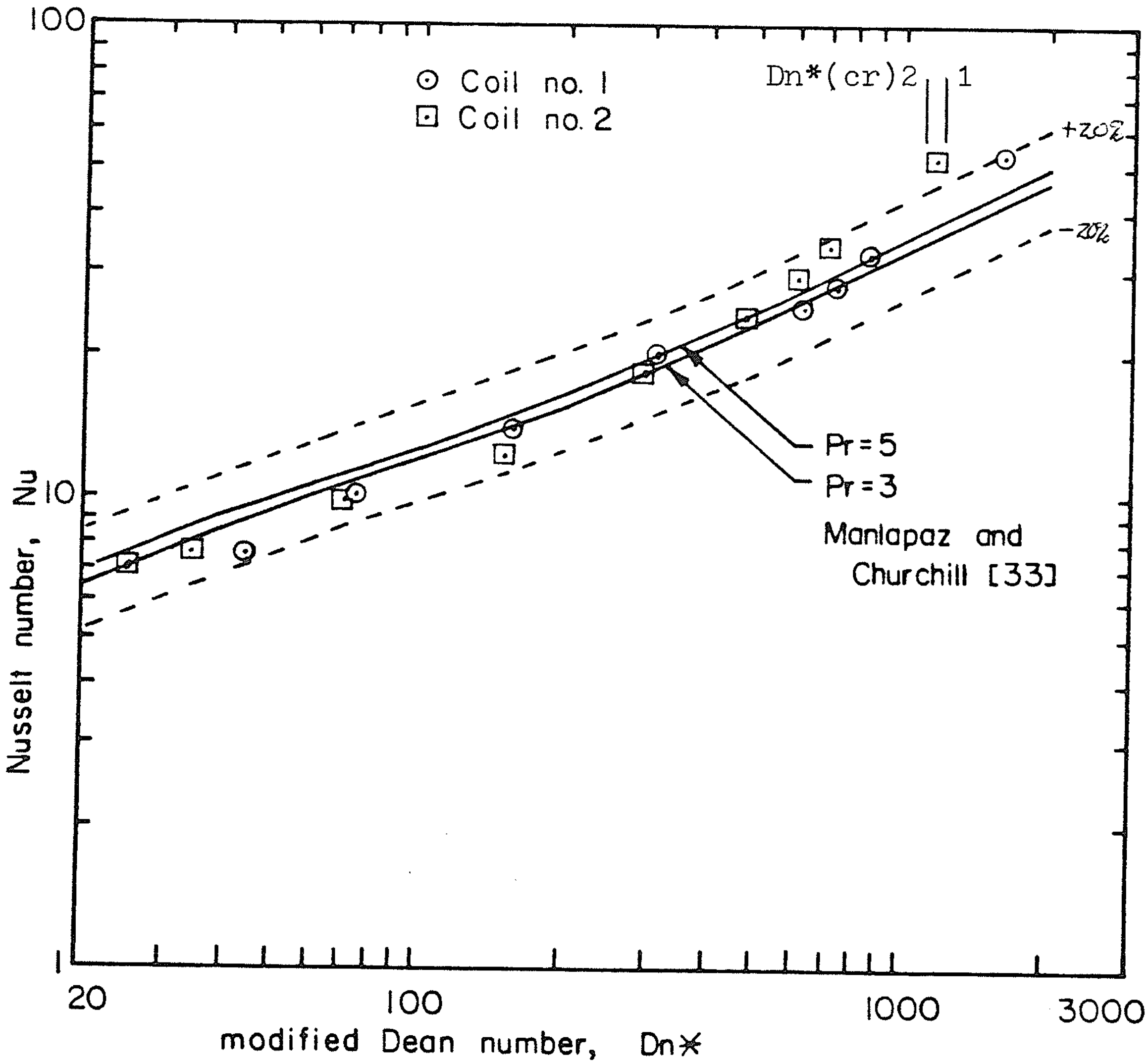


Figure 4.41: Comparison of Coils 1 and 2 with Manlapaz and Churchill

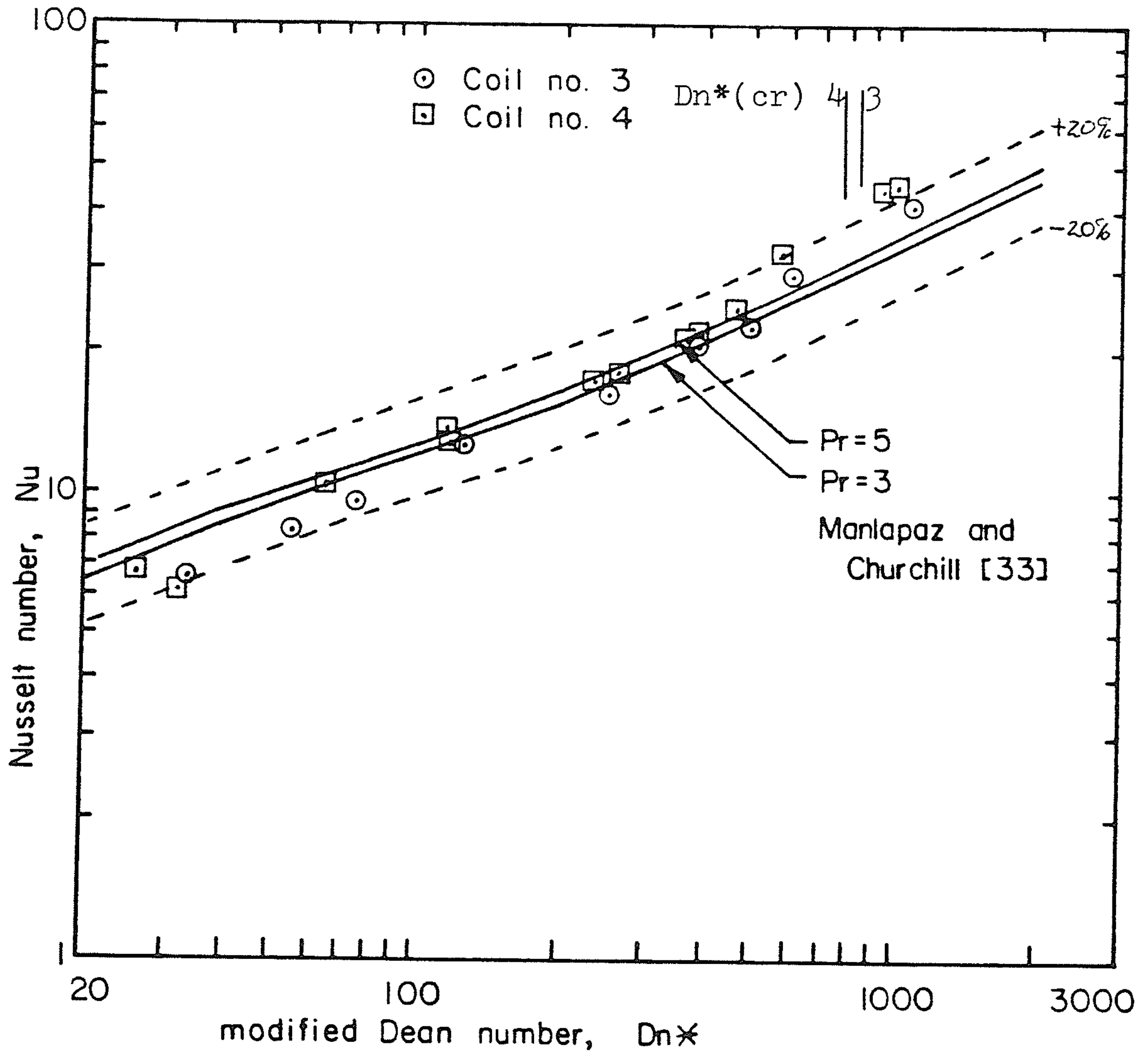


Figure 4.42: Comparison of Coils 3 and 4 with Manlapaz and Churchill

overall Nusselt number results. The correlation of Manlapaz and Churchill [33] may therefore be acceptable for laminar water flow of 70<Dn*<600 for a coiled tube length ratio of about L/d=530, whereas the estimated asymptotic results of Dravid et al.[15] are better in consideration of the fully developed Nusselt number generally.

Finally, the Nusselt number data for the four coils is presented as a function of the Dean number in Figure 4.43. It is evident from this figure that little effect of geometry is to be expected on heat transfer for similar Dc/d, within a high/low ratio of 2.0 and the present levels of experimental error. This point lends further substantiation to the preliminary analysis of this chapter and establishes the relative magnitudes of geometric progression required to produce observable trends for heat transfer.

4.3.3 Fully Developed Nusselt Number (Bottom Feeding)

The results for the overall Nusselt number in the bottom feeding (upward) flow direction were also examined. Due to the lack of differentiable results between the two diametral ratios tested for top feeding flows, only coils 1 and 2 were tested with bottom feeding flows. The

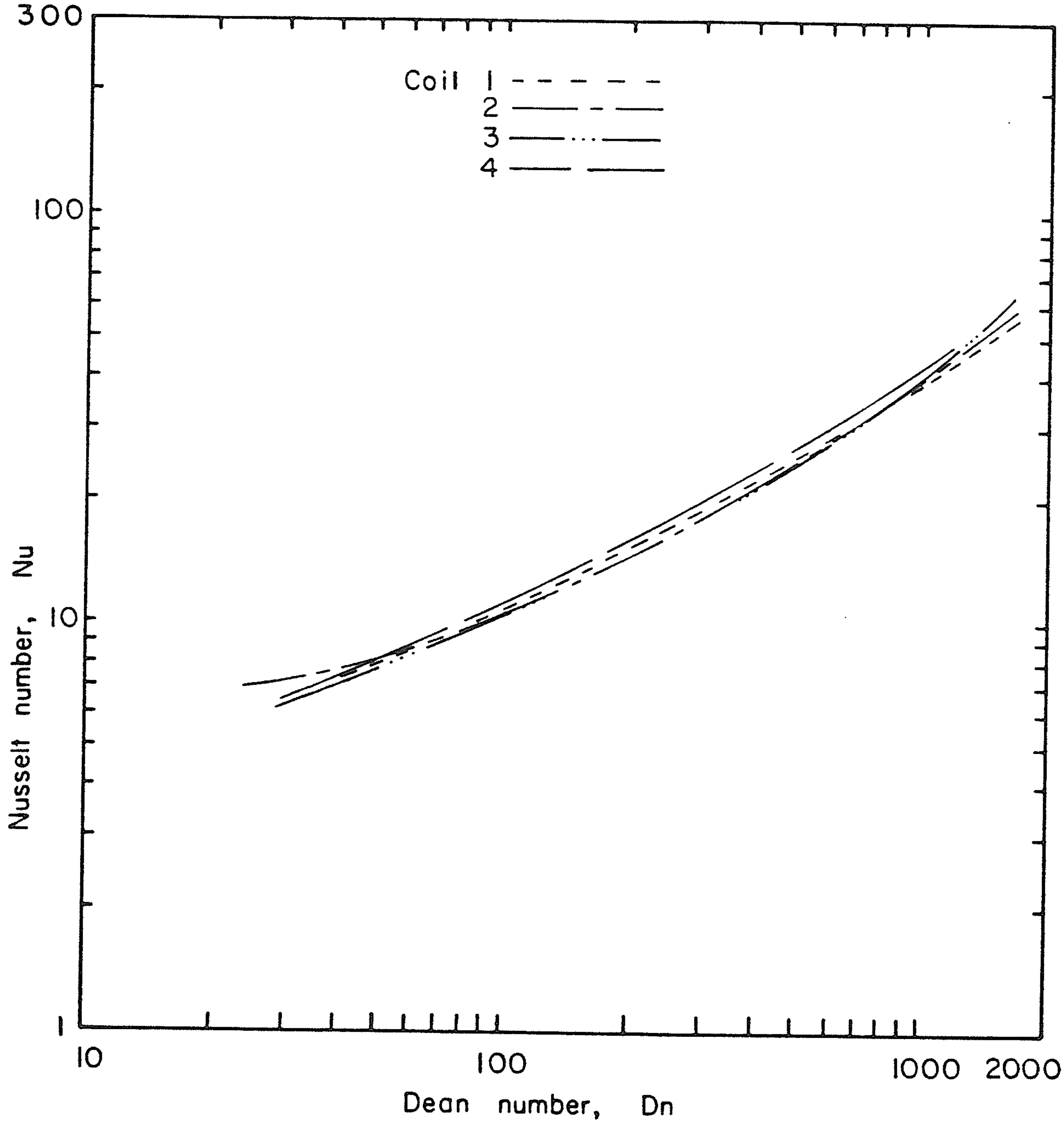


Figure 4.43: Comparison of Neumann Nusselt Number: Coils 1 to 4

results for Nusselt number as a function of Reynolds number, for each coil, in both top and bottom feeding flows are presented in Figure 4.44 and Figure 4.45 as compared with Sieder and Tate [58]. As illustrated, coil 1 (low pitch) exhibits negligible differences between top and bottom feeding flow, within the level of error for these experiments. However, coil 2 (high pitch) exhibits a radically augmented Nusselt number at low Reynolds numbers, in bottom feeding flow. The enhancement is about 60% for a bottom fed flow at Reynolds numbers below 300 and decreases to zero as the Reynolds number increases to about 3000. This phenomenon is not surprising since the progression toward high pitch for a vertical axis coil will approach that of a vertical straight tube whereas the progression to a high diametral ratio produces a horizontal straight tube effect. As was the case with the non- isothermal friction factor ratio data, the coil axis orientation and the pitch angle are seen to produce noticeable effects in low Reynolds number flow heat transfer. The effect of the feed direction reversal is simply a 180 degree shift in coil axis orientation. As noted in Table 4.1, the range of Grashof number encountered in the present study was 300 to 5000 which is generally insignificant in horizontal straight tubes and coils of close pitch. This is corroborated by calculation of the Gr/Dn^2 and Gr/Re^2 terms in

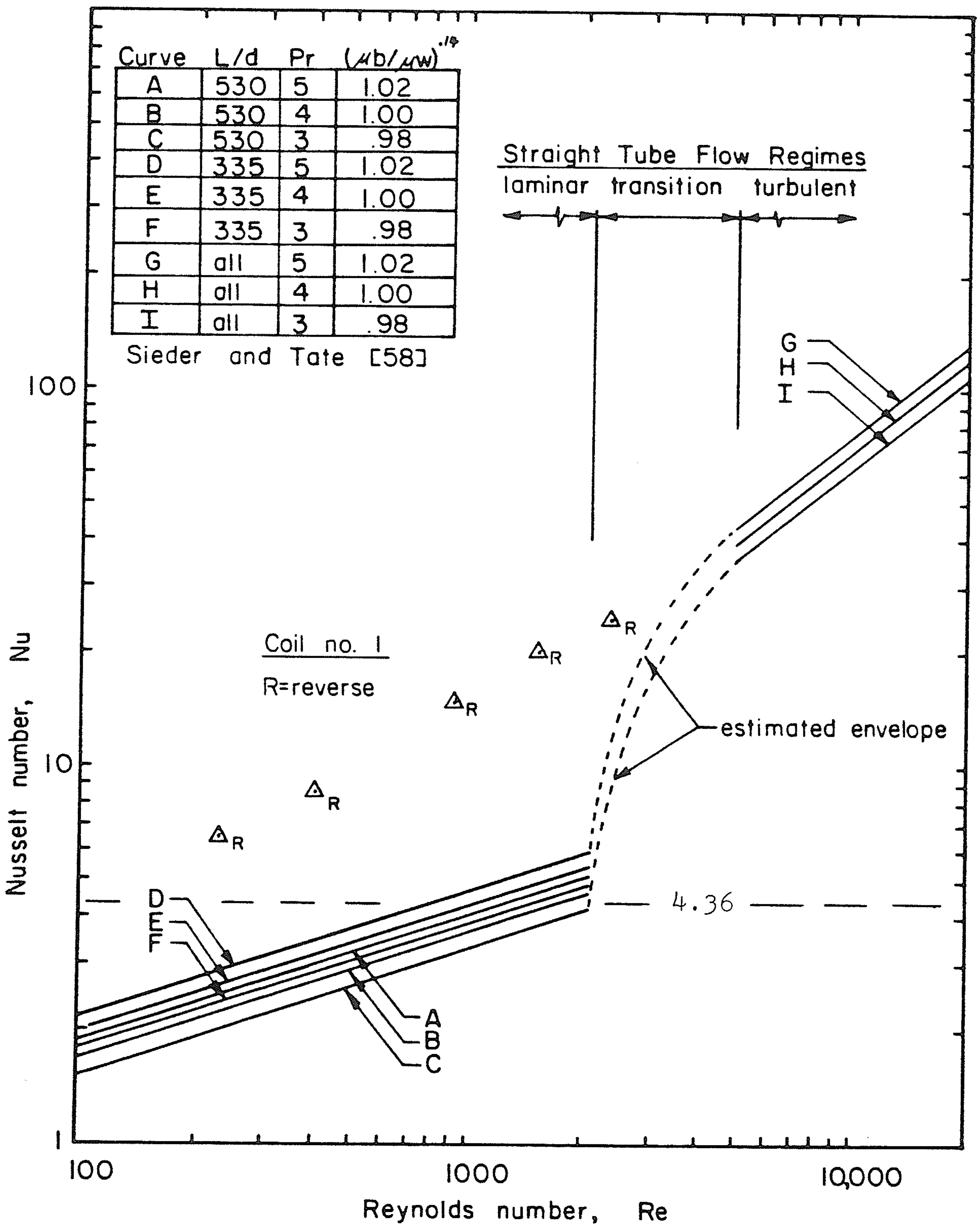


Figure 4.44: Comparison of Bottom Feeding: Coil No.1

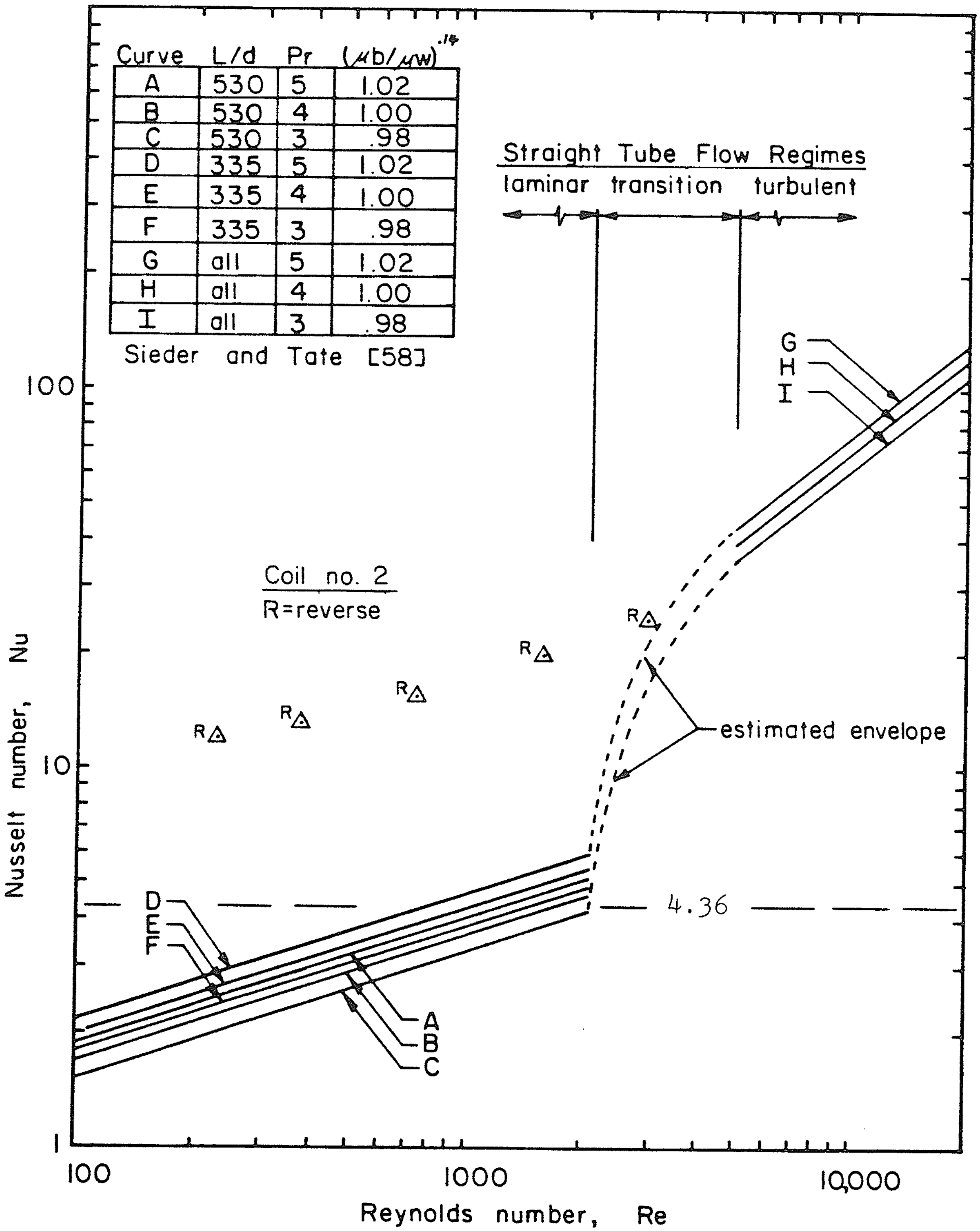


Figure 4.45: Comparison of Bottom Feeding: Coil No.2

the correlation of Abul-Hamayel and Bell [18], whose coil was of vertical axis, close pitch, and bottom fed.

The data for Nusselt number in coils 1 and 2 , in both top and bottom feeding flows, is presented as a function of the Dean number in Figure 4.46 and compared with Dravid et al.[15] in Figure 4.47. Again the substantial enhancement of the high pitch Nusselt number is seen for low Dean numbers in reverse flow, and decreasing to zero enhancement as the Dean number increases through Dn=300. However, the close pitched coil shows negligible difference in Nusselt number for reverse flow, within the limits of experimental error. The coil of Dravid et-al [15] was of close pitch, but no mention was made of its orientation.

Overall, the relative significance of the Grashof number's magnitude will have to be a function of the modified Dean number to include pitch, and the coil axis orientation. Dependent on the possible combinations of these parameters, different regions of force dominance will govern the heat transfer characteristics within the flow geometry. For weak vortex flows (low Dn*) the level of heating may cause the buoyancy forces to dominate whereas, as the vortices strengthen, a region of mixed dominance of

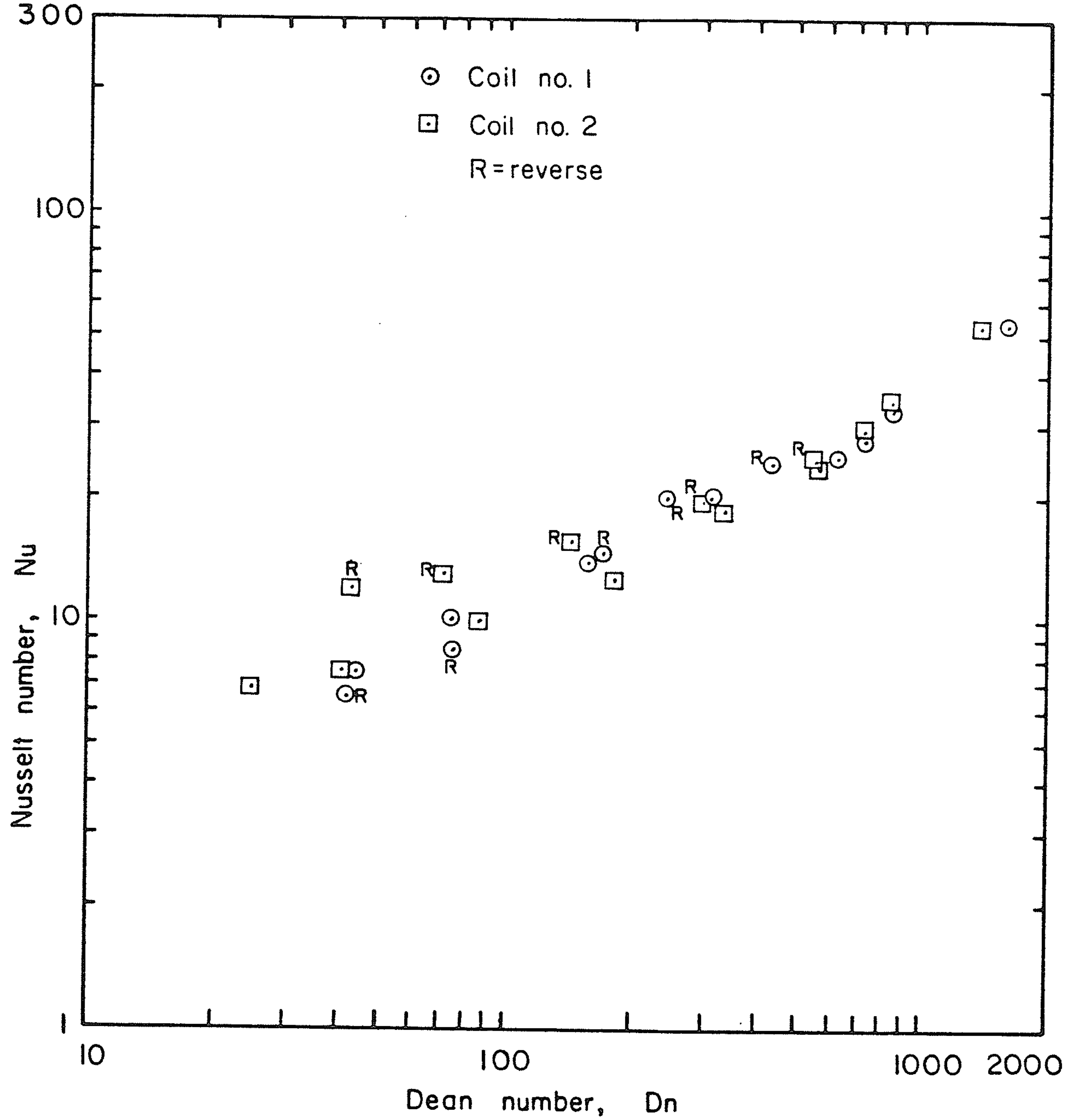


Figure 4.46: Comparison of Top and Bottom Feeding: Coils 1 and 2

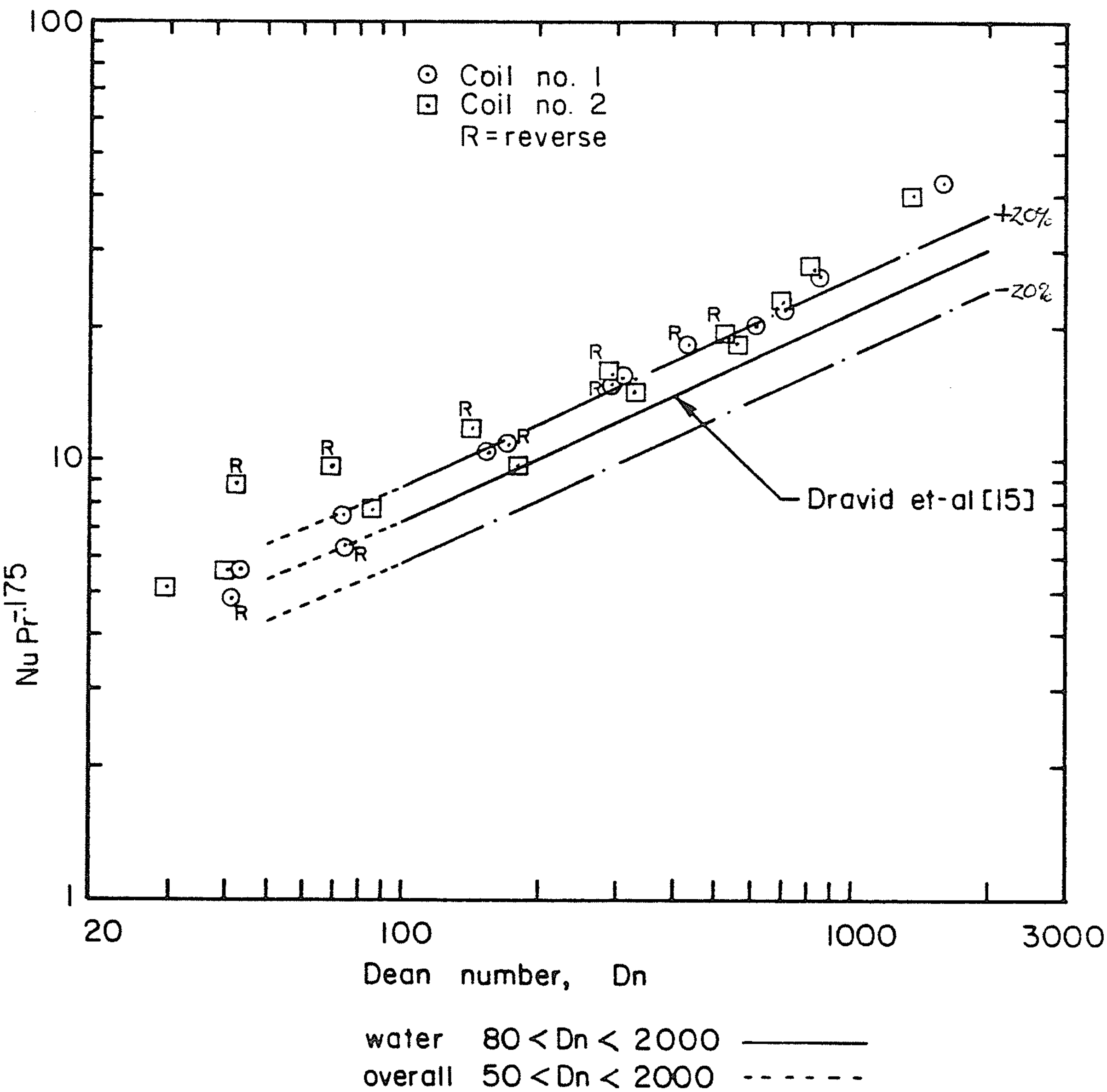


Figure 4.47: Comparison of Bottom Feeding with Dravid et al.

buoyancy and centrifugal forces will occur. At higher vortex flow strengths, however, the centrifugal forces will outweigh the buoyancy forces completely. It should be noted that the manifestation of buoyancy is usually a pair of contra-rotating vortices, but with a vertical dipole vector. Therefore, as one dominant force is equalized and replaced by another, the dipole vector will simply rotate from the buoyant orientation to the centrifugal orientation (in three dimensional space). This phenomenon was reported for a two dimensional rotation (in close pitched coils) experimentally by Singh and Bell [16], and numerically by Prusa and Yao [35] and Lee, Simon, and Chow [47]. The experimental verification used an eight point peripheral thermocouple station, and the numerical analyses used perturbation and the Boussinesq approximation, respectively. The Grashof number results of the present study are compared to the numerical results of Prusa and Yao [35] and Lee, Simon, and Chow [47] in Figure 4.48. The boundaries were developed from a figure presented by Lee, Simon, and Chow. The experimental envelope illustrated is for all the data of the present study, with the broken lines demonstrating the effects of flow reversal observed in coil 2 . As can be seen from Figure 4.48, the present study is expected to lie well within the region of centrifugal dominance according to both numerical analyses.

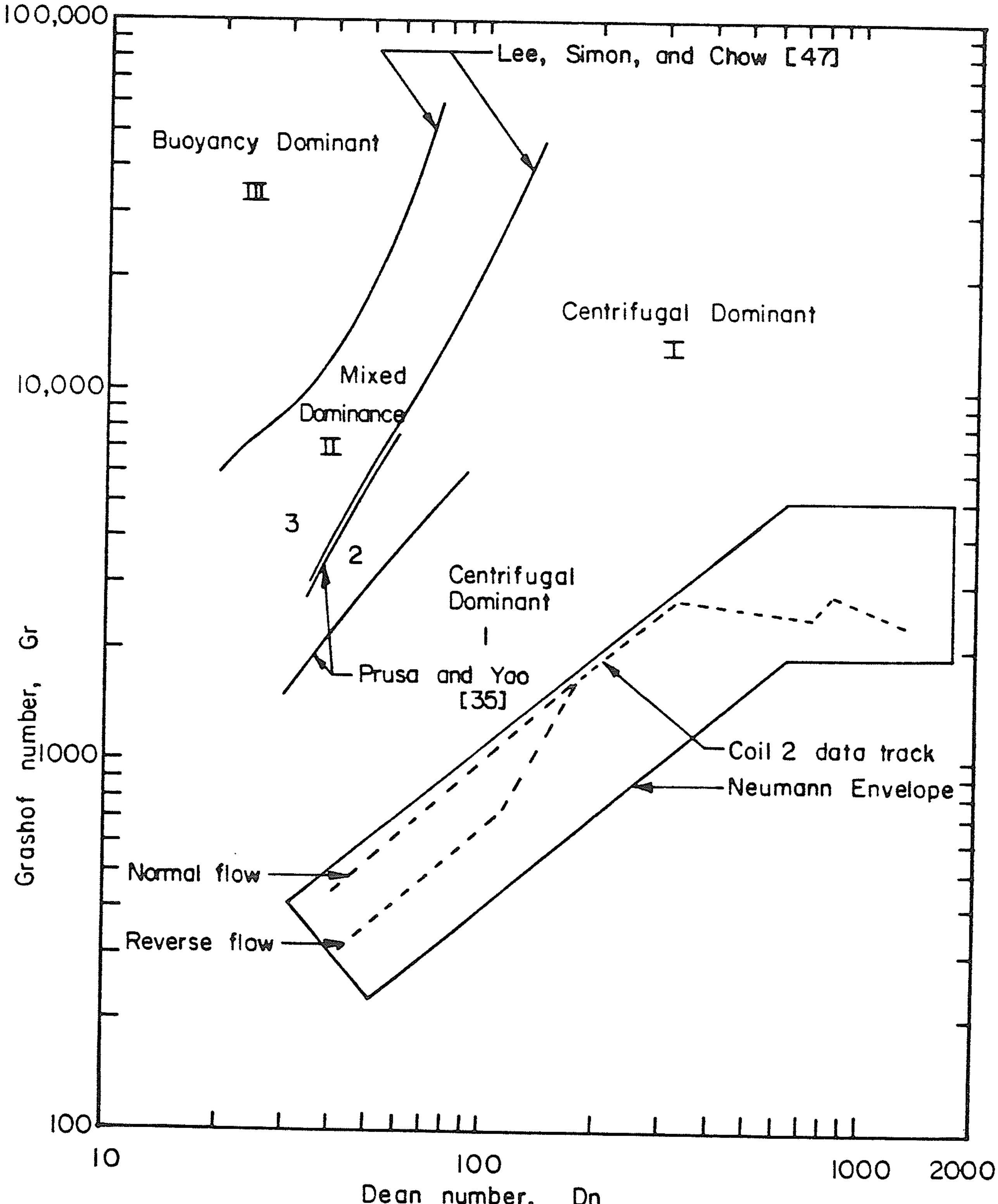


Figure 4.48: Comparison of Data Envelope with Force Dominance Regions of Prusa and Yao; and Lee, Simon, and Chow

These analyses, however, do not account for the pitch of the coil or the coil's overall orientation. It is also notable that the bottom feeding flow Grashof curve of coil 2 is below the top feeding flow Grashof curve. This indicates that the enhancement in Nusselt number was due to a reduction in (Twi-Tb) rather than an increase in the level of heating, for a given Reynolds number. This phenomenon is caused by the operational restriction that $Qe/\dot{m}$ = constant, in conjunction with the direction of flow.

4.4 Heat Transfer Results (Dirichlet Boundary Condition)

The experimental procedure was as described in chapter 3 with coil 2 shortened to L/d=335 to enable it to fit into the available steam facility. Due to an inability to obtain a constant wall temperature to within 1°C, however, the obtainable data was limited to high Reynolds number flows of coil 2 in top feeding flow. Hence only limited comments can be made on the results.

4.4.1 Overall Average Nusselt Number (Top Feeding)

The results for the overall average Nusselt number in the top feeding flow direction are presented in Table 4.2 and compared therein to the correlations of Sieder and Tate

Table 4.2: Dirichlet Test Results - Coil no. 2

Re	4933	5316	5890	6577
Dn	916	987	1094	1221
Dn *	765	824	913	1020
Pr	4.3	4.4	4.3	4.3
Gz	50.0	54.5	59.9	67.1
Gr	7260	8090	8690	8040
Nu	31.6	27.9	30.4	29.9
Dravid et-al [15]	26.3	27.5	28.8	30.4
Berg and Bonilla [21]	21	24	27	31
Kubair and Kuloor [23]	30	32	34	37
Manlapaz and Churchill [33]	27	29	30	31
Sieder and Tate [58]	39	43	46	51

Note: $(\mu_b/\mu_w)^{.14}$ taken as 1.03 from the observed results.

[58], Dravid et al.[15], Berg and Bonilla [21], Kubair and Kuloor [23], and Manlapaz and Churchill [33]. For the ranges 4500<Re<7000 and 900<Dn<1250 the data agree well with the correlation of Dravid et al.[15], to within ± 20%. However, it should be recalled that the analytical asymptotic Dirichlet value of the Nusselt number in laminar flow is 3.66, or about 16% less than the corresponding Neumann value of 4.36. Also, as demonstrated during discussion of the Neumann boundary condition, the Nusselt number results obtained at high Reynolds numbers will contain a high-side bias due to the elongated thermal entry length. In this instance the high bias will be greater than that exhibited by the Neumann boundary condition results due to the 37% reduction in L/d for this test section. Therefore, as can be seen from Table 4.2, the obtainable results of the present study agree to within ± 20% of both the Neumann and Dirichlet boundary condition correlations available. In addition, it should be noted that all of the Dirichlet boundary condition correlations include the effect of the thermal entry length due to the nature of the allowable measurements.

In terms of force dominance, there appears to be a substantial increase in the Grashof number for coil 2 under this boundary condition. This still places the present operating conditions well within the centrifugally dominant regions of Prusa and Yao [35] and Lee, Simon, and Chow [47], as illustrated in Figure 4.49. However, as noted previously, the numerical boundaries are only applicable to zero coil pitch.

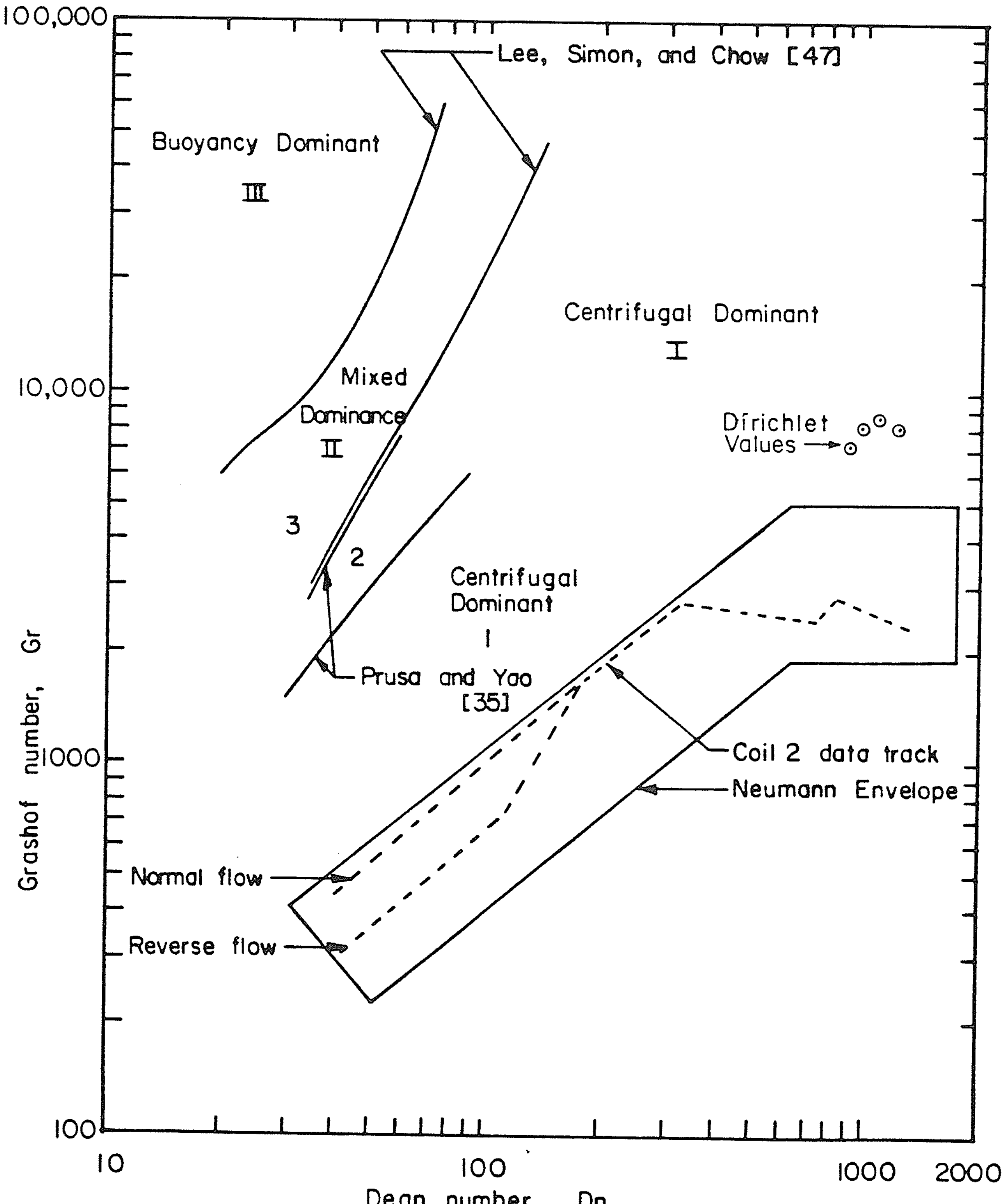


Figure 4.49: Comparison of Neumann and Dirichlet Data with Force Dominance Regions of Prusa and Yao; and Lee, Simon, and Chow

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

An experimental investigation was carried out to study the pressure drop and heat transfer characteristics in helically coiled tubes of substantial pitch, for their respective laminar flow ranges. Both uniform axial heating tests and uniform wall temperature tests were performed. Measurements of wall temperature, and calculation of friction factors and Nusselt numbers were obtained over as wide a range of conditions within the constraints of the current facilities. From the present study, the following conclusions can be drawn:

1. The isothermal friction factor results for laminar flow verified the validity of the modified Dean number, Dn*, as an isothermal correlation parameter using the correction of Truesdell and Adler [26] also used by Mishra and Gupta [10].

2. Use of the modified Dean number as a substitutive modification for the correlation of White [5] showed that the modified version of White was practically equivalent to the correlation of Mishra and Gupta [10].

3. The non-isothermal friction factors showed that, for high pitch in a vertical coil axis orientation, there is an augmentation of the friction factor at lower Reynolds numbers. This was postulated to be a direct result of the buoyancy vector's similar orientation to the coil pitch angle, or the magnitude of the buoyancy vector's projection in the tube axis direction.

4. The Neumann boundary condition Nusselt number results for top feeding flows, in agreed well with published correlations and showed little effect of pitch for the similar diametral ratios tested. This yields an initial substantiation of the modified Dean number as a general correlation parameter for heat transfer in all helically coiled tubes.

5. The numerical correlation of Manlapaz and Churchill [33], for the Neumann boundary condition, was shown to be an adequate representation of the overall Nusselt number in the normal flow direction, for laminar water flow in coils of L/d about 530.

6. The Neumann boundary condition Nusselt number results for bottom feeding flows in a high pitched

helically coiled tube re-emphasized that buoyancy effects may be significant depending upon the coil axis orientation and coil pitch angle.

Based on the literature review and the present results, the author offers the following recommendations for further study:

1. Additional work should be carried out to further substantiate the validity of both the modified Dean number and the geometric continuum map, for isothermal and non-isothermal performance in general.

2. The effect of coil orientation should be investigated more thoroughly, in comparison to straight tubes in different orientations.

3. The true relationship between the hydrodynamic entry length and the modified Dean number should be determined.

4. The relationship of thermal-to-hydrodynamic entry length as a function of the Prandtl number, for two and three dimensional flows, should be verified to allow

distinction between developing and fully developed flows.

5. Extensive free convection surveys should be conducted for different coil orientations and geometries, to allow representation of force dominance regions using the format of Figures 4.1 to 4.5.

6. The limiting boundaries of the geometric continuum map should be investigated more fully, including such geometries as Archimedian spirals of zero to substantial pitch.

7. The process of relaminarization should be studied more thoroughly in coiled tubes of appropriate geometry.

8. The process of secondary flow field decay downstream of different coiled tube geometries should be studied further.

9. The Dirichlet boundary condition in general should be further investigated upon upgrading of the present facilities.

10. Recommendations 1 to 9 should be repeated for turbulent and transitional flow regimes.

11. Recommendations 1 to 10 should be repeated for various non-circular tube cross-sections and possibly internally finned tubes.

12. Recommendations 1 to 11 should be repeated for various test fluids to accurately measure the Prandtl number's effect on various phenomena.

13. Recommendations 1 to 12 should be repeated for boiling, multi-phase flows and complex mixtures.

14. Better analytical/numerical models should be developed in an attempt to provide a single, unified analysis covering the entire geometric continuum map with respect to the different aspects of the above-mentioned conclusions and recommendations.

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APPENDICES

APPENDIX A: Steam Chamber Specification

(1) Major components manufactured and [quantities] supplied:
(1.1) Lid [1] (40" dia. x 1/4" plate)
(1.2) Upper tank sections [2] (36" i.d. x 20" high)
(1.3) Lower tank sections [1] (36" i.d. x 20"+ high)

(2) Accessories installed and [quantities]:
(2.1) 0-10 psig pressure gauge [1] -lid mount
(2.2) Low setting pressure relief valve [1] -lid mount
(2.3) Air release valve [1] -lid mount
(2.4) Carrying handles [2] -lid mount
(2.5) Thermometer/thermocouple well [1] -lid mount
(2.6) Steam inlet fitting [1] -lower section mount
(2.7) Steam trap c/w drain valve [1] -lower section mount
(2.8) Nut & bolt pairs for flange connections [60]
(2.9) Nuts for studs at slots [60]
(2.10) Studs for section slots [60]
(2.11) Curved plates 14" x 5" [3]
(2.12) Red rubber inter-flange gaskets [3]
(2.13) Red rubber cover plate seals [3]
(2.14) 1 1/2" mount couplings (pipe thread) [5]

(3) Canister material:
10 gauge galvanized steel on corrosion treated 1/4" mild steel flanges.

(4) Canister sections and lid individually weighed and weights recorded on external surface labels.

(5) All lid accessories placed at a radius of 6" or greater.

(6) Steam inlet fitting placed 90 degrees horizontally from slot, in counter-clockwise direction (looking down into tank).

(7) Flange hole locating tolerances provide for 20 different mating positions, between any two major components, in any standard orientation.

(8) Canister operation 0-200° C and 0-2 psig.

(9) All accessories removable for maintenance and interchangeable via identical mounting couplings.

APPENDIX B: Non-Engineering Materials Specifications

Two material forms not normally employed in engineering applications have been used in this project, namely brass wire and a high fire clay.

Electrical Discharge Machining Electrodes

Brass wire is normally used to hang pictures and in other artisan applications, and the particular wire obtained has an average diameter from .635mm (.025 inch) to .762mm (.030 inch). The use of the brass wire as electrical discharge machining electrodes in this project required that numerous measurements be taken. After cutting each electrode to a length of 5cm, the ends were filed round, the wire straightened, and the diameter checked at both ends to ensure that all electrodes were closely similar. Each electrode was used to machine only two pressure tap holes since the electrode itself wears away during this process. The electrodes were mounted in a pin-vise, which itself was mounted in a specially constructed clamping bar. The clamping bar resembles a tuning-fork such that the pin-vise can be located anywhere along the open-ended slot prior to clamping. This entire assembly was then mounted in the electrical discharge machine for processing of the test coils, as illustrated in Figure B.1. The test coils were flushed clean of the EDM coolant oil after the machining process was completed.

Tap Hole Clay Plugs

During attachment of the pressure tap tubes via silver soldering (temperature=1100°F, 600°C), the tap holes were temporarily filled with a high fire clay to avoid plugging the holes with solder and to avoid contamination of the inner tube surface. The clay used was a mixture of the following:

1.	A.P.Greenware fire clay	45
2.	Old Mine 4 Ball clay	20
3.	G.H.Goldart clay	10
4.	Custer Spar clay	5
5.	Grog *	4
	proportionately by weight	84

* pre-fired clay which is ground to a specific grain size.

When mixed with 11 kg of city water, the resultant clay was found to be a high fire body rated at approximately cone #9 on the ceramic pyrometry scale. This indicates that the

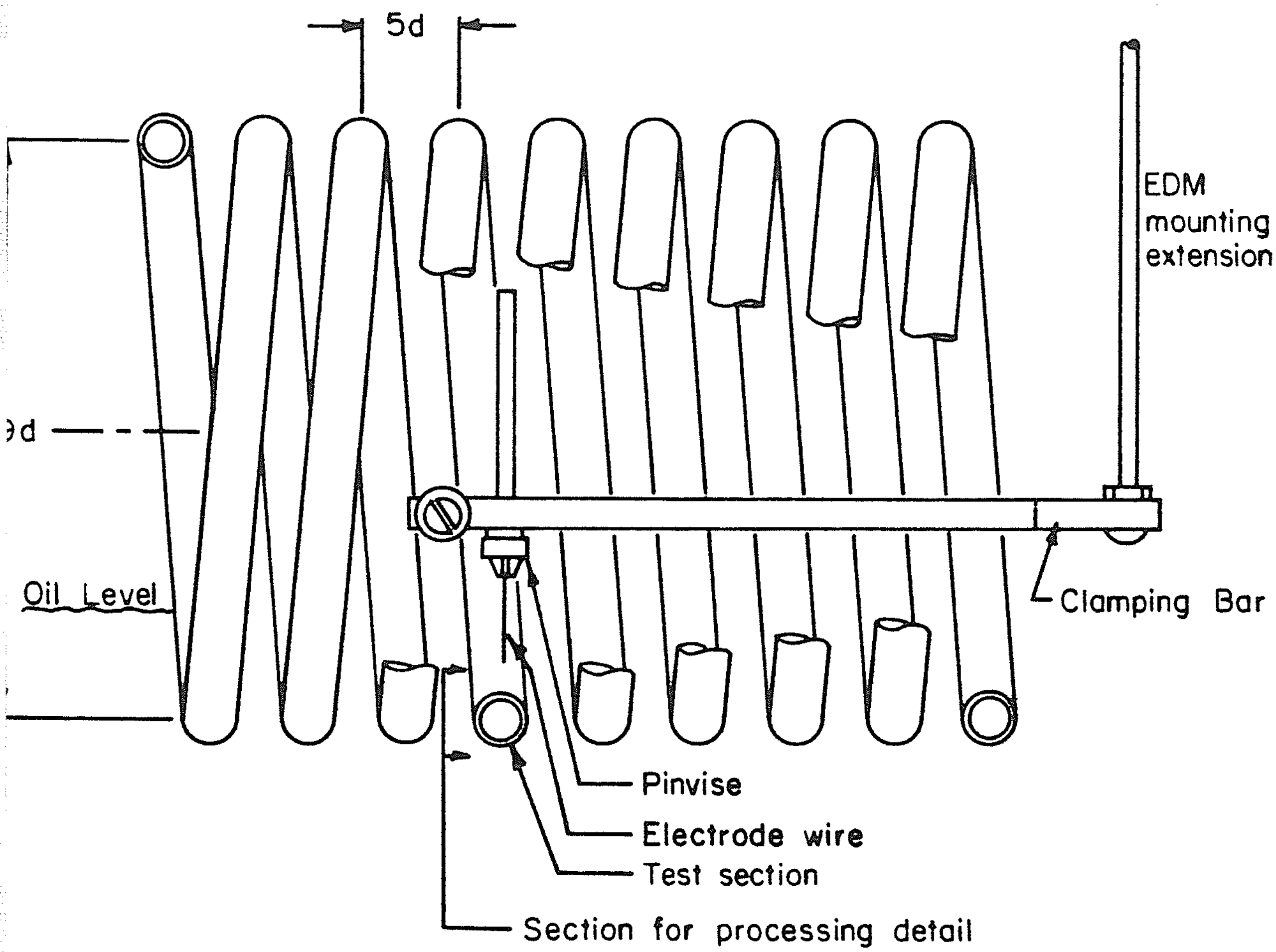


Figure B.1: EDM Drilling Rig Set-up

clay retains its consistency and does not deteriorate below 1280°C (2336°F). Subsequent tests with silver solder showed that the clay withstood the tap tube attachment process, and that the silver solder would not run over the clay surface. After tap tube attachment, the dried clay plug was removed by chipping the hole open using spare brass electrodes which also served to check the tap hole bore. The debris was then flushed clear of the test sections using compressed air.

The ceramic pyrometry scale is based on the Orton standard and covers the temperature range from 635°C to 1431°C. The general instrumenting process is illustrated in Figure B.2, and was substantiated by first processing a number of samples and subjecting these specimens to microscopic examination of the inner tube surface. For further details on ceramic materials, the reader is referred to:

[1] Nelson, G.C., Ceramics: A Potters Handbook, 5th ed., Holt, Rinehart, Winston, 1984.

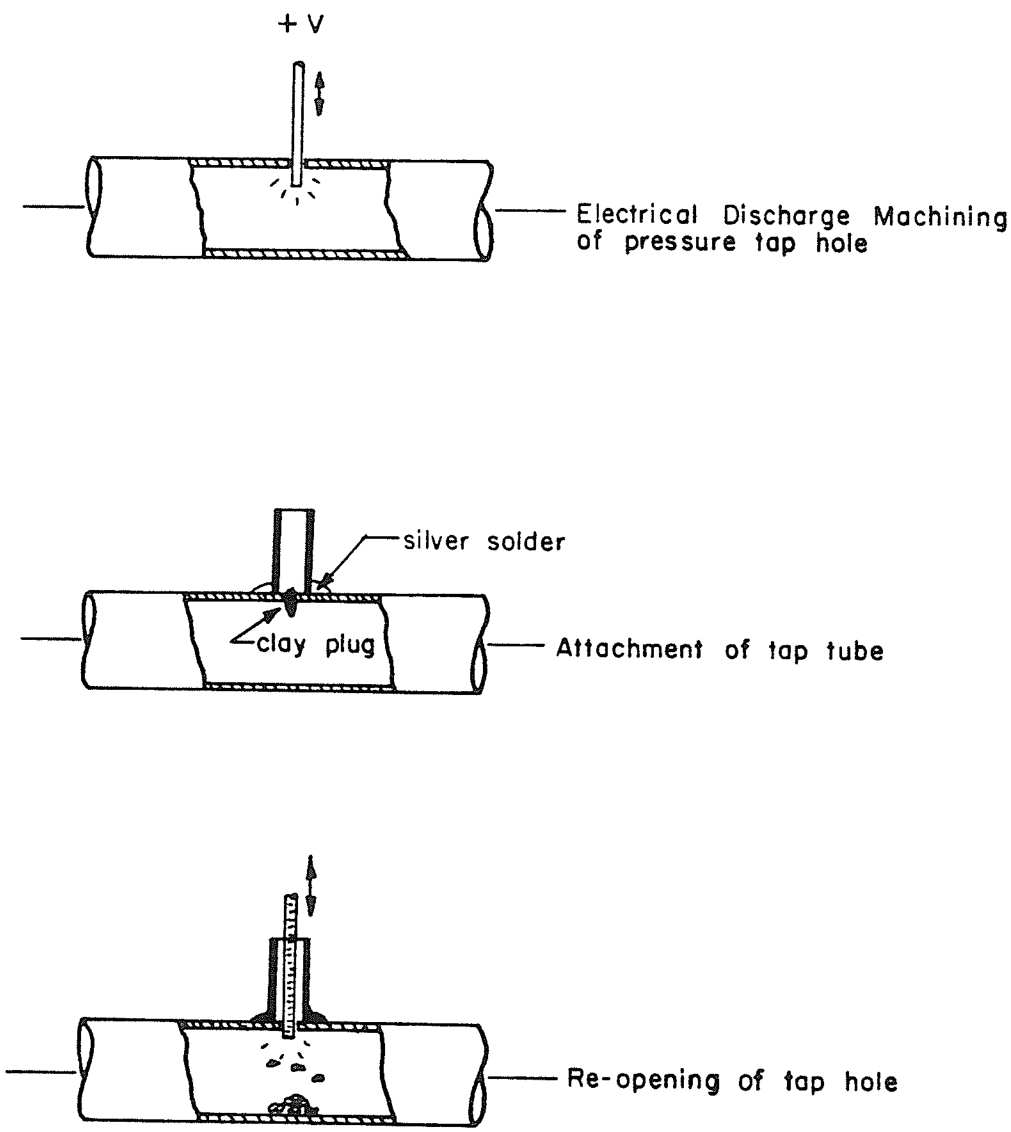


Figure B.2: Pressure Tap Drilling Process

APPENDIX C: Uncertainty Analysis and Equipment Error

Uncertainty has been evaluated for this project using the method of Kline and McClintock [1], as described by Holman [2]. This method essentially predicts the magnitude of uncertainty for a calculated quantity using the error magnitudes of the experimentally measured data. Generally, R as a function of n variables, each with its associated error margin, w, has an uncertainty, E, found as follows:

$$R=f_1(x_1,x_2,x_3,\ldots x_n)$$

$$E=f_2(w_1,w_2,w_3,\ldots w_n) \quad \text{using R in:}$$

$$E=\left\{ [(\partial R/\partial x_{1\,max})(w_{1\,max})]^2 + \ldots\ldots [(\partial R/\partial x_{n\,max})(w_{n\,max})]^2 \right\}^{1/2}$$

Equipment Specifications

Kiethley 177 DMM	at 5V	.003V error to 27°C
	at 10V	.005V error to 27°C
Leeds Northrop 938 Numatron 41X		.5°F error
Lambda Regulated Power Supply LL-905		.004V error
Rosemount 1151 DP Alphaline Transducer		.008V error
HP 6260A DC Power Supply		.026A error

Examples

#1 $Q=VI$

$$E=\left\{ [(\partial Q_e/\partial V)(.005)]^2 + [(\partial Q_e/\partial I)(.026)] \right\}$$

$$=\left\{ [(80x.005)^2] + [(10x.026)^2] \right\}^{1/2}$$

E=.477 Watts or .05%

#2 $R=Q/I$

$$E=\left\{ [(\partial R_n/\partial Q_e)(.477)]^2 + [(\partial R_n/\partial I)(.026)]^2 \right\}^{1/2}$$

$$=\left\{ [(1/I^2)(.477)]^2 + [(-Q/I^3)(.026)]^2 \right\}^{1/2}$$

$$=\left\{ [(1/Qe)(.477)]^2 + [(-1/I)(.026)]^2 \right\}^{1/2}$$

$$=\left\{ .00000028 + .000000106 \right\}^{1/2}$$

E=.000578 ohms or .5%

Uncertainties Listing

The following listing outlines the uncertainties for the major parameters calculated during the data conversion process:

Qe:	.05%
R :	.5 %
fc:	8. %
Qf:	4. %
Re:	4. %
Gr:	15. %
Nu:	15. %

References

[1] Kline, S.J., McClintock, F.A., "Describing Uncertainties in Single Sample Experiments", Mechanical Engrg., January, 1953.

[2] Holman, J.P., Experimental Methods for Engineers, McGraw-Hill, 1978.

APPENDIX D: #304 Stainless Steel Resistance Tests

To check the selected tube length for its resistance value, the following resistance experiment was run:

1. A random sample of uncoiled test section tubing was given a U bend of arbitrary radius in the region of its midpoint, and a similar arc-bend of around 50 degrees near one end.
2. The tube was sand-filled during bending and emptied before testing, similar to the manufacture of the helically coiled test sections (ref. chapter 3, section 4).
3. The test sample was marked off in 30.5cm (12 inch) increments from one (datum) end.
4. The tube was connected as shown in Figure D.1 to the equipment noted therein.
5. A current of 1.0 amperes was passed through the test sample and the voltage drop read between the datum end and the various gauge points marked. Since V=IR, the 1.0 ampere setting essentially permitted a direct readout of the selected gauge resistance within the limitations of the equipment.
6. The results are presented graphically in Figure D.2 along with data calculated from published values of #304 stainless steel resistivity and the same test sample geometry.
7. Based on the equipment specifications, the current and voltage (resistance) errors are .001 amperes and .0002 volts (ohms) respectively.
8. The electrical resistivities published are compared with that obtained from this experiment as follows:

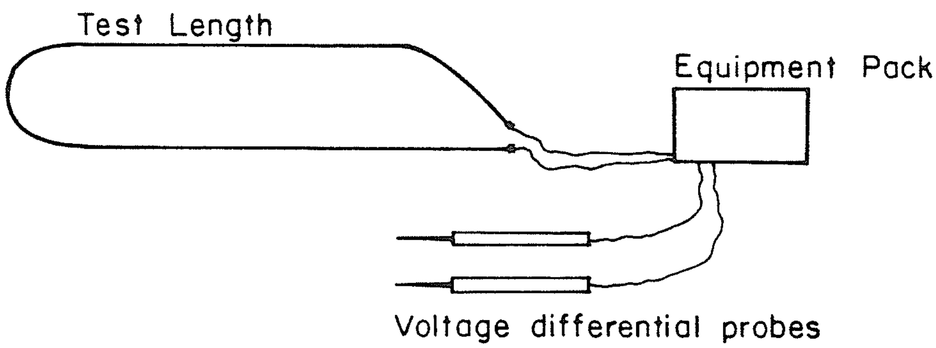
$7.372 \times 10^{-5}\ \Omega cm^2/cm$ (this expmt.)
$7.2 \times 10^{-5}\ \Omega cm^2/cm$ [1]
$7.023 \times 10^{-5}\ \Omega cm^2/cm$ [2]
$7.0 \times 10^{-5}\ \Omega cm^2/cm$ [3]

References

[1] Sourcebook on Industrial Alloy and Engineering Data, A.S.M., 1978.

[2] Vijay, M.M., "A Study of Heat Transfer in Two-Phase Two-Component Flow in a Vertical Tube", PhD Thesis, University of Manitoba, 1978.

[3] Peckner, D., and Bernstein, I.M., Handbook of



Equipment: Tektronix TM504 c/w :

(2) DM502A DMM's (autoranging)
(1) PS503A Dual Power Supply
(2) Leads (pt. probe to banana plug)
(2) Leads (banana plug to other)

I = 1.000 to 1.001 amperes

V is to .1% of read value +.05% of full scale (200mv)

V is ± .2mv (DMM limit)

Figure D.1: Resistance Test Set-up

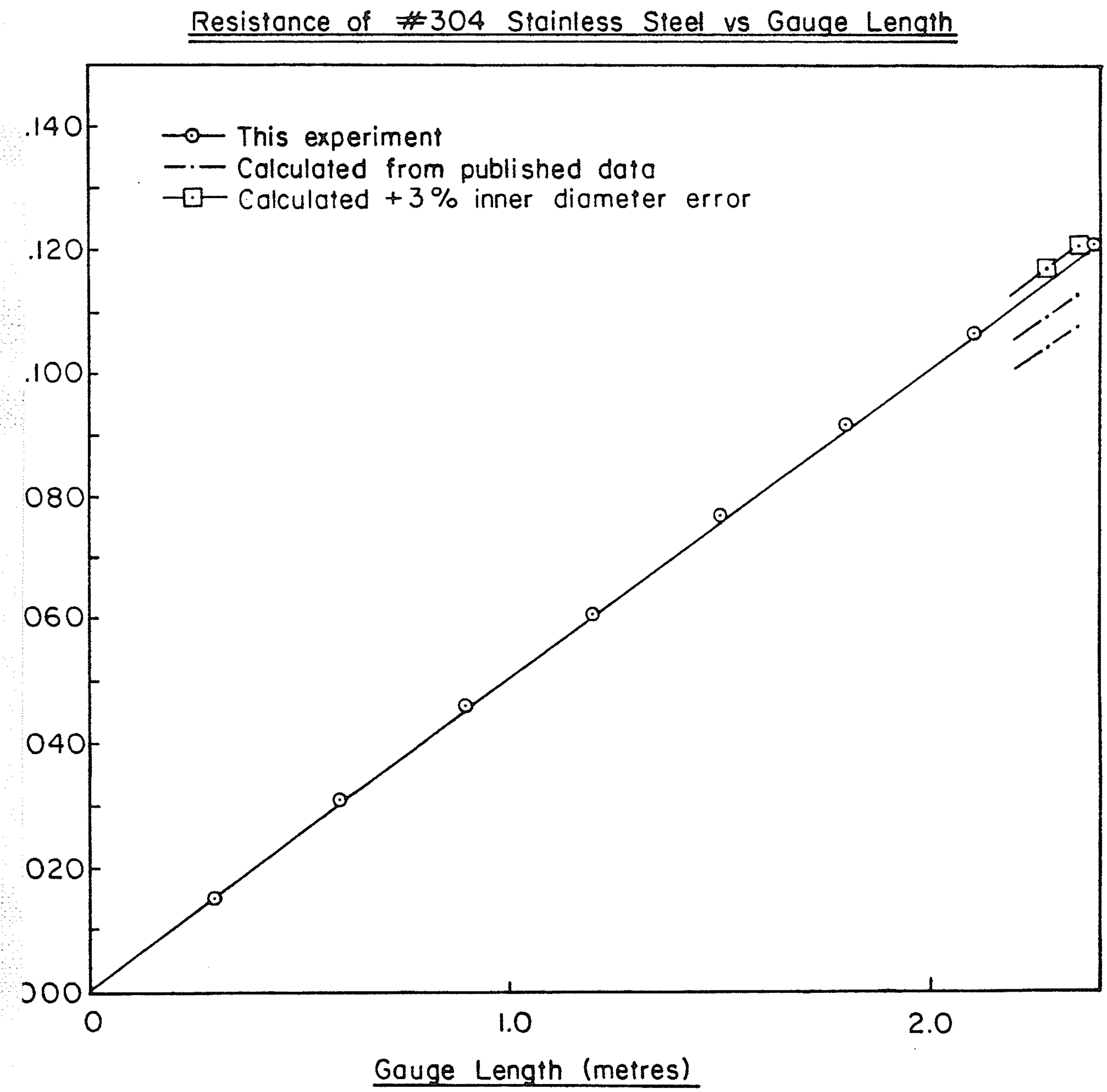


Figure D.2: Resistance Test Results

Stainless Steels, McGraw-Hill, 1977.

APPENDIX E: Data Conversion Software

The data conversion requirements of this project evolved into a full software package, developed in Fortran 77 under the UCSD-p operating system. It is run on an IBM personal computer having two disc drives for 12.7 cm flexible magnetic discs, and serial ports linked to an Epson FX-100 dot matrix printer and a Hewlett-Packard 7475A six pen plotter (although the plotting routine is monochromatic). The overall software package is illustrated schematically in Figure E.1, differentiating between the accessible data files and the actual programs, while outlining the disc-to-disc storage of the software components. Also indicated are the points of user-access to the data files and the points of user-interaction with running programs. Every effort was made to maintain simplicity of usage for the seperate software components. It is assumed for brevity that the reader has prior familiarity with either the UCSD-p system or the IBM personal computer---preferably both. Under these conditions, the software is defined as user-discernable rather than user-friendly. Complete program listings and user interactive notes are provided after the following discussion of the individual software components.

Programs

Program CREATOR text/code is used to create empty raw data files in batches as required by the user, for entry and storage of experimental data from the raw data sheet records. It is for this reason that the record sheets and the raw data files closely resemble each other in format as shown in Figure E.2 and Figure E.3 respectively. The textfile denoted N.TEXT is a dummy file aiding in the creation of raw data files.

Program RDC text/code is the actual data conversion component in the software package. Through user-interaction, it accesses the raw data file to be processed and converts thermocouple, pressure drop, and boundary condition data to non-dimensional heat transfer and fluid flow parameters. The program functions for isothermal, Neumann, and Dirichlet boundary conditions. User prompts are built-in since the program, and the raw and converted data files are stored on three or more seperate magnetic discs. During data conversion, RDC accesses other data files for thermocouple and flowmeter calibrations, water properties, and test coil specifications which include instrumentation locations. Following completion of data conversion, the program then creates a converted data file

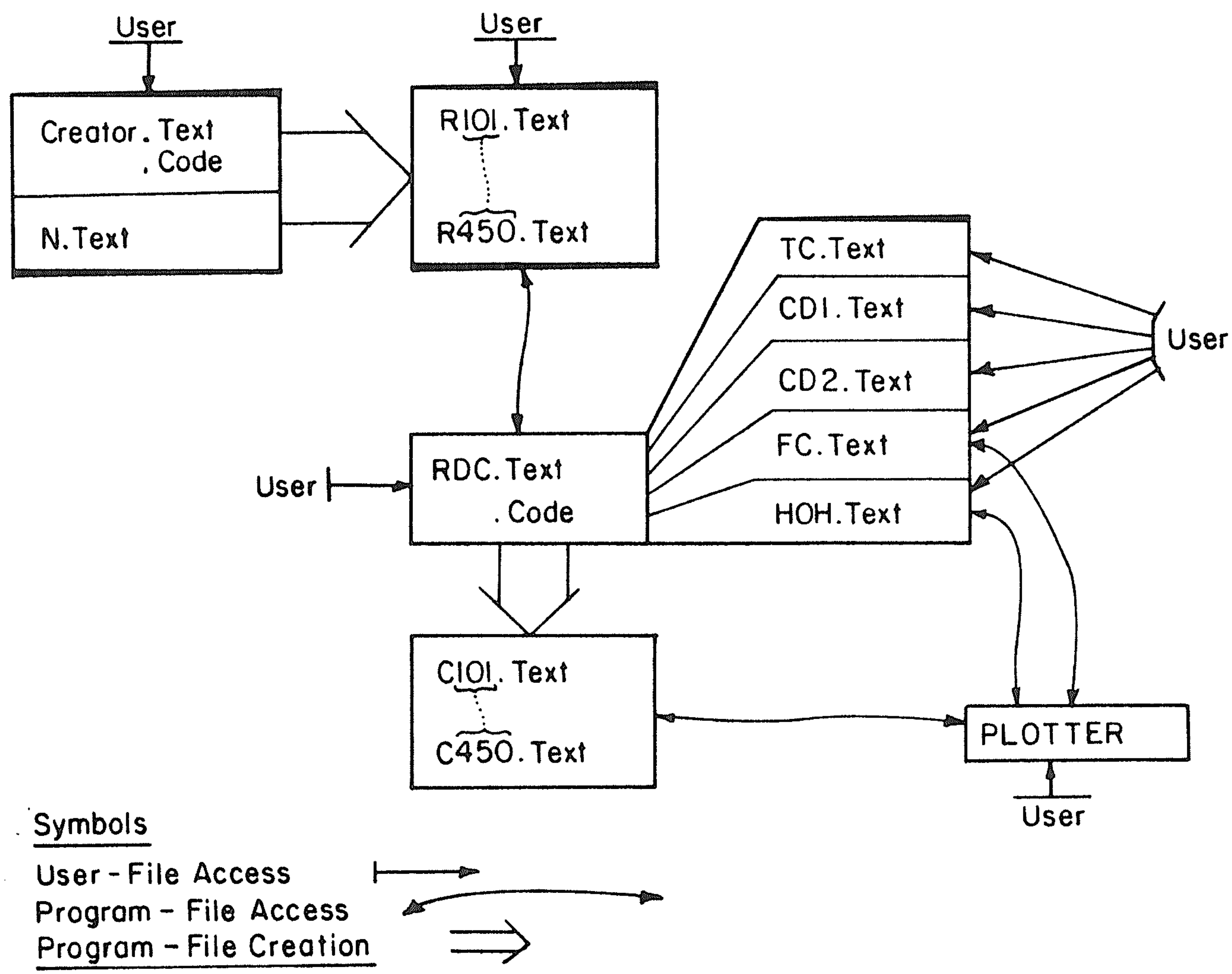


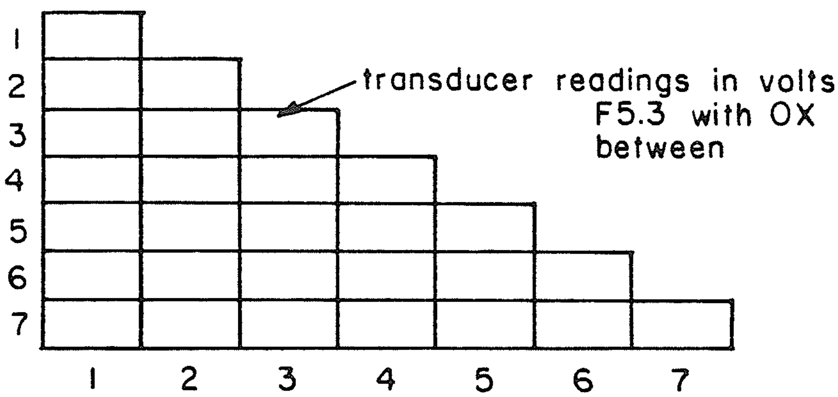
Figure E.1: Schematic of Data Conversion Process

Helically Coiled Tubes Research — Data Sheet

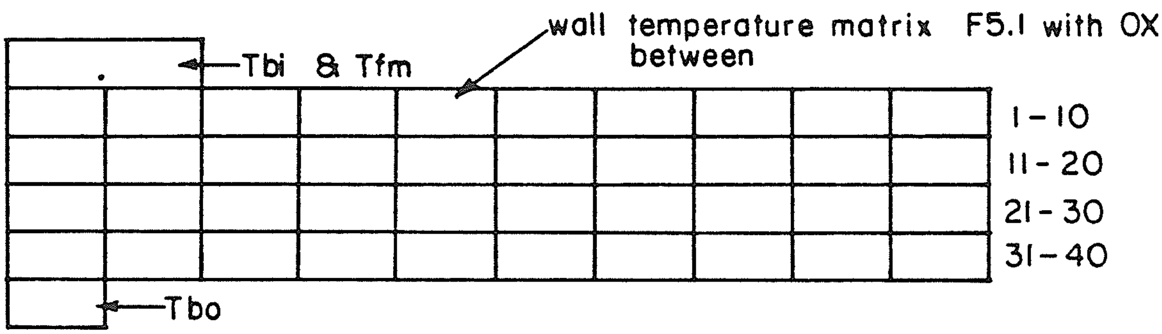
1. Coil Identification ____.__ (c c r r) F5.2
2. Date ______ (y y m m d d) I6
3. Flowmeter Reading __.___ (n f f f) F5.3
4. Boundary Condition Data

   _.________ (b p p p v v v v v) F10.8

5. Pressure Drop Data



6. Temperature Data (°F)



7. Remarks

c = coil no.
r = run no.
y = year
m = month
d = day
n = flow meter no.
n = 1 45 cc/min.
n = 2 215cc/min.
n = 3 1080cc/min.
n = 4 4200cc/min.
f = reading (0-150)
b = boundary condition
1 = ~~Neumann~~
2 = Dirichlet
3 = Isothermal
p = pressure/current
v = voltage (delete dec. pt.)

Figure E.2: Sample Data Recording Sheet

```
  .00
000000
 .000
 .00000000
 .000
 .000 .000
 .000 .000 .000
 .000 .000 .000 .000
 .000 .000 .000 .000 .000
 .000 .000 .000 .000 .000 .000
 .000 .000 .000 .000 .000 .000 .000
   .00000
   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
   .0
C175.TEXT
```

Figure E.3: Sample Raw Data File

and stores the converted data along with specific coil and run condition data. The storage procedure uses a convenient layout format allowing for later hardcopy production by simply transferring the file (by name) to the linked printer. A sample layout of a converted data file is shown in Figure E.4.

Data Files

The decision to make extensive use of independent data files in this software package was made to facilitate ease of data handling while minimizing the risk of typographical errors and loss of data. Thus raw data files are accessed, converted, and stored in unique files based on the test coil and run conditions. The main data files are labelled R or C for raw or converted, followed immediately by a three digit number representing the single digit coil number and the two digit run number, sequentially. In addition, a data file is used to list the test coil specifications and instrumentation locations non-dimensionally, with respect to the tube inner diameter (CD1.TEXT or CD2.TEXT).

To avoid cumbersome and approximate equations for thermocouple and flowmeter calibrations, and water properties cluttering up the main data conversion program, data files are also employed. For example, water properties are usually calculated based using a number of equations covering different temperature domains, for each property. These equations are products of curve-fitting or other routines based on published experimental data. This has been avoided by fitting a simple graphic curve to plotted experimental data, and visually digitizing the curve in single degree Celsius increments. Thus the data published in five degree increments has been "filled out" to the point where a simple linear interpolation equation can be applied after scanning the temperature domain alone. Similar procedures are applied to the instrumentation calibration data. Examples of the raw and converted data files have been provided previously in Figure E.3 and Figure E.4 respectively. The actual converted data files are provided in Appendix G.

Examples of the specifications, calibration, and properties data files are provided following, in Figure E.5 through Figure E.8 (inclusive), respectively.

User Notes

Program CREATOR

```
Coil Number: 4      D/d: 50       h/d: 58      L/d: 528
Run Number:   19.                 h/D: 1.160   Dc/d   56.8
Flowrate:           .006044 kg/s      T(bulk inlet):  37.4C
Inlet Velocity:      .3715 m/s        T(bulk outlet): 49.1C
Residence Time:          8 s          T(bulk average):43.3C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      294.0 W      Tube Resistance:    .118 ohms
Power Absorbed: 295.5 W      Tube Conductivity:15.50 W/mK
Heat Balance:      -.5 %
Stn       x/d    Twi(C)   Tb(C)    Rex      Prx      Grx      Nux
 1          6    39.7     37.6    2450.    4.58   .155E+04  28.62
 2         16    40.9     37.8    2461.    4.56   .228E+04  19.70
 3         30    41.1     38.1    2477.    4.52   .219E+04  20.86
 4         43    41.4     38.4    2491.    4.49   .225E+04  20.67
 5         55    41.3     38.7    2505.    4.46   .202E+04  23.42
 6         69    41.4     39.0    2522.    4.43   .193E+04  24.92
 7         80    41.7     39.2    2534.    4.41   .197E+04  24.76
 8         91    42.1     39.5    2546.    4.39   .212E+04  23.35
 9        115    42.8     40.0    2573.    4.34   .231E+04  22.12
10        138    43.6     40.5    2601.    4.28   .268E+04  19.61
11        162    44.5     41.0    2631.    4.23   .306E+04  17.74
12        179    44.5     41.4    2650.    4.20   .282E+04  19.66
13        201    44.9     41.9    2674.    4.16   .279E+04  20.42
14        224    45.4     42.4    2699.    4.11   .288E+04  20.31
15        246    45.9     42.9    2722.    4.07   .299E+04  20.00
16        297    47.2     44.0    2783.    3.98   .333E+04  19.12
17        341    47.6     45.0    2828.    3.90   .281E+04  23.69
18        424    50.2     46.8    2919.    3.77   .411E+04  17.77
19        498    52.0     48.5    3004.    3.66   .459E+04  17.18
20        524    52.1     49.0    3035.    3.61   .410E+04  19.78

-------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0129   .0000   .0000   .0000   .0000   .0000
2    62.3              .0126   .0000   .0000   .0000   .0000
3      .0    57.3              .0128   .0000   .0000   .0000
4      .0      .0    56.8              .0000   .0000   .0000
5      .0      .0      .0      .0              .0000   .0000
6      .0      .0      .0      .0      .0              .0000
7      .0      .0      .0      .0      .0      .0
       1       2       3       4       5       6       7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    2743.                  fc:        .0128
Dn:     388.                  fc/fs:   2.19
Pr:       4.04                Dn*:   364.
Gr:        .264E+04           Gr/Re:      .963E+00
Nu:      21.15                   Gz:   16.48
-------------------------------------------------------
```

Figure E.4: Sample Converted Data File

Diametral Ratio	29.	29.	49.	50.
Pitch Ratio	5.	60.	5.	58.
Pressure Tap Locations	5.	5.	3.	3.
	100.	115.	167.	175.
	193.	225.	321.	337.
	287.	332.	475.	494.
	379.	439.	529.	525.
	472.	525.	0.	0.
	521.	0.	0.	0.
Total Length of Coiled Tube	526.	530.	532.	528.
Pitch Angle (degrees)	4.7	46.1	3.0	30.1
Number of Coil Turns	5.6	4.7	3.4	3.1
Entry Fitting Depth	6.8	7.1	6.5	6.6
Squareness	0.	0.	0.	0.
Exit Fitting Depth	6.9	6.7	6.9	6.4
Squareness	0.	0.	0.	0.
Thermocouple Locations	10.	7.	6.	6.
	21.	19.	16.	16.
	33.	29.	25.	30.
	44.	39.	35.	43.
	56.	46.	46.	55.
	67.	60.	57.	69.
	78.	88.	70.	80.
	107.	126.	90.	91.
	133.	147.	115.	115.
	153.	172.	135.	138.
	183.	206.	155.	162.
	213.	244.	178.	179.
	242.	274.	217.	201.
	273.	304.	249.	224.
	330.	333.	289.	246.
	367.	365.	307.	297.
	440.	406.	383.	341.
	465.	446.	461.	424.
	502.	496.	510.	498.
	518.	525.	527.	524.

Temporary End of File ------------------------------------

Figure E.5: Sample Coil Data File

Sightglass Graduations	Flowmeter #1	#2	#3	#4
20.	0.	0.000650	0.003400	0.014500
30.	0.	0.000950	0.005200	0.021500
40.	0.000170	0.001200	0.007000	0.028500
50.	0.000230	0.001550	0.008750	0.035500
60.	0.000290	0.001850	0.010000	0.042000
70.	0.000350	0.002150	0.012300	0.049000
80.	0.000410	0.002450	0.014100	0.056000
90.	0.000470	0.002750	0.016200	0.062500
100.	0.000530	0.003050	0.017850	0.
110.	0.000590	0.003350	0.	0.
120.	0.000650	0.003550	0.	0.
130.	0.000710	0.003700	0.	0.
140.	0.000770	0.003950	0.	0.
150.	0.000830	0.004150	0.	0.

Figure E.6: Sample Flowmeter Calibration File

Corrective Differentials

.8	0.8	3.5	3.6	.0	
.9	0.9	3.9	4.4	.0	
.9	0.9	4.2	4.3	.0	
1.4	1.4	5.7	6.2	.0	
1.1	1.1	4.6	5.0	.0	
1.0	1.0	4.7	5.1	.0	
.7	0.7	3.7	3.8	.0	
.8	0.8	3.8	3.9	.0	
.8	0.8	3.5	3.7	.0	
1.2	1.2	4.1	4.2	.0	
.0	0.0	0.0	0.0	.0	
.4	0.4	2.8	2.8	.0	
.8	0.8	3.7	3.9	.0	
.8	0.8	3.7	3.8	.0	
.7	.7	3.1	3.0	.0	
.4	0.4	2.4	2.2	.0	
.8	.8	3.0	2.9	.0	
.0	.0	.0	.0	.0	
1.7	1.7	3.7	3.9	.0	
.0	0.0	0.0	.0	.0	
.7	0.7	2.8	3.1	.0	
.7	0.7	2.4	2.7	.0	
.5	0.5	2.4	2.7	.0	
.7	0.7	2.7	2.9	.0	
.6	0.6	2.5	2.7	.0	
.6	0.6	2.4	2.7	.0	
1.2	1.2	4.1	5.7	.0	
1.1	1.1	3.7	4.1	.0	
.8	0.8	2.9	3.1	.0	
.8	0.8	2.8	2.9	.0	
1.0	1.0	3.0	3.7	.0	
.9	.9	3.1	3.6	.0	
.8	0.8	2.8	3.3	.0	
.8	0.8	2.7	3.2	.0	
.6	0.6	2.5	2.7	.0	
.6	.6	2.4	2.6	.0	
1.3	1.3	4.3	4.8	.0	
1.4	1.4	4.4	4.9	.0	
1.6	1.6	5.0	5.9	.0	
1.6	1.6	5.0	6.0	.0	
.4	0.4	0.5	1.0	1.0	
.4	0.4	0.5	1.0	1.0	
.4	0.4	0.5	1.0	1.0	
68.0	90.0	140.0	155.0	180.0	Temperature of calibration (F)
0.0	0.0	0.0	0.0	0.0	

Figure E.7: Sample Thermocouple Calibration File

20.	998.5	4182.0	10.05	.6010	7.00	2.050	1.010
21.	998.2	4181.3	9.80	.6025	6.85	2.175	.981
22.	998.0	4180.7	9.60	.6045	6.65	2.275	.961
23.	997.7	4180.3	9.38	.6060	6.50	2.375	.940
24.	997.4	4179.8	9.14	.6075	6.30	2.475	.916
25.	997.2	4179.5	8.94	.6090	6.15	2.575	.897
26.	996.9	4179.2	8.72	.6110	5.95	2.675	.875
27.	996.6	4178.9	8.52	.6125	5.80	2.775	.855
28.	996.3	4178.7	8.35	.6140	5.65	2.850	.838
29.	996.0	4178.5	8.15	.6155	5.55	2.950	.818
30.	995.7	4178.4	8.00	.6170	5.40	3.025	.803
31.	995.4	4178.2	7.85	.6185	5.25	3.125	.789
32.	995.1	4178.2	7.65	.6200	5.15	3.225	.767
33.	994.8	4178.1	7.54	.6210	5.00	3.300	.758
34.	994.4	4178.1	7.39	.6225	4.90	3.400	.743
35.	994.1	4178.0	7.22	.6240	4.80	3.475	.726
36.	993.7	4178.0	7.09	.6255	4.70	3.550	.714
37.	993.3	4178.0	6.95	.6240	4.60	3.625	.700
38.	992.9	4178.1	6.81	.6280	4.50	3.700	.686
39.	992.6	4178.2	6.67	.6295	4.40	3.775	.672
40.	992.2	4178.3	6.54	.6305	4.30	3.850	.659
41.	991.8	4178.5	6.40	.6320	4.20	3.925	.645
42.	991.4	4178.7	6.28	.6330	4.10	4.000	.633
43.	991.0	4179.0	6.17	.6345	4.05	4.075	.623
44.	990.6	4179.3	6.05	.6355	3.95	4.150	.611
45.	990.2	4179.5	5.95	.6370	3.85	4.225	.601
46.	989.7	4179.8	5.85	.6380	3.80	4.275	.591
47.	989.3	4180.1	5.75	.6390	3.70	4.375	.581
48.	988.9	4180.4	5.65	.6400	3.65	4.425	.571
49.	988.5	4180.7	5.55	.6415	3.55	4.500	.561
50.	988.0	4181.1	5.45	.6425	3.50	4.575	.552
51.	987.6	4181.4	5.37	.6435	3.45	4.650	.544
52.	987.2	4181.8	5.30	.6445	3.40	4.725	.537
53.	986.6	4182.1	5.20	.6455	3.35	4.775	.527
54.	986.2	4182.5	5.12	.6465	3.30	4.850	.519
55.	985.7	4182.9	5.07	.6480	3.25	4.925	.514
56.	985.2	4183.3	4.97	.6490	3.20	5.000	.504
57.	984.8	4183.7	4.90	.6500	3.15	5.050	.498
58.	984.2	4184.2	4.82	.6510	3.10	5.125	.490
59.	983.8	4184.6	4.75	.6520	3.05	5.175	.483
60.	983.3	4185.0	4.67	.6530	3.00	5.250	.475
61.	982.8	4185.5	4.60	.6545	2.94	5.300	.468
62.	982.2	4186.0	4.52	.6555	2.90	5.350	.460
63.	981.7	4186.5	4.45	.6560	2.85	5.425	.453
64.	981.1	4187.0	4.37	.6575	2.80	5.475	.446
65.	980.5	4187.5	4.32	.6585	2.75	5.525	.441
66.	980.0	4188.0	4.25	.6595	2.72	5.600	.434
67.	979.4	4188.5	4.18	.6605	2.67	5.650	.427
68.	978.8	4189.1	4.12	.6615	2.63	5.725	.421
69.	978.2	4189.7	4.07	.6625	2.60	5.775	.416
70.	977.7	4190.3	4.03	.6630	2.57	5.850	.412

Figure E.8: Sample Water Properties Data File

1. The user is asked to input the file numbers of the first and last file to be created, in format 2I3.
   Example: 401450 requests creation of files
   R401.TEXT through R450.TEXT
2. The program will signal the console at completion.
3. It is suggested that the user create small groups of raw data files at a time, noting that a run-time error will occur if the volume directory is filled up. If this happens, the last couple of files should be destroyed and a sub-volume created using the remainder of the disc memory. Doing otherwise will limit the disc to approximately seventy-five data files, which require less than half the disc capability.
4. For further details refer to the operating system's manual.

Raw Data Files

1. To enter raw data into a data file the user is required to load the particular file into the system workplace while in the FILER mode and then transfer through to the EDIT mode. The user may then enter the experimental data by EXCHANGING the zeroes in the file for raw data.
2. The zeroes are emplaced at creation of the data file to indicate to the user the required format for input to the data conversion program.
3. It is strongly recommended that only the exchange-edit function be used to input the raw data and that it is done carefully so not to delete any zeroes.
4. Any missing positions in the raw data file, whether zeroes or real data, will cause a run-time error in the main conversion program.
5. After raw data entry, the system workspace is updated and the file is saved back onto the raw data disc.
6. It should be noted that all data files are to be accessed in this manner for editting purposes. This includes the files:

   TC1.TEXT to TC4.TEXT, TC.TEXT
   CD1.TEXT and CD2.TEXT
   FC.TEXT
   HOH.TEXT

Program RDC

1. The user is first asked to input the name of the raw data file to be converted, and to replace the conversion disc in the right drive by the raw data file disc containing the particular raw data file.
2. If the particular raw data file is part of a sub-volume on the disc, then it is hoped that the

user has had the foresight to change the right drive's identification prefix prior to initiating conversion program execution. If this has not been done, an error will result and the prefix change must be effected before proceeding.

3. The program will provide a console prompt to switch back to the conversion disc when necessary.
4. The process of 1. and 3. is repeated later when the program is ready to store the converted data on the converted data disc.
5. After the data is stored, the program asks if another file is to be processed. An affirmative response returns the user to 1. while a negative response will begin to terminate the program.
6. During data processing, if one thermocouple of a pair is entered as faulty (denoted as a zero reading), the program automatically duplicates the other member of the pair. This yields a fair peripheral temperature average since both of the independent thermocouple calibrations are still employed.
7. If both thermocouples of a pair are faulty (entered zero), the station is skipped for all further calculations excepting bulk temperature.
8. Note 7. is also applicable to zero- entered pressure drop readings, but denotes that the combination is not read rather than an instrumentation fault.

References

[1] Grant, C.W., Butah, J., Introduction to the UCSD p-System, Sybex, 1982.

[2] Fortran Reference Manual, SofTech Microsystems, 1981.

Program Listings as follows:

```
      PROGRAM CR
      CHARACTER F*11
      R=0.
      I=0
      WRITE(*,'(A®)')'First and last file nos. to be created?(2I3)'
      READ(*,'(2I3)')K,L
      OPEN(1,FILE='N.TEXT')
      WRITE(1,6)(J,J=K,L)
6     FORMAT(100('R',I3,'.TEXT'/))
      CLOSE(1)
      OPEN(1,FILE='N.TEXT')
      DO2 JJ=K,L
      READ(1,'(A11)')F
      OPEN(2,FILE=F,STATUS='NEW')
      WRITE(2,4)R,(I,J=1,6),(R,J=1,72),JJ
4     FORMAT(F5.2/6I1/F5.3/F10.8/F5.3/2F5.3/3F5.3/4F5.3/5F5.3/
     *6F5.3/7F5.3/F9.5/4(10F5.1/)F5.1/'C',I3,'.TEXT')
2     CLOSE(2)
      WRITE(*,'(A®)')'Creation completed in less than 7 days!'
      END
```

```
      PROGRAM RDC
      REAL T(43),CD(5,36),P(7,7),TB(20),PR(8,8),L(21,10),
     *FC(2,5),LMTD,MX,NU(25,50),TC(5,44)
      CHARACTER C*11,R*11,CH*1
      A=.000016417
      DI=.004572
      DO42 J=1,50
      DO42 I=1,25
42    NU(I,J)=0.
      IJK=0
      OPEN(3,FILE='PRINTER:')
39    DO32 I=1,7
      DO32,J=1,7
32    P(I,J)=0.
      IJK=IJK+1
      HB=0.
      WRITE(*,'(A®)')'Raw Data File Name?(Insert raw data disc)'
      READ(*,'(A11)')R
      OPEN(2,FILE=R)
      READ(2,1)CI,IY,IM,ID,FM,BC,((P(I,J),J=1,I),I=1,7),TI,(T(I),I=1,
     *40),TO,C
1     FORMAT(F5.2/3I2/F5.3/F10.8/F5.3/2F5.3/3F5.3/4F5.3/5F5.3/6F5.3/
     *7F5.3/F9.5/4(10F5.1/)F5.1/A11)
      CLOSE(2)
      WRITE(*,'(A11)')C
      WRITE(*,'(A®)')'Insert conversion disc and "RETURN"'
      READ(*,'(A11)')R
      IF=FM
      FM=(FM-IF)*1000.
      IB=IFIX(BC)
      IF(IB.EQ.0)GOTO25
      BC=(BC-IB)*1000.
      CC=CI
      IC=IFIX(CI)
      NU(19,IJK)=CC
      CI=(CI-IC)*100.
      WRITE(*,'(F6.0)')CI
      R='CD1.TEXT'
      IF(IB/2*2.EQ.IB)R='CD2.TEXT'
      OPEN(2,FILE=R)
      IF(IB/2*2.NE.IB)READ(2,3)((CD(I,J),I=1,4),J=1,36)
      IF(IB/2*2.EQ.IB)READ(2,60)((CD(I,J),I=1,5),J=1,16)
3     FORMAT(36(33X,4F7.2/))
60    FORMAT(16(33X,5F7.2/))
      CLOSE(2)
      WRITE(*,'(A8)')'CD INPUT'
      AS=3.14159*DI*DI*CD(IC,10)
      DC=CD(IC,1)*(1.+(CD(IC,2)/CD(IC,1)/3.14159)**(2.))
      R='TC1.TEXT'
      IF(IC.EQ.2)R='TC2.TEXT'
      IF(IC.EQ.3)R='TC3.TEXT'
```

```
      IF(IC.EQ.4)R='TC4.TEXT'
      IF(IB/2*2.EQ.IB)R='TCD.TEXT'
      OPEN(2,FILE=R)
      READ(2,30)TC
30    FORMAT(44(3X,5F5.1/))
      CLOSE(2)
      WRITE(*,'(A8)')'TC INPUT'
      TFM=(TI-FLOAT(IFIX(TI*10.))/10.)*10000.
      IF(TFM.LT.TI)TFM=TO
      TI=FLOAT(IFIX(TI*10.))/10.
      T(41)=TI
      T(42)=TO
      T(43)=TFM
      DO31 I=1,43
      IF(T(I).EQ.0..AND.I/2*2.EQ.I)T(I)=T(I-1)
      IF(T(I).EQ.0..AND.I/2*2.NE.I)T(I)=T(I+1)
      DO31 J=1,5
      IF(T(I).GT.TC(J+1,44).OR.T(I).LE.10.)GOTO31
      IF(T(I).GE.TC(J,44).AND.I.LE.40.AND.IB.EQ.1)T(I)=(T(I)+
     *(T(I)-TC(J,44))/(TC(J+1,44)-TC(J,44))*(TC(J+1,I)-TC(J,I))
     *-32.)*5./9.
      IF(T(I).GT.TC(J,44).AND.I.LE.40.AND.IB.EQ.2)T(I)=(T(I)-
     *(T(I)-TC(J,44))/(TC(J+1,44)-TC(J,44))*(TC(J+1,I)-TC(J,I))
     *-32.)*5./9.
      IF(T(I).GE.TC(J,44).AND.I.GT.40)T(I)=(T(I)-(T(I)-TC(J,44))/
     *(TC(J+1,44)-TC(J,44))*(TC(J+1,I)-TC(J,I))-32.)*5./9.
31    CONTINUE
      K=0
      TWA=0.
      IF(IB.GE.3.OR.T(1).LE.10.)GOTO61
      DO34 I=2,36
      IF(T(I).LE.20.)GOTO34
      TWA=TWA+T(I)
      K=K+1
34    CONTINUE
      TWA=TWA/FLOAT(K)
61    TI=T(41)
      TO=T(42)
      TFM=T(43)
      TA=(TI+TO)/2.
      TMF=(TWA+TA)/2.
      OPEN(2,FILE='FC.TEXT')
      READ(2,14)(FC(2,J),J=1,5)
14    FORMAT(F4.0,2X,4F11.6)
      DO15 I=1,13
      DO4 J=1,5
4     FC(1,J)=FC(2,J)
      READ(2,14)(FC(2,J),J=1,5)
      IF(FC(2,1).GE.FM)GOTO16
15    CONTINUE
16    CLOSE(2)
```

```
      WRITE(*,'(A10)')'FC SCANNED'
      MX=(FM-FC(1,1))/(FC(2,1)-FC(1,1))
      FM=(FC(2,IF+1)-FC(1,IF+1))*MX+FC(1,IF+1)
      OPEN(2,FILE='HOH.TEXT')
      READ(2,13)(PR(2,K),K=1,8)
13    FORMAT(F3.0,F5.1,F7.1,F6.2,F6.4,F5.2,2F6.3)
      DO18 I=1,46
      DO17 J=1,8
17    PR(1,J)=PR(2,J)
      READ(2,13)(PR(2,K),K=1,8)
      IF(PR(2,1).GE.TA)GOTO19
18    CONTINUE
19    CLOSE(2)
      WRITE(*,'(A11)')'HOH SCANNED'
      TX=(TA-PR(1,1))/(PR(2,1)-PR(1,1))
      DO22 I=1,8
22    PR(7,I)=(PR(2,I)-PR(1,I))*TX+PR(1,I)
      FM=FM*(PR(7,2)+(TA-TFM)*.27)/998.5
      QF=FM*PR(7,3)*ABS(TO-TI)
      U=FM/A/PR(7,2)
      RT=CD(IC,10)*DI/U*1.25
      OPEN(2,FILE='HOH.TEXT')
      READ(2,13)(PR(2,K),K=1,8)
      DO43 I=1,40
      DO44 J=1,8
44    PR(1,J)=PR(2,J)
      READ(2,13)(PR(2,K),K=1,8)
      IF(PR(2,1).GE.TMF)GOTO47
43    CONTINUE
47    CLOSE(2)
      WRITE(*,'(A11)')'HOH SCANNED'
      TX=(TMF-PR(1,1))/(PR(2,1)-PR(1,1))
      DO45 I=1,8
45    PR(8,I)=(PR(2,I)-PR(1,I))*TX+PR(1,I)
      K=0
      F=0.
      IF(TI.GT.TO.OR.IB.EQ.2)GOTO49
      DO5 I=1,7
      P(I,I)=0.
      DO5 J=1,I
      IF(P(I,J).EQ.0.)GOTO5
      P(I,J)=190.5*(P(I,J)-1.)
      P(J,I)=P(I,J)*4.9033/ABS(CD(IC,2+I)-CD(IC,2+J))/U/U/1000.
      IF(I.GT.(IFIX(CD(IC,12))+1).OR.J.GT.(IFIX(CD(IC,12))+1))GOTO5
      F=F+P(J,I)
      K=K+1
5     CONTINUE
      F=F/FLOAT(K)
49    GOTO(24,2,41,41),IB
2     DT1=TWA-TI
      DT2=TWA-TO
```

```
      D=ALOG(DT2/DT1)
      LMTD=(DT2-DT1)/D
      AMTD=ABS(DT1+DT2)/2.
24    IF(IB.EQ.1)LMTD=TWA-TA
41    NU(1,IJK)=FM*DI/A/PR(7,4)*10000.
      NU(2,IJK)=NU(1,IJK)*SQRT(1./CD(IC,1))
      NU(3,IJK)=PR(7,4)*PR(7,3)*.0001/PR(7,5)
      IF(IB.GE.3)GOTO26
      NU(4,IJK)=9.8066*PR(7,7)*(DI**3.)*LMTD/PR(7,8)/PR(7,8)
     **100000000.
      NU(5,IJK)=QF*DI/AS/LMTD/PR(7,5)
      IF(IB.EQ.2)GOTO26
      QE=FLOAT(IFIX(BC))*(BC-IFIX(BC))*10.
      IF(BC.GT.85.)QE=FLOAT(IFIX(BC))*(BC-IFIX(BC))*100.
      RS=QE/FLOAT(IFIX(BC))/FLOAT(IFIX(BC))
      SK=.013862*TWA+14.88734
      HB=(QE-QF)/QE*100.
      NU(20,IJK)=HB
      NU(15,IJK)=QE*DI/AS/LMTD/PR(7,5)
      DT=.02899*QE/CD(IC,10)/DI/SK
      DO40 I=1,21
      DO40 J=1,9
40    L(I,J)=0.
      DO12 J=1,20
      TB(J)=(TO-TI)*CD(IC,J+16)/CD(IC,10)+TI
      L(J,5)=T(2*J)-DT-TB(J)
      L(J,6)=L(J,5)
      IF(T(2*J).GT.T(2*J-1))L(J,6)=T(2*J-1)-DT-TB(J)
      IF(T(2*J).LE.T(2*J-1))L(J,5)=T(2*J-1)-DT-TB(J)
      T(J)=(T(2*J)+T(2*J-1))/2.-DT
      IF(T(J).LT.TB(J))GOTO12
      OPEN(2,FILE='HOH.TEXT')
      READ(2,13)(PR(2,K),K=1,8)
      DO20 I=1,8
20    PR(5,I)=PR(2,I)
      DO7 I=1,46
      IF(PR(5,1).GE.TB(J))GOTO11
      DO10 K=1,8
10    PR(4,K)=PR(5,K)
11    DO6 K=1,8
6     PR(1,K)=PR(2,K)
      READ(2,13)(PR(2,K),K=1,8)
      IF(PR(1,1).GE.TB(J))GOTO29
      DO28 K=1,8
28    PR(5,K)=PR(2,K)
29    IF(PR(2,1).GE.TB(J).AND.PR(1,1).LT.TB(J))TBX=(TB(J)-PR(4,1))/
     *(PR(5,1)-PR(4,1))
      IF(PR(2,1).GE.T(J))GOTO8
7     CONTINUE
8     CLOSE(2)
      WRITE(*,'(A11)')'HOH SCANNED'
```

```
      TX=(T(J)-PR(1,1))/(PR(2,1)-PR(1,1))
      DO9 K=1,8
      PR(6,K)=(PR(5,K)-PR(4,K))*TBX+PR(4,K)
9     PR(3,K)=(PR(2,K)-PR(1,K))*TX+PR(1,K)
      L(J,1)=FM*DI/A/PR(6,4)*10000.
      L(J,2)=PR(6,4)*PR(6,3)*.0001/PR(6,5)
      L(J,3)=9.8066*PR(6,7)*(DI**3.)*(T(J)-TB(J))/PR(6,8)/
     *PR(6,8)*100000000.
      L(J,4)=QE*DI/(T(J)-TB(J))/PR(6,5)/AS
      IF(L(J,5).LE.TB(J).OR.L(J,6).LE.TB(J))GOTO48
      L(J,7)=QE*DI/2./PR(6,5)*(1./L(J,5)+1./L(J,6))
48    L(J,8)=L(J,3)/LMTD*ABS(TO-TI)/CD(IC,10)
      L(J,9)=((PR(6,4)/PR(3,4))**.14)
12    CONTINUE
      DO46 I=1,9
      K=0
      DO23 J=3,18
      IF(T(J).LE.TB(J))GOTO23
      K=K+1
      L(21,I)=L(21,I)+L(J,I)
23    CONTINUE
      L(21,I)=L(21,I)/FLOAT(K)
46    CONTINUE
      NU(4,IJK)=L(21,3)
      NU(5,IJK)=L(21,4)
      NU(12,IJK)=L(21,7)
      NU(14,IJK)=L(21,8)
      NU(16,IJK)=L(21,9)
      NU(21,IJK)=L(21,2)
26    NU(6,IJK)=F
      NU(7,IJK)=NU(6,IJK)*NU(1,IJK)/16.
      NU(8,IJK)=PR(8,4)*PR(8,3)*.0001/PR(8,5)
      NU(9,IJK)=9.8066*PR(8,7)*(DI**3.)*LMTD/PR(8,8)/PR(8,8)
     **100000000.
      NU(17,IJK)=NU(4,IJK)/NU(1,IJK)
      NU(18,IJK)=NU(3,IJK)*NU(4,IJK)
      NU(10,IJK)=NU(9,IJK)/LMTD*ABS(TO-TI)/CD(IC,10)
      NU(11,IJK)=NU(4,IJK)/LMTD*ABS(TO-TI)/CD(IC,10)
      NU(22,IJK)=NU(1,IJK)*NU(3,IJK)/CD(IC,10)*3.14159/4.
      NU(23,IJK)=NU(1,IJK)*NU(8,IJK)/CD(IC,10)*3.14159/4.
      NU(25,IJK)=NU(1,IJK)/SQRT(DC)
35    WRITE(*,'(A47/)')'Insert converted data disc for storage & RET
      READ(*,'(A11)')R
      WRITE(3,51)IC,IFIX(CD(IC,1)),IFIX(CD(IC,2)),IFIX(CD(IC,10)),
     *CI,CD(IC,2)/CD(IC,1),DC,FM,TI,U,TO,IFIX(RT),TA
      GOTO(36,37,38,38),IB
36    WRITE(3,52)QE,RS,QF,SK,HB,(I,IFIX(CD(IC,16+I)),T(I),TB(I),
     *(L(I,J),J=1,4),I=1,20)
      GOTO38
37    WRITE(3,55)QF,LMTD,AMTD,T(1),TWA
38    IF(IB.GE.3)WRITE(3,56)
```

```
      IF(IB.EQ.2)GOTO66
      WRITE(3,57)(P(1,J),J=2,7),P(2,1),(P(2,J),J=3,7),
     *           (P(3,J),J=1,2),(P(3,J),J=4,7),
     *           (P(4,J),J=1,3),(P(4,J),J=5,7),
     *           (P(5,J),J=1,4),(P(5,J),J=6,7),
     *           (P(6,J),J=1,5),P(6,7),(P(7,J),J=1,6)
      IF(IB.GE.3)WRITE(3,58)NU(1,IJK),NU(6,IJK),NU(2,IJK),
     *NU(7,IJK),NU(3,IJK),NU(25,IJK)
66    IF(IB.LT.3)WRITE(3,59)((NU(J+K-1,IJK),J=1,6,5),K=1,2),NU(3,IJK)
     *NU(25,IJK),NU(4,IJK),NU(17,IJK),NU(5,IJK),NU(22,IJK)
      WRITE(*,'(A15,A11)')'End storage of ',C
25    WRITE(*,'(A37/)')'Converted data stored---Another file?'
      READ(*,'(A11)')R
      IF(R.EQ.'Y')GOTO39
      IF(R.EQ.'NO')STOP
51    FORMAT(14X,'Coil Number:',I2,5X,'D/d:',I3,5X,'h/d:',I3,5X,
     *'L/d:',I4/14X,'Run Number:',F6.0,14X,'h/D:',F6.3,2X,'Dc/d',
     *F6.1/14X,'Flowrate:',7X,F8.6,' kg/s',6X,'T(bulk inlet):',
     *F6.1,'C'/14X,'Inlet Velocity:',F9.4,' m/s',7X,'T(bulk outlet):'
     *F5.1,'C'/14X,'Residence Time:',I9,' s',9X,'T(bulk average):',
     *F4.1,'C'/14X,28('--'))
52    FORMAT(14X,'Boundary Condition:  Neumann'/14X,'Power Input:',
     *F9.1,' W     Tube Resistance:',F7.3,' ohms'/14X,
     *'Power Absorbed:',F6.1,' W     Tube Conductivity:',F5.2,' W/mK'
     *14X,'Heat Balance:',F8.1,' %'/14X,'Stn     x/d   Twi(C)  Tb(C)'
     *'   Rex    Prx     Grx    Nux'/20(14X,I2,I9,F8.1,F7.1,F8.0,
     *F6.2,E10.3,F6.2/)/14X,28('--'))
53    FORMAT(13X,'*',I2,I9,F8.1,F7.1,F8.0,F6.1,E10.3,F6.2/
     *18(14X,I2,I9,F8.1,F7.1,F8.0,F6.1,E10.3,F6.2/))
54    FORMAT(14X,'Average of Fully Developed:',F7.0,F6.1,E10.3,F6.2/
     *13X,'*Indicates approximate initiation of FULLY DEVELOPED FLOW'
     *14X,28('--'))
55    FORMAT(14X,'Boundary Condition:  Dirichlet'/14X,'Power Absor',
     *'bed:',32X,F7.1,' W'/14X,'Logarithmic Mean Temperature',
     *' Difference (LMTD):',F7.1,' C'/14X,'Arithmetic Mean Temperatur
     *'e Difference (AMTD): ',F7.1,' C'/14X,'Environmental ',
     *'Temperature:',21X,F7.1,' C'/14X,'Average Wall Temperature:',
     *22X,F7.1,' C'/14X,28('--'))
56    FORMAT(14X,'Boundary Condition:  Isothermal'/14X,28('--'))
57    FORMAT(14X,'Static Differential Pressures and Friction ',
     *'Factors'/14X,'1',10X,6F7.4/14X,'2',F7.1,10X,5F7.4/14X,'3',
     *2F7.1,10X,4F7.4/14X,'4',3F7.1,10X,3F7.4/14X,'5',4F7.1,10X,
     *2F7.4/14X,'6',5F7.1,10X,F7.4/14X,'7',6F7.1/20X,'1',6X,'2',
     *6X,'3',6X,'4',6X,'5',6X,'6',6X,'7'/14X,'Upper triangle:',
     *' friction factors (dimensionless)'/14X,'Lower triangle:',
     *' pressure differentials (mm HOH)'/14X,28('--'))
58    FORMAT(14X,'Non-Dimensional Flow Parameters'/14X,'Re:',
     *F8.0,14X,'fc:'F12.4/14X,'Dn:',F8.0,14X,'fc/fs:',F7.2/14X,
     *'Pr:'F10.2,12X,'Dn*:',F7.0/14X,28('--'))
59    FORMAT(14X,'Non-Dimensional Flow Parameters'/14X,'Re:',
     *F8.0,14X,'fc:'F12.4/14X,'Dn:',F8.0,14X,'fc/fs:',F7.2/
```

```
*14X,'Pr:',F10.2,12X,'Dn*:',F7.0/14X,'Gr:      ',E10.3,7X,
*'Gr/Re:  ',E10.3/14X,'Nu: ',F9.2,15X,'Gz:',F7.2/14X,
*28('--'))
 END
```

APPENDIX F: Sample Data Reduction

The following sample calculations are presented based on the raw data presented in Figures F.1 through F.4 using the appropriate software/calibration files:

Neumann Boundary Condition

(Figure F.1 and Figure F.2)

$\dot{m}$ = .006081	kg/s	T(bulk inlet) = 37.4°C
ΔP= 1.301	volts (stn.2-3)	T(bulk outlet)= 49.2°C
		T(wall avg) = 46.3°C
Qe= 294	watts	T(wall stn.10)= 43.5°C
V = 5.88	volts	T(bulk stn.10)= 40.5°C
I = 50	amperes	T(bulk avg) = 43.3°C

D/d = 50		x/d(10) = 138
h/d = 58		L/d = 528
Dc/d= 56.8	(calc'd)	d = .004572 metres
		As = .03467 m^2

Fluid Properties at Bulk Average and Station 10

	Bulk Average	Station 10	Units
cp =	4179.0	4178.3	J/kg K
k =	.6345	.6305	W/m K
μ =	6.17×10^{-4}	6.54×10^{-4}	kg/m s
ρ =	991.0	992.2	kg/m^3
β =	4.075×10^{-4}	3.850×10^{-4}	1/ K
ν =	$.623\times10^{-6}$	$.659\times10^{-6}$	m^2/s
Pr =	4.05	4.30	

Qf = $\dot{m}$ cp (Tbo-Tbi)
 = .006081 x 4179 x 11.77
 = 299 watts

HB = (Qe-Qf) x100/Qe
 = (294-299)x100/294
 = -1.7% heat balance

R = V/I
 = 5.88/50
 = .1176 Ω

ks = .013862 x Tw(avg) + 14.88734
 = 15.49 W/m·K

```
 4.19
850113
3.035
1.05058800
 .000
1.327 .000
 .0001.301 .000
 .000 .0001.298 .000
 .000 .000 .000 .000 .000
 .000 .000 .000 .000 .000 .000
 .000 .000 .000 .000 .000 .000 .000
 99.40872
103.1103.5105.3105.8105.4106.0105.5107.0106.8105.3
105.8106.6106.2107.4107.4107.0107.9108.6109.6111.0
110.9112.0111.9111.2111.8112.4113.3112.3114.2113.7
115.8116.1117.7116.8121.7120.4124.6123.7124.0125.4
120.5
C419.TEXT
```

Figure F.1: Raw Data File: R419.text

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   19.                h/D: 1.160   Dc/d  56.8
Flowrate:           .006044 kg/s      T(bulk inlet):  37.4C
Inlet Velocity:      .3715 m/s        T(bulk outlet): 49.1C
Residence Time:          8 s          T(bulk average):43.3C
------------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      294.0 W      Tube Resistance:    .118 ohms
Power Absorbed: 295.5 W        Tube Conductivity:15.50 W/mK
Heat Balance:       -.5 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	39.7	37.6	2450.	4.58	.155E+04	28.62
2	16	40.9	37.8	2461.	4.56	.228E+04	19.70
3	30	41.1	38.1	2477.	4.52	.219E+04	20.86
4	43	41.4	38.4	2491.	4.49	.225E+04	20.67
5	55	41.3	38.7	2505.	4.46	.202E+04	23.42
6	69	41.4	39.0	2522.	4.43	.193E+04	24.92
7	80	41.7	39.2	2534.	4.41	.197E+04	24.76
8	91	42.1	39.5	2546.	4.39	.212E+04	23.35
9	115	42.8	40.0	2573.	4.34	.231E+04	22.12
10	138	43.6	40.5	2601.	4.28	.268E+04	19.61
11	162	44.5	41.0	2631.	4.23	.306E+04	17.74
12	179	44.5	41.4	2650.	4.20	.282E+04	19.66
13	201	44.9	41.9	2674.	4.16	.279E+04	20.42
14	224	45.4	42.4	2699.	4.11	.288E+04	20.31
15	246	45.9	42.9	2722.	4.07	.299E+04	20.00
16	297	47.2	44.0	2783.	3.98	.333E+04	19.12
17	341	47.6	45.0	2828.	3.90	.281E+04	23.69
18	424	50.2	46.8	2919.	3.77	.411E+04	17.77
19	498	52.0	48.5	3004.	3.66	.459E+04	17.18
20	524	52.1	49.0	3035.	3.61	.410E+04	19.78

```
------------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0129  .0000  .0000  .0000  .0000  .0000
2   62.3              .0126  .0000  .0000  .0000  .0000
3     .0   57.3              .0128  .0000  .0000  .0000
4     .0     .0   56.8              .0000  .0000  .0000
5     .0     .0     .0     .0              .0000  .0000
6     .0     .0     .0     .0     .0              .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
------------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    2743.                 fc:       .0128
Dn:     388.                 fc/fs:   2.19
Pr:       4.04               Dn*:   364.
Gr:        .264E+04          Gr/Re:    .963E+00
Nu:      21.15                  Gz:  16.48
------------------------------------------------------------
```

Figure F.2: Converted Data File: C419.text

Tw(inner)= Tw(outer) - .02899 x Qe / (L/d x d x ks)
= 46.3 - .228
= 46.1 (average)

1.301 volts-------> 57.34mm HOH
L/d = 337 - 175 = 162 station 2 to station 3

$fc = 4.9033 \times \Delta p(mm) / (1000 \times u^2 \times L/d)$

$= .01242$

$fs = 16/Re = 16/2744 = .00583$ -----> $fc/fs = 2.13$

Non-Dimensional Parameters

Bulk Average | Station 10

$Re = (\dot{m}/Ac)(d/\mu)$

$$= \frac{.006081 \times .004572}{.000016417 \times 6.17 \times 10^{-4}}$$

= 2744 = 2588

$Nu = Qe \times d / (k \times As \times (Twi-Tb))$

$$= \frac{294 \times .004572}{.6345 \times .03467 \times 2.77}$$

= 22.0 = 20.3

$$Gr = \frac{g \beta d_i^3 (Twi-Tb)}{\nu^3}$$

= 2601 = 2493

$Dn = Re_*(D/d)^{-1/2}$
= 388
$Dn^* = Re\ (Dc/d)^{-1/2}$
= 364
$Gz = (\pi/4)\ RePr\ (L/d)$
= 16.5

Dirichlet Boundary Condition

(Figure F.3 and Figure F.4)

```
 2.54
851020
3.079
2.00000000
 .000
 .000 .000
 .000 .000 .000
 .000 .000 .000 .000
 .000 .000 .000 .000 .000
 .000 .000 .000 .000 .000 .000
 .000 .000 .000 .000 .000 .000 .000
 88.80951
192.0127.0127.5125.6    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
119.0
C254.TEXT
```

Figure F.3: Raw Data File: R254.text

```
Coil Number: 2     D/d: 29      h/d: 60     L/d: 335
Run Number:   54.               h/D: 2.069  Dc/d  41.6
Flowrate:          .013851 kg/s     T(bulk inlet):  31.6C
Inlet Velocity:     .8503 m/s       T(bulk outlet): 48.3C
Residence Time:         2 s         T(bulk average):39.9C
--------------------------------------------------------
Boundary Condition:  Dirichlet
Power Absorbed:                                   969.1 W
Logarithmic Mean Temperature Difference (LMTD):    10.5 C
Arithmetic Mean Temperature Difference (AMTD):     12.6 C
Environmental Temperature:                        192.0 C
Average Wall Temperature:                          52.6 C
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5890.                 fc:        .0000
Dn:    1094.                 fc/fs:     .00
Pr:       4.34               Dn*:    913.
Gr:         .869E+04         Gr/Re:     .148E+01
Nu:      30.41                  Gz:  59.94
--------------------------------------------------------
```

Figure F.4: Converted Data File: C254.text

$\dot{m}$	= .013859	kg/s	T(bulk inlet)	=	31.5°C
Tw	= 52.8	°C	T(bulk outlet)	=	48.3°C
Tw	= 53.1	°C	T(bulk avg)	=	39.9°C
Tw	= 52.0	°C	T(wall avg)	=	52.6°C
			T(steam)	=	88.9°C

cp	= 4178.3	J/kg K	L/d	=	335
k	= .6305	W/m K	D/d	=	29
μ	= 6.54×10^{-4}	kg/m s	h/d	=	60
β	= 3.85×10^{-4}	1/ K	Dc/d	=	41.58 (calc'd)
ν	= $.659 \times 10^{-6}$	m^2/s	As	=	.021999 m^2
ρ	= 992.2	kg/m^3			
Pr	= 4.30				

LMTD = (Tbo-Tbi)/ { ln [(Tw-Tbi)/(Tw-Tbo)] }
= 11.08 °C

AMTD = 12.50 °C

Qf = 972 watts = h x As x LMTD

h = 3988 W/m^2 K
Nu = 28.9

Re = 5901
Dn = 1096
Dn*= 915
Gz = 59.5

APPENDIX G

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:    1.                h/D:  .172   Dc/d  29.1
Flowrate:          .015736 kg/s      T(bulk inlet):  30.0C
Inlet Velocity:     .9626 m/s        T(bulk outlet): 30.0C
Residence Time:         3 s          T(bulk average):30.0C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0081  .0000  .0000  .0000  .0000  .0000
2  145.2             .0083  .0000  .0000  .0000  .0000
3     .0  145.2             .0080  .0000  .0000  .0000
4     .0     .0  141.9             .0083  .0000  .0000
5     .0     .0     .0  144.4             .0083  .0000
6     .0     .0     .0     .0  145.2             .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5478.                fc:        .0082
Dn:    1017.                fc/fs:   2.80
Pr:       5.42              Dn*:  1016.
--------------------------------------------------------
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 2. h/D: .172 Dc/d 29.1
Flowrate: .012266 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .7503 m/s T(bulk outlet): 30.0C
Residence Time: 4 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0096	.0000	.0000	.0000	.0000	.0000
2	104.6		.0098	.0000	.0000	.0000	.0000
3	.0	104.8		.0095	.0000	.0000	.0000
4	.0	.0	102.9		.0099	.0000	.0000
5	.0	.0	.0	104.4		.0098	.0000
6	.0	.0	.0	.0	104.6		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 4270. fc: .0097
Dn: 793. fc/fs: 2.59
Pr: 5.42 Dn*: 792.

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:    3.                h/D:  .172   Dc/d  29.1
Flowrate:          .008726 kg/s      T(bulk inlet):   29.7C
Inlet Velocity:     .5338 m/s        T(bulk outlet): 29.7C
Residence Time:         5 s          T(bulk average):29.7C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1           .0122  .0000  .0000  .0000  .0000  .0000
2   67.4           .0126  .0000  .0000  .0000  .0000
3     .0   68.0           .0122  .0000  .0000  .0000
4     .0     .0   66.7           .0126  .0000  .0000
5     .0     .0     .0   67.2           .0124  .0000
6     .0     .0     .0     .0   67.1           .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   3022.               fc:       .0124
Dn:    561.               fc/fs:   2.34
Pr:      5.45             Dn*:   560.
---------------------------------------------------------
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 4. h/D: .172 Dc/d 29.1
Flowrate: .005186 kg/s T(bulk inlet): 29.4C
Inlet Velocity: .3172 m/s T(bulk outlet): 29.4C
Residence Time: 9 s T(bulk average):29.4C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0185	.0000	.0000	.0000	.0000	.0000
2	36.0		.0190	.0000	.0000	.0000	.0000
3	.0	36.2		.0178	.0000	.0000	.0000
4	.0	.0	34.3		.0181	.0000	.0000
5	.0	.0	.0	34.1		.0179	.0000
6	.0	.0	.0	.0	34.1		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1787. fc: .0182
Dn: 332. fc/fs: 2.04
Pr: 5.48 Dn*: 331.

```
Coil Number: 1      D/d: 29      h/d:  5     L/d: 526
Run Number:     5.               h/D:  .172  Dc/d  29.1
Flowrate:          .004140 kg/s      T(bulk inlet):  28.9C
Inlet Velocity:     .2532 m/s        T(bulk outlet): 28.9C
Residence Time:        11 s          T(bulk average):28.9C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0206  .0000  .0000  .0000  .0000  .0000
2   25.5             .0213  .0000  .0000  .0000  .0000
3     .0    25.9            .0212  .0000  .0000  .0000
4     .0      .0   26.1            .0217  .0000  .0000
5     .0      .0     .0   26.1            .0219  .0000
6     .0      .0     .0     .0   26.7            .0000
7     .0      .0     .0     .0     .0     .0
      1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   1411.              fc:       .0214
Dn:    262.              fc/fs:   1.88
Pr:       5.55           Dn*:   262.
--------------------------------------------------------
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 6. h/D: .172 Dc/d 29.1
Flowrate: .003691 kg/s T(bulk inlet): 28.9C
Inlet Velocity: .2257 m/s T(bulk outlet): 28.9C
Residence Time: 13 s T(bulk average): 28.9C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0218	.0000	.0000	.0000	.0000	.0000
2	21.5		.0229	.0000	.0000	.0000	.0000
3	.0	22.1		.0222	.0000	.0000	.0000
4	.0	.0	21.7		.0229	.0000	.0000
5	.0	.0	.0	21.9		.0225	.0000
6	.0	.0	.0	.0	21.7		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1258. fc: .0225
Dn: 234. fc/fs: 1.77
Pr: 5.55 Dn*: 233.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 7. h/D: .172 Dc/d 29.1
Flowrate: .003043 kg/s T(bulk inlet): 28.6C
Inlet Velocity: .1861 m/s T(bulk outlet): 28.6C
Residence Time: 16 s T(bulk average): 28.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0256	.0000	.0000	.0000	.0000	.0000
2	17.1		.0250	.0000	.0000	.0000	.0000
3	.0	16.4		.0238	.0000	.0000	.0000
4	.0	.0	15.8		.0240	.0000	.0000
5	.0	.0	.0	15.6		.0238	.0000
6	.0	.0	.0	.0	15.6		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1030. fc: .0244
Dn: 191. fc/fs: 1.57
Pr: 5.59 Dn*: 191.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 8. h/D: .172 Dc/d 29.1

Flowrate: .002295 kg/s T(bulk inlet): 28.6C
Inlet Velocity: .1403 m/s T(bulk outlet): 28.6C
Residence Time: 21 s T(bulk average): 28.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0290	.0000	.0000	.0000	.0279	.0000
2	11.0		.0291	.0000	.0000	.0000	.0000
3	.0	10.9		.0278	.0000	.0000	.0000
4	.0	.0	10.5		.0289	.0000	.0000
5	.0	.0	.0	10.7		.0291	.0000
6	52.4	.0	.0	.0	10.9		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 777. fc: .0286
Dn: 144. fc/fs: 1.39
Pr: 5.59 Dn*: 144.

```
Coil Number: 1      D/d: 29      h/d:  5     L/d: 526
Run Number:    9.               h/D:  .172  Dc/d  29.1
Flowrate:          .001546 kg/s      T(bulk inlet):  28.3C
Inlet Velocity:     .0946 m/s        T(bulk outlet): 28.3C
Residence Time:        31  s         T(bulk average):28.3C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0440  .0389  .0000  .0000  .0387  .0000
2     7.6             .0404  .0000  .0393  .0000  .0000
3    13.3     6.9            .0400  .0388  .0000  .0000
4      .0      .0     6.9           .0409  .0000  .0000
5      .0    20.0    13.1     6.9          .0404  .0000
6    33.0      .0      .0      .0     6.9         .0000
7      .0      .0      .0      .0      .0     .0
       1       2       3       4       5      6       7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     520.                 fc:        .0402
Dn:      97.                 fc/fs:   1.30
Pr:       5.63               Dn*:     96.
--------------------------------------------------------
```

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   10.                h/D:  .172   Dc/d   29.1
Flowrate:          .000828 kg/s      T(bulk inlet):  28.3C
Inlet Velocity:     .0506 m/s        T(bulk outlet): 28.3C
Residence Time:        59 s          T(bulk average):28.3C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0000  .0659  .0646  .0633  .0616  .0000
2     .0            .0000  .0643  .0627  .0617  .0000
3    6.5     .0            .0000  .0646  .0627  .0000
4    9.5    6.3     .0            .0000  .0650  .0000
5   12.4    9.1    6.3     .0            .0000  .0000
6   15.0   12.0    9.1    6.3     .0            .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    278.                 fc:        .0636
Dn:     52.                 fc/fs:    1.11
Pr:      5.63               Dn*:     52.
---------------------------------------------------------
```

```
Coil Number: 1      D/d: 29      h/d:  5     L/d: 526
Run Number:   11.                h/D:  .172  Dc/d  29.1
Flowrate:          .000678 kg/s      T(bulk inlet):  28.3C
Inlet Velocity:     .0415 m/s        T(bulk outlet): 28.3C
Residence Time:        72 s          T(bulk average):28.3C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0751  .0755  .0732  .0000
2      .0            .0000  .0000  .0759  .0744  .0000
3      .0     .0            .0000  .0000  .0739  .0000
4     7.4     .0     .0            .0000  .0000  .0000
5     9.9    7.4     .0     .0            .0000  .0000
6    12.0    9.7    7.2     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    228.              fc:        .0747
Dn:     42.              fc/fs:    1.06
Pr:      5.63            Dn*:     42.
-------------------------------------------------------
```

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   12.                h/D:  .172   Dc/d  29.1
Flowrate:          .000529 kg/s     T(bulk inlet):  28.3C
Inlet Velocity:     .0323 m/s       T(bulk outlet): 28.3C
Residence Time:        92 s         T(bulk average):28.3C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0951  .0956  .0938  .0000
2      .0            .0000  .0000  .0961  .0961  .0000
3      .0     .0            .0000  .0000  .0961  .0000
4     5.7     .0     .0            .0000  .0000  .0000
5     7.6    5.7     .0     .0            .0000  .0000
6     9.3    7.6    5.7     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     178.                fc:       .0954
Dn:      33.                fc/fs:   1.06
Pr:       5.63              Dn*:     33.
--------------------------------------------------------
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 13. h/D: .172 Dc/d 29.1
Flowrate: .000379 kg/s T(bulk inlet): 28.1C
Inlet Velocity: .0232 m/s T(bulk outlet): 28.1C
Residence Time: 129 s T(bulk average):28.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.1356	.1255	.1228	.0000
2	.0		.0000	.0000	.1371	.1262	.0000
3	.0	.0		.0000	.0000	.1308	.0000
4	4.2	.0	.0		.0000	.0000	.0000
5	5.1	4.2	.0	.0		.0000	.0000
6	6.3	5.1	4.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 127. fc: .1297
Dn: 24. fc/fs: 1.03
Pr: 5.67 Dn*: 23.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 14. h/D: .172 Dc/d 29.1
Flowrate: .000230 kg/s T(bulk inlet): 27.8C
Inlet Velocity: .0140 m/s T(bulk outlet): 27.8C
Residence Time: 214 s T(bulk average):27.8C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.1903	.1829	.0000
2	.0		.0000	.0000	.0000	.1786	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	2.9	.0	.0	.0		.0000	.0000
6	3.4	2.7	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 76. fc: .1839
Dn: 14. fc/fs: .88
Pr: 5.71 Dn*: 14.

```
Coil Number: 1      D/d: 29      h/d:  5     L/d: 526
Run Number:   15.                h/D:  .172  Dc/d  29.1
Flowrate:          .017137 kg/s      T(bulk inlet):  30.8C
Inlet Velocity:     1.0487 m/s       T(bulk outlet): 30.8C
Residence Time:          2 s         T(bulk average):30.8C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0075  .0000  .0000  .0000  .0000  .0000
2  159.3             .0075  .0000  .0000  .0000  .0000
3      .0  156.2            .0072  .0000  .0000  .0000
4      .0      .0  152.4           .0075  .0000  .0000
5      .0      .0      .0  155.1          .0074  .0000
6      .0      .0      .0      .0  154.9         .0000
7      .0      .0      .0      .0      .0     .0
       1       2       3       4       5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    6061.                fc:        .0074
Dn:    1125.                fc/fs:   2.81
Pr:       5.32              Dn*:  1124.
--------------------------------------------------------
```

```
Coil Number: 1     D/d: 29     h/d:  5     L/d: 526
Run Number:   16.              h/D:  .172  Dc/d  29.1
Flowrate:          .017240 kg/s     T(bulk inlet):  32.2C
Inlet Velocity:   1.0554 m/s        T(bulk outlet): 32.2C
Residence Time:        2 s          T(bulk average):32.2C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0077  .0000  .0000  .0000  .0000  .0000
2  167.1             .0077  .0000  .0000  .0000  .0000
3     .0  162.5             .0074  .0000  .0000  .0000
4     .0     .0  158.3             .0077  .0000  .0000
5     .0     .0     .0  161.7             .0077  .0000
6     .0     .0     .0     .0  161.7             .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   6296.              fc:        .0076
Dn:   1169.              fc/fs:   3.01
Pr:      5.14            Dn*:  1167.
--------------------------------------------------------
```

Coil Number: 1   D/d: 29   h/d: 5   L/d: 526
Run Number: 17.   h/D: .172   Dc/d 29.1
Flowrate: .016314 kg/s   T(bulk inlet): 47.5C
Inlet Velocity: 1.0070 m/s   T(bulk outlet): 57.7C
Residence Time: 2 s   T(bulk average):52.6C

Boundary Condition: Neumann
Power Input: 674.1 W   Tube Resistance: .120 ohms
Power Absorbed: 692.2 W   Tube Conductivity:15.64 W/mK
Heat Balance: -2.7 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	50.2	47.7	8001.	3.71	.307E+04	57.01
2	21	50.9	47.9	8031.	3.70	.380E+04	46.58
3	33	51.3	48.2	8064.	3.68	.406E+04	44.07
4	44	51.6	48.4	8095.	3.66	.415E+04	43.49
5	56	51.5	48.6	8128.	3.65	.384E+04	47.62
6	67	51.0	48.8	8159.	3.63	.293E+04	63.00
7	78	52.1	49.0	8191.	3.61	.414E+04	45.10
8	107	52.1	49.6	8274.	3.58	.350E+04	54.80
9	133	52.8	50.1	8348.	3.54	.387E+04	50.68
10	153	53.7	50.5	8395.	3.52	.462E+04	43.19
11	183	53.7	51.1	8467.	3.49	.396E+04	51.69
12	213	53.8	51.6	8531.	3.46	.331E+04	63.20
13	242	54.5	52.2	8604.	3.43	.362E+04	59.27
14	273	55.4	52.8	8702.	3.38	.421E+04	52.43
15	330	56.2	53.9	8859.	3.32	.392E+04	59.15
16	367	56.8	54.6	8927.	3.29	.386E+04	61.49
17	440	58.4	56.0	9143.	3.20	.437E+04	58.11
18	465	58.9	56.5	9206.	3.18	.458E+04	56.26
19	502	59.0	57.2	9304.	3.14	.351E+04	75.29
20	518	59.7	57.5	9351.	3.12	.436E+04	61.46

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0068	.0000	.0000	.0000	.0000
3	.0	131.3		.0065	.0000	.0000	.0000
4	.0	.0	126.1		.0068	.0000	.0000
5	.0	.0	.0	129.2		.0067	.0000
6	.0	.0	.0	.0	129.7		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 8670.   fc: .0067
Dn: 1610.   fc/fs: 3.64
Pr: 3.40   Dn*: 1608.
Gr: .393E+04   Gr/Re: .454E+00
Nu: 53.35   Gz: 43.98

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 18. h/D: .172 Dc/d 29.1
Flowrate: .008756 kg/s T(bulk inlet): 45.8C
Inlet Velocity: .5404 m/s T(bulk outlet): 59.1C
Residence Time: 5 s T(bulk average):52.4C

Boundary Condition: Neumann
Power Input: 502.7 W Tube Resistance: .119 ohms
Power Absorbed: 485.2 W Tube Conductivity:15.64 W/mK
Heat Balance: 3.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	49.2	46.1	4173.	3.83	.361E+04	33.26
2	21	50.0	46.3	4193.	3.81	.434E+04	28.10
3	33	50.6	46.6	4214.	3.79	.466E+04	26.57
4	44	50.8	46.9	4235.	3.77	.471E+04	26.72
5	56	50.7	47.2	4257.	3.75	.425E+04	30.06
6	67	50.3	47.5	4278.	3.73	.349E+04	37.01
7	78	51.4	47.8	4299.	3.71	.455E+04	28.80
8	107	51.3	48.5	4355.	3.65	.371E+04	36.51
9	133	52.6	49.2	4406.	3.61	.464E+04	30.17
10	153	53.5	49.7	4447.	3.57	.537E+04	26.72
11	183	53.8	50.4	4502.	3.52	.487E+04	30.47
12	213	54.0	51.2	4551.	3.48	.421E+04	36.38
13	242	55.0	51.9	4595.	3.44	.473E+04	33.37
14	273	55.8	52.7	4661.	3.39	.501E+04	32.66
15	330	57.0	54.1	4768.	3.31	.494E+04	35.30
16	367	57.7	55.1	4815.	3.27	.471E+04	38.19
17	440	60.0	56.9	4969.	3.16	.584E+04	33.32
18	465	60.1	57.5	5019.	3.12	.496E+04	40.30
19	502	60.3	58.5	5093.	3.08	.375E+04	55.51
20	518	60.6	58.9	5123.	3.06	.363E+04	58.14

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0102	.0000	.0000	.0000	.0000
3	.0	56.6		.0097	.0000	.0000	.0000
4	.0	.0	54.3		.0104	.0000	.0000
5	.0	.0	.0	57.2		.0112	.0000
6	.0	.0	.0	.0	61.9		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 4639. fc: .0104
Dn: 861. fc/fs: 3.01
Pr: 3.41 Dn*: 860.
Gr: .467E+04 Gr/Re: .101E+01
Nu: 32.66 Gz: 23.61

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 19. h/D: .172 Dc/d 29.1
Flowrate: .007606 kg/s T(bulk inlet): 45.0C
Inlet Velocity: .4690 m/s T(bulk outlet): 55.9C
Residence Time: 6 s T(bulk average):50.4C

Boundary Condition: Neumann
Power Input: 359.4 W Tube Resistance: .119 ohms
Power Absorbed: 347.4 W Tube Conductivity:15.60 W/mK
Heat Balance: 3.3 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	47.7	45.2	3571.	3.89	.282E+04	29.23
2	21	48.4	45.4	3585.	3.87	.330E+04	25.25
3	33	48.8	45.7	3600.	3.86	.353E+04	23.85
4	44	49.0	45.9	3614.	3.84	.357E+04	23.84
5	56	48.8	46.1	3630.	3.82	.311E+04	27.71
6	67	48.7	46.4	3644.	3.81	.268E+04	32.57
7	78	49.6	46.6	3658.	3.79	.353E+04	25.05
8	107	49.6	47.2	3697.	3.75	.296E+04	30.86
9	133	50.6	47.7	3732.	3.71	.360E+04	25.92
10	153	51.3	48.2	3759.	3.68	.407E+04	23.41
11	183	51.7	48.8	3801.	3.63	.390E+04	25.19
12	213	51.7	49.4	3844.	3.59	.312E+04	32.49
13	242	52.5	50.0	3887.	3.55	.351E+04	29.69
14	273	53.2	50.6	3924.	3.51	.370E+04	28.97
15	330	54.4	51.8	3988.	3.45	.389E+04	28.97
16	367	54.9	52.6	4042.	3.40	.362E+04	32.22
17	440	56.7	54.1	4142.	3.31	.436E+04	28.61
18	465	57.4	54.6	4163.	3.29	.485E+04	26.15
19	502	57.4	55.4	4211.	3.25	.356E+04	36.74
20	518	58.7	55.7	4239.	3.22	.548E+04	24.33

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0113	.0000	.0000	.0000	.0000
3	.0	47.2		.0108	.0000	.0000	.0000
4	.0	.0	45.7		.0119	.0000	.0000
5	.0	.0	.0	49.0		.0145	.0000
6	.0	.0	.0	.0	60.4		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 3912. fc: .0121
Dn: 726. fc/fs: 2.96
Pr: 3.52 Dn*: 725.
Gr: .362E+04 Gr/Re: .926E+00
Nu: 27.84 Gz: 20.57

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 20. h/D: .172 Dc/d 29.1
Flowrate: .006743 kg/s T(bulk inlet): 43.7C
Inlet Velocity: .4155 m/s T(bulk outlet): 53.7C
Residence Time: 7 s T(bulk average):48.7C

Boundary Condition: Neumann
Power Input: 295.7 W Tube Resistance: .118 ohms
Power Absorbed: 281.3 W Tube Conductivity:15.58 W/mK
Heat Balance: 4.8 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	46.2	43.9	3097.	3.99	.241E+04	26.45
2	21	46.8	44.1	3109.	3.97	.280E+04	23.04
3	33	47.1	44.3	3121.	3.95	.291E+04	22.41
4	44	47.3	44.5	3132.	3.94	.293E+04	22.44
5	56	47.2	44.8	3144.	3.92	.261E+04	25.49
6	67	47.0	45.0	3155.	3.91	.222E+04	30.31
7	78	47.8	45.2	3166.	3.89	.293E+04	23.14
8	107	47.9	45.7	3195.	3.85	.248E+04	27.99
9	133	48.8	46.2	3222.	3.82	.294E+04	24.22
10	153	49.6	46.6	3244.	3.79	.351E+04	20.72
11	183	49.7	47.2	3276.	3.75	.314E+04	23.89
12	213	49.9	47.7	3309.	3.71	.271E+04	28.33
13	242	50.5	48.3	3341.	3.67	.291E+04	27.09
14	273	51.2	48.9	3376.	3.63	.304E+04	26.69
15	330	52.0	50.0	3443.	3.55	.282E+04	30.36
16	367	52.8	50.7	3480.	3.51	.308E+04	28.66
17	440	54.5	52.0	3547.	3.44	.383E+04	24.39
18	465	55.8	52.5	3579.	3.40	.517E+04	18.46
19	502	54.9	53.2	3624.	3.36	.278E+04	35.50
20	518	56.3	53.5	3641.	3.34	.453E+04	22.06

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0127	.0000	.0000	.0000	.0000
3	.0	41.7		.0121	.0000	.0000	.0000
4	.0	.0	40.2		.0123	.0000	.0000
5	.0	.0	.0	39.8		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 3365. fc: .0124
Dn: 625. fc/fs: 2.61
Pr: 3.64 Dn*: 624.
Gr: .308E+04 Gr/Re: .915E+00
Nu: 25.29 Gz: 18.29

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   21.                h/D:  .172   Dc/d  29.1
Flowrate:            .003978 kg/s      T(bulk inlet):  32.4C
Inlet Velocity:       .2441 m/s        T(bulk outlet): 46.8C
Residence Time:         12  s          T(bulk average):39.6C
--------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      240.3 W      Tube Resistance:    .119 ohms
Power Absorbed: 239.6 W      Tube Conductivity:15.44 W/mK
Heat Balance:         .3 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	35.2	32.7	1462.	5.10	.133E+04	20.44
2	21	35.7	33.0	1468.	5.08	.149E+04	18.53
3	33	35.8	33.3	1478.	5.04	.137E+04	20.45
4	44	35.8	33.6	1487.	5.01	.126E+04	22.70
5	56	36.3	33.9	1497.	4.97	.138E+04	21.19
6	67	36.6	34.2	1507.	4.93	.141E+04	21.16
7	78	37.3	34.5	1517.	4.89	.164E+04	18.62
8	107	38.1	35.3	1543.	4.80	.176E+04	18.19
9	133	38.8	36.0	1563.	4.73	.184E+04	18.11
10	153	39.6	36.6	1581.	4.69	.202E+04	17.03
11	183	40.0	37.4	1607.	4.60	.185E+04	19.57
12	213	40.9	38.2	1634.	4.51	.201E+04	18.80
13	242	41.5	39.0	1661.	4.43	.191E+04	20.78
14	273	42.5	39.9	1689.	4.35	.216E+04	19.24
15	330	43.9	41.4	1745.	4.19	.221E+04	20.62
16	367	44.8	42.4	1778.	4.11	.228E+04	21.04
17	440	46.6	44.4	1845.	3.95	.229E+04	23.24
18	465	48.1	45.1	1866.	3.89	.326E+04	16.90
19	502	47.9	46.1	1898.	3.82	.199E+04	28.99
20	518	48.6	46.6	1913.	3.79	.243E+04	24.28

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0181	.0000	.0000	.0000	.0000	.0000
2	21.0		.0187	.0000	.0000	.0000	.0000
3	.0	21.1		.0177	.0000	.0000	.0000
4	.0	.0	20.2		.0189	.0000	.0000
5	.0	.0	.0	21.1		.0172	.0000
6	.0	.0	.0	.0	19.4		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:    1680.               fc:        .0181
Dn:     312.               fc/fs:   1.90
Pr:       4.37             Dn*:    312.
Gr:        .192E+04        Gr/Re:     .114E+01
Nu:      19.85                 Gz:   10.97
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 22. h/D: .172 Dc/d 29.1
Flowrate: .002079 kg/s T(bulk inlet): 32.1C
Inlet Velocity: .1276 m/s T(bulk outlet): 44.2C
Residence Time: 23 s T(bulk average):38.2C

Boundary Condition: Neumann
Power Input: 106.7 W Tube Resistance: .119 ohms
Power Absorbed: 105.0 W Tube Conductivity:15.41 W/mK
Heat Balance: 1.6 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	34.0	32.3	761.	5.13	.864E+03	13.76
2	21	34.2	32.6	763.	5.11	.872E+03	13.79
3	33	34.4	32.9	766.	5.08	.801E+03	15.20
4	44	34.8	33.1	770.	5.06	.909E+03	13.59
5	56	35.1	33.4	774.	5.03	.948E+03	13.27
6	67	35.2	33.7	778.	5.00	.877E+03	14.59
7	78	35.6	33.9	782.	4.97	.999E+03	13.03
8	107	36.3	34.6	794.	4.89	.107E+04	12.75
9	133	36.9	35.2	804.	4.82	.110E+04	12.83
10	153	37.5	35.6	811.	4.77	.121E+04	11.93
11	183	38.0	36.3	822.	4.71	.109E+04	13.77
12	213	38.7	37.0	833.	4.65	.115E+04	13.68
13	242	39.2	37.7	845.	4.57	.112E+04	14.54
14	273	40.0	38.4	857.	4.49	.118E+04	14.32
15	330	41.1	39.7	880.	4.36	.112E+04	16.35
16	367	42.0	40.5	896.	4.28	.127E+04	15.10
17	440	43.6	42.2	926.	4.13	.133E+04	15.91
18	465	44.7	42.8	935.	4.08	.181E+04	11.99
19	502	44.6	43.6	950.	4.01	.102E+04	22.23
20	518	45.1	44.0	957.	3.98	.118E+04	19.62

Static Differential Pressures and Friction Factors

1		.0290	.0000	.0000	.0000	.0000	.0000
2	9.1		.0290	.0000	.0000	.0000	.0000
3	.0	9.0		.0281	.0000	.0000	.0000
4	.0	.0	8.8		.0300	.0000	.0000
5	.0	.0	.0	9.1		.0247	.0000
6	.0	.0	.0	.0	7.6		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 853. fc: .0282
Dn: 158. fc/fs: 1.50
Pr: 4.51 Dn*: 158.
Gr: .112E+04 Gr/Re: .132E+01
Nu: 13.93 Gz: 5.75

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 23. h/D: .172 Dc/d 29.1
Flowrate: .001046 kg/s T(bulk inlet): 31.0C
Inlet Velocity: .0641 m/s T(bulk outlet): 41.7C
Residence Time: 46 s T(bulk average):36.4C

Boundary Condition: Neumann
Power Input: 47.6 W Tube Resistance: .119 ohms
Power Absorbed: 46.8 W Tube Conductivity:15.39 W/mK
Heat Balance: 1.8 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	32.3	31.2	373.	5.27	.526E+03	9.29
2	21	32.5	31.4	375.	5.24	.539E+03	9.23
3	33	32.8	31.7	377.	5.20	.559E+03	9.08
4	44	33.1	31.9	380.	5.17	.618E+03	8.38
5	56	33.3	32.1	382.	5.14	.620E+03	8.48
6	67	33.5	32.4	383.	5.13	.620E+03	8.57
7	78	33.8	32.6	384.	5.11	.653E+03	8.22
8	107	34.4	33.2	388.	5.05	.684E+03	8.09
9	133	35.0	33.7	392.	4.99	.711E+03	8.06
10	153	35.5	34.1	395.	4.95	.790E+03	7.46
11	183	35.9	34.7	401.	4.87	.739E+03	8.30
12	213	36.5	35.3	406.	4.80	.742E+03	8.56
13	242	37.0	35.9	410.	4.74	.730E+03	8.97
14	273	37.8	36.6	415.	4.69	.807E+03	8.44
15	330	38.8	37.7	425.	4.57	.762E+03	9.56
16	367	39.6	38.5	432.	4.48	.827E+03	9.20
17	440	41.0	40.0	445.	4.34	.860E+03	9.63
18	465	41.8	40.5	450.	4.29	.112E+04	7.61
19	502	41.8	41.2	457.	4.21	.528E+03	16.91
20	518	42.3	41.5	460.	4.19	.689E+03	13.19

Static Differential Pressures and Friction Factors

1		.0526	.0495	.0000	.0000	.0000	.0000
2	4.2		.0000	.0474	.0497	.0000	.0000
3	7.8	.0		.0000	.0501	.0000	.0000
4	.0	7.4	.0		.0000	.0467	.0000
5	.0	11.6	7.8	.0		.0000	.0000
6	.0	.0	.0	7.2	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 414. fc: .0493
Dn: 77. fc/fs: 1.28
Pr: 4.71 Dn*: 77.
Gr: .740E+03 Gr/Re: .179E+01
Nu: 8.54 Gz: 2.91

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 24. h/D: .172 Dc/d 29.1
Flowrate: .000581 kg/s T(bulk inlet): 29.0C
Inlet Velocity: .0356 m/s T(bulk outlet): 40.0C
Residence Time: 84 s T(bulk average):34.5C

Boundary Condition: Neumann
Power Input: 27.1 W Tube Resistance: .120 ohms
Power Absorbed: 26.6 W Tube Conductivity:15.36 W/mK
Heat Balance: 1.6 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	30.1	29.2	199.	5.51	.392E+03	6.22
2	21	30.3	29.4	200.	5.48	.359E+03	6.88
3	33	30.6	29.7	201.	5.45	.388E+03	6.46
4	44	30.9	29.9	202.	5.43	.439E+03	5.79
5	56	31.1	30.2	203.	5.40	.422E+03	6.13
6	67	31.4	30.4	204.	5.37	.437E+03	5.99
7	78	31.6	30.6	205.	5.35	.454E+03	5.87
8	107	32.3	31.2	207.	5.27	.491E+03	5.66
9	133	32.8	31.8	210.	5.19	.528E+03	5.53
10	153	33.4	32.2	212.	5.14	.620E+03	4.83
11	183	33.8	32.8	214.	5.09	.543E+03	5.67
12	213	34.5	33.4	216.	5.02	.572E+03	5.60
13	242	35.1	34.1	219.	4.95	.588E+03	5.68
14	273	35.7	34.7	222.	4.87	.631E+03	5.52
15	330	36.9	35.9	228.	4.75	.630E+03	5.91
16	367	37.7	36.7	231.	4.68	.730E+03	5.35
17	440	39.2	38.2	238.	4.51	.742E+03	5.74
18	465	39.9	38.7	241.	4.46	.899E+03	4.88
19	502	40.1	39.5	245.	4.38	.487E+03	9.42
20	518	40.5	39.8	246.	4.35	.527E+03	8.88

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0000	.0785	.0785	.0000	.0774	.0000
2	.0		.0000	.0000	.0794	.0000	.0000
3	3.8	.0		.0000	.0000	.0794	.0000
4	5.7	.0	.0		.0000	.0000	.0000
5	.0	5.7	.0	.0		.0000	.0000
6	9.3	.0	5.7	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	221.	fc:	.0786
Dn:	41.	fc/fs:	1.09
Pr:	4.90	Dn*:	41.
Gr:	.570E+03	Gr/Re:	.257E+01
Nu:	5.66	Gz:	1.62

```
Coil Number: 1      D/d: 29      h/d:  5     L/d: 526
Run Number:   25.               h/D:  .172  Dc/d  29.1
Flowrate:          .001900 kg/s     T(bulk inlet):  32.4C
Inlet Velocity:     .1166 m/s       T(bulk outlet): 45.7C
Residence Time:       25  s         T(bulk average):39.0C
```

```
Boundary Condition:  Neumann
Power Input:     107.4 W      Tube Resistance:    .119 ohms
Power Absorbed: 105.6 W      Tube Conductivity:15.43 W/mK
Heat Balance:      1.7 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	34.3	32.6	698.	5.10	.886E+03	13.69
2	21	34.6	32.9	701.	5.08	.881E+03	13.94
3	33	34.7	33.2	705.	5.05	.815E+03	15.36
4	44	35.3	33.5	709.	5.02	.979E+03	13.02
5	56	35.7	33.8	713.	4.98	.106E+04	12.33
6	67	35.7	34.1	717.	4.95	.916E+03	14.47
7	78	36.2	34.4	722.	4.91	.107E+04	12.67
8	107	36.9	35.1	734.	4.82	.111E+04	12.71
9	133	37.6	35.8	743.	4.76	.116E+04	12.63
10	153	38.2	36.3	750.	4.71	.129E+04	11.71
11	183	38.7	37.0	761.	4.65	.114E+04	13.84
12	213	39.4	37.8	773.	4.56	.121E+04	13.58
13	242	40.1	38.5	785.	4.48	.120E+04	14.29
14	273	40.9	39.3	798.	4.40	.129E+04	13.99
15	330	42.2	40.7	822.	4.26	.127E+04	15.44
16	367	43.2	41.7	837.	4.17	.144E+04	14.34
17	440	45.0	43.5	866.	4.02	.152E+04	14.92
18	465	46.1	44.2	877.	3.97	.208E+04	11.30
19	502	46.1	45.1	890.	3.90	.114E+04	21.62
20	518	46.6	45.5	897.	3.87	.127E+04	19.71

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0301	.0000	.0000	.0000
3	.0	.0		.0000	.0325	.0000	.0000
4	.0	15.6	.0		.0000	.0000	.0000
5	.0	.0	16.8	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:     794.                  fc:        .0313
Dn:     147.                  fc/fs:   1.55
Pr:       4.42                Dn*:   147.
Gr:        .122E+04           Gr/Re:     .154E+01
Nu:      13.54                  Gz:    5.24
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 27. h/D: .172 Dc/d 29.1
Flowrate: .001148 kg/s T(bulk inlet): 36.2C
Inlet Velocity: .0702 m/s T(bulk outlet): 26.3C
Residence Time: 42 s T(bulk average):31.2C

Boundary Condition: Neumann
Power Input: 47.4 W Tube Resistance: .119 ohms
Power Absorbed: 47.7 W Tube Conductivity:15.36 W/mK
Heat Balance: -.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	36.8	36.0	451.	4.73	.507E+03	12.94
2	21	36.7	35.8	449.	4.75	.599E+03	10.82
3	33	36.5	35.6	448.	4.78	.597E+03	10.74
4	44	36.3	35.4	446.	4.80	.589E+03	10.77
5	56	36.2	35.2	444.	4.82	.666E+03	9.40
6	67	35.8	34.9	442.	4.84	.538E+03	11.51
7	78	35.8	34.7	440.	4.87	.648E+03	9.43
8	107	35.4	34.2	435.	4.94	.722E+03	8.16
9	133	34.9	33.7	430.	4.99	.698E+03	8.17
10	153	34.6	33.3	427.	5.04	.683E+03	8.13
11	183	34.1	32.8	422.	5.09	.718E+03	7.49
12	213	33.6	32.2	419.	5.14	.711E+03	7.37
13	242	33.1	31.6	414.	5.21	.732E+03	6.89
14	273	32.5	31.1	408.	5.29	.666E+03	7.20
15	330	31.4	30.0	399.	5.42	.627E+03	7.13
16	367	30.5	29.3	394.	5.50	.532E+03	8.05
17	440	29.2	27.9	382.	5.70	.474E+03	8.14
18	465	28.8	27.4	378.	5.76	.500E+03	7.49
19	502	28.2	26.7	373.	5.85	.496E+03	7.19
20	518	27.6	26.4	370.	5.90	.407E+03	8.54

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.1	.0	.0		.0000	.0000	.0000
5	1.1	1.1	.0	.0		.0000	.0000
6	1.1	1.1	1.1	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 410. fc: .0000
Dn: 76. fc/fs: .00
Pr: 5.27 Dn*: 76.
Gr: .631E+03 Gr/Re: .154E+01
Nu: 8.51 Gz: 3.22

Coil Number: 1   D/d: 29   h/d: 5   L/d: 526
Run Number: 28.   h/D: .172   Dc/d 29.1
Flowrate: .000661 kg/s   T(bulk inlet): 35.0C
Inlet Velocity: .0404 m/s   T(bulk outlet): 25.3C
Residence Time: 74 s   T(bulk average):30.2C

Boundary Condition: Neumann
Power Input: 26.7 W   Tube Resistance: .119 ohms
Power Absorbed: 26.8 W   Tube Conductivity:15.34 W/mK
Heat Balance: -.4 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	35.4	34.9	254.	4.85	.306E+03	11.33
2	21	35.3	34.7	253.	4.88	.414E+03	8.28
3	33	35.2	34.4	252.	4.90	.424E+03	7.97
4	44	34.9	34.2	250.	4.93	.382E+03	8.73
5	56	34.8	34.0	249.	4.96	.453E+03	7.25
6	67	34.4	33.8	248.	4.98	.313E+03	10.36
7	78	34.4	33.6	247.	5.00	.421E+03	7.59
8	107	34.0	33.1	244.	5.06	.498E+03	6.19
9	133	33.5	32.6	243.	5.11	.497E+03	6.06
10	153	33.2	32.2	241.	5.14	.489E+03	6.06
11	183	32.7	31.7	239.	5.20	.519E+03	5.49
12	213	32.2	31.1	235.	5.29	.529E+03	5.13
13	242	31.7	30.6	233.	5.35	.526E+03	4.98
14	273	31.1	30.0	230.	5.42	.476E+03	5.29
15	330	30.1	29.0	226.	5.54	.479E+03	4.94
16	367	29.2	28.3	222.	5.64	.373E+03	6.00
17	440	27.8	26.9	216.	5.82	.315E+03	6.49
18	465	27.4	26.5	213.	5.89	.318E+03	6.18
19	502	26.8	25.8	210.	6.00	.324E+03	5.75
20	518	26.5	25.5	208.	6.05	.304E+03	5.98

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.0	.0	.0		.0000	.0000	.0000
5	1.0	1.0	.0	.0		.0000	.0000
6	1.1	1.0	1.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 231.   fc: .0000
Dn: 43.   fc/fs: .00
Pr: 5.40   Dn*: 43.
Gr: .438E+03   Gr/Re: .190E+01
Nu: 6.54   Gz: 1.86

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   29.               h/D:  .172   Dc/d  29.1
Flowrate:          .001072 kg/s      T(bulk inlet):  28.7C
Inlet Velocity:     .0657 m/s        T(bulk outlet): 39.1C
Residence Time:       45  s          T(bulk average):33.9C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:       47.5 W      Tube Resistance:    .119 ohms
Power Absorbed:    46.7 W      Tube Conductivity:15.35 W/mK
Heat Balance:       1.6 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	29.9	28.9	365.	5.55	.403E+03	10.35
2	21	30.1	29.1	367.	5.52	.411E+03	10.30
3	33	30.3	29.3	368.	5.50	.411E+03	10.46
4	44	30.6	29.5	370.	5.47	.442E+03	9.85
5	56	30.7	29.8	372.	5.44	.418E+03	10.57
6	67	30.9	30.0	373.	5.42	.401E+03	11.17
7	78	31.2	30.2	375.	5.39	.421E+03	10.78
8	107	31.8	30.8	379.	5.33	.454E+03	10.37
9	133	32.3	31.3	383.	5.26	.480E+03	10.21
10	153	32.9	31.7	387.	5.20	.583E+03	8.71
11	183	33.4	32.3	392.	5.13	.560E+03	9.41
12	213	33.9	32.9	395.	5.08	.555E+03	9.75
13	242	34.6	33.5	400.	5.02	.632E+03	8.89
14	273	35.2	34.1	405.	4.95	.662E+03	8.85
15	330	36.2	35.2	415.	4.81	.634E+03	9.92
16	367	37.1	35.9	421.	4.74	.734E+03	8.91
17	440	38.5	37.4	433.	4.61	.755E+03	9.45
18	465	38.5	37.9	437.	4.54	.470E+03	15.59
19	502	39.1	38.6	444.	4.47	.380E+03	20.11
20	518	39.5	38.9	447.	4.43	.450E+03	17.32

```
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0000  .0000  .0553  .0516  .0492  .0000
2      .0           .0000  .0000  .0559  .0478  .0000
3      .0     .0           .0000  .0000  .0551  .0000
4   13.7      .0     .0           .0000  .0000  .0000
5   17.0    13.7     .0     .0           .0000  .0000
6   20.2    15.6   13.5     .0     .0           .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     403.                fc:         .0525
Dn:      75.                fc/fs:    1.32
Pr:       4.97              Dn*:      75.
Gr:        .538E+03         Gr/Re:      .134E+01
Nu:      10.18                 Gz:    2.99
-------------------------------------------------------
```

Coil Number: 1   D/d: 29   h/d: 5   L/d: 526
Run Number: 30.   h/D: .172   Dc/d 29.1
Flowrate: .000643 kg/s   T(bulk inlet): 27.4C
Inlet Velocity: .0393 m/s   T(bulk outlet): 37.2C
Residence Time: 76 s   T(bulk average): 32.3C

Boundary Condition: Neumann
Power Input: 26.5 W   Tube Resistance: .118 ohms
Power Absorbed: 26.4 W   Tube Conductivity: 15.33 W/mK
Heat Balance: .6 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	28.4	27.6	212.	5.74	.303E+03	6.98
2	21	28.6	27.8	213.	5.71	.293E+03	7.32
3	33	28.8	28.0	214.	5.68	.307E+03	7.08
4	44	28.9	28.2	215.	5.65	.276E+03	8.01
5	56	29.2	28.4	217.	5.62	.291E+03	7.73
6	67	29.3	28.6	218.	5.59	.270E+03	8.49
7	78	29.5	28.8	219.	5.56	.258E+03	9.00
8	107	30.1	29.4	221.	5.49	.286E+03	8.44
9	133	30.6	29.9	223.	5.43	.313E+03	7.93
10	153	31.0	30.2	225.	5.39	.353E+03	7.21
11	183	31.6	30.8	227.	5.33	.351E+03	7.51
12	213	32.1	31.4	230.	5.25	.365E+03	7.55
13	242	32.8	31.9	233.	5.17	.450E+03	6.41
14	273	33.4	32.5	236.	5.12	.500E+03	5.95
15	330	34.4	33.6	240.	5.01	.461E+03	6.84
16	367	35.1	34.2	244.	4.93	.526E+03	6.29
17	440	36.4	35.6	251.	4.77	.538E+03	6.67
18	465	36.6	36.1	253.	4.73	.330E+03	11.16
19	502	37.1	36.8	256.	4.67	.238E+03	16.14
20	518	37.5	37.1	258.	4.65	.327E+03	11.98

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0771	.0726	.0698	.0000
2	.0		.0000	.0000	.0714	.0698	.0000
3	.0	.0		.0000	.0000	.0692	.0000
4	6.9	.0	.0		.0000	.0000	.0000
5	8.6	6.3	.0	.0		.0000	.0000
6	10.3	8.2	6.1	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 235.   fc: .0717
Dn: 44.   fc/fs: 1.05
Pr: 5.13   Dn*: 44.
Gr: .367E+03   Gr/Re: .156E+01
Nu: 7.64   Gz: 1.80

Coil Number: 1   D/d: 29   h/d: 5   L/d: 526
Run Number: 31.   h/D: .172   Dc/d 29.1
Flowrate: .002535 kg/s   T(bulk inlet): 37.5C
Inlet Velocity: .1552 m/s   T(bulk outlet): 27.2C
Residence Time: 19 s   T(bulk average):32.4C

Boundary Condition: Neumann
Power Input: 106.2 W   Tube Resistance: .118 ohms
Power Absorbed: 109.3 W   Tube Conductivity:15.38 W/mK
Heat Balance: -2.9 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	38.3	37.3	1023.	4.61	.669E+03	23.80
2	21	38.4	37.1	1018.	4.64	.907E+03	17.35
3	33	38.2	36.9	1014.	4.66	.928E+03	16.72
4	44	38.0	36.7	1009.	4.68	.879E+03	17.42
5	56	37.9	36.4	1004.	4.70	.963E+03	15.67
6	67	37.3	36.2	1000.	4.72	.678E+03	21.96
7	78	37.4	36.0	996.	4.73	.887E+03	16.55
8	107	36.9	35.4	986.	4.79	.950E+03	14.99
9	133	36.6	34.9	976.	4.84	.104E+04	13.37
10	153	36.3	34.5	967.	4.89	.107E+04	12.60
11	183	35.6	34.0	954.	4.97	.971E+03	13.38
12	213	35.2	33.4	943.	5.03	.101E+04	12.30
13	242	34.8	32.8	933.	5.09	.104E+04	11.57
14	273	34.0	32.2	925.	5.14	.937E+03	12.54
15	330	33.0	31.1	901.	5.29	.921E+03	11.68
16	367	32.0	30.3	888.	5.38	.733E+03	13.97
17	440	30.5	28.9	864.	5.55	.641E+03	14.62
18	465	29.8	28.4	854.	5.62	.557E+03	16.17
19	502	29.2	27.7	840.	5.72	.549E+03	15.55
20	518	28.7	27.4	835.	5.76	.490E+03	17.07

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.2	.0	.0		.0000	.0000	.0000
5	1.2	1.2	.0	.0		.0000	.0000
6	1.3	1.2	1.2	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 928.   fc: .0000
Dn: 172.   fc/fs: .00
Pr: 5.12   Dn*: 172.
Gr: .888E+03   Gr/Re: .957E+00
Nu: 14.72   Gz: 7.10

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   32.                h/D:  .172   Dc/d  29.1
Flowrate:          .004099 kg/s      T(bulk inlet):  42.2C
Inlet Velocity:     .2512 m/s        T(bulk outlet): 28.2C
Residence Time:        11 s          T(bulk average):35.2C
```

Boundary Condition: Neumann
Power Input: 241.1 W   Tube Resistance: .119 ohms
Power Absorbed: 239.4 W   Tube Conductivity: 15.44 W/mK
Heat Balance: .7 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	43.6	41.9	1816.	4.15	.159E+04	29.50
2	21	43.9	41.6	1806.	4.18	.204E+04	22.70
3	33	43.7	41.3	1795.	4.20	.211E+04	21.55
4	44	43.2	41.0	1785.	4.23	.196E+04	22.86
5	56	43.2	40.7	1773.	4.26	.214E+04	20.54
6	67	42.1	40.4	1761.	4.29	.143E+04	30.24
7	78	42.4	40.1	1750.	4.32	.194E+04	21.87
8	107	41.8	39.4	1724.	4.39	.195E+04	20.84
9	133	41.4	38.7	1700.	4.46	.209E+04	18.62
10	153	41.1	38.1	1681.	4.52	.220E+04	17.13
11	183	40.1	37.3	1654.	4.61	.192E+04	18.77
12	213	39.6	36.5	1628.	4.69	.204E+04	16.88
13	242	38.8	35.8	1603.	4.76	.192E+04	17.12
14	273	37.9	34.9	1579.	4.84	.184E+04	17.10
15	330	36.6	33.4	1527.	5.02	.175E+04	16.29
16	367	35.3	32.4	1502.	5.12	.149E+04	18.14
17	440	33.3	30.5	1441.	5.36	.129E+04	18.21
18	465	32.3	29.8	1423.	5.44	.106E+04	21.35
19	502	31.2	28.9	1396.	5.55	.967E+03	21.90
20	518	30.9	28.4	1382.	5.62	.959E+03	21.34

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.4	.0	.0		.0000	.0000	.0000
5	1.5	1.4	.0	.0		.0000	.0000
6	1.6	1.5	1.4	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:   1587.              fc:       .0000
Dn:    295.              fc/fs:    .00
Pr:     4.81             Dn*:   294.
Gr:      .182E+04        Gr/Re:    .115E+01
Nu:    19.84                Gz:  11.41
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 33. h/D: .172 Dc/d 29.1
Flowrate: .006082 kg/s T(bulk inlet): 41.1C
Inlet Velocity: .3727 m/s T(bulk outlet): 29.6C
Residence Time: 8 s T(bulk average):35.3C

Boundary Condition: Neumann
Power Input: 294.8 W Tube Resistance: .118 ohms
Power Absorbed: 293.2 W Tube Conductivity:15.44 W/mK
Heat Balance: .6 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	10	42.6	40.9	2639.	4.24	.155E+04	34.87
2	21	42.9	40.6	2625.	4.27	.193E+04	27.60
3	33	42.7	40.4	2610.	4.30	.200E+04	26.23
4	44	42.4	40.1	2597.	4.32	.189E+04	27.35
5	56	42.4	39.9	2583.	4.35	.207E+04	24.61
6	67	41.3	39.6	2571.	4.37	.137E+04	36.67
7	78	41.8	39.4	2558.	4.39	.191E+04	25.97
8	107	41.3	38.7	2526.	4.45	.194E+04	24.64
9	133	41.0	38.2	2496.	4.51	.207E+04	22.37
10	153	40.8	37.7	2474.	4.56	.224E+04	20.11
11	183	39.9	37.1	2441.	4.64	.195E+04	22.37
12	213	39.4	36.4	2409.	4.70	.198E+04	21.07
13	242	38.9	35.8	2380.	4.76	.198E+04	20.36
14	273	38.1	35.1	2350.	4.82	.184E+04	21.13
15	330	36.9	33.9	2285.	4.98	.173E+04	20.73
16	367	35.9	33.0	2248.	5.07	.152E+04	22.29
17	440	34.2	31.4	2182.	5.24	.137E+04	22.50
18	465	33.0	30.9	2153.	5.32	.100E+04	29.48
19	502	32.4	30.1	2120.	5.41	.102E+04	27.33
20	518	32.1	29.7	2107.	5.45	.100E+04	27.26

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.6	.0	.0		.0000	.0000	.0000
5	1.8	1.6	.0	.0		.0000	.0000
6	2.0	1.8	1.6	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 2360. fc: .0000
Dn: 438. fc/fs: .00
Pr: 4.80 Dn*: 438.
Gr: .180E+04 Gr/Re: .765E+00
Nu: 24.24 Gz: 16.92

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   34.                h/D:  .172   Dc/d  29.1
Flowrate:          .000947 kg/s      T(bulk inlet):  30.6C
Inlet Velocity:     .0580 m/s        T(bulk outlet): 30.6C
Residence Time:        51 s          T(bulk average):30.6C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0790  .0000  .0000  .0000  .0000  .0000
2     5.1             .0000  .0000  .0000  .0000  .0000
3      .0      .0            .0000  .0000  .0000  .0000
4      .0      .0      .0           .0000  .0000  .0000
5      .0      .0      .0     .0           .0000  .0000
6      .0      .0      .0     .0     .0           .0000
7      .0      .0      .0     .0     .0     .0
       1       2       3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    333.                fc:      .0790
Dn:     62.                fc/fs:  1.65
Pr:      5.35              Dn*:    62.
---------------------------------------------------------
```

Coil Number: 1   D/d: 29   h/d: 5   L/d: 526
Run Number: 35.   h/D: .172   Dc/d 29.1
Flowrate: .001545 kg/s   T(bulk inlet): 30.6C
Inlet Velocity: .0946 m/s   T(bulk outlet): 30.6C
Residence Time: 31 s   T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0451	.0000	.0000	.0000	.0000	.0000
2	7.8		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 544.   fc: .0451
Dn: 101.   fc/fs: 1.53
Pr: 5.35   Dn*: 101.

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   36.                h/D:  .172   Dc/d  29.1
Flowrate:           .002144 kg/s      T(bulk inlet):  30.6C
Inlet Velocity:      .1312 m/s        T(bulk outlet): 30.6C
Residence Time:        22 s           T(bulk average):30.6C
----------------------------------------------------------
Boundary Condition:  Isothermal
----------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0332  .0000  .0000  .0000  .0000  .0000
2    11.0             .0000  .0000  .0000  .0000  .0000
3      .0      .0            .0000  .0000  .0000  .0000
4      .0      .0     .0            .0000  .0000  .0000
5      .0      .0     .0     .0            .0000  .0000
6      .0      .0     .0     .0     .0            .0000
7      .0      .0     .0     .0     .0     .0
       1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
----------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    754.               fc:        .0332
Dn:    140.               fc/fs:   1.56
Pr:      5.35             Dn*:   140.
----------------------------------------------------------
```

Coil Number: 1   D/d: 29   h/d: 5   L/d: 526
Run Number: 37.   h/D: .172   Dc/d 29.1
Flowrate: .002742 kg/s   T(bulk inlet): 30.6C
Inlet Velocity: .1678 m/s   T(bulk outlet): 30.6C
Residence Time: 17 s   T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0300	.0000	.0000	.0000	.0000	.0000
2	16.4		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 965.   fc: .0300
Dn: 179.   fc/fs: 1.81
Pr: 5.35   Dn*: 179.

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   38.                h/D:  .172   Dc/d  29.1
Flowrate:          .003340 kg/s      T(bulk inlet):  30.6C
Inlet Velocity:     .2044 m/s        T(bulk outlet): 30.6C
Residence Time:        14 s          T(bulk average):30.6C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0247  .0000  .0000  .0000  .0000  .0000
2   20.0             .0000  .0000  .0000  .0000  .0000
3     .0      .0            .0000  .0000  .0000  .0000
4     .0      .0     .0            .0000  .0000  .0000
5     .0      .0     .0     .0            .0000  .0000
6     .0      .0     .0     .0     .0            .0000
7     .0      .0     .0     .0     .0     .0
      1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   1175.               fc:       .0247
Dn:    218.               fc/fs:   1.82
Pr:      5.35             Dn*:   218.
-------------------------------------------------------
```

```
Coil Number: 1     D/d: 29     h/d:  5     L/d: 526
Run Number:   39.              h/D:  .172  Dc/d  29.1
Flowrate:          .003689 kg/s    T(bulk inlet):   30.6C
Inlet Velocity:     .2257 m/s      T(bulk outlet): 30.6C
Residence Time:        13 s        T(bulk average):30.6C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0241  .0000  .0000  .0000  .0000  .0000
2    23.8            .0000  .0000  .0000  .0000  .0000
3      .0      .0           .0000  .0000  .0000  .0000
4      .0      .0     .0           .0000  .0000  .0000
5      .0      .0     .0     .0           .0000  .0000
6      .0      .0     .0     .0     .0           .0000
7      .0      .0     .0     .0     .0     .0
       1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    1298.               fc:        .0241
Dn:     241.               fc/fs:   1.96
Pr:        5.35            Dn*:    241.
--------------------------------------------------------
```

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 40. h/D: .172 Dc/d 29.1
Flowrate: .004138 kg/s T(bulk inlet): 30.6C
Inlet Velocity: .2532 m/s T(bulk outlet): 30.6C
Residence Time: 11 s T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0227	.0000	.0000	.0000	.0000	.0000
2	28.2		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1456. fc: .0227
Dn: 270. fc/fs: 2.07
Pr: 5.35 Dn*: 270.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 41. h/D: .172 Dc/d 29.1
Flowrate: .006082 kg/s T(bulk inlet): 30.6C
Inlet Velocity: .3721 m/s T(bulk outlet): 30.6C
Residence Time: 8 s T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0150	.0000	.0000	.0000	.0000	.0000
2	40.2		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 2139. fc: .0150
Dn: 397. fc/fs: 2.00
Pr: 5.35 Dn*: 397.

Coil Number: 1	D/d: 29	h/d: 5	L/d: 526
Run Number: 42.		h/D: .172	Dc/d 29.1
Flowrate: .007852 kg/s		T(bulk inlet): 30.6C	
Inlet Velocity: .4804 m/s		T(bulk outlet): 30.6C	
Residence Time: 6 s		T(bulk average):30.6C	

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0155	.0000	.0000	.0000	.0000	.0000
2	69.3		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	2762.	fc:	.0155
Dn:	513.	fc/fs:	2.68
Pr:	5.35	Dn*:	512.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 43. h/D: .172 Dc/d 29.1
Flowrate: .010658 kg/s T(bulk inlet): 30.6C
Inlet Velocity: .6521 m/s T(bulk outlet): 30.6C
Residence Time: 4 s T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0095	.0000	.0000	.0000	.0000	.0000
2	77.9		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 3749. fc: .0095
Dn: 696. fc/fs: 2.22
Pr: 5.35 Dn*: 695.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 44. h/D: .172 Dc/d 29.1
Flowrate: .012622 kg/s T(bulk inlet): 30.6C
Inlet Velocity: .7723 m/s T(bulk outlet): 30.6C
Residence Time: 3 s T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0082	.0000	.0000	.0000	.0000	.0000
2	95.3		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 4440. fc: .0082
Dn: 825. fc/fs: 2.29
Pr: 5.35 Dn*: 823.

Coil Number: 1 D/d: 29 h/d: 5 L/d: 526
Run Number: 45. h/D: .172 Dc/d 29.1
Flowrate: .015733 kg/s T(bulk inlet): 30.6C
Inlet Velocity: .9626 m/s T(bulk outlet): 30.6C
Residence Time: 3 s T(bulk average):30.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0069	.0000	.0000	.0000	.0000	.0000
2	124.8		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 5535. fc: .0069
Dn: 1028. fc/fs: 2.40
Pr: 5.35 Dn*: 1026.

```
Coil Number: 1      D/d: 29      h/d:  5      L/d: 526
Run Number:   46.                h/D:  .172   Dc/d  29.1
Flowrate:          .020040 kg/s      T(bulk inlet):  30.6C
Inlet Velocity:    1.2262 m/s        T(bulk outlet): 30.6C
Residence Time:         2 s          T(bulk average):30.6C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0080  .0000  .0000  .0000  .0000  .0000
2   233.6           .0000  .0000  .0000  .0000  .0000
3      .0     .0           .0000  .0000  .0000  .0000
4      .0     .0     .0           .0000  .0000  .0000
5      .0     .0     .0     .0           .0000  .0000
6      .0     .0     .0     .0     .0           .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    7050.                fc:        .0080
Dn:    1309.                fc/fs:   3.53
Pr:       5.35              Dn*:  1307.
---------------------------------------------------------
```

```
Coil Number: 2     D/d: 29      h/d: 60      L/d: 530
Run Number:    1.               h/D: 2.069   Dc/d  41.6
Flowrate:          .016984 kg/s     T(bulk inlet):  28.6C
Inlet Velocity:    1.0386 m/s       T(bulk outlet): 28.6C
Residence Time:         2 s         T(bulk average):28.6C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0072  .0000  .0000  .0000  .0000  .0000
2  173.2             .0073  .0000  .0000  .0000  .0000
3      .0  177.4            .0074  .0000  .0000  .0000
4      .0     .0  175.3            .0071  .0000  .0000
5      .0     .0     .0  167.8            .0066  .0000
6      .0     .0     .0     .0  125.3            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5749.               fc:        .0073
Dn:    1068.               fc/fs:   2.61
Pr:       5.59             Dn*:   892.
---------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 2. h/D: 2.069 Dc/d 41.6
Flowrate: .015323 kg/s T(bulk inlet): 28.6C
Inlet Velocity: .9370 m/s T(bulk outlet): 28.6C
Residence Time: 3 s T(bulk average): 28.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0075	.0000	.0000	.0000	.0000	.0000
2	147.8		.0077	.0000	.0000	.0000	.0000
3	.0	151.4		.0077	.0000	.0000	.0000
4	.0	.0	148.0		.0077	.0000	.0000
5	.0	.0	.0	148.2		.0069	.0000
6	.0	.0	.0	.0	106.7		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	5187.	fc:	.0077
Dn:	963.	fc/fs:	2.48
Pr:	5.59	Dn*:	804.

```
Coil Number: 2     D/d: 29      h/d: 60     L/d: 530
Run Number:    3.               h/D: 2.069  Dc/d  41.6
Flowrate:          .013168 kg/s     T(bulk inlet):  28.6C
Inlet Velocity:      .8053 m/s      T(bulk outlet): 28.6C
Residence Time:          3 s        T(bulk average):28.6C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0087  .0000  .0000  .0000  .0000  .0000
2  127.3             .0087  .0000  .0000  .0000  .0000
3      .0  126.9            .0089  .0000  .0000  .0000
4      .0      .0  126.1           .0089  .0000  .0000
5      .0      .0      .0  125.3          .0081  .0000
6      .0      .0      .0      .0   92.0         .0000
7      .0      .0      .0      .0      .0     .0
       1       2       3       4       5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    4457.               fc:        .0088
Dn:     828.               fc/fs:   2.45
Pr:       5.59             Dn*:    691.
--------------------------------------------------------
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:     4.               h/D: 2.069   Dc/d  41.6
Flowrate:           .008854 kg/s     T(bulk inlet):   28.6C
Inlet Velocity:       .5414 m/s      T(bulk outlet):  28.6C
Residence Time:           5 s        T(bulk average): 28.6C
```

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0119	.0000	.0000	.0000	.0000	.0000
2	78.1		.0119	.0000	.0000	.0000	.0000
3	.0	78.5		.0118	.0000	.0000	.0000
4	.0	.0	75.4		.0113	.0000	.0000
5	.0	.0	.0	72.6		.0103	.0000
6	.0	.0	.0	.0	53.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:   2997.            fc:       .0117
Dn:    556.            fc/fs:   2.20
Pr:      5.59          Dn*:   465.
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:     5.               h/D: 2.069   Dc/d  41.6
Flowrate:            .004470 kg/s      T(bulk inlet):  28.1C
Inlet Velocity:       .2733 m/s        T(bulk outlet): 28.1C
Residence Time:          11 s          T(bulk average):28.1C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0183  .0000  .0000  .0000  .0000  .0000
2   30.7             .0185  .0000  .0000  .0000  .0000
3     .0   31.1             .0194  .0000  .0000  .0000
4     .0     .0   31.6             .0192  .0000  .0000
5     .0     .0     .0   31.2             .0166  .0000
6     .0     .0     .0     .0   21.7             .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    1493.                fc:        .0189
Dn:     277.                fc/fs:    1.76
Pr:       5.67              Dn*:    232.
-------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 6. h/D: 2.069 Dc/d 41.6
Flowrate: .004081 kg/s T(bulk inlet): 28.1C
Inlet Velocity: .2495 m/s T(bulk outlet): 28.1C
Residence Time: 12 s T(bulk average):28.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0203	.0000	.0000	.0000	.0000	.0000
2	28.4		.0202	.0000	.0000	.0000	.0000
3	.0	28.2		.0206	.0000	.0000	.0000
4	.0	.0	28.0		.0203	.0000	.0000
5	.0	.0	.0	27.6		.0173	.0000
6	.0	.0	.0	.0	18.9		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1363. fc: .0204
Dn: 253. fc/fs: 1.73
Pr: 5.67 Dn*: 211.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 7. h/D: 2.069 Dc/d 41.6
Flowrate: .003717 kg/s T(bulk inlet): 28.1C
Inlet Velocity: .2272 m/s T(bulk outlet): 28.1C
Residence Time: 13 s T(bulk average):28.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0212	.0000	.0000	.0000	.0000	.0000
2	24.6		.0209	.0000	.0000	.0000	.0000
3	.0	24.2		.0213	.0000	.0000	.0000
4	.0	.0	24.0		.0211	.0000	.0000
5	.0	.0	.0	23.8		.0179	.0000
6	.0	.0	.0	.0	16.2		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1241. fc: .0211
Dn: 230. fc/fs: 1.64
Pr: 5.67 Dn*: 193.

```
Coil Number: 2      D/d: 29        h/d: 60      L/d: 530
Run Number:    8.                  h/D: 2.069   Dc/d  41.6
Flowrate:           .003103 kg/s      T(bulk inlet):   28.1C
Inlet Velocity:      .1897 m/s        T(bulk outlet):  28.1C
Residence Time:         15 s          T(bulk average):28.1C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0236   .0000   .0000   .0000   .0000   .0000
2    19.1             .0229   .0000   .0000   .0000   .0000
3      .0    18.5             .0233   .0000   .0000   .0000
4      .0      .0    18.3             .0230   .0000   .0000
5      .0      .0      .0    18.1             .0196   .0000
6      .0      .0      .0      .0    12.4             .0000
7      .0      .0      .0      .0      .0      .0
       1       2       3       4       5       6       7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    1036.                fc:        .0232
Dn:     192.                fc/fs:   1.50
Pr:       5.67              Dn*:    161.
--------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 9. h/D: 2.069 Dc/d 41.6
Flowrate: .002175 kg/s T(bulk inlet): 27.8C
Inlet Velocity: .1330 m/s T(bulk outlet): 27.8C
Residence Time: 22 s T(bulk average):27.8C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0293	.0000	.0000	.0000	.0000	.0000
2	11.6		.0288	.0000	.0000	.0000	.0000
3	.0	11.4		.0296	.0000	.0000	.0000
4	.0	.0	11.4		.0291	.0000	.0000
5	.0	.0	.0	11.2		.0246	.0000
6	.0	.0	.0	.0	7.6		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	722.	fc:	.0292
Dn:	134.	fc/fs:	1.32
Pr:	5.71	Dn*:	112.

```
Coil Number: 2      D/d: 29       h/d: 60      L/d: 530
Run Number:    10.                h/D: 2.069   Dc/d  41.6
Flowrate:            .001577 kg/s      T(bulk inlet):   27.8C
Inlet Velocity:       .0964 m/s        T(bulk outlet): 27.8C
Residence Time:          31  s         T(bulk average):27.8C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0000  .0393  .0000  .0000  .0000  .0000
2       .0            .0000  .0394  .0000  .0000  .0000
3    16.4      .0            .0000  .0390  .0000  .0000
4       .0   16.2      .0           .0000  .0365  .0000
5       .0     .0   15.8      .0           .0000  .0000
6       .0     .0     .0    13.3     .0           .0000
7       .0     .0     .0      .0     .0      .0
        1      2      3       4      5       6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     523.              fc:        .0392
Dn:      97.              fc/fs:   1.28
Pr:       5.71            Dn*:     81.
---------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 11. h/D: 2.069 Dc/d 41.6
Flowrate: .000828 kg/s T(bulk inlet): 27.2C
Inlet Velocity: .0506 m/s T(bulk outlet): 27.2C
Residence Time: 59 s T(bulk average): 27.2C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0669	.0000	.0000	.0000
2	.0		.0000	.0000	.0663	.0000	.0000
3	.0	.0		.0000	.0000	.0644	.0000
4	11.4	.0	.0		.0000	.0000	.0000
5	.0	11.2	.0	.0		.0000	.0000
6	.0	.0	10.1	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 272. fc: .0666
Dn: 51. fc/fs: 1.13
Pr: 5.78 Dn*: 42.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 12. h/D: 2.069 Dc/d 41.6
Flowrate: .000679 kg/s T(bulk inlet): 27.5C
Inlet Velocity: .0415 m/s T(bulk outlet): 27.5C
Residence Time: 73 s T(bulk average):27.5C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0797	.0000	.0000	.0000
2	.0		.0000	.0000	.0804	.0000	.0000
3	.0	.0		.0000	.0000	.0760	.0000
4	9.1	.0	.0		.0000	.0000	.0000
5	.0	9.1	.0	.0		.0000	.0000
6	.0	.0	8.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 224. fc: .0800
Dn: 42. fc/fs: 1.12
Pr: 5.75 Dn*: 35.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 13. h/D: 2.069 Dc/d 41.6
Flowrate: .000529 kg/s T(bulk inlet): 27.5C
Inlet Velocity: .0323 m/s T(bulk outlet): 27.5C
Residence Time: 93 s T(bulk average): 27.5C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.1038	.0000	.0000	.0000
2	.0		.0000	.0000	.1048	.0000	.0000
3	.0	.0		.0000	.0000	.0983	.0000
4	7.2	.0	.0		.0000	.0000	.0000
5	.0	7.2	.0	.0		.0000	.0000
6	.0	.0	6.3	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 175. fc: .1043
Dn: 32. fc/fs: 1.14
Pr: 5.75 Dn*: 27.

```
Coil Number: 2     D/d: 29      h/d: 60      L/d: 530
Run Number:   14.               h/D: 2.069   Dc/d  41.6
Flowrate:          .000379 kg/s     T(bulk inlet):  27.2C
Inlet Velocity:     .0232 m/s       T(bulk outlet): 27.2C
Residence Time:       130 s         T(bulk average):27.2C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0000  .1482  .1371  .0000
2      .0            .0000  .0000  .0000  .1399  .0000
3      .0     .0            .0000  .0000  .0000  .0000
4      .0     .0     .0            .0000  .0000  .0000
5     7.0     .0     .0     .0            .0000  .0000
6     7.8    6.3     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     125.              fc:        .1482
Dn:      23.              fc/fs:    1.15
Pr:       5.78            Dn*:     19.
-------------------------------------------------------
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:   16.                h/D: 2.069   Dc/d  41.6
Flowrate:            .017250 kg/s     T(bulk inlet):  30.3C
Inlet Velocity:      1.0554 m/s       T(bulk outlet): 30.3C
Residence Time:           2 s         T(bulk average):30.3C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0074  .0000  .0000  .0000  .0000  .0000
2  185.0              .0072  .0000  .0000  .0000  .0000
3     .0  178.9              .0074  .0000  .0000  .0000
4     .0     .0  179.3              .0073  .0000  .0000
5     .0     .0     .0  176.4              .0065  .0000
6     .0     .0     .0     .0  126.3              .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   6036.                fc:        .0073
Dn:   1121.                fc/fs:   2.75
Pr:      5.39              Dn*:   936.
---------------------------------------------------------
```

```
Coil Number: 2     D/d: 29      h/d: 60     L/d: 530
Run Number:   17.               h/D: 2.069  Dc/d  41.6
Flowrate:          .015853 kg/s     T(bulk inlet):  30.6C
Inlet Velocity:     .9700 m/s       T(bulk outlet): 30.6C
Residence Time:         3 s         T(bulk average):30.6C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0079  .0000  .0000  .0000  .0000  .0000
2  166.7             .0076  .0000  .0000  .0000  .0000
3      .0  160.2            .0078  .0000  .0000  .0000
4      .0      .0  160.0           .0077  .0000  .0000
5      .0      .0     .0  157.9           .0068  .0000
6      .0      .0     .0     .0  112.4           .0000
7      .0      .0     .0     .0     .0     .0
       1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5577.               fc:        .0077
Dn:    1036.               fc/fs:   2.70
Pr:       5.35             Dn*:   865.
--------------------------------------------------------
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:   18.                h/D: 2.069   Dc/d  41.6
Flowrate:          .018643 kg/s      T(bulk inlet):  30.8C
Inlet Velocity:     1.1408 m/s       T(bulk outlet): 30.8C
Residence Time:          2 s         T(bulk average):30.8C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0073  .0000  .0000  .0000  .0000  .0000
2  214.5             .0071  .0000  .0000  .0000  .0000
3      .0  206.9            .0073  .0000  .0000  .0000
4      .0      .0  206.5           .0072  .0000  .0000
5      .0      .0      .0  203.8          .0064  .0000
6      .0      .0      .0      .0  146.1         .0000
7      .0      .0      .0      .0      .0     .0
       1       2       3       4       5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    6593.               fc:        .0072
Dn:    1224.               fc/fs:   2.98
Pr:       5.32             Dn*:  1022.
-------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 19. h/D: 2.069 Dc/d 41.6
Flowrate: .017093 kg/s T(bulk inlet): 36.4C
Inlet Velocity: 1.0499 m/s T(bulk outlet): 46.1C
Residence Time: 2 s T(bulk average):41.3C

Boundary Condition: Neumann
Power Input: 662.2 W Tube Resistance: .118 ohms
Power Absorbed: 689.0 W Tube Conductivity:15.48 W/mK
Heat Balance: -4.0 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	38.6	36.6	6790.	4.69	.138E+04	68.25
2	19	39.5	36.8	6819.	4.67	.187E+04	50.93
3	29	40.1	37.0	6844.	4.66	.215E+04	44.75
4	39	39.7	37.1	6869.	4.64	.177E+04	54.97
5	46	40.1	37.3	6887.	4.62	.199E+04	49.39
6	60	39.7	37.5	6923.	4.59	.158E+04	62.99
7	88	40.2	38.0	6996.	4.53	.160E+04	63.81
8	126	41.7	38.7	7097.	4.46	.227E+04	47.00
9	147	41.7	39.1	7152.	4.42	.201E+04	54.30
10	172	42.1	39.6	7217.	4.37	.207E+04	54.14
11	206	42.4	40.2	7308.	4.31	.185E+04	62.75
12	244	43.7	40.9	7418.	4.24	.247E+04	48.85
13	274	44.3	41.4	7497.	4.20	.259E+04	48.00
14	304	45.1	42.0	7576.	4.15	.289E+04	44.37
15	333	45.5	42.5	7647.	4.10	.288E+04	45.69
16	365	45.6	43.1	7727.	4.06	.252E+04	53.75
17	406	46.4	43.8	7841.	3.99	.267E+04	52.93
18	446	47.1	44.6	7941.	3.94	.274E+04	53.52
19	496	48.1	45.5	8063.	3.87	.291E+04	52.59
20	525	47.7	46.0	8136.	3.83	.198E+04	78.86

Static Differential Pressures and Friction Factors

1		.0070	.0000	.0000	.0000	.0000	.0000
2	173.0		.0067	.0000	.0000	.0000	.0000
3	.0	165.2		.0068	.0000	.0000	.0000
4	.0	.0	164.4		.0068	.0000	.0000
5	.0	.0	.0	162.9		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 7474. fc: .0068
Dn: 1388. fc/fs: 3.19
Pr: 4.21 Dn*: 1159.
Gr: .225E+04 Gr/Re: .301E+00
Nu: 52.58 Gz: 46.62

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:   20.                h/D: 2.069   Dc/d  41.6
Flowrate:            .010138 kg/s     T(bulk inlet):  36.9C
Inlet Velocity:       .6231 m/s       T(bulk outlet): 48.5C
Residence Time:           4 s         T(bulk average):42.7C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:     498.9 W      Tube Resistance:   .118 ohms
Power Absorbed: 490.9 W      Tube Conductivity:15.50 W/mK
Heat Balance:       1.6 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	39.7	37.1	4070.	4.64	.183E+04	40.09
2	19	40.5	37.4	4091.	4.61	.224E+04	33.12
3	29	41.0	37.6	4110.	4.58	.243E+04	30.95
4	39	40.7	37.8	4128.	4.56	.210E+04	36.23
5	46	40.7	37.9	4141.	4.54	.202E+04	37.96
6	60	40.7	38.2	4167.	4.51	.185E+04	42.06
7	88	41.4	38.9	4221.	4.44	.198E+04	40.88
8	126	42.9	39.7	4291.	4.36	.266E+04	31.92
9	147	43.0	40.1	4331.	4.32	.242E+04	36.02
10	172	43.6	40.7	4382.	4.26	.255E+04	35.30
11	206	44.1	41.4	4448.	4.19	.242E+04	38.78
12	244	45.6	42.3	4517.	4.12	.319E+04	30.77
13	274	46.5	42.9	4570.	4.07	.351E+04	28.89
14	304	47.4	43.6	4628.	4.01	.390E+04	26.92
15	333	48.0	44.2	4684.	3.96	.396E+04	27.41
16	365	47.7	44.9	4738.	3.91	.302E+04	37.25
17	406	49.2	45.8	4811.	3.85	.386E+04	30.28
18	446	49.6	46.7	4884.	3.78	.347E+04	35.28
19	496	51.0	47.8	4978.	3.71	.404E+04	31.90
20	525	51.0	48.4	5034.	3.66	.341E+04	38.99

```
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0099  .0000  .0000  .0000  .0000  .0000
2    86.3             .0095  .0000  .0000  .0000  .0000
3      .0    82.9            .0097  .0000  .0000  .0000
4      .0      .0    82.5           .0096  .0000  .0000
5      .0      .0      .0    81.0          .0000  .0000
6      .0      .0      .0      .0     .0          .0000
7      .0      .0      .0      .0     .0     .0
       1       2       3       4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    4554.                 fc:         .0097
Dn:     846.                 fc/fs:    2.75
Pr:       4.09               Dn*:    706.
Gr:        .283E+04          Gr/Re:      .622E+00
Nu:      34.18                  Gz:   27.57
-------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 21. h/D: 2.069 Dc/d 41.6
Flowrate: .008675 kg/s T(bulk inlet): 37.4C
Inlet Velocity: .5331 m/s T(bulk outlet): 47.3C
Residence Time: 5 s T(bulk average):42.3C

Boundary Condition: Neumann
Power Input: 358.0 W Tube Resistance: .118 ohms
Power Absorbed: 359.8 W Tube Conductivity:15.49 W/mK
Heat Balance: -.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	39.7	37.5	3512.	4.59	.154E+04	34.95
2	19	40.3	37.7	3528.	4.56	.186E+04	29.32
3	29	40.7	37.9	3542.	4.54	.204E+04	26.96
4	39	40.5	38.1	3555.	4.52	.174E+04	31.95
5	46	40.7	38.2	3565.	4.51	.187E+04	29.93
6	60	40.4	38.5	3585.	4.48	.142E+04	39.98
7	88	41.1	39.0	3624.	4.42	.161E+04	36.48
8	126	42.5	39.7	3675.	4.36	.226E+04	27.05
9	147	42.7	40.1	3704.	4.32	.217E+04	28.75
10	172	43.3	40.6	3742.	4.27	.232E+04	27.68
11	206	43.7	41.2	3792.	4.21	.225E+04	29.61
12	244	45.0	41.9	3843.	4.15	.282E+04	24.59
13	274	45.7	42.5	3882.	4.10	.311E+04	22.93
14	304	46.4	43.1	3921.	4.06	.329E+04	22.28
15	333	46.9	43.6	3963.	4.01	.331E+04	22.77
16	365	46.4	44.2	4007.	3.96	.231E+04	33.73
17	406	47.9	45.0	4059.	3.91	.317E+04	25.50
18	446	48.1	45.7	4111.	3.85	.269E+04	31.12
19	496	49.5	46.7	4177.	3.79	.334E+04	26.26
20	525	49.4	47.2	4217.	3.75	.268E+04	33.65

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0107	.0000	.0000	.0000	.0000	.0000
2	68.2		.0104	.0000	.0000	.0000	.0000
3	.0	66.5		.0105	.0000	.0000	.0000
4	.0	.0	65.3		.0103	.0000	.0000
5	.0	.0	.0	63.8		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 3870. fc: .0105
Dn: 719. fc/fs: 2.54
Pr: 4.12 Dn*: 600.
Gr: .240E+04 Gr/Re: .620E+00
Nu: 28.83 Gz: 23.61

```
Coil Number: 2      D/d: 29       h/d: 60       L/d: 530
Run Number:    22.                h/D: 2.069    Dc/d   41.6
Flowrate:           .006759 kg/s      T(bulk inlet):   37.7C
Inlet Velocity:      .4155 m/s        T(bulk outlet): 48.1C
Residence Time:         7  s          T(bulk average):42.9C
```

```
Boundary Condition:  Neumann
Power Input:     297.5 W      Tube Resistance:    .119 ohms
Power Absorbed: 294.4 W      Tube Conductivity:15.50 W/mK
Heat Balance:       1.0 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	40.0	37.8	2756.	4.55	.154E+04	29.53
2	19	40.6	38.1	2769.	4.52	.183E+04	25.23
3	29	40.9	38.3	2780.	4.50	.196E+04	23.78
4	39	40.7	38.5	2792.	4.48	.169E+04	27.87
5	46	41.0	38.6	2800.	4.47	.182E+04	26.12
6	60	40.7	38.9	2816.	4.44	.137E+04	35.29
7	88	41.6	39.4	2847.	4.39	.171E+04	29.25
8	126	42.9	40.2	2890.	4.31	.228E+04	22.88
9	147	43.1	40.6	2916.	4.27	.213E+04	25.08
10	172	43.8	41.1	2946.	4.22	.240E+04	22.93
11	206	44.2	41.8	2984.	4.17	.228E+04	24.98
12	244	45.4	42.5	3025.	4.10	.280E+04	21.11
13	274	46.5	43.1	3057.	4.06	.340E+04	17.91
14	304	47.4	43.7	3092.	4.01	.376E+04	16.75
15	333	47.0	44.3	3125.	3.96	.293E+04	22.17
16	365	47.6	44.9	3158.	3.91	.301E+04	22.26
17	406	48.5	45.7	3201.	3.85	.316E+04	21.92
18	446	49.5	46.5	3245.	3.80	.360E+04	20.03
19	496	50.2	47.5	3301.	3.73	.337E+04	22.48
20	525	49.8	48.0	3334.	3.69	.219E+04	35.46

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0128	.0000	.0000	.0000	.0000	.0000
2	49.7		.0123	.0000	.0000	.0000	.0000
3	.0	47.6		.0125	.0000	.0000	.0000
4	.0	.0	47.2		.0123	.0000	.0000
5	.0	.0	.0	46.5		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

```
Non-Dimensional Flow Parameters
Re:   3047.                  fc:        .0125
Dn:     566.                 fc/fs:   2.38
Pr:       4.07               Dn*:    473.
Gr:        .252E+04          Gr/Re:      .827E+00
Nu:      23.77                  Gz:  18.38
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 23. h/D: 2.069 Dc/d 41.6
Flowrate: .003931 kg/s T(bulk inlet): 37.3C
Inlet Velocity: .2417 m/s T(bulk outlet): 51.2C
Residence Time: 12 s T(bulk average):44.3C

Boundary Condition: Neumann
Power Input: 241.7 W Tube Resistance: .119 ohms
Power Absorbed: 229.5 W Tube Conductivity:15.51 W/mK
Heat Balance: 5.1 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	39.8	37.5	1590.	4.60	.170E+04	21.22
2	19	40.4	37.8	1600.	4.56	.188E+04	19.59
3	29	40.7	38.0	1609.	4.53	.197E+04	18.94
4	39	40.5	38.3	1617.	4.50	.166E+04	22.79
5	46	40.9	38.5	1623.	4.48	.181E+04	21.22
6	60	40.8	38.8	1636.	4.44	.152E+04	25.74
7	88	42.1	39.6	1660.	4.37	.207E+04	19.73
8	126	43.6	40.6	1695.	4.27	.256E+04	16.94
9	147	43.9	41.1	1715.	4.22	.245E+04	18.30
10	172	44.6	41.8	1737.	4.16	.258E+04	18.00
11	206	45.4	42.7	1765.	4.09	.263E+04	18.48
12	244	46.7	43.7	1799.	4.00	.309E+04	16.55
13	274	47.6	44.5	1824.	3.94	.328E+04	16.24
14	304	48.6	45.3	1849.	3.88	.371E+04	14.93
15	333	49.2	46.0	1873.	3.83	.364E+04	15.71
16	365	49.8	46.9	1900.	3.77	.347E+04	17.28
17	406	50.8	48.0	1936.	3.69	.361E+04	17.47
18	446	51.8	49.0	1973.	3.62	.371E+04	17.91
19	496	53.1	50.3	2019.	3.53	.393E+04	17.98
20	525	53.5	51.1	2041.	3.48	.348E+04	20.99

Static Differential Pressures and Friction Factors

1		.0189	.0000	.0000	.0000	.0000	.0000
2	24.8		.0187	.0000	.0000	.0000	.0000
3	.0	24.6		.0190	.0000	.0000	.0000
4	.0	.0	24.2		.0185	.0000	.0000
5	.0	.0	.0	23.6		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1817. fc: .0188
Dn: 337. fc/fs: 2.13
Pr: 3.96 Dn*: 282.
Gr: .274E+04 Gr/Re: .151E+01
Nu: 18.51 Gz: 10.66

```
Coil Number: 2      D/d: 29       h/d: 60       L/d: 530
Run Number:    24.                h/D: 2.069    Dc/d   41.6
Flowrate:          .002190 kg/s       T(bulk inlet):   36.5C
Inlet Velocity:     .1346 m/s         T(bulk outlet): 48.7C
Residence Time:        22  s          T(bulk average):42.6C
---------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      107.8 W      Tube Resistance:    .120 ohms
Power Absorbed: 111.6 W      Tube Conductivity:15.48 W/mK
Heat Balance:      -3.5 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	38.1	36.7	871.	4.68	.975E+03	15.79
2	19	38.6	36.9	876.	4.66	.115E+04	13.62
3	29	38.8	37.2	880.	4.63	.118E+04	13.49
4	39	38.9	37.4	885.	4.61	.104E+04	15.44
5	46	39.2	37.6	887.	4.59	.122E+04	13.34
6	60	39.3	37.9	893.	4.55	.104E+04	15.85
7	88	40.1	38.5	905.	4.48	.118E+04	14.47
8	126	41.3	39.4	921.	4.39	.151E+04	11.94
9	147	41.6	39.9	930.	4.35	.143E+04	12.96
10	172	42.2	40.4	942.	4.29	.153E+04	12.52
11	206	42.9	41.2	957.	4.21	.153E+04	13.14
12	244	44.1	42.1	973.	4.14	.187E+04	11.25
13	274	44.8	42.8	985.	4.08	.199E+04	10.95
14	304	45.7	43.5	998.	4.02	.227E+04	9.94
15	333	46.3	44.2	1011.	3.97	.230E+04	10.17
16	365	46.8	44.9	1023.	3.91	.206E+04	11.79
17	406	47.7	45.8	1040.	3.84	.217E+04	11.66
18	446	48.6	46.8	1056.	3.78	.217E+04	12.26
19	496	49.7	47.9	1078.	3.70	.223E+04	12.59
20	525	50.0	48.6	1091.	3.65	.186E+04	15.54

Static Differential Pressures and Friction Factors

1		.0281	.0000	.0000	.0000	.0000	.0000
2	11.4		.0272	.0000	.0000	.0000	.0000
3	.0	11.0		.0275	.0000	.0000	.0000
4	.0	.0	10.9		.0270	.0000	.0000
5	.0	.0	.0	10.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:     981.               fc:        .0274
Dn:     182.               fc/fs:   1.68
Pr:       4.10             Dn*:   152.
Gr:        .165E+04        Gr/Re:     .169E+01
Nu:      12.57                Gz:   5.96
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:   25.                h/D: 2.069   Dc/d  41.6
Flowrate:           .001116 kg/s     T(bulk inlet):   33.5C
Inlet Velocity:      .0685 m/s       T(bulk outlet): 45.6C
Residence Time:        44 s          T(bulk average):39.5C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:       47.6 W     Tube Resistance:    .119 ohms
Power Absorbed:   56.4 W     Tube Conductivity:15.43 W/mK
Heat Balance:     -18.4 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	34.3	33.7	418.	5.00	.359E+03	15.78
2	19	34.7	33.9	420.	4.97	.446E+03	12.93
3	29	35.0	34.2	422.	4.94	.482E+03	12.16
4	39	35.2	34.4	424.	4.91	.482E+03	12.35
5	46	35.4	34.5	426.	4.89	.537E+03	11.20
6	60	35.5	34.9	429.	4.85	.373E+03	16.44
7	88	36.2	35.5	435.	4.78	.452E+03	14.07
8	126	37.3	36.4	442.	4.71	.649E+03	10.29
9	147	37.8	36.8	446.	4.67	.641E+03	10.73
10	172	38.4	37.4	451.	4.60	.730E+03	9.73
11	206	39.2	38.2	458.	4.51	.738E+03	10.05
12	244	40.3	39.1	467.	4.42	.961E+03	8.12
13	274	41.1	39.7	473.	4.36	.111E+04	7.34
14	304	41.9	40.4	480.	4.29	.125E+04	6.75
15	333	42.6	41.1	487.	4.22	.136E+04	6.48
16	365	43.0	41.8	493.	4.16	.113E+04	8.08
17	406	44.0	42.8	502.	4.08	.122E+04	7.84
18	446	44.8	43.7	510.	4.01	.119E+04	8.48
19	496	46.0	44.8	521.	3.92	.133E+04	8.03
20	525	46.3	45.5	527.	3.87	.953E+03	11.53

Static Differential Pressures and Friction Factors

1		.0000	.0407	.0420	.0422	.0000	.0000
2	.0		.0000	.0413	.0418	.0000	.0000
3	8.6	.0		.0000	.0446	.0000	.0000
4	13.1	8.6	.0		.0000	.0000	.0000
5	17.5	13.0	9.1	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

```
Non-Dimensional Flow Parameters
Re:     471.               fc:         .0421
Dn:      87.               fc/fs:    1.24
Pr:       4.38             Dn*:      73.
Gr:        .831E+03        Gr/Re:      .176E+01
Nu:      10.01                Gz:    3.06
-------------------------------------------------------
```

```
Coil Number: 2      D/d: 29       h/d: 60      L/d: 530
Run Number:   26.                 h/D: 2.069   Dc/d  41.6
Flowrate:           .001573 kg/s      T(bulk inlet):  30.2C
Inlet Velocity:      .0964 m/s        T(bulk outlet): 41.0C
Residence Time:         31 s          T(bulk average):35.6C
---------------------------------------------------------
Boundary Condition:  Neumann
Power Input:        74.1 W     Tube Resistance:    .119 ohms
Power Absorbed:     71.1 W     Tube Conductivity:15.38 W/mK
Heat Balance:        4.1 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	31.0	30.3	551.	5.38	.309E+03	22.91
2	19	31.5	30.6	553.	5.35	.443E+03	16.23
3	29	31.7	30.8	556.	5.33	.458E+03	15.92
4	39	32.0	31.0	558.	5.31	.473E+03	15.63
5	46	32.3	31.1	560.	5.29	.559E+03	13.37
6	60	32.4	31.4	564.	5.25	.489E+03	15.66
7	88	32.4	32.0	572.	5.16	.247E+03	32.53
8	126	34.1	32.7	579.	5.09	.714E+03	11.69
9	147	34.4	33.2	583.	5.05	.654E+03	13.04
10	172	34.9	33.7	589.	5.00	.683E+03	12.94
11	206	35.2	34.4	598.	4.91	.497E+03	18.63
12	244	36.6	35.1	608.	4.82	.915E+03	10.62
13	274	37.2	35.8	615.	4.76	.949E+03	10.57
14	304	38.0	36.4	623.	4.71	.109E+04	9.57
15	333	38.5	37.0	630.	4.66	.108E+04	9.98
16	365	38.9	37.6	638.	4.58	.956E+03	11.70
17	406	39.8	38.5	649.	4.48	.999E+03	11.75
18	446	40.5	39.3	660.	4.40	.943E+03	13.05
19	496	41.5	40.3	674.	4.30	.104E+04	12.58
20	525	41.6	40.9	683.	4.24	.612E+03	22.12

Static Differential Pressures and Friction Factors

1		.0466	.0000	.0000	.0000	.0000	.0000
2	9.7		.0438	.0000	.0000	.0000	.0000
3	.0	9.1		.0460	.0000	.0000	.0000
4	.0	.0	9.3		.0451	.0000	.0000
5	.0	.0	.0	9.1		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	613.	fc:	.0454
Dn:	114.	fc/fs:	1.74
Pr:	4.78	Dn*:	95.
Gr:	.731E+03	Gr/Re:	.119E+01
Nu:	14.17	Gz:	4.34

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 27. h/D: 2.069 Dc/d 41.6
Flowrate: .000594 kg/s T(bulk inlet): 27.8C
Inlet Velocity: .0364 m/s T(bulk outlet): 38.4C
Residence Time: 83 s T(bulk average):33.1C

Boundary Condition: Neumann
Power Input: 27.1 W Tube Resistance: .120 ohms
Power Absorbed: 26.5 W Tube Conductivity:15.34 W/mK
Heat Balance: 2.2 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	28.6	27.9	198.	5.69	.275E+03	7.96
2	19	28.9	28.2	199.	5.66	.273E+03	8.17
3	29	29.1	28.4	200.	5.63	.297E+03	7.64
4	39	29.2	28.6	201.	5.60	.266E+03	8.67
5	46	29.5	28.7	202.	5.58	.313E+03	7.44
6	60	29.6	29.0	203.	5.54	.250E+03	9.53
7	88	29.9	29.5	205.	5.47	.161E+03	15.32
8	126	31.1	30.3	208.	5.38	.350E+03	7.39
9	147	31.5	30.7	210.	5.33	.345E+03	7.71
10	172	31.9	31.2	212.	5.27	.330E+03	8.35
11	206	32.4	31.9	216.	5.17	.256E+03	11.42
12	244	33.7	32.7	219.	5.10	.531E+03	5.72
13	274	34.4	33.3	221.	5.04	.616E+03	5.10
14	304	35.1	33.9	223.	4.97	.695E+03	4.70
15	333	35.7	34.5	226.	4.90	.719E+03	4.73
16	365	36.1	35.1	230.	4.82	.631E+03	5.61
17	406	36.9	35.9	233.	4.74	.646E+03	5.72
18	446	37.6	36.7	237.	4.67	.554E+03	7.01
19	496	38.6	37.7	242.	4.56	.615E+03	6.69
20	525	38.7	38.3	245.	4.50	.258E+03	16.50

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0949	.0942	.0000	.0000
2	.0		.0000	.0000	.0958	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	8.4	.0	.0		.0000	.0000	.0000
5	11.0	8.4	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 220. fc: .0950
Dn: 41. fc/fs: 1.31
Pr: 5.06 Dn*: 34.
Gr: .435E+03 Gr/Re: .198E+01
Nu: 7.63 Gz: 1.65

Coil Number: 2   D/d: 29   h/d: 60   L/d: 530
Run Number: 28.   h/D: 2.069   Dc/d 41.6
Flowrate: .000427 kg/s   T(bulk inlet): 27.2C
Inlet Velocity: .0262 m/s   T(bulk outlet): 41.4C
Residence Time: 115 s   T(bulk average):34.3C

Boundary Condition: Neumann
Power Input: 27.1 W   Tube Resistance: .120 ohms
Power Absorbed: 25.3 W   Tube Conductivity:15.35 W/mK
Heat Balance: 6.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	28.1	27.4	141.	5.76	.269E+03	7.89
2	19	28.5	27.7	142.	5.72	.279E+03	7.76
3	29	28.7	28.0	142.	5.68	.267E+03	8.26
4	39	28.9	28.3	143.	5.64	.244E+03	9.22
5	46	29.2	28.5	144.	5.61	.295E+03	7.76
6	60	29.4	28.8	145.	5.56	.242E+03	9.75
7	88	30.0	29.6	147.	5.47	.159E+03	15.58
8	126	34.0	30.6	150.	5.35	.157E+04	1.68
9	147	32.0	31.2	152.	5.28	.390E+03	7.04
10	172	32.7	31.8	155.	5.18	.417E+03	6.98
11	206	33.3	32.7	157.	5.09	.296E+03	10.29
12	244	34.9	33.8	160.	4.99	.647E+03	5.02
13	274	35.8	34.6	163.	4.89	.727E+03	4.71
14	304	36.7	35.4	166.	4.80	.840E+03	4.28
15	333	37.5	36.1	168.	4.72	.905E+03	4.14
16	365	38.2	37.0	171.	4.65	.809E+03	4.89
17	406	39.2	38.1	175.	4.52	.819E+03	5.13
18	446	40.1	39.2	179.	4.41	.753E+03	5.94
19	496	41.5	40.5	184.	4.28	.812E+03	5.95
20	525	41.6	41.3	187.	4.21	.318E+03	15.93

Static Differential Pressures and Friction Factors

1		.0000	.0000	.1420	.1447	.0000	.0000
2	.0		.0000	.0000	.1517	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	6.5	.0	.0		.0000	.0000	.0000
5	8.8	6.9	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 162.   fc: .1461
Dn: 30.   fc/fs: 1.48
Pr: 4.92   Dn*: 25.
Gr: .586E+03   Gr/Re: .362E+01
Nu: 6.92   Gz: 1.18

```
Coil Number: 2     D/d: 29     h/d: 60     L/d: 530
Run Number:   30.              h/D: 2.069  Dc/d  41.6
Flowrate:         .001048 kg/s      T(bulk inlet):  37.4C
Inlet Velocity:    .0641 m/s        T(bulk outlet): 26.8C
Residence Time:       47  s         T(bulk average):32.1C
---------------------------------------------------------
Boundary Condition:  Neumann
Power Input:       47.3 W     Tube Resistance:    .118 ohms
Power Absorbed:    46.7 W     Tube Conductivity:15.37 W/mK
Heat Balance:       1.4 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	37.8	37.3	422.	4.62	.351E+03	20.00
2	19	38.0	37.1	420.	4.65	.688E+03	10.07
3	29	38.0	36.9	419.	4.67	.763E+03	8.96
4	39	37.6	36.6	417.	4.68	.617E+03	10.95
5	46	37.5	36.5	416.	4.69	.657E+03	10.18
6	60	37.0	36.2	413.	4.72	.534E+03	12.32
7	88	35.9	35.7	409.	4.77	.151E+03	42.23
8	126	36.0	34.9	403.	4.85	.685E+03	8.92
9	147	35.4	34.5	399.	4.90	.550E+03	10.80
10	172	34.8	34.0	395.	4.96	.485E+03	11.87
11	206	33.8	33.3	389.	5.04	.306E+03	17.95
12	244	33.3	32.5	384.	5.11	.413E+03	12.76
13	274	32.9	31.9	381.	5.17	.498E+03	10.27
14	304	32.3	31.3	375.	5.26	.490E+03	9.92
15	333	31.7	30.7	370.	5.33	.425E+03	10.94
16	365	31.0	30.1	365.	5.41	.396E+03	11.24
17	406	30.3	29.3	360.	5.50	.431E+03	9.84
18	446	29.4	28.5	353.	5.61	.383E+03	10.43
19	496	28.4	27.5	346.	5.75	.357E+03	10.40
20	525	27.8	26.9	342.	5.83	.323E+03	11.05

```
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0000  .0000  .0000  .0000  .0000  .0000
2     .0            .0000  .0000  .0000  .0000  .0000
3     .0     .0            .0000  .0000  .0000  .0000
4    1.1     .0     .0            .0000  .0000  .0000
5    1.1    1.1     .0     .0            .0000  .0000
6    1.1    1.1    1.1     .0     .0            .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     382.               fc:        .0000
Dn:      71.               fc/fs:     .00
Pr:       5.15             Dn*:     59.
Gr:        .486E+03        Gr/Re:     .127E+01
Nu:      13.10                Gz:    2.91
---------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 31. h/D: 2.069 Dc/d 41.6
Flowrate: .000667 kg/s T(bulk inlet): 34.6C
Inlet Velocity: .0408 m/s T(bulk outlet): 25.9C
Residence Time: 74 s T(bulk average):30.2C

Boundary Condition: Neumann
Power Input: 26.0 W Tube Resistance: .115 ohms
Power Absorbed: 24.1 W Tube Conductivity:15.33 W/mK
Heat Balance: 7.1 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	34.7	34.4	254.	4.91	.168E+03	19.34
2	19	35.0	34.2	253.	4.93	.425E+03	7.57
3	29	34.9	34.1	252.	4.95	.484E+03	6.57
4	39	34.6	33.9	251.	4.97	.387E+03	8.12
5	46	34.6	33.8	250.	4.98	.439E+03	7.11
6	60	34.2	33.6	249.	5.01	.365E+03	8.42
7	88	33.2	33.1	247.	5.06	.519E+02	57.39
8	126	33.3	32.5	244.	5.11	.436E+03	6.62
9	147	32.8	32.1	243.	5.14	.336E+03	8.48
10	172	32.2	31.7	241.	5.19	.247E+03	11.19
11	206	31.5	31.2	238.	5.28	.141E+03	18.66
12	244	31.1	30.6	235.	5.35	.241E+03	10.47
13	274	30.8	30.1	232.	5.41	.303E+03	8.08
14	304	30.4	29.6	230.	5.47	.337E+03	7.04
15	333	29.8	29.1	228.	5.52	.282E+03	8.19
16	365	29.2	28.6	226.	5.59	.257E+03	8.62
17	406	28.6	27.9	222.	5.69	.276E+03	7.61
18	446	28.0	27.3	219.	5.78	.250E+03	8.07
19	496	27.1	26.4	215.	5.90	.220E+03	8.63
20	525	26.6	26.0	213.	5.97	.203E+03	9.01

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.0	.0	.0		.0000	.0000	.0000
5	1.0	1.0	.0	.0		.0000	.0000
6	1.0	1.0	1.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 233. fc: .0000
Dn: 43. fc/fs: .00
Pr: 5.39 Dn*: 36.
Gr: .302E+03 Gr/Re: .130E+01
Nu: 11.91 Gz: 1.86

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 530
Run Number:   33.                h/D: 2.069   Dc/d  41.6
Flowrate:          .000475 kg/s      T(bulk inlet):   36.5C
Inlet Velocity:     .0291 m/s        T(bulk outlet): 24.4C
Residence Time:       104 s          T(bulk average):30.5C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:        26.5 W     Tube Resistance:    .118 ohms
Power Absorbed:     24.1 W     Tube Conductivity:15.35 W/mK
Heat Balance:        9.0 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	37.4	36.4	188.	4.70	.654E+03	5.70
2	19	37.0	36.1	187.	4.73	.608E+03	6.03
3	29	37.1	35.9	186.	4.75	.761E+03	4.75
4	39	36.3	35.7	186.	4.77	.427E+03	8.37
5	46	36.1	35.5	185.	4.79	.411E+03	8.62
6	60	35.8	35.2	184.	4.82	.416E+03	8.37
7	88	35.5	34.5	181.	4.89	.606E+03	5.53
8	126	34.8	33.7	178.	5.00	.642E+03	4.92
9	147	34.0	33.2	176.	5.05	.476E+03	6.43
10	172	33.5	32.6	175.	5.11	.497E+03	5.98
11	206	32.7	31.8	172.	5.18	.430E+03	6.61
12	244	31.7	30.9	168.	5.31	.353E+03	7.50
13	274	31.1	30.3	166.	5.39	.396E+03	6.39
14	304	30.6	29.6	164.	5.47	.436E+03	5.56
15	333	29.8	28.9	162.	5.55	.382E+03	6.08
16	365	29.0	28.2	159.	5.66	.332E+03	6.59
17	406	28.1	27.2	156.	5.78	.330E+03	6.24
18	446	27.1	26.3	153.	5.92	.279E+03	6.87
19	496	25.9	25.2	149.	6.11	.230E+03	7.58
20	525	25.4	24.5	146.	6.21	.265E+03	6.23

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	1.0	.0	.0		.0000	.0000	.0000
5	1.0	1.0	.0	.0		.0000	.0000
6	1.0	1.0	1.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

```
Non-Dimensional Flow Parameters
Re:     167.                fc:         .0000
Dn:      31.                fc/fs:      .00
Pr:       5.36              Dn*:     26.
Gr:        .448E+03         Gr/Re:      .269E+01
Nu:      6.55                  Gz:    1.33
-------------------------------------------------------
```

Coil Number: 2   D/d: 29   h/d: 60   L/d: 530
Run Number: 34.   h/D: 2.069   Dc/d 41.6
Flowrate: .001933 kg/s   T(bulk inlet): 43.5C
Inlet Velocity: .1186 m/s   T(bulk outlet): 30.2C
Residence Time: 25 s   T(bulk average):36.8C

Boundary Condition: Neumann
Power Input: 107.3 W   Tube Resistance: .119 ohms
Power Absorbed: 107.1 W   Tube Conductivity:15.45 W/mK
Heat Balance: .2 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	45.2	43.3	878.	4.04	.191E+04	11.65
2	19	44.5	43.0	873.	4.06	.145E+04	15.03
3	29	44.6	42.8	869.	4.08	.178E+04	12.12
4	39	43.6	42.5	865.	4.10	.108E+04	19.70
5	46	43.4	42.3	862.	4.12	.101E+04	20.92
6	60	42.9	42.0	857.	4.15	.840E+03	24.78
7	88	43.2	41.3	846.	4.21	.170E+04	11.81
8	126	42.0	40.3	829.	4.30	.143E+04	13.25
9	147	41.2	39.8	820.	4.35	.114E+04	16.08
10	172	40.7	39.2	810.	4.41	.123E+04	14.46
11	206	40.0	38.3	796.	4.50	.130E+04	13.01
12	244	38.7	37.4	781.	4.61	.958E+03	16.69
13	274	38.1	36.6	769.	4.68	.102E+04	14.99
14	304	37.4	35.9	758.	4.75	.101E+04	14.50
15	333	36.8	35.1	748.	4.82	.103E+04	13.63
16	365	35.9	34.3	735.	4.92	.911E+03	14.69
17	406	35.0	33.3	719.	5.04	.914E+03	13.66
18	446	34.0	32.3	707.	5.13	.851E+03	13.94
19	496	32.3	31.1	687.	5.29	.576E+03	18.73
20	525	31.5	30.3	677.	5.38	.519E+03	19.80

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	1.1	.0		.0000	.0000	.0000	.0000
4	1.1	1.1	.0		.0000	.0000	.0000
5	1.1	1.1	1.1	.0		.0000	.0000
6	1.2	1.1	1.1	1.1	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	772.	fc:	.0000
Dn:	143.	fc/fs:	.00
Pr:	4.67	Dn*:	120.
Gr:	.114E+04	Gr/Re:	.147E+01
Nu:	15.52	Gz:	5.34

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 35. h/D: 2.069 Dc/d 41.6
Flowrate: .003885 kg/s T(bulk inlet): 46.0C
Inlet Velocity: .2384 m/s T(bulk outlet): 31.7C
Residence Time: 12 s T(bulk average):38.8C

Boundary Condition: Neumann
Power Input: 238.3 W Tube Resistance: .118 ohms
Power Absorbed: 231.3 W Tube Conductivity:15.49 W/mK
Heat Balance: 2.9 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	48.9	45.8	1843.	3.85	.356E+04	15.66
2	19	48.0	45.5	1832.	3.87	.289E+04	19.02
3	29	48.1	45.2	1824.	3.89	.320E+04	16.96
4	39	47.0	44.9	1816.	3.91	.226E+04	23.74
5	46	46.9	44.7	1810.	3.92	.231E+04	23.01
6	60	46.2	44.4	1799.	3.95	.199E+04	26.19
7	88	46.7	43.6	1774.	4.01	.317E+04	15.84
8	126	45.4	42.6	1741.	4.10	.267E+04	17.79
9	147	44.4	42.0	1723.	4.14	.225E+04	20.55
10	172	44.0	41.3	1701.	4.20	.237E+04	18.86
11	206	43.2	40.4	1670.	4.29	.240E+04	17.64
12	244	41.7	39.4	1635.	4.39	.182E+04	21.91
13	274	41.2	38.6	1609.	4.47	.198E+04	19.26
14	304	40.3	37.8	1582.	4.56	.180E+04	20.22
15	333	39.7	37.0	1557.	4.65	.189E+04	18.46
16	365	38.8	36.2	1531.	4.72	.173E+04	19.04
17	406	37.8	35.1	1500.	4.83	.167E+04	18.57
18	446	36.5	34.0	1463.	4.96	.146E+04	19.84
19	496	34.7	32.6	1427.	5.10	.109E+04	24.53
20	525	34.2	31.9	1409.	5.18	.120E+04	21.30

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	1.2	.0		.0000	.0000	.0000	.0000
4	1.3	1.2	.0		.0000	.0000	.0000
5	1.4	1.3	1.2	.0		.0000	.0000
6	1.5	1.4	1.3	1.2	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1617. fc: .0000
Dn: 300. fc/fs: .00
Pr: 4.44 Dn*: 251.
Gr: .219E+04 Gr/Re: .135E+01
Nu: 19.87 Gz: 10.64

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 36. h/D: 2.069 Dc/d 41.6
Flowrate: .007319 kg/s T(bulk inlet): 42.9C
Inlet Velocity: .4490 m/s T(bulk outlet): 33.0C
Residence Time: 6 s T(bulk average):37.9C

Boundary Condition: Neumann
Power Input: 293.3 W Tube Resistance: .117 ohms
Power Absorbed: 301.8 W Tube Conductivity:15.47 W/mK
Heat Balance: -2.9 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	45.9	42.7	3288.	4.09	.303E+04	19.50
2	19	45.1	42.5	3275.	4.10	.247E+04	23.62
3	29	45.2	42.3	3264.	4.12	.275E+04	21.04
4	39	44.4	42.1	3254.	4.13	.212E+04	27.10
5	46	44.4	42.0	3246.	4.14	.221E+04	25.78
6	60	43.8	41.8	3230.	4.17	.192E+04	29.30
7	88	44.3	41.2	3198.	4.21	.273E+04	19.96
8	126	43.3	40.5	3152.	4.28	.237E+04	22.09
9	147	42.6	40.1	3125.	4.32	.207E+04	24.77
10	172	42.2	39.7	3096.	4.37	.209E+04	23.88
11	206	41.7	39.0	3058.	4.42	.209E+04	22.98
12	244	40.7	38.3	3013.	4.50	.178E+04	25.94
13	274	40.2	37.8	2979.	4.56	.178E+04	25.01
14	304	39.6	37.2	2945.	4.63	.166E+04	26.01
15	333	39.4	36.7	2913.	4.68	.183E+04	22.85
16	365	38.5	36.1	2879.	4.73	.160E+04	25.31
17	406	37.8	35.3	2839.	4.80	.157E+04	24.71
18	446	36.8	34.6	2794.	4.89	.136E+04	27.20
19	496	35.8	33.6	2738.	5.00	.123E+04	28.23
20	525	35.1	33.1	2708.	5.06	.108E+04	31.00

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	1.2		.0000	.0000	.0000	.0000	.0000
3	1.5	1.2		.0000	.0000	.0000	.0000
4	.0	1.5	1.2		.0000	.0000	.0000
5	.0	.0	1.5	1.3		.0000	.0000
6	.0	.0	.0	1.4	1.2		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 2989. fc: .0000
Dn: 555. fc/fs: .00
Pr: 4.54 Dn*: 464.
Gr: .200E+04 Gr/Re: .668E+00
Nu: 24.62 Gz: 20.10

Coil Number: 2 D/d: 29 h/d: 60 L/d: 530
Run Number: 37. h/D: 2.069 Dc/d 41.6
Flowrate: .000444 kg/s T(bulk inlet): 78.0C
Inlet Velocity: .0274 m/s T(bulk outlet): 25.2C
Residence Time: 110 s T(bulk average):51.6C

Boundary Condition: Neumann
Power Input: 109.5 W Tube Resistance: .122 ohms
Power Absorbed: 98.1 W Tube Conductivity:15.75 W/mK
Heat Balance: 10.4 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	7	75.0	77.3	0.	.00	.000E+00	.00
2	19	75.9	76.1	0.	.00	.000E+00	.00
3	29	76.5	75.1	287.	2.74	.363E+04	16.08
4	39	73.6	74.1	0.	.00	.000E+00	.00
5	46	74.0	73.4	287.	2.74	.167E+04	34.88
6	60	73.7	72.0	287.	2.74	.456E+04	12.80
7	88	70.7	69.2	287.	2.74	.401E+04	14.55
8	126	69.2	65.4	288.	2.73	.102E+05	5.83
9	147	66.8	63.3	280.	2.82	.873E+04	6.30
10	172	64.6	60.9	268.	2.95	.851E+04	5.83
11	206	60.9	57.5	254.	3.13	.678E+04	6.36
12	244	58.3	53.7	240.	3.33	.770E+04	4.81
13	274	55.5	50.7	229.	3.51	.695E+04	4.67
14	304	52.6	47.7	218.	3.71	.614E+04	4.59
15	333	49.5	44.8	207.	3.92	.509E+04	4.81
16	365	46.0	41.6	196.	4.18	.401E+04	5.18
17	406	41.9	37.5	180.	4.59	.315E+04	5.22
18	446	37.7	33.5	166.	5.01	.233E+04	5.55
19	496	32.0	28.6	150.	5.60	.137E+04	6.79
20	525	29.6	25.7	141.	6.02	.125E+04	5.97

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 232. fc: .0000
Dn: 43. fc/fs: .00
Pr: 3.46 Dn*: 36.
Gr: .556E+04 Gr/Re: .240E+02
Nu: 9.16 Gz: 1.19

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 38. h/D: 2.069 Dc/d 41.6
Flowrate: .000947 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .0580 m/s T(bulk outlet): 30.0C
Residence Time: 33 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.1264	.0000	.0000	.0000	.0000
3	.0	9.5		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 330. fc: .1264
Dn: 61. fc/fs: 2.61
Pr: 5.42 Dn*: 51.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 39. h/D: 2.069 Dc/d 41.6
Flowrate: .001546 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .0946 m/s T(bulk outlet): 30.0C
Residence Time: 20 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0617	.0000	.0000	.0000	.0000
3	.0	12.4		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 538. fc: .0617
Dn: 100. fc/fs: 2.08
Pr: 5.42 Dn*: 83.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 40. h/D: 2.069 Dc/d 41.6
Flowrate: .002144 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .1312 m/s T(bulk outlet): 30.0C
Residence Time: 14 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0385	.0000	.0000	.0000	.0000
3	.0	14.9		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 746. fc: .0385
Dn: 139. fc/fs: 1.80
Pr: 5.42 Dn*: 116.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 41. h/D: 2.069 Dc/d 41.6
Flowrate: .002742 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .1678 m/s T(bulk outlet): 30.0C
Residence Time: 11 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0284	.0000	.0000	.0000	.0000
3	.0	17.9		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 955. fc: .0284
Dn: 177. fc/fs: 1.69
Pr: 5.42 Dn*: 148.

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 335
Run Number:   42.                h/D: 2.069   Dc/d  41.6
Flowrate:          .003341 kg/s      T(bulk inlet):  30.0C
Inlet Velocity:     .2044 m/s        T(bulk outlet): 30.0C
Residence Time:         9 s          T(bulk average):30.0C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0000  .0000  .0000  .0000
2      .0            .0242  .0000  .0000  .0000  .0000
3      .0    22.7           .0000  .0000  .0000  .0000
4      .0      .0     .0           .0000  .0000  .0000
5      .0      .0     .0     .0           .0000  .0000
6      .0      .0     .0     .0     .0           .0000
7      .0      .0     .0     .0     .0     .0
       1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    1163.                fc:        .0242
Dn:     216.                fc/fs:   1.76
Pr:        5.42             Dn*:   180.
-------------------------------------------------------
```

```
Coil Number: 2     D/d: 29      h/d: 60      L/d: 335
Run Number:   43.               h/D: 2.069   Dc/d  41.6
Flowrate:         .003690 kg/s      T(bulk inlet):  30.0C
Inlet Velocity:     .2257 m/s       T(bulk outlet): 30.0C
Residence Time:         8 s         T(bulk average):30.0C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0000  .0000  .0000  .0000
2      .0            .0243  .0000  .0000  .0000  .0000
3      .0    27.8           .0000  .0000  .0000  .0000
4      .0     .0     .0            .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   1284.               fc:        .0243
Dn:    239.               fc/fs:   1.95
Pr:      5.42             Dn*:   199.
--------------------------------------------------------
```

```
Coil Number: 2     D/d: 29     h/d: 60     L/d: 335
Run Number:   44.              h/D: 2.069  Dc/d  41.6
Flowrate:          .004138 kg/s     T(bulk inlet):  30.0C
Inlet Velocity:      .2532 m/s      T(bulk outlet): 30.0C
Residence Time:          7 s        T(bulk average):30.0C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0000  .0000  .0000  .0000  .0000  .0000
2      .0           .0220  .0000  .0000  .0000  .0000
3      .0   31.6           .0000  .0000  .0000  .0000
4      .0     .0     .0           .0000  .0000  .0000
5      .0     .0     .0     .0           .0000  .0000
6      .0     .0     .0     .0     .0           .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   1441.              fc:       .0220
Dn:    268.              fc/fs:   1.98
Pr:      5.42            Dn*:   223.
--------------------------------------------------------
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 335
Run Number:   45.                h/D: 2.069   Dc/d  41.6
Flowrate:          .005903 kg/s      T(bulk inlet):  30.0C
Inlet Velocity:     .3611 m/s        T(bulk outlet): 30.0C
Residence Time:         5 s          T(bulk average):30.0C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0000  .0000  .0000  .0000  .0000  .0000
2     .0            .0148  .0000  .0000  .0000  .0000
3     .0   43.2            .0000  .0000  .0000  .0000
4     .0     .0     .0            .0000  .0000  .0000
5     .0     .0     .0     .0            .0000  .0000
6     .0     .0     .0     .0     .0            .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    2055.                fc:       .0148
Dn:     382.                fc/fs:   1.90
Pr:       5.42              Dn*:   319.
---------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 46. h/D: 2.069 Dc/d 41.6
Flowrate: .007678 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .4697 m/s T(bulk outlet): 30.0C
Residence Time: 4 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0122	.0000	.0000	.0000	.0000
3	.0	60.4		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 2673. fc: .0122
Dn: 496. fc/fs: 2.04
Pr: 5.42 Dn*: 415.

Coil Number: 2   D/d: 29   h/d: 60   L/d: 335
Run Number: 47.   h/D: 2.069   Dc/d 41.6
Flowrate: .009723 kg/s   T(bulk inlet): 30.0C
Inlet Velocity: .5948 m/s   T(bulk outlet): 30.0C
Residence Time: 3 s   T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0115	.0000	.0000	.0000	.0000
3	.0	91.2		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 3385.   fc: .0115
Dn: 629.   fc/fs: 2.43
Pr: 5.42   Dn*: 525.

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 48. h/D: 2.069 Dc/d 41.6
Flowrate: .013342 kg/s T(bulk inlet): 30.0C
Inlet Velocity: .8162 m/s T(bulk outlet): 30.0C
Residence Time: 2 s T(bulk average):30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0091	.0000	.0000	.0000	.0000
3	.0	136.2		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 4645. fc: .0091
Dn: 863. fc/fs: 2.65
Pr: 5.42 Dn*: 720.

```
Coil Number: 2      D/d: 29       h/d: 60      L/d: 335
Run Number:   49.                 h/D: 2.069   Dc/d  41.6
Flowrate:          .015108 kg/s       T(bulk inlet):   30.0C
Inlet Velocity:      .9242 m/s        T(bulk outlet): 30.0C
Residence Time:          2 s          T(bulk average):30.0C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0000  .0000  .0000  .0000
2      .0            .0074  .0000  .0000  .0000  .0000
3      .0  141.2            .0000  .0000  .0000  .0000
4      .0      .0     .0           .0000  .0000  .0000
5      .0      .0     .0     .0           .0000  .0000
6      .0      .0     .0     .0     .0           .0000
7      .0      .0     .0     .0     .0     .0
       1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5259.                fc:        .0074
Dn:     977.                fc/fs:   2.42
Pr:       5.42              Dn*:   816.
--------------------------------------------------------
```

```
Coil Number: 2     D/d: 29      h/d: 60      L/d: 335
Run Number:   50.               h/D: 2.069   Dc/d  41.6
Flowrate:          .017950 kg/s     T(bulk inlet):  30.0C
Inlet Velocity:    1.0981 m/s       T(bulk outlet): 30.0C
Residence Time:         1 s         T(bulk average):30.0C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0000  .0000  .0000  .0000  .0000  .0000
2      .0           .0075  .0000  .0000  .0000  .0000
3      .0  204.2           .0000  .0000  .0000  .0000
4      .0     .0     .0           .0000  .0000  .0000
5      .0     .0     .0     .0           .0000  .0000
6      .0     .0     .0     .0     .0           .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    6248.               fc:        .0075
Dn:    1160.               fc/fs:    2.95
Pr:       5.42             Dn*:    969.
---------------------------------------------------------
```

Coil Number: 2 D/d: 29 h/d: 60 L/d: 335
Run Number: 51. h/D: 2.069 Dc/d 41.6
Flowrate: .019346 kg/s T(bulk inlet): 30.0C
Inlet Velocity: 1.1835 m/s T(bulk outlet): 30.0C
Residence Time: 1 s T(bulk average): 30.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0075	.0000	.0000	.0000	.0000
3	.0	235.3		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 6734. fc: .0075
Dn: 1251. fc/fs: 3.15
Pr: 5.42 Dn*: 1044.

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 335
Run Number:   52.                h/D: 2.069   Dc/d  41.6
Flowrate:          .011554 kg/s      T(bulk inlet):  31.5C
Inlet Velocity:      .7093 m/s       T(bulk outlet): 48.7C
Residence Time:          2 s         T(bulk average):40.1C
---------------------------------------------------------
Boundary Condition:  Dirichlet
Power Absorbed:                                    832.5 W
Logarithmic Mean Temperature Difference (LMTD):      8.7 C
Arithmetic Mean Temperature Difference (AMTD):      11.4 C
Environmental Temperature:                          86.4 C
Average Wall Temperature:                           51.5 C
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   4933.                fc:        .0000
Dn:    916.                fc/fs:     .00
Pr:      4.32              Dn*:    765.
Gr:       .726E+04         Gr/Re:     .147E+01
Nu:     31.63                 Gz:  49.98
---------------------------------------------------------
```

```
Coil Number: 2     D/d: 29       h/d: 60      L/d: 335
Run Number:    53.               h/D: 2.069   Dc/d  41.6
Flowrate:           .012597 kg/s      T(bulk inlet):  31.5C
Inlet Velocity:      .7732 m/s        T(bulk outlet): 47.6C
Residence Time:          2 s          T(bulk average):39.5C
--------------------------------------------------------
Boundary Condition:  Dirichlet
Power Absorbed:                                      846.4 W
Logarithmic Mean Temperature Difference (LMTD):     10.0 C
Arithmetic Mean Temperature Difference (AMTD):      12.1 C
Environmental Temperature:                           86.1 C
Average Wall Temperature:                            51.6 C
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5316.              fc:         .0000
Dn:     987.              fc/fs:     .00
Pr:       4.38            Dn*:    824.
Gr:         .809E+04      Gr/Re:      .152E+01
Nu:      27.91               Gz:   54.54
--------------------------------------------------------
```

```
Coil Number: 2      D/d: 29      h/d: 60      L/d: 335
Run Number:    54.               h/D: 2.069   Dc/d  41.6
Flowrate:           .013851 kg/s     T(bulk inlet):   31.6C
Inlet Velocity:      .8503 m/s       T(bulk outlet): 48.3C
Residence Time:          2 s         T(bulk average):39.9C
--------------------------------------------------------
Boundary Condition:  Dirichlet
Power Absorbed:                                    969.1 W
Logarithmic Mean Temperature Difference (LMTD):    10.5 C
Arithmetic Mean Temperature Difference (AMTD):     12.6 C
Environmental Temperature:                         192.0 C
Average Wall Temperature:                           52.6 C
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5890.                fc:        .0000
Dn:    1094.                fc/fs:     .00
Pr:       4.34              Dn*:    913.
Gr:        .869E+04         Gr/Re:      .148E+01
Nu:      30.41                 Gz:  59.94
--------------------------------------------------------
```

Coil Number: 2	D/d: 29	h/d: 60	L/d: 335
Run Number: 55.		h/D: 2.069	Dc/d 41.6
Flowrate:	.015492 kg/s	T(bulk inlet):	33.0C
Inlet Velocity:	.9510 m/s	T(bulk outlet):	46.7C
Residence Time:	2 s	T(bulk average):	39.8C

Boundary Condition: Dirichlet	
Power Absorbed:	886.5 W
Logarithmic Mean Temperature Difference (LMTD):	9.8 C
Arithmetic Mean Temperature Difference (AMTD):	11.3 C
Environmental Temperature:	86.4 C
Average Wall Temperature:	51.2 C

Non-Dimensional Flow Parameters

Re:	6577.	fc:	.0000
Dn:	1221.	fc/fs:	.00
Pr:	4.35	Dn*:	1020.
Gr:	.804E+04	Gr/Re:	.122E+01
Nu:	29.91	Gz:	67.05

```
Coil Number: 3     D/d: 49      h/d:  5     L/d: 532
Run Number:    1.               h/D:  .102  Dc/d  49.1
Flowrate:          .015535 kg/s     T(bulk inlet):  28.1C
Inlet Velocity:     .9498 m/s       T(bulk outlet): 28.1C
Residence Time:         3 s         T(bulk average):28.1C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0084  .0000  .0000  .0000  .0000  .0000
2  253.7             .0084  .0000  .0000  .0000  .0000
3      .0  238.1            .0084  .0000  .0000  .0000
4      .0     .0  236.6            .0085  .0000  .0000
5      .0     .0     .0   84.8            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   5188.               fc:       .0084
Dn:    741.               fc/fs:   2.72
Pr:       5.67            Dn*:   741.
---------------------------------------------------------
```

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 2. h/D: .102 Dc/d 49.1
Flowrate: .012271 kg/s T(bulk inlet): 28.4C
Inlet Velocity: .7503 m/s T(bulk outlet): 28.4C
Residence Time: 4 s T(bulk average):28.4C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0099	.0000	.0000	.0000	.0000	.0000
2	186.1		.0099	.0000	.0000	.0000	.0000
3	.0	175.3		.0100	.0000	.0000	.0000
4	.0	.0	176.2		.0106	.0000	.0000
5	.0	.0	.0	65.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 4137. fc: .0099
Dn: 591. fc/fs: 2.56
Pr: 5.62 Dn*: 591.

```
Coil Number: 3      D/d: 49     h/d:  5     L/d: 532
Run Number:    3.               h/D:  .102  Dc/d  49.1
Flowrate:          .008729 kg/s     T(bulk inlet):  28.6C
Inlet Velocity:     .5338 m/s       T(bulk outlet): 28.6C
Residence Time:         5 s         T(bulk average):28.6C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0130  .0000  .0000  .0000  .0000  .0000
2  123.8             .0129  .0000  .0000  .0000  .0000
3      .0  115.3            .0129  .0000  .0000  .0000
4      .0     .0  115.8            .0135  .0000  .0000
5      .0     .0     .0   42.3            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   2955.             fc:        .0129
Dn:    422.             fc/fs:   2.39
Pr:       5.59          Dn*:   422.
-------------------------------------------------------
```

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 4. h/D: .102 Dc/d 49.1
Flowrate: .005188 kg/s T(bulk inlet): 28.3C
Inlet Velocity: .3172 m/s T(bulk outlet): 28.3C
Residence Time: 9 s T(bulk average):28.3C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0181	.0000	.0000	.0000	.0000	.0000
2	60.8		.0188	.0000	.0000	.0000	.0000
3	.0	59.4		.0186	.0000	.0000	.0000
4	.0	.0	58.9		.0193	.0000	.0000
5	.0	.0	.0	21.3		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1744. fc: .0185
Dn: 249. fc/fs: 2.02
Pr: 5.63 Dn*: 249.

```
Coil Number: 3      D/d: 49      h/d:  5     L/d: 532
Run Number:    5.                h/D:  .102  Dc/d  49.1
Flowrate:          .004141 kg/s     T(bulk inlet):  27.5C
Inlet Velocity:      .2532 m/s      T(bulk outlet): 27.5C
Residence Time:         12 s        T(bulk average):27.5C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0220  .0000  .0000  .0000  .0000  .0000
2    47.2            .0235  .0000  .0000  .0000  .0000
3      .0   47.2            .0248  .0000  .0000  .0000
4      .0     .0   49.9            .0310  .0000  .0000
5      .0     .0     .0   21.9            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   1367.                fc:        .0234
Dn:    195.                fc/fs:   2.00
Pr:       5.75             Dn*:   195.
--------------------------------------------------------
```

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 6. h/D: .102 Dc/d 49.1
Flowrate: .003718 kg/s T(bulk inlet): 27.2C
Inlet Velocity: .2272 m/s T(bulk outlet): 27.2C
Residence Time: 13 s T(bulk average): 27.2C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0229	.0000	.0000	.0000	.0000	.0000
2	39.6		.0230	.0000	.0000	.0000	.0000
3	.0	37.3		.0230	.0000	.0000	.0000
4	.0	.0	37.3		.0234	.0000	.0000
5	.0	.0	.0	13.3		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1221. fc: .0230
Dn: 174. fc/fs: 1.75
Pr: 5.78 Dn*: 174.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 7. h/D: .102 Dc/d 49.1
Flowrate: .003044 kg/s T(bulk inlet): 27.0C
Inlet Velocity: .1861 m/s T(bulk outlet): 27.0C
Residence Time: 16 s T(bulk average):27.0C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0255	.0000	.0000	.0000	.0000	.0000
2	29.5		.0249	.0000	.0000	.0000	.0000
3	.0	27.1		.0249	.0000	.0000	.0000
4	.0	.0	27.1		.0255	.0000	.0000
5	.0	.0	.0	9.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 995. fc: .0251
Dn: 142. fc/fs: 1.56
Pr: 5.81 Dn*: 142.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 8. h/D: .102 Dc/d 49.1
Flowrate: .002296 kg/s T(bulk inlet): 26.9C
Inlet Velocity: .1403 m/s T(bulk outlet): 26.9C
Residence Time: 21 s T(bulk average): 26.9C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0310	.0000	.0000	.0000	.0000	.0000
2	20.4		.0302	.0000	.0000	.0000	.0000
3	.0	18.7		.0302	.0000	.0000	.0000
4	.0	.0	18.7		.0308	.0000	.0000
5	.0	.0	.0	6.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 749. fc: .0304
Dn: 107. fc/fs: 1.43
Pr: 5.82 Dn*: 107.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 9. h/D: .102 Dc/d 49.1
Flowrate: .001547 kg/s T(bulk inlet): 26.7C
Inlet Velocity: .0946 m/s T(bulk outlet): 26.7C
Residence Time: 32 s T(bulk average):26.7C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0420	.0427	.0425	.0421	.0000	.0000
2	12.6		.0407	.0424	.0418	.0000	.0000
3	24.8	11.4		.0407	.0417	.0000	.0000
4	36.6	23.8	11.4		.0426	.0000	.0000
5	40.4	27.6	15.8	4.2		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 502. fc: .0418
Dn: 72. fc/fs: 1.31
Pr: 5.86 Dn*: 72.

Coil Number: 3	D/d: 49	h/d: 5	L/d: 532				
Run Number: 10.		h/D: .102	Dc/d 49.1				

Flowrate: .000829 kg/s   T(bulk inlet): 26.7C
Inlet Velocity: .0506 m/s   T(bulk outlet): 26.7C
Residence Time: 60 s   T(bulk average): 26.7C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0755	.0687	.0672	.0665	.0000	.0000
2	6.5		.0686	.0686	.0674	.0000	.0000
3	11.4	5.5		.0662	.0683	.0000	.0000
4	16.6	11.0	5.3		.0810	.0000	.0000
5	18.3	12.8	7.4	2.3		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	269.	fc:	.0691
Dn:	38.	fc/fs:	1.16
Pr:	5.86	Dn*:	38.

```
Coil Number: 3     D/d: 49      h/d:  5     L/d: 532
Run Number:   11.               h/D:  .102  Dc/d  49.1
Flowrate:          .000679 kg/s     T(bulk inlet):  26.4C
Inlet Velocity:     .0415 m/s       T(bulk outlet): 26.4C
Residence Time:        73 s         T(bulk average):26.4C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0827  .0836  .0805  .0815  .0000  .0000
2     4.8            .0811  .0811  .0810  .0000  .0000
3     9.3    4.4            .0811  .0809  .0000  .0000
4    13.3    8.8    4.4            .1005  .0000  .0000
5    15.0   10.3    5.9    1.9            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    219.                fc:      .0817
Dn:     31.                fc/fs:  1.12
Pr:      5.91              Dn*:    31.
--------------------------------------------------------
```

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 12. h/D: .102 Dc/d 49.1
Flowrate: .000535 kg/s T(bulk inlet): 26.1C
Inlet Velocity: .0327 m/s T(bulk outlet): 26.1C
Residence Time: 92 s T(bulk average): 26.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.1065	.1017	.1000	.0997	.0000	.0000
2	3.8		.1021	.1021	.1014	.0000	.0000
3	7.0	3.4		.1021	.1008	.0000	.0000
4	10.3	6.9	3.4		.1294	.0000	.0000
5	11.4	8.0	4.6	1.5		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 171. fc: .1024
Dn: 24. fc/fs: 1.10
Pr: 5.95 Dn*: 24.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 13. h/D: .102 Dc/d 49.1
Flowrate: .000367 kg/s T(bulk inlet): 26.1C
Inlet Velocity: .0224 m/s T(bulk outlet): 26.1C
Residence Time: 135 s T(bulk average):26.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.1457	.1374	.1374	.0000	.0000
2	.0		.0000	.1444	.1434	.0000	.0000
3	4.8	.0		.0000	.1515	.0000	.0000
4	6.7	4.6	.0		.0000	.0000	.0000
5	7.4	5.3	3.2	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 118. fc: .1425
Dn: 17. fc/fs: 1.05
Pr: 5.95 Dn*: 17.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 14. h/D: .102 Dc/d 49.1
Flowrate: .000230 kg/s T(bulk inlet): 25.8C
Inlet Velocity: .0140 m/s T(bulk outlet): 25.8C
Residence Time: 216 s T(bulk average): 25.8C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.2238	.2010	.1984	.0000	.0000
2	.0		.0000	.2157	.2097	.0000	.0000
3	2.9	.0		.0000	.2281	.0000	.0000
4	3.8	2.7	.0		.0000	.0000	.0000
5	4.2	3.0	1.9	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 73. fc: .2135
Dn: 10. fc/fs: .97
Pr: 5.99 Dn*: 10.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 16. h/D: .102 Dc/d 49.1
Flowrate: .015824 kg/s T(bulk inlet): 40.9C
Inlet Velocity: .9740 m/s T(bulk outlet): 51.7C
Residence Time: 3 s T(bulk average):46.3C

Boundary Condition: Neumann
Power Input: 682.0 W Tube Resistance: .121 ohms
Power Absorbed: 718.8 W Tube Conductivity:15.55 W/mK
Heat Balance: -5.4 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	44.1	41.0	6885.	4.23	.274E+04	45.62
2	16	44.5	41.2	6911.	4.21	.292E+04	43.24
3	25	45.1	41.4	6935.	4.20	.336E+04	37.96
4	35	45.3	41.6	6962.	4.18	.342E+04	37.66
5	46	45.4	41.8	6992.	4.16	.335E+04	39.01
6	57	44.9	42.0	7022.	4.14	.268E+04	49.26
7	70	45.9	42.3	7054.	4.12	.344E+04	38.89
8	90	46.3	42.7	7105.	4.09	.352E+04	38.74
9	115	46.4	43.2	7173.	4.04	.314E+04	44.60
10	135	46.6	43.6	7231.	4.01	.304E+04	47.20
11	155	47.6	44.0	7288.	3.98	.367E+04	39.90
12	178	47.9	44.5	7346.	3.94	.368E+04	40.76
13	217	48.7	45.3	7444.	3.88	.374E+04	41.66
14	249	49.3	46.0	7527.	3.84	.384E+04	41.70
15	289	50.2	46.8	7634.	3.78	.415E+04	40.38
16	307	50.9	47.1	7683.	3.75	.455E+04	37.55
17	383	52.1	48.7	7897.	3.64	.446E+04	41.19
18	461	53.7	50.3	8120.	3.53	.483E+04	40.96
19	510	54.3	51.3	8237.	3.47	.451E+04	45.85
20	527	54.5	51.6	8275.	3.46	.431E+04	48.67

Static Differential Pressures and Friction Factors

1		.0075	.0000	.0000	.0000	.0000	.0000
2	237.2		.0074	.0000	.0000	.0000	.0000
3	.0	219.6		.0074	.0000	.0000	.0000
4	.0	.0	219.3		.0077	.0000	.0000
5	.0	.0	.0	80.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 7572. fc: .0074
Dn: 1082. fc/fs: 3.50
Pr: 3.81 Dn*: 1081.
Gr: .368E+04 Gr/Re: .486E+00
Nu: 41.09 Gz: 42.60

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 17. h/D: .102 Dc/d 49.1
Flowrate: .008905 kg/s T(bulk inlet): 39.4C
Inlet Velocity: .5481 m/s T(bulk outlet): 52.5C
Residence Time: 5 s T(bulk average):45.9C

Boundary Condition: Neumann
Power Input: 508.0 W Tube Resistance: .120 ohms
Power Absorbed: 485.0 W Tube Conductivity:15.54 W/mK
Heat Balance: 4.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	42.9	39.6	3760.	4.37	.272E+04	31.47
2	16	43.4	39.8	3779.	4.35	.292E+04	29.72
3	25	44.0	40.0	3795.	4.33	.326E+04	26.96
4	35	44.2	40.3	3815.	4.30	.328E+04	27.14
5	46	44.4	40.6	3838.	4.28	.329E+04	27.50
6	57	43.7	40.8	3860.	4.25	.248E+04	37.06
7	70	45.0	41.1	3886.	4.22	.341E+04	27.50
8	90	45.4	41.6	3922.	4.18	.343E+04	28.10
9	115	45.6	42.2	3966.	4.13	.316E+04	31.50
10	135	45.8	42.7	4001.	4.09	.299E+04	34.06
11	155	46.9	43.2	4037.	4.04	.364E+04	28.65
12	178	47.3	43.8	4082.	4.00	.359E+04	30.04
13	217	48.2	44.7	4150.	3.92	.376E+04	30.03
14	249	49.2	45.5	4205.	3.87	.407E+04	28.77
15	289	50.3	46.5	4276.	3.80	.446E+04	27.60
16	307	51.2	46.9	4309.	3.77	.511E+04	24.66
17	383	52.7	48.8	4453.	3.63	.512E+04	26.86
18	461	54.8	50.7	4599.	3.51	.596E+04	25.22
19	510	55.7	51.9	4674.	3.44	.576E+04	27.42
20	527	55.9	52.3	4709.	3.42	.559E+04	28.76

Static Differential Pressures and Friction Factors

1		.0000	.0105	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	204.8	.0		.0095	.0095	.0000	.0000
4	.0	.0	89.9		.0096	.0000	.0000
5	.0	.0	121.3	31.8		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 4235. fc: .0100
Dn: 605. fc/fs: 2.65
Pr: 3.84 Dn*: 605.
Gr: .381E+04 Gr/Re: .900E+00
Nu: 28.85 Gz: 23.99

Coil Number: 3   D/d: 49   h/d: 5   L/d: 532
Run Number: 18.   h/D: .102   Dc/d 49.1
Flowrate: .007632 kg/s   T(bulk inlet): 37.2C
Inlet Velocity: .4690 m/s   T(bulk outlet): 48.2C
Residence Time: 6 s   T(bulk average):42.7C

Boundary Condition: Neumann
Power Input: 364.8 W   Tube Resistance: .121 ohms
Power Absorbed: 351.9 W   Tube Conductivity:15.50 W/mK
Heat Balance: 3.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	40.7	37.3	3075.	4.62	.240E+04	22.40
2	16	41.0	37.5	3088.	4.59	.251E+04	21.72
3	25	41.4	37.7	3100.	4.57	.268E+04	20.55
4	35	41.5	37.9	3113.	4.55	.263E+04	21.14
5	46	41.7	38.1	3128.	4.52	.265E+04	21.30
6	57	41.0	38.3	3143.	4.50	.203E+04	28.08
7	70	42.1	38.6	3160.	4.47	.263E+04	22.05
8	90	42.4	39.0	3188.	4.42	.263E+04	22.59
9	115	42.5	39.5	3220.	4.38	.239E+04	25.64
10	135	42.8	40.0	3247.	4.34	.236E+04	26.60
11	155	43.7	40.4	3276.	4.30	.283E+04	22.70
12	178	44.2	40.8	3310.	4.25	.297E+04	22.30
13	217	45.1	41.7	3362.	4.18	.314E+04	22.07
14	249	45.5	42.3	3403.	4.12	.298E+04	24.07
15	289	46.9	43.2	3455.	4.05	.368E+04	20.27
16	307	47.3	43.5	3480.	4.02	.378E+04	20.16
17	383	48.9	45.1	3578.	3.90	.413E+04	19.96
18	461	50.6	46.7	3678.	3.78	.468E+04	19.08
19	510	51.6	47.7	3744.	3.71	.483E+04	19.40
20	527	51.6	48.1	3767.	3.68	.454E+04	20.99

Static Differential Pressures and Friction Factors

1		.0000	.0124	.0122	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	177.5	.0		.0116	.0115	.0000	.0000
4	257.4	.0	80.4		.0116	.0000	.0000
5	.0	.0	107.1	28.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 3425.   fc: .0121
Dn: 489.   fc/fs: 2.59
Pr: 4.09   Dn*: 489.
Gr: .301E+04   Gr/Re: .880E+00
Nu: 22.41   Gz: 20.68

```
Coil Number: 3      D/d: 49      h/d:  5     L/d: 532
Run Number:   19.                h/D:  .102  Dc/d  49.1
Flowrate:           .006230 kg/s      T(bulk inlet):  35.4C
Inlet Velocity:      .3825 m/s        T(bulk outlet): 46.0C
Residence Time:          7 s          T(bulk average):40.7C
```

```
Boundary Condition:  Neumann
Power Input:     299.8 W     Tube Resistance:    .120 ohms
Power Absorbed: 277.1 W     Tube Conductivity:15.47 W/mK
Heat Balance:        7.6 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	38.4	35.5	2425.	4.78	.185E+04	21.52
2	16	38.7	35.7	2434.	4.76	.194E+04	20.82
3	25	39.1	35.9	2442.	4.75	.207E+04	19.63
4	35	39.2	36.1	2451.	4.73	.205E+04	20.09
5	46	39.4	36.3	2462.	4.71	.205E+04	20.38
6	57	38.8	36.5	2472.	4.69	.155E+04	27.37
7	70	39.6	36.8	2485.	4.67	.193E+04	22.29
8	90	40.1	37.2	2505.	4.63	.201E+04	21.90
9	115	40.4	37.7	2531.	4.57	.196E+04	23.04
10	135	40.7	38.1	2552.	4.52	.195E+04	23.73
11	155	41.4	38.5	2573.	4.48	.223E+04	21.26
12	178	41.8	38.9	2598.	4.43	.226E+04	21.58
13	217	42.6	39.7	2638.	4.36	.239E+04	21.29
14	249	43.1	40.4	2674.	4.30	.232E+04	22.74
15	289	44.1	41.2	2719.	4.22	.263E+04	21.10
16	307	44.7	41.5	2738.	4.19	.286E+04	19.73
17	383	46.3	43.0	2814.	4.06	.324E+04	18.80
18	461	48.0	44.6	2897.	3.93	.368E+04	17.98
19	510	49.0	45.6	2945.	3.86	.385E+04	17.98
20	527	49.2	45.9	2962.	3.84	.370E+04	18.98

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0000	.0150	.0000	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	142.3	.0		.0133	.0133	.0000	.0000
4	.0	.0	61.3		.0135	.0000	.0000
5	.0	.0	82.9	21.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

```
Non-Dimensional Flow Parameters
Re:   2693.                 fc:         .0142
Dn:    385.                 fc/fs:   2.39
Pr:      4.26               Dn*:   385.
Gr:        .232E+04         Gr/Re:      .863E+00
Nu:     21.43                  Gz:   16.95
```

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 20. h/D: .102 Dc/d 49.1
Flowrate: .003447 kg/s T(bulk inlet): 41.3C
Inlet Velocity: .2124 m/s T(bulk outlet): 57.4C
Residence Time: 14 s T(bulk average):49.3C

Boundary Condition: Neumann
Power Input: 248.9 W Tube Resistance: .123 ohms
Power Absorbed: 232.5 W Tube Conductivity:15.58 W/mK
Heat Balance: 6.6 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	44.9	41.4	1512.	4.19	.318E+04	14.68
2	16	45.6	41.7	1521.	4.17	.359E+04	13.24
3	25	45.8	42.0	1529.	4.14	.350E+04	13.75
4	35	45.7	42.3	1537.	4.12	.318E+04	15.38
5	46	45.8	42.7	1546.	4.09	.300E+04	16.55
6	57	45.2	43.0	1555.	4.06	.220E+04	22.90
7	70	46.7	43.4	1567.	4.03	.333E+04	15.48
8	90	47.5	44.0	1586.	3.98	.361E+04	14.77
9	115	47.6	44.7	1606.	3.92	.312E+04	17.73
10	135	48.1	45.4	1623.	3.88	.305E+04	18.65
11	155	49.2	46.0	1640.	3.84	.369E+04	15.83
12	178	49.8	46.7	1660.	3.79	.372E+04	16.33
13	217	50.6	47.8	1694.	3.70	.350E+04	18.38
14	249	52.3	48.8	1724.	3.63	.456E+04	14.77
15	289	53.2	50.0	1762.	3.55	.447E+04	15.97
16	307	54.3	50.6	1776.	3.51	.537E+04	13.61
17	383	56.3	52.9	1842.	3.38	.549E+04	14.72
18	461	59.5	55.2	1902.	3.26	.746E+04	11.93
19	510	60.5	56.7	1951.	3.17	.709E+04	13.37
20	527	60.5	57.2	1967.	3.14	.620E+04	15.60

Static Differential Pressures and Friction Factors

1		.0000	.0202	.0196	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	59.2	.0		.0195	.0187	.0000	.0000
4	85.0	.0	27.6		.0192	.0000	.0000
5	.0	.0	35.8	9.5		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1740. fc: .0198
Dn: 249. fc/fs: 2.15
Pr: 3.59 Dn*: 248.
Gr: .396E+04 Gr/Re: .227E+01
Nu: 16.05 Gz: 9.23

```
Coil Number: 3     D/d: 49      h/d:  5     L/d: 532
Run Number:   21.               h/D:  .102  Dc/d  49.1
Flowrate:          .002044 kg/s      T(bulk inlet):  33.3C
Inlet Velocity:     .1255 m/s        T(bulk outlet): 46.0C
Residence Time:       24 s           T(bulk average):39.7C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:     110.4 W      Tube Resistance:    .123 ohms
Power Absorbed: 108.4 W      Tube Conductivity:15.43 W/mK
Heat Balance:      1.8 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	35.1	33.5	762.	5.02	.906E+03	14.28
2	16	35.3	33.7	766.	4.99	.918E+03	14.31
3	25	35.6	33.9	769.	4.97	.938E+03	14.21
4	35	35.8	34.2	773.	4.94	.929E+03	14.57
5	46	36.1	34.4	778.	4.91	.101E+04	13.66
6	57	36.3	34.7	783.	4.87	.967E+03	14.50
7	70	36.9	35.0	788.	4.83	.119E+04	12.02
8	90	37.5	35.5	795.	4.79	.130E+04	11.28
9	115	37.9	36.1	804.	4.73	.122E+04	12.41
10	135	38.2	36.6	812.	4.69	.111E+04	14.01
11	155	39.0	37.0	819.	4.65	.135E+04	11.94
12	178	39.4	37.6	829.	4.58	.134E+04	12.40
13	217	40.2	38.5	845.	4.48	.131E+04	13.35
14	249	41.1	39.3	858.	4.40	.143E+04	12.76
15	289	42.2	40.2	875.	4.31	.164E+04	11.79
16	307	42.8	40.7	883.	4.27	.182E+04	10.89
17	383	44.6	42.5	914.	4.11	.207E+04	10.55
18	461	46.9	44.3	946.	3.95	.270E+04	8.90
19	510	47.3	45.5	965.	3.87	.198E+04	12.81
20	527	47.3	45.9	971.	3.84	.162E+04	15.98

Static Differential Pressures and Friction Factors

1		.0322	.0312	.0284	.0282	.0000	.0000
2	17.0		.0316	.0277	.0274	.0000	.0000
3	31.8	15.6		.0243	.0251	.0000	.0000
4	43.1	27.4	12.0		.0308	.0000	.0000
5	47.6	31.8	16.8	5.3		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:     865.               fc:        .0292
Dn:     124.               fc/fs:   1.58
Pr:       4.36             Dn*:   123.
Gr:        .140E+04        Gr/Re:     .161E+01
Nu:      12.45                Gz:   5.57
-------------------------------------------------------
```

```
Coil Number: 3      D/d: 49       h/d:   5       L/d: 532
Run Number:   22.                 h/D:  .102     Dc/d   49.1
Flowrate:          .001260 kg/s        T(bulk inlet):   32.3C
Inlet Velocity:      .0773 m/s         T(bulk outlet): 45.8C
Residence Time:         39 s           T(bulk average):39.0C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:       75.4 W      Tube Resistance:    .121 ohms
Power Absorbed:  70.9 W      Tube Conductivity:15.42 W/mK
Heat Balance:       5.9 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	33.9	32.4	462.	5.12	.784E+03	10.64
2	16	34.2	32.7	463.	5.10	.819E+03	10.30
3	25	34.4	32.9	465.	5.08	.813E+03	10.48
4	35	34.7	33.2	467.	5.05	.818E+03	10.57
5	46	35.1	33.4	470.	5.02	.918E+03	9.60
6	57	35.2	33.7	472.	4.99	.825E+03	10.88
7	70	35.7	34.1	475.	4.95	.984E+03	9.33
8	90	36.3	34.6	481.	4.89	.105E+04	9.03
9	115	36.7	35.2	488.	4.82	.971E+03	10.16
10	135	37.2	35.7	492.	4.77	.996E+03	10.18
11	155	38.0	36.2	497.	4.72	.116E+04	8.99
12	178	38.4	36.8	503.	4.67	.112E+04	9.63
13	217	39.2	37.8	513.	4.56	.103E+04	11.09
14	249	40.1	38.6	522.	4.47	.116E+04	10.36
15	289	41.2	39.6	532.	4.37	.131E+04	9.68
16	307	41.9	40.1	537.	4.33	.156E+04	8.39
17	383	43.9	42.0	559.	4.15	.181E+04	8.07
18	461	46.3	44.0	580.	3.98	.248E+04	6.52
19	510	47.0	45.2	592.	3.89	.197E+04	8.70
20	527	47.1	45.6	596.	3.86	.168E+04	10.38

Static Differential Pressures and Friction Factors

1		.0543	.0000	.0417	.0000	.0000	.0000
2	10.9		.0000	.0406	.0384	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	24.0	15.2	.0		.0000	.0000	.0000
5	.0	17.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

```
Non-Dimensional Flow Parameters
Re:     526.                fc:         .0455
Dn:      75.                fc/fs:    1.50
Pr:       4.43              Dn*:    75.
Gr:        .119E+04         Gr/Re:      .226E+01
Nu:       9.56                 Gz:    3.44
-------------------------------------------------------
```

```
Coil Number: 3      D/d: 49       h/d:  5      L/d: 532
Run Number:   23.                 h/D:  .102   Dc/d  49.1
Flowrate:           .000972 kg/s      T(bulk inlet):   30.2C
Inlet Velocity:      .0596 m/s        T(bulk outlet): 41.9C
Residence Time:         51  s         T(bulk average):36.0C
--------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      49.1 W      Tube Resistance:    .123 ohms
Power Absorbed:   47.7 W      Tube Conductivity:15.37 W/mK
Heat Balance:      2.8 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	30.8	30.3	340.	5.38	.223E+03	20.99
2	16	31.7	30.5	342.	5.36	.517E+03	9.16
3	25	31.9	30.7	343.	5.34	.535E+03	8.97
4	35	32.1	30.9	344.	5.31	.557E+03	8.75
5	46	32.5	31.2	346.	5.28	.619E+03	8.03
6	57	32.5	31.4	349.	5.24	.537E+03	9.45
7	70	33.0	31.7	351.	5.20	.648E+03	8.02
8	90	33.5	32.2	355.	5.14	.720E+03	7.45
9	115	34.0	32.7	357.	5.10	.676E+03	8.13
10	135	34.4	33.2	360.	5.06	.669E+03	8.42
11	155	34.9	33.6	363.	5.01	.730E+03	7.94
12	178	35.3	34.1	367.	4.95	.714E+03	8.40
13	217	36.1	35.0	374.	4.84	.684E+03	9.28
14	249	36.8	35.7	379.	4.77	.704E+03	9.36
15	289	37.8	36.6	386.	4.69	.856E+03	8.11
16	307	38.3	37.0	389.	4.66	.966E+03	7.37
17	383	40.1	38.6	403.	4.47	.114E+04	6.86
18	461	42.1	40.4	417.	4.30	.145E+04	5.96
19	510	42.7	41.4	426.	4.19	.114E+04	8.09
20	527	42.9	41.8	429.	4.16	.972E+03	9.68

```
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0642  .0000  .0519  .0516  .0000  .0000
2    7.6              .0000  .0504  .0495  .0000  .0000
3     .0      .0             .0000  .0000  .0000  .0000
4   17.7    11.2      .0            .0585  .0000  .0000
5   19.6    13.0      .0     2.3           .0000  .0000
6     .0      .0      .0      .0     .0           .0000
7     .0      .0      .0      .0     .0     .0
      1       2       3       4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     382.                 fc:        .0555
Dn:      55.                 fc/fs:   1.33
Pr:       4.73               Dn*:    55.
Gr:        .763E+03          Gr/Re:     .200E+01
Nu:       8.16                  Gz:   2.67
--------------------------------------------------------
```

Coil Number: 3   D/d: 49   h/d: 5   L/d: 532
Run Number: 24.   h/D: .102   Dc/d 49.1
Flowrate: .000629 kg/s   T(bulk inlet): 26.8C
Inlet Velocity: .0385 m/s   T(bulk outlet): 37.5C
Residence Time: 78 s   T(bulk average):32.2C

Boundary Condition: Neumann
Power Input: 28.1 W   Tube Resistance: .125 ohms
Power Absorbed: 28.1 W   Tube Conductivity:15.32 W/mK
Heat Balance: -.3 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	27.6	27.0	205.	5.82	.235E+03	9.04
2	16	28.0	27.2	206.	5.79	.306E+03	7.04
3	25	28.2	27.3	207.	5.77	.304E+03	7.16
4	35	28.4	27.5	208.	5.74	.326E+03	6.77
5	46	28.8	27.8	209.	5.71	.373E+03	6.00
6	57	28.9	28.0	210.	5.69	.337E+03	6.75
7	70	29.2	28.2	211.	5.65	.372E+03	6.24
8	90	29.6	28.6	213.	5.59	.390E+03	6.14
9	115	30.0	29.1	215.	5.52	.369E+03	6.74
10	135	30.4	29.6	217.	5.47	.349E+03	7.30
11	155	30.8	30.0	219.	5.42	.352E+03	7.42
12	178	31.3	30.4	221.	5.37	.379E+03	7.09
13	217	32.0	31.2	224.	5.27	.398E+03	7.14
14	249	32.7	31.8	228.	5.18	.418E+03	7.19
15	289	33.6	32.7	231.	5.10	.511E+03	6.13
16	307	34.1	33.0	232.	5.07	.559E+03	5.69
17	383	35.9	34.5	240.	4.89	.791E+03	4.46
18	461	37.5	36.1	248.	4.73	.929E+03	4.15
19	510	37.9	37.1	253.	4.64	.586E+03	7.00
20	527	38.1	37.4	254.	4.60	.449E+03	9.31

Static Differential Pressures and Friction Factors

1		.0769	.0694	.0708	.0695	.0000	.0000
2	3.8		.0737	.0000	.0000	.0000	.0000
3	6.7	3.4		.0737	.0000	.0000	.0000
4	10.1	.0	3.4		.1050	.0000	.0000
5	11.0	.0	.0	1.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 230.   fc: .0729
Dn: 33.   fc/fs: 1.05
Pr: 5.14   Dn*: 33.
Gr: .447E+03   Gr/Re: .195E+01
Nu: 6.40   Gz: 1.74

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 25. h/D: .102 Dc/d 49.1
Flowrate: .018495 kg/s T(bulk inlet): 51.1C
Inlet Velocity: 1.1408 m/s T(bulk outlet): 51.1C
Residence Time: 2 s T(bulk average):51.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0092	.0082	.0000	.0000	.0000
3	.0	377.2		.0069	.0000	.0000	.0000
4	.0	666.8	283.1		.0085	.0000	.0000
5	.0	.0	.0	122.1		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	9601.	fc:	.0081
Dn:	1372.	fc/fs:	4.86
Pr:	3.49	Dn*:	1371.

Coil Number: 3 D/d: 49 h/d: 5 L/d: 532
Run Number: 26. h/D: .102 Dc/d 49.1
Flowrate: .015722 kg/s T(bulk inlet): 51.6C
Inlet Velocity: .9700 m/s T(bulk outlet): 51.6C
Residence Time: 3 s T(bulk average):51.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0091	.0082	.0000	.0000	.0000
3	.0	270.3		.0072	.0000	.0000	.0000
4	.0	485.0	213.4		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 8221. fc: .0082
Dn: 1174. fc/fs: 4.21
Pr: 3.46 Dn*: 1174.

Coil Number: 3	D/d: 49	h/d: 5	L/d: 532
Run Number: 27.		h/D: .102	Dc/d 49.1
Flowrate:	.017102 kg/s	T(bulk inlet):	52.2C
Inlet Velocity:	1.0554 m/s	T(bulk outlet):	52.2C
Residence Time:	2 s	T(bulk average):	52.2C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0000	.0000	.0000	.0000
2	.0		.0087	.0077	.0000	.0000	.0000
3	.0	303.7		.0068	.0000	.0000	.0000
4	.0	539.5	236.2		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	9018.	fc:	.0077
Dn:	1288.	fc/fs:	4.35
Pr:	3.43	Dn*:	1288.

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:    1.                h/D: 1.160   Dc/d  56.8
Flowrate:         .017826 kg/s       T(bulk inlet):  25.2C
Inlet Velocity:    1.0889 m/s        T(bulk outlet): 25.2C
Residence Time:         2 s          T(bulk average):25.2C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0079  .0000  .0000  .0000  .0000  .0000
2   328.6            .0077  .0000  .0000  .0000  .0000
3      .0   302.5           .0080  .0000  .0000  .0000
4      .0      .0   302.5          .0064  .0000  .0000
5      .0      .0      .0    47.6         .0000  .0000
6      .0      .0      .0      .0     .0         .0000
7      .0      .0      .0      .0     .0     .0
       1       2       3       4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5576.              fc:        .0079
Dn:     789.              fc/fs:   2.74
Pr:       6.11            Dn*:    740.
--------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:     2.               h/D: 1.160   Dc/d   56.8
Flowrate:          .013183 kg/s       T(bulk inlet):  24.8C
Inlet Velocity:      .8053 m/s        T(bulk outlet): 24.8C
Residence Time:          3 s          T(bulk average):24.8C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0092  .0000  .0000  .0000  .0000  .0000
2   208.8           .0091  .0000  .0000  .0000  .0000
3      .0   195.3          .0094  .0000  .0000  .0000
4      .0      .0   195.3         .0071  .0000  .0000
5      .0      .0      .0   29.1         .0000  .0000
6      .0      .0      .0     .0     .0         .0000
7      .0      .0      .0     .0     .0     .0
       1       2       3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    4086.                 fc:        .0092
Dn:     578.                 fc/fs:    2.36
Pr:        6.17              Dn*:   542.
---------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 3. h/D: 1.160 Dc/d 56.8
Flowrate: .008739 kg/s T(bulk inlet): 24.8C
Inlet Velocity: .5338 m/s T(bulk outlet): 24.8C
Residence Time: 5 s T(bulk average):24.8C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0126	.0000	.0000	.0000	.0000	.0000
2	125.7		.0129	.0000	.0000	.0000	.0000
3	.0	121.0		.0132	.0000	.0000	.0000
4	.0	.0	120.0		.0108	.0000	.0000
5	.0	.0	.0	19.4		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 2712. fc: .0129
Dn: 384. fc/fs: 2.18
Pr: 6.16 Dn*: 360.

Coil Number: 4	D/d: 50	h/d: 58	L/d: 528
Run Number: 4.		h/D: 1.160	Dc/d 56.8
Flowrate:	.004145 kg/s	T(bulk inlet):	24.8C
Inlet Velocity:	.2532 m/s	T(bulk outlet):	24.8C
Residence Time:	11 s	T(bulk average):	24.8C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0247	.0000	.0000	.0000	.0000	.0000
2	55.6		.0252	.0000	.0000	.0000	.0000
3	.0	53.3		.0257	.0000	.0000	.0000
4	.0	.0	52.8		.0329	.0000	.0000
5	.0	.0	.0	13.3		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	1286.	fc:	.0252
Dn:	182.	fc/fs:	2.03
Pr:	6.16	Dn*:	171.

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:    5.                h/D: 1.160   Dc/d   56.8
Flowrate:          .002297 kg/s       T(bulk inlet):  24.8C
Inlet Velocity:     .1403 m/s         T(bulk outlet): 24.8C
Residence Time:        21 s           T(bulk average):24.8C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0378  .0000  .0000  .0000  .0000  .0000
2    26.1             .0381  .0000  .0000  .0000  .0000
3      .0   24.8             .0393  .0000  .0000  .0000
4      .0     .0   24.8             .0765  .0000  .0000
5      .0     .0     .0    9.5             .0000  .0000
6      .0     .0     .0     .0     .0             .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     713.              fc:        .0384
Dn:     101.              fc/fs:    1.71
Pr:       6.16            Dn*:     95.
-------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:     6.               h/D: 1.160   Dc/d  56.8
Flowrate:           .000529 kg/s      T(bulk inlet):  24.8C
Inlet Velocity:      .0323 m/s        T(bulk outlet): 24.8C
Residence Time:         93 s          T(bulk average):24.8C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0156  .0535  .0582  .0000  .0000  .0000
2     .6             .0000  .0000  .0000  .0000  .0000
3    3.8      .0            .0000  .0000  .0000  .0000
4    6.1      .0     .0            .0000  .0000  .0000
5     .0      .0     .0     .0            .0000  .0000
6     .0      .0     .0     .0     .0            .0000
7     .0      .0     .0     .0     .0     .0
      1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     164.                fc:        .0424
Dn:      23.                fc/fs:     .44
Pr:       6.16              Dn*:     22.
--------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:     7.               h/D: 1.160   Dc/d  56.8
Flowrate:           .000236 kg/s      T(bulk inlet):   22.8C
Inlet Velocity:      .0144 m/s        T(bulk outlet):  22.8C
Residence Time:        209 s          T(bulk average):22.8C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000   .0000   .2295   .0000   .0000   .0000
2      .0             .0000   .0000   .0000   .0000   .0000
3      .0     .0              .0000   .0000   .0000   .0000
4     4.8     .0      .0              .0000   .0000   .0000
5      .0     .0      .0      .0              .0000   .0000
6      .0     .0      .0      .0      .0              .0000
7      .0     .0      .0      .0      .0      .0
       1      2       3       4       5       6       7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:      70.                 fc:        .2295
Dn:      10.                 fc/fs:    1.00
Pr:       6.51               Dn*:      9.
--------------------------------------------------------
```

Coil Number: 4   D/d: 50   h/d: 58   L/d: 528
Run Number: 8.   h/D: 1.160   Dc/d 56.8
Flowrate: .014479 kg/s   T(bulk inlet): 25.6C
Inlet Velocity: .8846 m/s   T(bulk outlet): 25.6C
Residence Time: 3 s   T(bulk average):25.6C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0089	.0000	.0000	.0000	.0000	.0000
2	245.4		.0092	.0000	.0000	.0000	.0000
3	.0	238.1		.0095	.0000	.0000	.0000
4	.0	.0	238.1		.0044	.0000	.0000
5	.0	.0	.0	21.5		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 4573.   fc: .0092
Dn: 647.   fc/fs: 2.63
Pr: 6.04   Dn*: 607.

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 9. h/D: 1.160 Dc/d 56.8
Flowrate: .015876 kg/s T(bulk inlet): 25.7C
Inlet Velocity: .9700 m/s T(bulk outlet): 25.7C
Residence Time: 3 s T(bulk average): 25.7C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0087	.0000	.0000	.0000	.0000	.0000
2	287.7		.0090	.0000	.0000	.0000	.0000
3	.0	279.7		.0092	.0000	.0000	.0000
4	.0	.0	278.1		.0045	.0000	.0000
5	.0	.0	.0	26.7		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 5035. fc: .0090
Dn: 712. fc/fs: 2.83
Pr: 6.01 Dn*: 668.

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   10.                h/D: 1.160   Dc/d   56.8
Flowrate:          .017972 kg/s       T(bulk inlet):   25.8C
Inlet Velocity:    1.0981 m/s         T(bulk outlet): 25.8C
Residence Time:         2 s           T(bulk average):25.8C
```

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0084	.0000	.0000	.0000	.0000	.0000
2	355.3		.0083	.0000	.0000	.0000	.0000
3	.0	331.5		.0090	.0000	.0000	.0000
4	.0	.0	348.6		.0050	.0000	.0000
5	.0	.0	.0	38.1		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	5716.	fc:	.0086
Dn:	808.	fc/fs:	3.07
Pr:	5.99	Dn*:	758.

```
Coil Number: 4      D/d: 50      h/d: 58     L/d: 528
Run Number:   11.                h/D: 1.160  Dc/d  56.8
Flowrate:           .021466 kg/s     T(bulk inlet):  25.9C
Inlet Velocity:    1.3116 m/s        T(bulk outlet): 25.9C
Residence Time:         2 s          T(bulk average):25.9C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0082  .0000  .0000  .0000  .0000  .0000
2  497.2             .0084  .0000  .0000  .0000  .0000
3     .0  476.6             .0087  .0000  .0000  .0000
4     .0     .0  481.0             .0053  .0000  .0000
5     .0     .0     .0   57.2             .0000  .0000
6     .0     .0     .0     .0     .0             .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   6837.                fc:       .0085
Dn:    967.                fc/fs:   3.61
Pr:      5.98              Dn*:   907.
--------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   12.                h/D: 1.160   Dc/d   56.8
Flowrate:           .024961 kg/s     T(bulk inlet):   25.9C
Inlet Velocity:    1.5251 m/s       T(bulk outlet): 25.9C
Residence Time:         1 s         T(bulk average):25.9C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1           .0084  .0000  .0000  .0000  .0000  .0000
2  685.8           .0084  .0000  .0000  .0000  .0000
3     .0  646.2           .0088  .0000  .0000  .0000
4     .0     .0  652.5           .0052  .0000  .0000
5     .0     .0     .0   77.2          .0000  .0000
6     .0     .0     .0     .0     .0          .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    7949.               fc:        .0085
Dn:    1124.               fc/fs:   4.24
Pr:       5.98             Dn*:  1055.
---------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   13.                h/D: 1.160   Dc/d   56.8
Flowrate:          .015131 kg/s      T(bulk inlet):   24.6C
Inlet Velocity:      .9242 m/s       T(bulk outlet):  24.6C
Residence Time:          3 s         T(bulk average):24.6C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0085  .0000  .0000  .0000  .0000  .0000
2  255.3            .0083  .0000  .0000  .0000  .0000
3     .0  235.3            .0082  .0000  .0000  .0000
4     .0     .0  223.8            .0011  .0000  .0000
5     .0     .0     .0    6.1            .0000  .0000
6     .0     .0     .0     .0     .0            .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    4673.                  fc:        .0083
Dn:     661.                  fc/fs:   2.44
Pr:       6.19                Dn*:    620.
-------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 14. h/D: 1.160 Dc/d 56.8
Flowrate: .000296 kg/s T(bulk inlet): 22.8C
Inlet Velocity: .0181 m/s T(bulk outlet): 22.8C
Residence Time: 167 s T(bulk average): 22.8C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.1925	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	6.3	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 87. fc: .1925
Dn: 12. fc/fs: 1.05
Pr: 6.51 Dn*: 12.

Coil Number: 4	D/d: 50	h/d: 58	L/d: 528
Run Number: 15.		h/D: 1.160	Dc/d 56.8
Flowrate:	.014349 kg/s	T(bulk inlet):	39.4C
Inlet Velocity:	.8830 m/s	T(bulk outlet):	52.1C
Residence Time:	3 s	T(bulk average):	45.8C

Boundary Condition: Neumann

Power Input:	771.5 W	Tube Resistance:	.118 ohms
Power Absorbed:	758.2 W	Tube Conductivity:	15.54 W/mK
Heat Balance:	1.7 %		

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	42.9	39.6	6059.	4.37	.266E+04	49.26
2	16	44.0	39.8	6088.	4.35	.342E+04	38.76
3	30	44.3	40.1	6130.	4.32	.348E+04	38.87
4	43	44.6	40.5	6171.	4.29	.355E+04	38.84
5	55	44.5	40.7	6210.	4.26	.327E+04	42.86
6	69	44.7	41.1	6254.	4.22	.320E+04	44.74
7	80	44.9	41.3	6285.	4.20	.323E+04	44.85
8	91	45.1	41.6	6316.	4.18	.319E+04	46.18
9	115	45.6	42.2	6384.	4.13	.321E+04	47.31
10	138	46.6	42.7	6446.	4.09	.376E+04	41.44
11	162	47.2	43.3	6516.	4.04	.392E+04	40.91
12	179	47.2	43.7	6568.	4.00	.357E+04	45.96
13	201	47.8	44.2	6632.	3.96	.380E+04	44.42
14	224	48.4	44.8	6693.	3.92	.391E+04	44.36
15	246	48.9	45.3	6752.	3.88	.394E+04	45.08
16	297	50.0	46.5	6895.	3.79	.409E+04	46.04
17	341	51.1	47.6	7022.	3.72	.442E+04	44.97
18	424	53.0	49.6	7276.	3.58	.466E+04	46.89
19	498	55.0	51.4	7476.	3.47	.552E+04	42.77
20	524	55.0	52.0	7537.	3.44	.469E+04	51.62

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0077	.0000	.0000	.0000	.0000	.0000
2	209.4		.0078	.0000	.0000	.0000	.0000
3	.0	200.4		.0081	.0000	.0000	.0000
4	.0	.0	201.2		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	6802.	fc:	.0078
Dn:	962.	fc/fs:	3.33
Pr:	3.85	Dn*:	902.
Gr:	.370E+04	Gr/Re:	.544E+00
Nu:	43.98	Gz:	38.96

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 16. h/D: 1.160 Dc/d 56.8
Flowrate: .015835 kg/s T(bulk inlet): 39.8C
Inlet Velocity: .9741 m/s T(bulk outlet): 50.1C
Residence Time: 3 s T(bulk average):45.0C

Boundary Condition: Neumann
Power Input: 660.8 W Tube Resistance: .117 ohms
Power Absorbed: 682.5 W Tube Conductivity:15.53 W/mK
Heat Balance: -3.3 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	42.6	39.9	6734.	4.34	.220E+04	52.10
2	16	43.6	40.1	6762.	4.32	.291E+04	39.79
3	30	43.8	40.4	6802.	4.29	.292E+04	40.24
4	43	44.1	40.7	6839.	4.27	.294E+04	40.56
5	55	44.0	40.9	6874.	4.24	.274E+04	44.21
6	69	44.2	41.2	6912.	4.22	.269E+04	45.69
7	80	44.3	41.4	6940.	4.20	.266E+04	46.80
8	91	44.5	41.6	6968.	4.18	.263E+04	47.89
9	115	45.0	42.1	7030.	4.14	.271E+04	47.58
10	138	45.7	42.5	7086.	4.10	.308E+04	42.92
11	162	46.2	43.0	7145.	4.07	.320E+04	42.22
12	179	46.2	43.3	7191.	4.04	.287E+04	47.87
13	201	46.7	43.7	7252.	4.00	.307E+04	45.88
14	224	47.2	44.2	7312.	3.96	.321E+04	44.91
15	246	47.6	44.6	7365.	3.93	.324E+04	45.44
16	297	48.6	45.6	7490.	3.86	.335E+04	45.96
17	341	49.3	46.5	7600.	3.80	.330E+04	48.80
18	424	51.0	48.1	7819.	3.68	.369E+04	47.10
19	498	52.9	49.5	8025.	3.58	.463E+04	40.36
20	524	52.8	50.1	8098.	3.54	.384E+04	49.86

Static Differential Pressures and Friction Factors

1		.0075	.0000	.0000	.0000	.0000	.0000
2	249.6		.0074	.0000	.0000	.0000	.0000
3	.0	231.1		.0077	.0000	.0000	.0000
4	.0	.0	233.7		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 7408. fc: .0075
Dn: 1048. fc/fs: 3.48
Pr: 3.91 Dn*: 983.
Gr: .302E+04 Gr/Re: .408E+00
Nu: 45.25 Gz: 43.04

```
Coil Number: 4      D/d: 50       h/d: 58      L/d: 528
Run Number:    17.                h/D: 1.160   Dc/d   56.8
Flowrate:            .009411 kg/s      T(bulk inlet):   37.5C
Inlet Velocity:       .5786 m/s        T(bulk outlet): 49.7C
Residence Time:           5 s          T(bulk average):43.6C
-------------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      499.3 W      Tube Resistance:    .118 ohms
Power Absorbed: 479.7 W      Tube Conductivity:15.51 W/mK
Heat Balance:       3.9 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	40.3	37.6	3819.	4.58	.190E+04	39.80
2	16	41.5	37.9	3837.	4.55	.269E+04	28.48
3	30	41.8	38.2	3863.	4.51	.269E+04	29.01
4	43	42.2	38.5	3887.	4.48	.279E+04	28.45
5	55	42.1	38.8	3910.	4.45	.259E+04	31.25
6	69	42.3	39.1	3936.	4.42	.253E+04	32.56
7	80	42.6	39.3	3955.	4.40	.261E+04	32.03
8	91	42.7	39.6	3975.	4.37	.249E+04	34.05
9	115	43.0	40.1	4020.	4.32	.243E+04	36.01
10	138	44.2	40.7	4066.	4.26	.306E+04	29.52
11	162	44.8	41.2	4113.	4.21	.316E+04	29.54
12	179	44.7	41.6	4144.	4.18	.285E+04	33.44
13	201	45.4	42.1	4183.	4.13	.305E+04	32.12
14	224	45.9	42.7	4222.	4.09	.313E+04	32.11
15	246	46.4	43.2	4262.	4.05	.320E+04	32.22
16	297	47.5	44.4	4357.	3.95	.332E+04	33.02
17	341	48.0	45.4	4432.	3.88	.290E+04	39.68
18	424	50.5	47.3	4581.	3.74	.395E+04	32.07
19	498	52.4	49.0	4722.	3.62	.458E+04	29.99
20	524	52.5	49.6	4773.	3.58	.407E+04	34.72

Static Differential Pressures and Friction Factors

1		.0101	.0000	.0000	.0000	.0000	.0000
2	118.7		.0097	.0000	.0000	.0000	.0000
3	.0	107.6		.0100	.0000	.0000	.0000
4	.0	.0	106.7		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

```
Non-Dimensional Flow Parameters
Re:    4297.                    fc:          .0099
Dn:     608.                    fc/fs:    2.67
Pr:       4.01                  Dn*:    570.
Gr:        .292E+04             Gr/Re:       .680E+00
Nu:      32.32                     Gz:   25.65
-------------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 18. h/D: 1.160 Dc/d 56.8
Flowrate: .007631 kg/s T(bulk inlet)· 37.0C
Inlet Velocity: .4690 m/s T(bulk outlet): 48.4C
Residence Time: 6 s T(bulk average):42.7C

Boundary Condition: Neumann
Power Input: 356.1 W Tube Resistance: .118 ohms
Power Absorbed: 364.2 W Tube Conductivity:15.49 W/mK
Heat Balance: -2.3 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	39.4	37.1	3065.	4.64	.161E+04	32.70
2	16	40.6	37.3	3079.	4.61	.228E+04	23.27
3	30	40.8	37.6	3098.	4.57	.226E+04	23.87
4	43	41.1	37.9	3116.	4.54	.237E+04	23.17
5	55	41.1	38.2	3132.	4.51	.215E+04	25.94
6	69	41.2	38.5	3152.	4.48	.205E+04	27.67
7	80	41.4	38.7	3168.	4.46	.203E+04	28.33
8	91	41.5	39.0	3184.	4.43	.199E+04	29.24
9	115	42.2	39.5	3216.	4.38	.216E+04	27.87
10	138	43.2	40.0	3248.	4.34	.270E+04	22.88
11	162	44.1	40.5	3284.	4.28	.305E+04	20.90
12	179	44.0	40.9	3311.	4.25	.278E+04	23.44
13	201	44.5	41.3	3342.	4.20	.281E+04	23.79
14	224	45.0	41.8	3374.	4.16	.291E+04	23.61
15	246	45.4	42.3	3403.	4.12	.293E+04	24.03
16	297	46.8	43.4	3472.	4.03	.344E+04	21.63
17	341	47.2	44.4	3534.	3.95	.297E+04	26.36
18	424	49.5	46.2	3643.	3.82	.389E+04	21.92
19	498	51.5	47.8	3746.	3.71	.470E+04	19.63
20	524	51.6	48.3	3783.	3.67	.429E+04	22.09

Static Differential Pressures and Friction Factors

1		.0111	.0000	.0000	.0000	.0000	.0000
2	85.7		.0108	.0000	.0000	.0000	.0000
3	.0	78.5		.0110	.0000	.0000	.0000
4	.0	.0	77.5		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 3426. fc: .0110
Dn: 485. fc/fs: 2.35
Pr: 4.09 Dn*: 455.
Gr: .266E+04 Gr/Re: .775E+00
Nu: 24.67 Gz: 20.84

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 19. h/D: 1.160 Dc/d 56.8
Flowrate: .006044 kg/s T(bulk inlet): 37.4C
Inlet Velocity: .3715 m/s T(bulk outlet): 49.1C
Residence Time: 8 s T(bulk average):43.3C

Boundary Condition: Neumann
Power Input: 294.0 W Tube Resistance: .118 ohms
Power Absorbed: 295.5 W Tube Conductivity:15.50 W/mK
Heat Balance: -.5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	39.7	37.6	2450.	4.58	.155E+04	28.62
2	16	40.9	37.8	2461.	4.56	.228E+04	19.70
3	30	41.1	38.1	2477.	4.52	.219E+04	20.86
4	43	41.4	38.4	2491.	4.49	.225E+04	20.67
5	55	41.3	38.7	2505.	4.46	.202E+04	23.42
6	69	41.4	39.0	2522.	4.43	.193E+04	24.92
7	80	41.7	39.2	2534.	4.41	.197E+04	24.76
8	91	42.1	39.5	2546.	4.39	.212E+04	23.35
9	115	42.8	40.0	2573.	4.34	.231E+04	22.12
10	138	43.6	40.5	2601.	4.28	.268E+04	19.61
11	162	44.5	41.0	2631.	4.23	.306E+04	17.74
12	179	44.5	41.4	2650.	4.20	.282E+04	19.66
13	201	44.9	41.9	2674.	4.16	.279E+04	20.42
14	224	45.4	42.4	2699.	4.11	.288E+04	20.31
15	246	45.9	42.9	2722.	4.07	.299E+04	20.00
16	297	47.2	44.0	2783.	3.98	.333E+04	19.12
17	341	47.6	45.0	2828.	3.90	.281E+04	23.69
18	424	50.2	46.8	2919.	3.77	.411E+04	17.77
19	498	52.0	48.5	3004.	3.66	.459E+04	17.18
20	524	52.1	49.0	3035.	3.61	.410E+04	19.78

Static Differential Pressures and Friction Factors

1		.0129	.0000	.0000	.0000	.0000	.0000
2	62.3		.0126	.0000	.0000	.0000	.0000
3	.0	57.3		.0128	.0000	.0000	.0000
4	.0	.0	56.8		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 2743. fc: .0128
Dn: 388. fc/fs: 2.19
Pr: 4.04 Dn*: 364.
Gr: .264E+04 Gr/Re: .963E+00
Nu: 21.15 Gz: 16.48

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 20. h/D: 1.160 Dc/d 56.8
Flowrate: .003837 kg/s T(bulk inlet): 37.2C
Inlet Velocity: .2359 m/s T(bulk outlet): 51.0C
Residence Time: 12 s T(bulk average):44.1C

Boundary Condition: Neumann
Power Input: 238.9 W Tube Resistance: .118 ohms
Power Absorbed: 222.3 W Tube Conductivity:15.50 W/mK
Heat Balance: 7.0 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	39.4	37.3	1547.	4.61	.147E+04	24.22
2	16	40.7	37.6	1556.	4.58	.221E+04	16.35
3	30	40.8	37.9	1567.	4.54	.211E+04	17.50
4	43	41.1	38.3	1578.	4.50	.213E+04	17.66
5	55	41.1	38.6	1589.	4.47	.191E+04	20.08
6	69	41.5	39.0	1601.	4.43	.201E+04	19.49
7	80	42.2	39.3	1610.	4.40	.232E+04	17.19
8	91	42.5	39.5	1619.	4.38	.240E+04	16.87
9	115	42.9	40.2	1640.	4.32	.226E+04	18.59
10	138	44.1	40.8	1662.	4.25	.287E+04	15.18
11	162	44.8	41.4	1683.	4.20	.311E+04	14.51
12	179	44.9	41.9	1697.	4.16	.281E+04	16.46
13	201	45.6	42.4	1715.	4.11	.306E+04	15.56
14	224	46.0	43.0	1733.	4.06	.287E+04	17.03
15	246	46.8	43.6	1753.	4.01	.327E+04	15.45
16	297	48.2	45.0	1794.	3.91	.350E+04	15.45
17	341	48.6	46.1	1830.	3.82	.284E+04	20.05
18	424	51.7	48.3	1901.	3.67	.436E+04	14.56
19	498	53.6	50.2	1967.	3.53	.477E+04	14.61
20	524	53.8	50.9	1987.	3.49	.422E+04	17.00

Static Differential Pressures and Friction Factors

1		.0197	.0000	.0000	.0000	.0000	.0000
2	38.5		.0190	.0000	.0000	.0000	.0000
3	.0	34.9		.0187	.0000	.0000	.0000
4	.0	.0	33.3		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1769. fc: .0191
Dn: 250. fc/fs: 2.11
Pr: 3.97 Dn*: 235.
Gr: .274E+04 Gr/Re: .155E+01
Nu: 16.98 Gz: 10.45

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   21.                h/D: 1.160   Dc/d  56.8
Flowrate:          .002104 kg/s      T(bulk inlet):   32.4C
Inlet Velocity:     .1291 m/s        T(bulk outlet): 44.3C
Residence Time:       23  s          T(bulk average):38.4C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:     107.1 W      Tube Resistance:    .119 ohms
Power Absorbed: 104.3 W      Tube Conductivity:15.41 W/mK
Heat Balance:       2.6 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	33.9	32.6	773.	5.11	.673E+03	17.84
2	16	34.6	32.8	775.	5.09	.963E+03	12.60
3	30	34.7	33.1	779.	5.06	.863E+03	14.30
4	43	35.0	33.4	784.	5.03	.877E+03	14.34
5	55	35.3	33.7	788.	5.00	.910E+03	14.08
6	69	35.5	34.0	793.	4.96	.896E+03	14.61
7	80	35.8	34.2	798.	4.93	.934E+03	14.25
8	91	36.0	34.5	802.	4.90	.908E+03	14.89
9	115	36.5	35.0	812.	4.83	.914E+03	15.33
10	138	37.5	35.5	820.	4.78	.126E+04	11.43
11	162	38.0	36.1	828.	4.73	.125E+04	11.86
12	179	38.0	36.5	834.	4.70	.105E+04	14.39
13	201	38.7	37.0	843.	4.66	.118E+04	13.22
14	224	39.1	37.5	851.	4.59	.119E+04	13.57
15	246	39.8	38.0	860.	4.53	.136E+04	12.14
16	297	40.9	39.1	881.	4.42	.143E+04	12.39
17	341	41.5	40.1	898.	4.32	.119E+04	15.69
18	424	43.7	42.0	933.	4.15	.166E+04	12.57
19	498	45.3	43.6	962.	4.01	.168E+04	13.49
20	524	45.5	44.2	972.	3.96	.137E+04	17.04

Static Differential Pressures and Friction Factors

	1	2	3	4	5	6	7
1		.0309	.0000	.0000	.0000	.0000	.0000
2	18.1		.0287	.0000	.0000	.0000	.0000
3	.0	15.8		.0296	.0000	.0000	.0000
4	.0	.0	15.8		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

```
Re:    867.              fc:       .0298
Dn:    123.              fc/fs:   1.61
Pr:      4.49            Dn*:   115.
Gr:       .112E+04       Gr/Re:     .129E+01
Nu:     13.69               Gz:    5.79
-------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 22. h/D: 1.160 Dc/d 56.8
Flowrate: .000641 kg/s T(bulk inlet): 28.7C
Inlet Velocity: .0392 m/s T(bulk outlet): 37.3C
Residence Time: 76 s T(bulk average):33.0C

Boundary Condition: Neumann
Power Input: 26.8 W Tube Resistance: .119 ohms
Power Absorbed: 23.0 W Tube Conductivity:15.33 W/mK
Heat Balance: 14.0 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	29.5	28.8	218.	5.56	.257E+03	9.09
2	16	29.9	29.0	219.	5.54	.388E+03	6.10
3	30	30.0	29.2	220.	5.51	.345E+03	6.96
4	43	30.3	29.4	221.	5.48	.354E+03	6.87
5	55	30.4	29.6	222.	5.46	.346E+03	7.11
6	69	30.6	29.8	222.	5.44	.324E+03	7.69
7	80	30.8	30.0	223.	5.41	.347E+03	7.27
8	91	31.0	30.2	224.	5.39	.345E+03	7.38
9	115	31.3	30.6	226.	5.35	.341E+03	7.67
10	138	32.0	31.0	227.	5.31	.487E+03	5.51
11	162	32.4	31.4	229.	5.25	.493E+03	5.62
12	179	32.6	31.6	231.	5.21	.468E+03	6.06
13	201	33.0	32.0	233.	5.16	.525E+03	5.57
14	224	33.4	32.4	235.	5.12	.557E+03	5.34
15	246	33.9	32.7	236.	5.10	.648E+03	4.67
16	297	34.7	33.6	239.	5.01	.666E+03	4.77
17	341	35.1	34.3	243.	4.93	.509E+03	6.55
18	424	36.9	35.6	250.	4.77	.834E+03	4.33
19	498	37.9	36.8	256.	4.67	.718E+03	5.41
20	524	37.9	37.3	258.	4.62	.478E+03	8.32

Static Differential Pressures and Friction Factors

1		.0988	.0926	.0927	.0000	.0000	.0000
2	5.3		.1011	.0989	.0000	.0000	.0000
3	9.7	5.1		.1043	.0000	.0000	.0000
4	14.3	9.9	5.1		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 237. fc: .0981
Dn: 33. fc/fs: 1.45
Pr: 5.07 Dn*: 31.
Gr: .474E+03 Gr/Re: .200E+01
Nu: 6.21 Gz: 1.79

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 23. h/D: 1.160 Dc/d 56.8
Flowrate: .000564 kg/s T(bulk inlet): 25.3C
Inlet Velocity: .0345 m/s T(bulk outlet): 35.7C
Residence Time: 87 s T(bulk average):30.5C

Boundary Condition: Neumann
Power Input: 27.0 W Tube Resistance: .120 ohms
Power Absorbed: 24.4 W Tube Conductivity:15.29 W/mK
Heat Balance: 9.6 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	26.2	25.5	178.	6.06	.234E+03	7.79
2	16	26.6	25.6	178.	6.02	.299E+03	6.20
3	30	26.7	25.9	180.	5.98	.262E+03	7.24
4	43	27.0	26.2	181.	5.94	.257E+03	7.55
5	55	27.1	26.4	182.	5.90	.248E+03	7.98
6	69	27.3	26.7	183.	5.86	.225E+03	8.96
7	80	27.6	26.9	184.	5.83	.251E+03	8.18
8	91	27.8	27.1	185.	5.80	.257E+03	8.11
9	115	28.3	27.6	186.	5.74	.255E+03	8.42
10	138	29.0	28.0	188.	5.68	.377E+03	5.88
11	162	29.5	28.5	190.	5.60	.381E+03	6.04
12	179	29.8	28.9	192.	5.55	.380E+03	6.22
13	201	30.3	29.3	194.	5.50	.443E+03	5.49
14	224	30.7	29.7	195.	5.45	.429E+03	5.83
15	246	31.3	30.2	197.	5.40	.520E+03	4.94
16	297	32.2	31.2	201.	5.28	.492E+03	5.59
17	341	33.1	32.0	205.	5.15	.569E+03	5.20
18	424	34.8	33.7	211.	5.00	.630E+03	5.13
19	498	36.0	35.1	218.	4.82	.567E+03	6.27
20	524	36.2	35.6	220.	4.77	.378E+03	9.65

Static Differential Pressures and Friction Factors

1		.1096	.1012	.1008	.0000	.0000	.0000
2	4.6		.1164	.1084	.0000	.0000	.0000
3	8.2	4.6		.1201	.0000	.0000	.0000
4	12.0	8.4	4.6		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 198. fc: .1094
Dn: 28. fc/fs: 1.35
Pr: 5.36 Dn*: 26.
Gr: .374E+03 Gr/Re: .189E+01
Nu: 6.67 Gz: 1.58

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 24. h/D: 1.160 Dc/d 56.8
Flowrate: .000175 kg/s T(bulk inlet): 23.9C
Inlet Velocity: .0107 m/s T(bulk outlet): 39.0C
Residence Time: 281 s T(bulk average):31.4C

Boundary Condition: Neumann
Power Input: 12.2 W Tube Resistance: .122 ohms
Power Absorbed: 11.0 W Tube Conductivity:15.31 W/mK
Heat Balance: 9.3 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	24.7	24.1	53.	6.28	.166E+03	4.43
2	16	25.2	24.3	54.	6.24	.246E+03	3.05
3	30	25.7	24.7	54.	6.17	.284E+03	2.73
4	43	26.1	25.1	55.	6.12	.306E+03	2.61
5	55	26.5	25.5	55.	6.06	.321E+03	2.56
6	69	26.9	25.9	56.	5.99	.338E+03	2.51
7	80	27.4	26.2	56.	5.94	.400E+03	2.18
8	91	27.8	26.5	57.	5.89	.455E+03	1.97
9	115	28.8	27.2	57.	5.79	.573E+03	1.65
10	138	29.8	27.8	58.	5.70	.738E+03	1.33
11	162	30.7	28.5	59.	5.60	.848E+03	1.22
12	179	31.2	29.0	60.	5.53	.912E+03	1.18
13	201	32.2	29.6	61.	5.46	.108E+04	1.03
14	224	32.9	30.3	61.	5.38	.116E+04	1.00
15	246	33.8	30.9	62.	5.31	.135E+04	.90
16	297	35.5	32.4	64.	5.12	.161E+04	.84
17	341	36.7	33.6	65.	5.00	.172E+04	.84
18	424	39.3	36.0	69.	4.73	.214E+04	.78
19	498	41.0	38.1	72.	4.52	.215E+04	.88
20	524	41.0	38.9	73.	4.44	.165E+04	1.20

Static Differential Pressures and Friction Factors

1		.4730	.4385	.4474	.0000	.0000	.0000
2	1.9		.6027	.5356	.0000	.0000	.0000
3	3.4	2.3		.6737	.0000	.0000	.0000
4	5.1	4.0	2.5		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	63.	fc:	.5285
Dn:	9.	fc/fs:	2.07
Pr:	5.24	Dn*:	8.
Gr:	.891E+03	Gr/Re:	.142E+02
Nu:	1.58	Gz:	.49

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   25.                h/D: 1.160   Dc/d  56.8
Flowrate:           .003992 kg/s    T(bulk inlet):   27.0C
Inlet Velocity:     .2457 m/s       T(bulk outlet):  66.3C
Residence Time:        12  s        T(bulk average):46.6C
-------------------------------------------------------
Boundary Condition:  Neumann
Power Input:      672.5 W     Tube Resistance:   .120 ohms
Power Absorbed: 655.5 W       Tube Conductivity:15.54 W/mK
Heat Balance:       2.5 %
```

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	34.2	27.4	1317.	5.75	.248E+04	21.41
2	16	36.8	28.2	1337.	5.65	.334E+04	16.68
3	30	37.0	29.2	1370.	5.51	.325E+04	18.56
4	43	37.8	30.2	1395.	5.39	.339E+04	18.87
5	55	38.1	31.1	1419.	5.29	.332E+04	20.47
6	69	40.2	32.1	1456.	5.14	.416E+04	17.77
7	80	41.6	33.0	1473.	5.08	.463E+04	16.56
8	91	42.1	33.8	1497.	4.99	.471E+04	17.20
9	115	43.1	35.6	1555.	4.78	.484E+04	18.69
10	138	46.3	37.3	1608.	4.62	.635E+04	15.74
11	162	48.1	39.1	1668.	4.42	.712E+04	15.54
12	179	48.4	40.3	1711.	4.30	.681E+04	17.49
13	201	50.2	42.0	1769.	4.15	.769E+04	17.00
14	224	51.3	43.7	1825.	4.01	.783E+04	18.23
15	246	53.5	45.3	1878.	3.88	.909E+04	17.01
16	297	57.1	49.1	2007.	3.61	.108E+05	17.24
17	341	59.6	52.4	2112.	3.41	.114E+05	18.93
18	424	65.5	58.5	2325.	3.07	.143E+05	19.44
19	498	69.9	64.1	2545.	2.78	.150E+05	23.18
20	524	71.4	66.0	2615.	2.70	.151E+05	24.87

```
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0189   .0000   .0000   .0000   .0000   .0000
2    40.0            .0170   .0000   .0000   .0000   .0000
3      .0    33.9            .0171   .0000   .0000   .0000
4      .0      .0    33.1            .0000   .0000   .0000
5      .0      .0      .0      .0            .0000   .0000
6      .0      .0      .0      .0      .0            .0000
7      .0      .0      .0      .0      .0      .0
       1       2       3       4       5       6       7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    1921.                  fc:        .0177
Dn:     272.                  fc/fs:   2.12
Pr:       3.79                Dn*:    255.
Gr:        .685E+04           Gr/Re:     .357E+01
Nu:      17.80                   Gz:  10.82
-------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 26. h/D: 1.160 Dc/d 56.8
Flowrate: .001640 kg/s T(bulk inlet): 31.9C
Inlet Velocity: .1013 m/s T(bulk outlet): 75.5C
Residence Time: 29 s T(bulk average):53.7C

Boundary Condition: Neumann
Power Input: 300.7 W Tube Resistance: .120 ohms
Power Absorbed: 299.1 W Tube Conductivity:15.58 W/mK
Heat Balance: .5 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	36.7	32.4	600.	5.12	.224E+04	14.90
2	16	38.8	33.2	608.	5.05	.304E+04	11.48
3	30	39.3	34.4	623.	4.91	.293E+04	12.84
4	43	40.8	35.4	638.	4.79	.337E+04	11.93
5	55	41.9	36.4	650.	4.70	.365E+04	11.63
6	69	42.8	37.6	665.	4.58	.377E+04	12.08
7	80	43.7	38.5	677.	4.48	.396E+04	12.10
8	91	44.7	39.4	690.	4.39	.422E+04	11.97
9	115	46.5	41.4	719.	4.20	.465E+04	12.18
10	138	48.9	43.3	744.	4.04	.563E+04	11.09
11	162	51.0	45.3	771.	3.88	.636E+04	10.86
12	179	51.6	46.7	790.	3.78	.584E+04	12.67
13	201	53.6	48.5	815.	3.65	.671E+04	12.03
14	224	55.6	50.4	843.	3.52	.752E+04	11.74
15	246	57.7	52.2	865.	3.42	.851E+04	11.20
16	297	60.5	56.4	924.	3.18	.765E+04	14.93
17	341	64.3	60.1	979.	2.99	.938E+04	14.15
18	424	70.1	66.9	1058.	2.74	.854E+04	18.82
19	498	76.2	73.0	1058.	2.74	.852E+04	18.87
20	524	77.6	75.2	1058.	2.74	.660E+04	24.35

Static Differential Pressures and Friction Factors

1		.0365	.0000	.0356	.0000	.0000	.0000
2	13.1		.0354	.0000	.0000	.0000	.0000
3	.0	12.0		.0377	.0000	.0000	.0000
4	36.6	.0	12.4		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 888. fc: .0363
Dn: 126. fc/fs: 2.02
Pr: 3.33 Dn*: 118.
Gr: .579E+04 Gr/Re: .653E+01
Nu: 12.64 Gz: 4.40

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 27. h/D: 1.160 Dc/d 56.8
Flowrate: .006030 kg/s T(bulk inlet): 36.1C
Inlet Velocity: .3711 m/s T(bulk outlet): 55.8C
Residence Time: 8 s T(bulk average):46.0C

Boundary Condition: Neumann
Power Input: 504.3 W Tube Resistance: .119 ohms
Power Absorbed: 497.5 W Tube Conductivity:15.54 W/mK
Heat Balance: 1.4 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	40.2	36.3	2384.	4.71	.256E+04	27.63
2	16	41.9	36.7	2402.	4.68	.355E+04	20.43
3	30	42.1	37.2	2427.	4.63	.343E+04	21.78
4	43	42.8	37.7	2451.	4.57	.366E+04	20.99
5	55	42.7	38.2	2474.	4.51	.335E+04	23.54
6	69	43.0	38.7	2501.	4.46	.329E+04	24.70
7	80	43.3	39.1	2522.	4.42	.331E+04	25.16
8	91	44.0	39.5	2543.	4.38	.363E+04	23.44
9	115	45.2	40.4	2590.	4.29	.408E+04	21.98
10	138	46.4	41.3	2637.	4.21	.465E+04	20.31
11	162	47.9	42.2	2682.	4.13	.541E+04	18.30
12	179	48.0	42.8	2712.	4.08	.511E+04	19.97
13	201	48.7	43.6	2755.	4.01	.517E+04	20.63
14	224	49.7	44.5	2798.	3.94	.556E+04	20.05
15	246	50.5	45.3	2837.	3.88	.581E+04	19.97
16	297	52.7	47.2	2931.	3.75	.674E+04	18.93
17	341	54.1	48.9	3018.	3.63	.691E+04	19.94
18	424	57.5	52.0	3167.	3.44	.853E+04	18.55
19	498	60.4	54.7	3303.	3.28	.979E+04	18.15
20	524	60.2	55.7	3358.	3.22	.812E+04	22.89

Static Differential Pressures and Friction Factors

1		.0132	.0000	.0130	.0000	.0000	.0000
2	63.8		.0130	.0000	.0000	.0000	.0000
3	.0	59.1		.0130	.0000	.0000	.0000
4	179.6	.0	57.2		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 2869. fc: .0130
Dn: 406. fc/fs: 2.34
Pr: 3.83 Dn*: 381.
Gr: .492E+04 Gr/Re: .171E+01
Nu: 21.14 Gz: 16.37

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 28. h/D: 1.160 Dc/d 56.8
Flowrate: .000396 kg/s T(bulk inlet): 26.3C
Inlet Velocity: .0242 m/s T(bulk outlet): 41.1C
Residence Time: 124 s T(bulk average):33.7C

Boundary Condition: Neumann
Power Input: 27.2 W Tube Resistance: .121 ohms
Power Absorbed: 24.4 W Tube Conductivity:15.33 W/mK
Heat Balance: 10.3 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	27.0	26.5	128.	5.89	.163E+03	12.27
2	16	27.8	26.8	129.	5.85	.341E+03	6.00
3	30	28.1	27.2	130.	5.79	.340E+03	6.19
4	43	28.5	27.5	131.	5.74	.348E+03	6.20
5	55	28.8	27.9	132.	5.70	.344E+03	6.40
6	69	29.1	28.3	133.	5.64	.322E+03	7.05
7	80	29.4	28.6	134.	5.60	.340E+03	6.83
8	91	29.8	28.9	135.	5.55	.360E+03	6.63
9	115	30.5	29.5	137.	5.47	.398E+03	6.25
10	138	31.5	30.2	138.	5.40	.561E+03	4.61
11	162	32.1	30.9	140.	5.32	.585E+03	4.62
12	179	32.5	31.3	142.	5.25	.559E+03	5.02
13	201	33.0	32.0	144.	5.16	.545E+03	5.43
14	224	33.8	32.6	145.	5.11	.662E+03	4.61
15	246	34.7	33.2	147.	5.05	.816E+03	3.86
16	297	36.2	34.6	151.	4.88	.952E+03	3.64
17	341	37.0	35.9	155.	4.75	.715E+03	5.20
18	424	39.6	38.2	162.	4.51	.106E+04	4.02
19	498	41.5	40.3	169.	4.31	.101E+04	4.75
20	524	41.6	41.0	172.	4.23	.561E+03	8.94

Static Differential Pressures and Friction Factors

1		.1480	.1477	.1523	.0000	.0000	.0000
2	3.0		.1669	.1646	.0000	.0000	.0000
3	5.9	3.2		.1824	.0000	.0000	.0000
4	9.0	6.3	3.4		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 148. fc: .1603
Dn: 21. fc/fs: 1.49
Pr: 4.99 Dn*: 20.
Gr: .557E+03 Gr/Re: .376E+01
Nu: 5.41 Gz: 1.10

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 29. h/D: 1.160 Dc/d 56.8
Flowrate: .001265 kg/s T(bulk inlet): 28.2C
Inlet Velocity: .0775 m/s T(bulk outlet): 41.2C
Residence Time: 38 s T(bulk average):34.7C

Boundary Condition: Neumann
Power Input: 74.9 W Tube Resistance: .120 ohms
Power Absorbed: 68.6 W Tube Conductivity:15.35 W/mK
Heat Balance: 8.4 %

Stn	x/d	Twi(C)	Tb(C)	Rex	Prx	Grx	Nux
1	6	29.3	28.4	426.	5.63	.366E+03	17.23
2	16	30.1	28.6	428.	5.59	.597E+03	10.77
3	30	30.3	29.0	432.	5.54	.553E+03	11.96
4	43	30.8	29.3	435.	5.50	.652E+03	10.34
5	55	31.1	29.6	437.	5.47	.645E+03	10.64
6	69	31.2	29.9	440.	5.43	.581E+03	12.06
7	80	31.6	30.2	442.	5.40	.632E+03	11.28
8	91	31.8	30.5	444.	5.36	.609E+03	11.91
9	115	32.4	31.0	449.	5.30	.652E+03	11.58
10	138	33.4	31.6	456.	5.21	.884E+03	8.96
11	162	33.9	32.2	462.	5.14	.899E+03	9.19
12	179	34.1	32.6	465.	5.10	.771E+03	10.92
13	201	34.5	33.2	469.	5.05	.726E+03	11.93
14	224	35.5	33.7	474.	4.99	.979E+03	9.19
15	246	36.2	34.3	480.	4.93	.112E+04	8.30
16	297	37.4	35.5	493.	4.78	.118E+04	8.53
17	341	38.0	36.6	503.	4.69	.975E+03	10.99
18	424	40.5	38.6	524.	4.46	.138E+04	8.71
19	498	42.0	40.5	544.	4.29	.134E+04	10.01
20	524	42.3	41.1	552.	4.22	.104E+04	13.38

Static Differential Pressures and Friction Factors

1		.0497	.0451	.0459	.0000	.0000	.0000
2	10.5		.0422	.0438	.0000	.0000	.0000
3	18.5	8.4		.0426	.0000	.0000	.0000
4	27.6	17.1	8.2		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 485. fc: .0449
Dn: 69. fc/fs: 1.36
Pr: 4.87 Dn*: 64.
Gr: .828E+03 Gr/Re: .171E+01
Nu: 10.40 Gz: 3.51

```
Coil Number: 4      D/d: 50       h/d: 58       L/d: 528
Run Number:    30.                h/D: 1.160    Dc/d   56.8
Flowrate:           .000949 kg/s      T(bulk inlet):   24.4C
Inlet Velocity:      .0580 m/s        T(bulk outlet): 24.4C
Residence Time:         52  s         T(bulk average):24.4C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0000  .0000  .0000  .0000  .0000  .0000
2      .0             .0000  .0793  .0000  .0000  .0000
3      .0      .0            .0673  .0000  .0000  .0000
4      .0    17.3     7.2           .0000  .0000  .0000
5      .0      .0      .0     .0           .0000  .0000
6      .0      .0      .0     .0     .0           .0000
7      .0      .0      .0     .0     .0     .0
       1       2       3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     292.                fc:        .0733
Dn:      41.                fc/fs:   1.34
Pr:        6.22             Dn*:     39.
--------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   31.                h/D: 1.160   Dc/d  56.8
Flowrate:          .001848 kg/s      T(bulk inlet):  24.4C
Inlet Velocity:     .1129 m/s        T(bulk outlet): 24.4C
Residence Time:        26 s          T(bulk average):24.4C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0000  .0000  .0000  .0000
2      .0            .0000  .0000  .0000  .0000  .0000
3      .0     .0            .0430  .0000  .0000  .0000
4      .0     .0    17.5           .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     569.                fc:        .0430
Dn:      80.                fc/fs:   1.53
Pr:       6.22              Dn*:     75.
--------------------------------------------------------
```

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   32.                h/D: 1.160   Dc/d   56.8
Flowrate:          .000769 kg/s      T(bulk inlet):   24.4C
Inlet Velocity:     .0470 m/s        T(bulk outlet): 24.4C
Residence Time:        64 s          T(bulk average):24.4C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .0750  .0000  .0000  .0000
2     .0             .0000  .0000  .0000  .0000  .0000
3     .0      .0            .0000  .0000  .0000  .0000
4   16.6      .0     .0            .0000  .0000  .0000
5     .0      .0     .0     .0            .0000  .0000
6     .0      .0     .0     .0     .0            .0000
7     .0      .0     .0     .0     .0     .0
      1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     237.             fc:        .0750
Dn:      33.             fc/fs:    1.11
Pr:       6.22           Dn*:     31.
---------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 33. h/D: 1.160 Dc/d 56.8
Flowrate: .000655 kg/s T(bulk inlet): 24.4C
Inlet Velocity: .0400 m/s T(bulk outlet): 24.4C
Residence Time: 75 s T(bulk average):24.4C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0000	.0000	.0855	.0000	.0000	.0000
2	.0		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	13.7	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 202. fc: .0855
Dn: 29. fc/fs: 1.08
Pr: 6.22 Dn*: 27.

```
Coil Number: 4     D/d: 50      h/d: 58     L/d: 528
Run Number:   34.               h/D: 1.160  Dc/d  56.8
Flowrate:          .000529 kg/s      T(bulk inlet):   24.4C
Inlet Velocity:     .0323 m/s        T(bulk outlet):  24.4C
Residence Time:        93 s          T(bulk average):24.4C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0000  .0000  .1037  .0000  .0000  .0000
2      .0            .0000  .0000  .0000  .0000  .0000
3      .0     .0            .0000  .0000  .0000  .0000
4    10.9     .0     .0            .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     163.                  fc:        .1037
Dn:      23.                  fc/fs:    1.06
Pr:       6.22                Dn*:     22.
--------------------------------------------------------
```

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 35. h/D: 1.160 Dc/d 56.8
Flowrate: .002748 kg/s T(bulk inlet): 23.3C
Inlet Velocity: .1678 m/s T(bulk outlet): 23.3C
Residence Time: 17 s T(bulk average):23.3C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0272	.0270	.0274	.0000	.0000	.0000
2	26.9		.0270	.0277	.0000	.0000	.0000
3	51.8	25.1		.0279	.0000	.0000	.0000
4	77.2	50.7	25.1		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 823. fc: .0274
Dn: 116. fc/fs: 1.41
Pr: 6.41 Dn*: 109.

Coil Number: 4 D/d: 50 h/d: 58 L/d: 528
Run Number: 36. h/D: 1.160 Dc/d 56.8
Flowrate: .003347 kg/s T(bulk inlet): 23.3C
Inlet Velocity: .2044 m/s T(bulk outlet): 23.3C
Residence Time: 14 s T(bulk average):23.3C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0222	.0224	.0228	.0000	.0000	.0000
2	32.6		.0226	.0231	.0000	.0000	.0000
3	63.8	31.2		.0235	.0000	.0000	.0000
4	95.4	62.7	31.4		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 1002. fc: .0228
Dn: 142. fc/fs: 1.43
Pr: 6.41 Dn*: 133.

```
Coil Number: 4      D/d: 50      h/d: 58      L/d: 528
Run Number:   37.                h/D: 1.160   Dc/d   56.8
Flowrate:          .003697 kg/s      T(bulk inlet):  23.3C
Inlet Velocity:     .2257  m/s       T(bulk outlet): 23.3C
Residence Time:        13  s         T(bulk average):23.3C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0222  .0000  .0000  .0000  .0000  .0000
2    39.6            .0226  .0000  .0000  .0000  .0000
3      .0   38.1            .0235  .0000  .0000  .0000
4      .0     .0   38.3            .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    1107.              fc:       .0228
Dn:     157.              fc/fs:   1.57
Pr:       6.41            Dn*:   147.
-------------------------------------------------------
```

Coil Number: 5 D/d: 4 h/d: 61 L/d: 286
Run Number: 1. h/D: 15.250 Dc/d 98.3
Flowrate: .000469 kg/s T(bulk inlet): 31.1C
Inlet Velocity: .0287 m/s T(bulk outlet): 31.1C
Residence Time: 57 s T(bulk average): 31.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.1595	.0000	.0000	.0000	.0000	.0000
2	7.6		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	167.	fc:	.1595
Dn:	83.	fc/fs:	1.66
Pr:	5.29	Dn*:	17.

Coil Number: 5 D/d: 4 h/d: 61 L/d: 286
Run Number: 2. h/D: 15.250 Dc/d 98.3
Flowrate: .000588 kg/s T(bulk inlet): 31.1C
Inlet Velocity: .0360 m/s T(bulk outlet): 31.1C
Residence Time: 45 s T(bulk average): 31.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.1088	.0000	.0000	.0000	.0000	.0000
2	8.2		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 209. fc: .1088
Dn: 105. fc/fs: 1.42
Pr: 5.29 Dn*: 21.

```
Coil Number: 5     D/d:  4     h/d: 61     L/d: 286
Run Number:    3.              h/D:15.250  Dc/d  98.3
Flowrate:         .000708 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:     .0433 m/s       T(bulk outlet): 31.1C
Residence Time:        37 s         T(bulk average):31.1C
-----------------------------------------------------------
Boundary Condition:  Isothermal
-----------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0839  .0000  .0000  .0000  .0000  .0000
2     9.1            .0000  .0000  .0000  .0000  .0000
3      .0     .0            .0000  .0000  .0000  .0000
4      .0     .0     .0            .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-----------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     252.               fc:        .0839
Dn:     126.               fc/fs:    1.32
Pr:       5.29             Dn*:     25.
-----------------------------------------------------------
```

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:     4.               h/D:15.250   Dc/d  98.3
Flowrate:          .000827 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:     .0506 m/s        T(bulk outlet): 31.1C
Residence Time:        32  s         T(bulk average):31.1C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0678  .0000  .0000  .0000  .0000  .0000
2   10.1             .0000  .0000  .0000  .0000  .0000
3      .0     .0            .0000  .0000  .0000  .0000
4      .0     .0     .0            .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     294.              fc:        .0678
Dn:     147.              fc/fs:    1.25
Pr:       5.29            Dn*:      30.
-------------------------------------------------------
```

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:    5.                h/D:15.250   Dc/d  98.3
Flowrate:          .000947 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:     .0580 m/s        T(bulk outlet): 31.1C
Residence Time:        28  s         T(bulk average):31.1C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0576  .0000  .0000  .0000  .0000  .0000
2    11.2             .0000  .0000  .0000  .0000  .0000
3      .0     .0             .0000  .0000  .0000  .0000
4      .0     .0      .0            .0000  .0000  .0000
5      .0     .0      .0     .0            .0000  .0000
6      .0     .0      .0     .0     .0            .0000
7      .0     .0      .0     .0     .0     .0
       1      2       3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     337.                fc:        .0576
Dn:     168.                fc/fs:   1.21
Pr:       5.29              Dn*:    34.
---------------------------------------------------------
```

```
Coil Number: 5      D/d:  4      h/d: 61       L/d: 286
Run Number:    6.                h/D:15.250   Dc/d  98.3
Flowrate:          .001545 kg/s       T(bulk inlet):   31.1C
Inlet Velocity:     .0946 m/s         T(bulk outlet): 31.1C
Residence Time:        17  s          T(bulk average):31.1C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0348  .0000  .0000  .0000  .0000  .0000
2    18.1             .0000  .0000  .0000  .0000  .0000
3      .0     .0             .0000  .0000  .0000  .0000
4      .0     .0      .0            .0000  .0000  .0000
5      .0     .0      .0     .0            .0000  .0000
6      .0     .0      .0     .0     .0            .0000
7      .0     .0      .0     .0     .0     .0
       1      2       3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     550.               fc:        .0348
Dn:     275.               fc/fs:   1.20
Pr:       5.29             Dn*:     55.
--------------------------------------------------------
```

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:    7.                h/D:15.250   Dc/d  98.3
Flowrate:           .002143 kg/s       T(bulk inlet):  31.1C
Inlet Velocity:      .1312 m/s         T(bulk outlet): 31.1C
Residence Time:         12 s           T(bulk average):31.1C
---------------------------------------------------------
Boundary Condition:  Isothermal
---------------------------------------------------------
Static Differential Pressures and Friction Factors
1            .0267  .0000  .0000  .0000  .0000  .0000
2    26.7           .0000  .0000  .0000  .0000  .0000
3      .0     .0           .0000  .0000  .0000  .0000
4      .0     .0     .0           .0000  .0000  .0000
5      .0     .0     .0     .0           .0000  .0000
6      .0     .0     .0     .0     .0           .0000
7      .0     .0     .0     .0     .0     .0
       1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
---------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     763.                fc:       .0267
Dn:     381.                fc/fs:   1.27
Pr:       5.29              Dn*:     77.
---------------------------------------------------------
```

Coil Number: 5	D/d: 4	h/d: 61	L/d: 286
Run Number: 8.		h/D:15.250	Dc/d 98.3
Flowrate: .002741 kg/s		T(bulk inlet): 31.1C	
Inlet Velocity: .1678 m/s		T(bulk outlet): 31.1C	
Residence Time: 9 s		T(bulk average):31.1C	

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0212	.0000	.0000	.0000	.0000	.0000
2	34.7		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	975.	fc:	.0212
Dn:	488.	fc/fs:	1.29
Pr:	5.29	Dn*:	98.

Coil Number: 5   D/d: 4   h/d: 61   L/d: 286
Run Number: 9.   h/D: 15.250   Dc/d 98.3
Flowrate: .003339 kg/s   T(bulk inlet): 31.1C
Inlet Velocity: .2044 m/s   T(bulk outlet): 31.1C
Residence Time: 7 s   T(bulk average): 31.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0184	.0000	.0000	.0000	.0000	.0000
2	44.8		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1188.   fc: .0184
Dn: 594.   fc/fs: 1.37
Pr: 5.29   Dn*: 120.

Coil Number: 5   D/d: 4   h/d: 61   L/d: 286
Run Number: 10.   h/D:15.250   Dc/d 98.3
Flowrate: .003688 kg/s   T(bulk inlet): 31.1C
Inlet Velocity: .2257 m/s   T(bulk outlet): 31.1C
Residence Time: 7 s   T(bulk average):31.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0184	.0000	.0000	.0000	.0000	.0000
2	54.5		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 1312.   fc: .0184
Dn: 656.   fc/fs: 1.51
Pr: 5.29   Dn*: 132.

```
Coil Number: 5     D/d:  4     h/d: 61     L/d: 286
Run Number:   11.              h/D:15.250  Dc/d  98.3
Flowrate:          .004825 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:     .2953 m/s        T(bulk outlet): 31.1C
Residence Time:         5 s          T(bulk average):31.1C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0121  .0000  .0000  .0000  .0000  .0000
2   61.3             .0000  .0000  .0000  .0000  .0000
3     .0     .0             .0000  .0000  .0000  .0000
4     .0     .0     .0             .0000  .0000  .0000
5     .0     .0     .0     .0             .0000  .0000
6     .0     .0     .0     .0     .0             .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   1717.                fc:       .0121
Dn:    858.                fc/fs:  1.30
Pr:      5.29              Dn*:   173.
--------------------------------------------------------
```

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:   12.                h/D:15.250   Dc/d  98.3
Flowrate:          .006978 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:     .4270 m/s        T(bulk outlet): 31.1C
Residence Time:         3 s          T(bulk average):31.1C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0092  .0000  .0000  .0000  .0000  .0000
2    97.2             .0000  .0000  .0000  .0000  .0000
3      .0      .0            .0000  .0000  .0000  .0000
4      .0      .0     .0            .0000  .0000  .0000
5      .0      .0     .0     .0            .0000  .0000
6      .0      .0     .0     .0     .0            .0000
7      .0      .0     .0     .0     .0     .0
       1       2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    2483.                fc:        .0092
Dn:    1241.                fc/fs:   1.42
Pr:       5.29              Dn*:   250.
--------------------------------------------------------
```

Coil Number: 5 D/d: 4 h/d: 61 L/d: 286
Run Number: 13. h/D:15.250 Dc/d 98.3
Flowrate: .008847 kg/s T(bulk inlet): 31.1C
Inlet Velocity: .5414 m/s T(bulk outlet): 31.1C
Residence Time: 3 s T(bulk average):31.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0074	.0000	.0000	.0000	.0000	.0000
2	126.5		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters
Re: 3148. fc: .0074
Dn: 1574. fc/fs: 1.46
Pr: 5.29 Dn*: 318.

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:   14.                h/D:15.250  Dc/d  98.3
Flowrate:           .010656 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:      .6521 m/s        T(bulk outlet): 31.1C
Residence Time:          2 s          T(bulk average):31.1C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0067  .0000  .0000  .0000  .0000  .0000
2  166.7             .0000  .0000  .0000  .0000  .0000
3     .0     .0             .0000  .0000  .0000  .0000
4     .0     .0     .0             .0000  .0000  .0000
5     .0     .0     .0     .0             .0000  .0000
6     .0     .0     .0     .0     .0             .0000
7     .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:   3791.                 fc:        .0067
Dn:   1896.                 fc/fs:   1.60
Pr:      5.29               Dn*:   382.
--------------------------------------------------------
```

Coil Number: 5 D/d: 4 h/d: 61 L/d: 286
Run Number: 15. h/D:15.250 Dc/d 98.3
Flowrate: .012032 kg/s T(bulk inlet): 31.1C
Inlet Velocity: .7363 m/s T(bulk outlet): 31.1C
Residence Time: 2 s T(bulk average):31.1C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0070	.0000	.0000	.0000	.0000	.0000
2	219.5		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 4281. fc: .0070
Dn: 2140. fc/fs: 1.86
Pr: 5.29 Dn*: 432.

```
Coil Number: 5     D/d:  4      h/d: 61      L/d: 286
Run Number:   16.               h/D:15.250  Dc/d  98.3
Flowrate:         .014684 kg/s      T(bulk inlet):  31.1C
Inlet Velocity:     .8986 m/s       T(bulk outlet): 31.1C
Residence Time:         1 s         T(bulk average):31.1C
-------------------------------------------------------
Boundary Condition:  Isothermal
-------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .0057  .0000  .0000  .0000  .0000  .0000
2  269.2             .0000  .0000  .0000  .0000  .0000
3      .0     .0            .0000  .0000  .0000  .0000
4      .0     .0     .0            .0000  .0000  .0000
5      .0     .0     .0     .0            .0000  .0000
6      .0     .0     .0     .0     .0            .0000
7      .0     .0     .0     .0     .0     .0
      1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
-------------------------------------------------------
Non-Dimensional Flow Parameters
Re:    5224.                fc:       .0057
Dn:    2612.                fc/fs:   1.87
Pr:       5.29              Dn*:   527.
-------------------------------------------------------
```

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:   17.                h/D:15.250   Dc/d  98.3
Flowrate:          .000487 kg/s      T(bulk inlet):  23.9C
Inlet Velocity:      .0298 m/s       T(bulk outlet): 23.9C
Residence Time:         54 s         T(bulk average):23.9C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1             .1146  .0000  .0000  .0000  .0000  .0000
2     5.9            .0000  .0000  .0000  .0000  .0000
3       .0     .0           .0000  .0000  .0000  .0000
4       .0     .0     .0           .0000  .0000  .0000
5       .0     .0     .0     .0           .0000  .0000
6       .0     .0     .0     .0     .0           .0000
7       .0     .0     .0     .0     .0     .0
        1      2      3      4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     148.                fc:        .1146
Dn:      74.                fc/fs:    1.06
Pr:       6.31              Dn*:     15.
--------------------------------------------------------
```

Coil Number: 5	D/d: 4	h/d: 61	L/d: 286
Run Number: 18.		h/D: 15.250	Dc/d 98.3
Flowrate:	.000583 kg/s	T(bulk inlet):	23.9C
Inlet Velocity:	.0356 m/s	T(bulk outlet):	23.9C
Residence Time:	45 s	T(bulk average):	23.9C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0904	.0000	.0000	.0000	.0000	.0000
2	6.7		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re:	177.	fc:	.0904
Dn:	89.	fc/fs:	1.00
Pr:	6.31	Dn*:	18.

```
Coil Number: 5      D/d:  4      h/d: 61      L/d: 286
Run Number:   19.                h/D:15.250  Dc/d  98.3
Flowrate:            .000715 kg/s      T(bulk inlet):  23.9C
Inlet Velocity:       .0437 m/s        T(bulk outlet): 23.9C
Residence Time:          37  s         T(bulk average):23.9C
--------------------------------------------------------
Boundary Condition:  Isothermal
--------------------------------------------------------
Static Differential Pressures and Friction Factors
1              .0739  .0000  .0000  .0000  .0000  .0000
2     8.2             .0000  .0000  .0000  .0000  .0000
3      .0     .0             .0000  .0000  .0000  .0000
4      .0     .0      .0            .0000  .0000  .0000
5      .0     .0      .0      .0           .0000  .0000
6      .0     .0      .0      .0     .0           .0000
7      .0     .0      .0      .0     .0     .0
       1      2       3       4      5      6      7
Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)
--------------------------------------------------------
Non-Dimensional Flow Parameters
Re:     217.               fc:       .0739
Dn:     109.               fc/fs:   1.00
Pr:       6.31             Dn*:     22.
--------------------------------------------------------
```

Coil Number: 5 D/d: 4 h/d: 61 L/d: 286
Run Number: 20. h/D:15.250 Dc/d 98.3
Flowrate: .000829 kg/s T(bulk inlet): 23.9C
Inlet Velocity: .0506 m/s T(bulk outlet): 23.9C
Residence Time: 32 s T(bulk average):23.9C

Boundary Condition: Isothermal

Static Differential Pressures and Friction Factors

1		.0614	.0000	.0000	.0000	.0000	.0000
2	9.1		.0000	.0000	.0000	.0000	.0000
3	.0	.0		.0000	.0000	.0000	.0000
4	.0	.0	.0		.0000	.0000	.0000
5	.0	.0	.0	.0		.0000	.0000
6	.0	.0	.0	.0	.0		.0000
7	.0	.0	.0	.0	.0	.0	
	1	2	3	4	5	6	7

Upper triangle: friction factors (dimensionless)
Lower triangle: pressure differentials (mm HOH)

Non-Dimensional Flow Parameters

Re: 252. fc: .0614
Dn: 126. fc/fs: .97
Pr: 6.31 Dn*: 25.
