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Title: A NUMERICAL SOLUTION FOR HEAT TRANSFER TO NON-NEWTONIAN FLUIDS WITH TEMPERATURE-DEPENDENT VISCOSITY FOR ARBITRARY CONDITIONS OF HEAT FLUX AND SURFACE TEMPERATURE

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Abstract approved:
Dr. James R. Welty

A numerical solution is presented for the coupled energy and momentum equations for steady, laminar flow of temperature-dependent power-law non-Newtonian fluids. A Newtonian fluid can be handled as a special case.

Two important geometrical cases are considered: 1. Pipe flow, and 2. Channel flow between two flat, parallel plates.

For pipe flow the dimensionless energy equation

$$U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial R} = \frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} + BrS\Phi$$

and the dimensionless momentum equation

$$\frac{1}{Pr}\left[U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial R}\right] = -\frac{dP}{dX} + S\frac{\partial^2 U}{\partial R^2} + \frac{S}{R}\frac{\partial U}{\partial R} + \frac{\partial S}{\partial R}\frac{\partial U}{\partial R}$$

are solved simultaneously; the Crank-Nicolson method is used for writing the second partial derivatives. A digital computer is used to solve the resulting numerical equations. For channel flow the corresponding equations are solved with the terms involving curvature deleted.

For a constitutive equation, the temperature-modified power-law

$$\tau = m(e^{\frac{\Delta H}{Rt}} \dot{\gamma})^n$$

is used.

Boundary conditions assumed to be known are the inlet fluid condition and the temperature or heat flux conditions at the wall of the conduit. The inlet temperature of the fluid is taken to be uniform, and the inlet velocity profile is assumed to be fully developed. Nevertheless, the computer program which is used can be easily modified to handle other inlet conditions. The wall temperature-heat flux boundary condition is handled in a manner sufficiently general to allow consideration of any arbitrarily-specified variation in the direction of flow. For channel flow, the two plates may have different temperature or heat flux conditions as well.

The thermal conductivity and density of the fluid are assumed to be uniform. Buoyancy effects are neglected, but the facility for handling viscous dissipation is included.

Computed results giving heat transfer information in the form of Nusselt number and pressure drop as a dimensionless pressure differential are presented for a number of heating conditions. Good agreement is shown with available analytical solutions for some special cases. For heating of a liquid with temperature-dependent viscosity, the Nusselt number is shown to be greater than for a liquid with temperature-independent viscosity, and the pressure drop is shown to be smaller than for a liquid with no viscosity-temperature dependence. Both the heat transfer and the pressure drop effects of temperature-dependent viscosity are sufficiently large to merit consideration in many design situations.

Complete listings of the CDC 3300 Fortran programs are included in the Appendix.

A Numerical Solution for Heat Transfer to Non-Newtonian Fluids with Temperature-Dependent Viscosity for Arbitrary Conditions of Heat Flux and Surface Temperature

by

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NOMENCLATURE

A	Area through which heat is transferred
$B1, B2, B3, B4$	Coefficients appearing in the finite difference equations
$Br = \frac{\eta \bar{u}^2}{k t_i}$	Brinkman number
c	Specific heat of the fluid
$C, C1, C2, C3, C4, A, B$	Constants in certain constitutive equations
D	Pipe diameter
e	Base of natural logarithms
Flux	Dimensionless heat flux (Flux $= \frac{\dot{q}}{A}\frac{D}{k t_i}$ for pipe flow and Flux $= \frac{\dot{q}}{A}\frac{L}{k t_i}$ for channel flow)
Gz	Graetz number ($Gz = \frac{\pi D^2 \bar{u} \rho c}{4 k x} = \frac{\pi}{4}\frac{1}{X}$)
h	Convective heat transfer coefficient
ΔH	Flow activation energy per mole
I	Index in the X direction
$\frac{I_2}{2}$	Second invariant of the rate of deformation tensor
J	Index in the R direction for pipe flow Index in the Y direction for channel flow
k	Thermal conductivity of the fluid
L	Distance between the two parallel plates
m	Constant in the power-law constitutive equation
n	Exponent in the power-law constitutive equation

N	Number of cells used across half the pipe Number of cells used across the channel
Nu	Nusselt number ($Nu = \frac{hD}{k}$ for pipe flow and $Nu = \frac{h(2L)}{k}$ for channel flow)
Nu_a	Average Nusselt number based on the arithmetic mean temperature difference
Nu_{mean}	Mean Nusselt number based on the log mean temperature difference
Nu Ratio	Ratio of Nusselt number so that for a reference situation (shown on the same sheet) at the same value of $x/(DRePr)$ for pipe flow or $x/(LRe'Pr)$ for channel flow
$O(\Delta X^2)$	Remainder with terms having factors of $(\Delta X)^2$ and higher powers of ΔX
p	Pressure
$P = \frac{p}{\rho \bar{u}^2 Pr}$	Dimensionless pressure
P_i	Dimensionless pressure at the inlet
$Pr = \frac{\eta_i c}{k}$	Prandtl number based on apparent viscosity
$\dot{q}$	Heat transfer rate
Q	Some unspecified variable used in explaining the Crank-Nicolson method of writing second partial derivatives
r	Radial distance from the center of the pipe
$R = r/D$	Dimensionless radius
R	Gas constant
Re	Reynolds number ($Re = \frac{\rho \bar{u} D}{\eta_i}$ for pipe flow and $Re = \frac{\rho \bar{u} L}{\eta_i}$ for channel flow)

$Re' = \frac{\rho \bar{u}(2L)}{\eta_i}$	Reynolds number based on hydraulic diameter for channel flow
$S = \frac{\eta}{\eta_i}$	Dimensionless apparent viscosity
t	Temperature
t_i	Temperature of the fluid at the inlet
t_w	Wall temperature
$T = t/t_i$	Dimensionless temperature
u	Velocity in the direction of bulk flow
$\bar{u}$	Average velocity in the direction of bulk flow
$U = \frac{u}{\bar{u}}$	Dimensionless velocity in the direction of bulk flow
v	Velocity perpendicular to direction of bulk flow
$V = \frac{v}{u} RePr$	Dimensionless velocity perpendicular to direction of bulk flow
x	Distance from the inlet in the direction of bulk flow
X	Dimensionless distance from the inlet ($X = \frac{x}{DRePr}$ for pipe flow and $X = \frac{x}{LRePr}$ for channel flow)
y	Distance perpendicular to the direction of bulk flow for channel flow
$Y = \frac{y}{L}$	Dimensionless distance perpendicular to direction of bulk flow for channel flow
$Z = x/(LRe'Pr)$	
$\alpha, \beta, \gamma, \delta, \phi$	Variables used in solving the numerical equations
$\dot{\gamma}$	Rate of shearing strain
η	Apparent viscosity of the fluid

η_i	Apparent viscosity of the fluid next to the wall at the inlet
μ_o	Constant in the Arrhenius equation
ρ	Density of the fluid
τ	Shear stress
τ_y	Yield stress for a Bingham plastic
Φ	Dimensionless version of the second invariant of the rate of deformation tensor ($\Phi = (\frac{D}{\bar{\bar{u}}})^2 \frac{I_2}{2}$ for pipe flow and $\Phi = (\frac{L}{\bar{\bar{u}}})^2 \frac{I_2}{2}$ for channel flow)

$\psi = \frac{\Delta H}{R} (\frac{1}{t_i} - \frac{1}{t_w})$

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I. INTRODUCTION

Non-Newtonian Fluids--Background Information

In attempting to deal analytically with a real material, a simple mathematical model for the material's rheological properties is desirable so long as the behavior of the material is adequately described. For elastic solids the proportionality between stress and strain (Hooke's law) gives a simple model which is sufficiently accurate for use in many engineering calculations. The corresponding model for viscous fluids is the Newtonian model which treats shear stress as being proportional to the rate of shearing strain (shear rate). Again the simple model is sufficiently accurate for many engineering calculations. However, in fluid mechanics the inadequacy of the simple Newtonian model soon becomes apparent. The so-called Weissenberg effect (10, p. 230-231), where a stirred liquid climbs the shaft of the stirring device, cannot be explained using the Newtonian model. Neither can the "elastic water" which flows over the edge of an upright pitcher (1) be explained from the simple (and very useful) but often inadequate Newtonian model. Departures from Newtonian behavior can be much more subtle. In the next few paragraphs a summary of the present-day engineering classification of fluids is given. This summary follows the system used in references (2; 40, p. 1-19; 9, p. 1-15).

Fluids may be broadly grouped as time-independent, time-dependent, and visco-elastic.

The time-independent fluids may be further divided into four groups called Newtonian, pseudoplastic, dilatant, and Bingham plastic. The power law,

$$\tau = m\dot{\gamma}^{n}$$

may be used to describe Newtonian, pseudoplastic, and dilatant behavior; other models have been used and have some advantages for pseudoplastic and dilatant fluids under some conditions. For a Newtonian fluid the exponent n equals unity, and the coefficient m is the coefficient of viscosity usually denoted by μ. Water, air, and light oils are ordinarily considered as being Newtonian fluids. A pseudoplastic fluid can be said to "thin out" at high shear rates; for a pseudoplastic the exponent n is less than unity. The "thinning out" effect can be seen by defining an "apparent viscosity" based on the Newtonian model:

$$\eta \equiv \frac{\tau}{\dot{\gamma}} = m\dot{\gamma}^{n-1} .$$

With the exponent n positive and less than unity, the apparent viscosity decreases with increasing shear rate. Pseudoplastic behavior is shown by almost all cellulose derivatives and their solutions. Dilatant fluids are said to "thicken" at high shear rates. The same apparent viscosity concept can be used to show that effect. For a dilatant fluid the exponent n is greater than unity; hence, the apparent viscosity increases as shear rate increases. Starch suspensions and quicksand are examples of dilatant fluids. The Bingham (or ideal) plastic model allows for support of shear stress below a certain threshold level; once that level is exceeded, the material flows in a Newtonian manner. In equation form that may be stated as

$$\tau - \tau_y = \mu_p \dot{\gamma} \quad \text{for} \quad \tau > \tau_y \ .$$

The Bingham plastic model is an idealized linear model similar to that for a Newtonian fluid; real plastics would be expected to show non-linear shear stress-shear rate characteristics as well as the yield stress phenomenon. Nevertheless, the Bingham plastic idealization has been found to be very useful because of fitting rheological data for some materials reasonably well with a simple functional relationship (38). Sewage sludge, grain suspensions in water, and drilling muds have been handled using the Bingham plastic model.

The apparent viscosity of time-dependent materials depends upon their history as well as the current shear rate. The apparent viscosity of thixotropic fluids decreases after stirring. Many industrial and most biological fluids show thixotropic behavior. A few examples are paints, inks, mayonnaise, and milk products. The antithesis of a thixotropic fluid is a <u>rheopectic</u> fluid which thickens with stirring. Rheopectic fluids are extremely rare, but a few are known. They are considered to be of insignificant industrial importance.

As the name implies, a <u>visco-elastic</u> material has both viscous and elastic properties. For discussion of mathematical models for treating visco-elastic materials, references (11, 12, 40) are suggested.

Temperature Effect

The temperature effect on the viscosity of certain fluids--both Newtonian and non-Newtonian--is well known and readily observed. For liquids the viscosity is decreased by raising the temperature. Food products such as honey, cream, and buttermilk furnish handy evidence of the effect of temperature on viscosity. Oils, paints, and most other heavy, thick fluids show marked changes of viscosity with temperature. Such changes become very important when studying the velocity distribution in situations where temperature gradients occur. For example, with a fully developed laminar velocity profile at the inlet of a heated pipe section, the velocity profile would be expected to become more nearly uniform downstream from the inlet;

therefore, higher heat transfer rates would be expected than for fully developed flow. In such situations some analytical means must be used to account for the temperature effect on viscosity. Some of the more common constitutive equations for treating materials with temperature-dependent viscosity are given in the next few paragraphs.

Newtonian Fluids

The Arrhenius equation

$$\mu = \mu_o e^{\frac{\Delta H}{Rt}}$$

is the classical model used to account for viscosity changes with temperature for Newtonian liquids.

Other models have been used by some investigators. Pigford (2~~9~~) and Rosenberg and Hellums (34) used an empirical model
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$$\frac{1}{\mu} = C_1 + C_2 t$$

in their investigations.

Non-Newtonian Fluids

For dealing with temperature dependent pseudoplastic materials, Christiansen *et al.*, (6, 7, 8) used a power law equation

$$\tau = m(\dot{\gamma} e^{\frac{\Delta H}{Rt}})^n$$

with a temperature term similar to that of the Arrhenius equation. That model is simpler than a theoretical model previously suggested by Ree and Eyring (30)

$$\tau = C\dot{\gamma} e^{\frac{\Delta H}{Rt}} + \frac{1}{B} \sinh^{-1}\left(\frac{\dot{\gamma} e^{\frac{\Delta H}{Rt}}}{A}\right)$$

and fits rheological data adequately for most purposes (6).

Gee and Lyon (13) used an empirical temperature-dependent constitutive equation

$$\tau = C_3 e^{\frac{\Delta H}{Rt}} \dot{\gamma} / (1 + C_4 \tau^n)$$

in dealing with a high polymer.

Heat Transfer to Newtonian and Non-Newtonian Fluids for Laminar Flow in Channels and Pipes

In attempting to organize the heat transfer literature for discussion, one finds the assignment of a publication to one well defined, specific category impossible because many publications cover several categories. To avoid tedious repetition in the discussion below, each publication is discussed only under the category of primary emphasis. A topical listing of the cited literature giving complete coverage is included as Appendix I. Unless otherwise stated the references cited in this discussion deal with steady, laminar flow.

Uniform Wall Temperature or Heat Flux

The classical Graetz-Nusselt problem applies to a situation where a viscous fluid with uniform properties flows either in a channel between two flat, parallel plates or in a pipe. The walls are assumed to be maintained at a uniform temperature, and the fluid is assumed to have a fully developed laminar velocity profile throughout the heated (or cooled) section. For solution of the Graetz-Nusselt problem the work of Sellars, Tribus, and Klein (36) is the usually accepted standard. They solved the energy partial differential equation by separation of variables and developed a method for evaluating the resulting constants and eigenvalues for both channel flow and pipe flow. For channel flow the accepted values (20, p. 130) are the ones due to Sellars, Tribus, and Klein, but for pipe flow, the values presented by Lipkis (25) in a discussion of the Sellars, Tribus, and Klein paper are used (20, p. 125). For uniform heat flux replacing the uniform wall temperature boundary condition, the same problem has been solved by Seigel, Sparrow, and Hallman (35) for pipe flow. Once again the separation of variables technique was used to solve the energy equation, and values are presented for the constants and eigenvalues.

Dropping the fully developed velocity profile assumption introduces the additional problem of solving the momentum equation for a developing velocity profile (the hydrodynamic entry length problem). For uniform wall temperature Kays (21) solved the combined hydrodynamic-thermal entry length problem for $Pr = .7$ using an approximate velocity profile and numerically integrating the energy equation. Goldberg (20, p. 142) extended Kays solution for other values of the Prandtl number. Heaton, Reynolds, and Kays (14) present an approximate analytical solution obtained by linearizing the energy equation. Their solutions apply for the case of uniform heat flux for the circular-tube annulus family which includes both pipe and channel flow. A numerical solution for combined hydrodynamic and thermal entry lengths in channels is presented by Hwang (16) and Hwang and Fan (17, 18). They first solved the momentum equation assuming uniform viscosity and then used the resulting velocities in solving the energy equation. Their work was limited to situations having uniform wall temperatures.

To solve the Graetz-Nusselt problem for a non-Newtonian liquid with temperature-independent viscosity, Lyche and Bird (26) used a separation of variables approach similar to that used by Sellars, Tribus, and Klein (36) for Newtonian fluids. The paper by Lyche and Bird is devoted to fully-developed pipe flow of a power-law pseudoplastic fluid.

The combined hydrodynamic entry length-thermal entry length problem for a pseudoplastic material has been solved by McKillop (27) and by Yau and Tien (41). Although using different solution techniques, both papers involve the use of the power-law constitutive equation.

Interest has been shown within the past few years in determining the effects of variable properties, viscosity being among them, on heat transfer (6, 7, 8, 9, 13, 22, 23, 24, 34). Pipe flow of Newtonian fluids with temperature-dependent viscosity was studied by Rosenberg and Hellums (34) using a numerical approach. Their work covers both fully developed flow at the inlet and the case of developing flow from an initially-uniform velocity, but it is limited to uniform temperature boundary conditions. Two papers have appeared which allow fluid properties other than viscosity to vary (22, 23). Although promising, neither appears to lend itself readily to the type problems encountered with high viscosity liquids.

All papers which have appeared to date (6, 7, 8, 9, 13, 24) for non-Newtonian fluids with temperature dependent viscosity apply to pipe flow with uniform wall temperature. Christiansen and co-workers (6, 7, 8) studied both heating and cooling for fully developed flow at the inlet. They used a temperature-modified power-law constitutive equation. Korayem (24) studied the developing region downstream from an initial uniform velocity at the entrance using the same constitutive equation. Gee and Lyon (13) presented the first study for non-Newtonian fluids with temperature-dependent viscosity in 1957. They took into account the effects of viscous dissipation and expansion cooling. Their analysis also allows solution with certain transient conditions. Coupal (9) dealt with viscous dissipation as well as the effect of temperature on viscosity.

Literature dealing with non-uniform wall temperature or heat flux is indeed sparse. Axial variations of wall temperature or heat flux are touched on in the paper by Sellars, Tribus, and Klein (36). Their work is limited to fully developed Newtonian flow in pipes. Reynolds (31, 32) deals with circumferential heat flux variations in pipe flow for fully developed Newtonian flow, and Inman (19) deals similarily with fully developed power-law flow. No literature exists concerning axial variations in wall temperature or heat flux for non-Newtonian fluid flow, nor is there any reported work which takes viscosity changes with temperature into account for situations having non-uniform wall temperature or heat flux.

Objective of the Present Investigation

The objective of the present investigation is the solution by numerical means of the simultaneous energy, momentum, and continuity partial differential equations for laminar flow of non-Newtonian fluids with temperature-dependent viscosity. The temperature-modified power-law constitutive equation is used. The solution is to yield certain design information such as heat transfer rates and pressure drop. Two important geometric cases are considered: a channel between two flat, parallel plates; and a circular pipe. Since non-Newtonian fluids are usually very viscous, the inlet velocity is assumed to be fully developed, but the inlet temperature is taken as uniform. (The program actually developed is easily modified and is suitable for the solution of the combined hydrodynamic-thermal entry length problem.) The temperature-heat flux boundary condition is left sufficiently general to allow consideration of any arbitrarily specified condition in the direction of flow. For the channel the two plates may have different temperature or heat flux conditions. The thermal conductivity and density of the fluid are assumed to be uniform. Buoyancy effects are neglected, but the facility for handling viscous dissipation is included.

II. PIPE FLOW

Governing Equations

The dimensionless partial differential equations of change used for pipe flow are as follows:

Energy Equation:

$$U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial R} = \frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} + BrS\Phi$$

Momentum Equation:

$$\frac{1}{Pr}\left[U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial R}\right] = -\frac{dP}{dX} + S\frac{\partial^2 U}{\partial R^2} + \frac{S}{R}\frac{\partial U}{\partial R} + \frac{\partial S}{\partial R}\frac{\partial U}{\partial R}$$

Continuity Equation:

$$\frac{\partial(RV)}{\partial R} + R\frac{\partial U}{\partial X} = 0$$

In addition an integral form of the continuity equation is used:

$$8\int_0^{1/2} UR\,\partial R = 1.$$

The energy equation includes the convection terms in both directions as well as a term for viscous dissipation; however, conduction in the direction of flow is neglected. The momentum equation neglects buoyancy effects, some secondary terms in the shear stress evaluation, and any pressure variation except that in the direction of flow. The flow is assumed to be steady and laminar. Two forms of the continuity equation are used: the integral form, which expresses the steady-flow assumption, and the differential form. Both equations as stated are for incompressible flow. Each of the four equations above is specialized in Appendix II from the appropriate starting point suggested by Bird, Stewart, and Lightfoot (3) with each simplification or deletion stated.

The set of simultaneous equations above includes two second-order, parabolic partial differential equations (energy and momentum) plus an integral equation and a first-order partial differential equation. For the situations considered in this investigation, the initial and boundary conditions are known but the final condition is not. Thus a marching solution is used in the direction of flow; a set of unknown values is calculated from known conditions upstream. The present solution may be considered as an extension of that used by others (4, 5, 16, 17, 18, 34) in treating problems with Newtonian fluids.

For a constitutive equation, the temperature-modified power-law is used:

$$\eta = \frac{\tau}{\dot{\gamma}} = me^{n\frac{\Delta H}{Rt}} \dot{\gamma}^{n-1} .$$

This empirical constitutive equation has been used by Christiansen and co-workers (6, 7, 8) and by others (9, 24) for studies of non-Newtonian fluids with temperature-dependent viscosity. It is relatively simple in form and represents measured data adequately for many uses (6). As shown in Appendix II, the dimensionless form of the equation for apparent viscosity is

$$S = e^{n\frac{\Delta H}{Rt_i}(\frac{1}{T} - 1)} \left[\frac{\Phi}{4(\frac{3n+1}{n})^2} \right]^{\frac{n-1}{2}}$$

Calculation of the dimensionless apparent viscosity consists of calculating

$$\Phi = (\frac{\partial U}{\partial R})^2$$

(the square of the dimensionless shear rate - See Appendix II) from a central finite-difference representation, then calculating S according to the temperature-modified equation above. Squaring the shear rate then later performing an operation, which, in effect, takes the square root insures that the dimensionless apparent viscosity is always positive.

Grid System and Numerical Equations

The grid system developed for the marker and cell method (39) is used (see Figure 1). Fluid properties such as temperature,

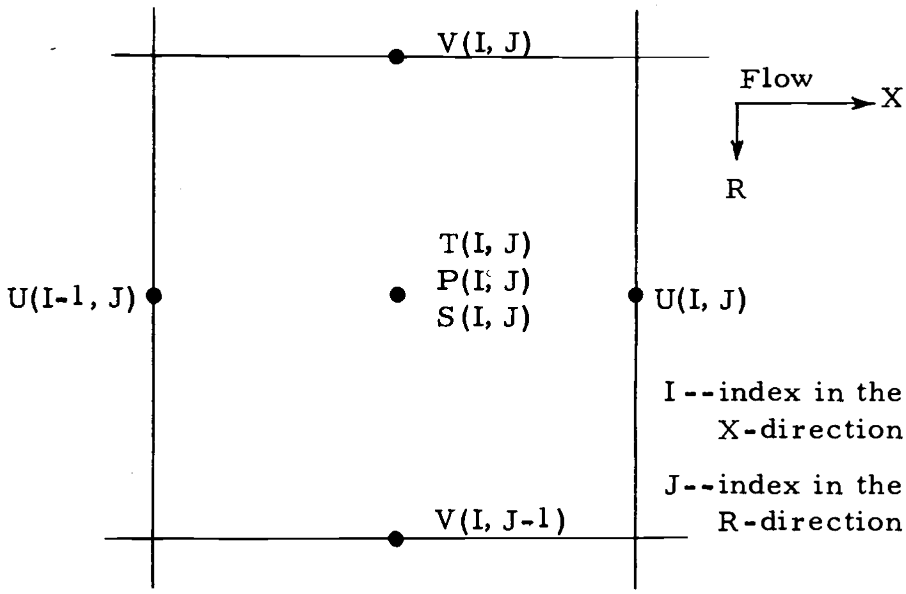

Figure 1. Cell layout.

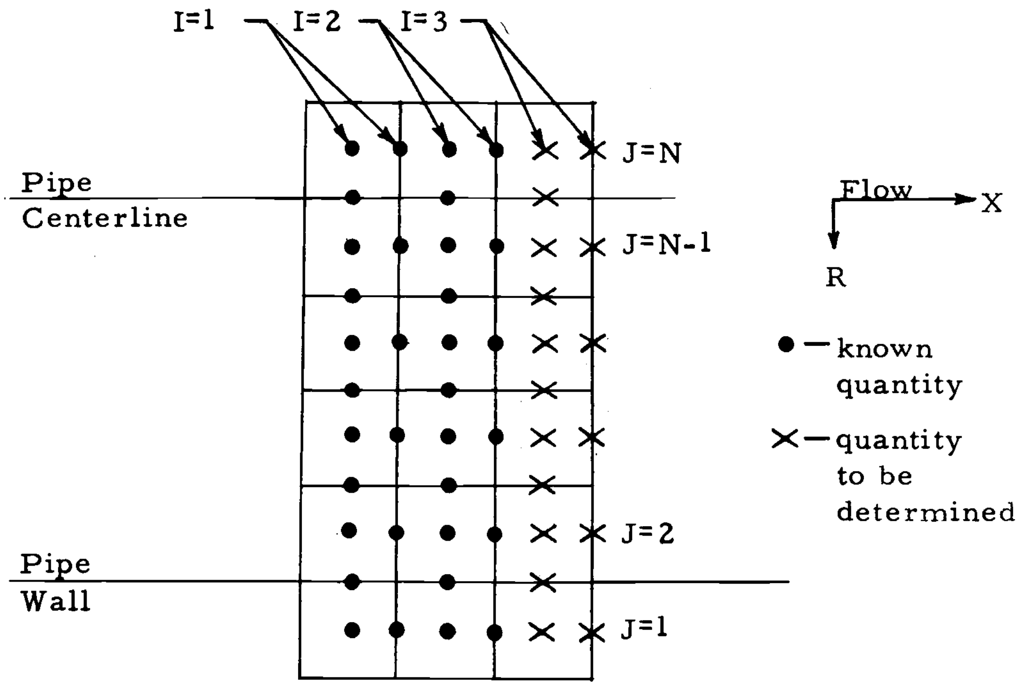

Figure 2. Grid system.

pressure, and apparent viscosity are defined at the center of a cell with the velocities defined on the cell boundaries. For problems of the type considered, the main advantage of this grid system is that rigorous handling of the incompressible differential equation of continuity is made possible. To carry out the marching solution for temperature, velocity, and pressure, three sets of cells are needed (see Figure 2). All velocities or properties at locations indicated with a dot, all variables with first index 2 or less, are assumed to be known and those at locations indicated with X, first index equal to 3, are unknown and must be determined. The artificial row of cells outside the wall and the row beyond the centerline are for application of the of the boundary conditions which is discussed later. The details of writing the difference equations are carried out in Appendix II.

The results of writing the energy equation about the point where T(2, J) is defined, using the Crank-Nicolson approach for the second derivative in R, is a set of simultaneous linear algebraic equations in the unknown temperatures:

$$T(3, J - 1) - B1(J)T(3, J) + B2(J)T(3, J + 1) = B3(J).$$

The set of numbers indicated by B1, B2, and B3 are functions of known velocities and known properties. The set of equations for the unknown temperatures is solved by an elimination scheme which is given in detail in Appendix III.

Writing the momentum equation about the point where U(2, J) is defined, again using the Crank-Nicolson representation for the second derivative with respect to R, yields a set of simultaneous pseudo-linear algebraic equations with velocities and pressure differential as unknowns:

$$U(3, J - 1) - B1(J)U(3, J) + B2(J)U(3, J + 1) - B3(J)\Delta P = B4(J).$$

The integral form of the continuity equation is written in numerical terms using the trapezoidal rule and is appended to the set of momentum equations to give N-1 equations with N-2 unknown velocities and the unknown pressure differential.

The set of equations thus formed is solved by an elimination scheme for which the details are given in Appendix III. In this set of equations, the numbers B1, B2, B3 and B4 are functions not only of known velocities and known properties but are also functions of the apparent viscosities S(3, J) which can be only estimated until the shear rates (calculated from the velocities) are known. Thus for a non-Newtonian fluid the equations are not actually linear, and an iterative procedure is needed. A simplified flow diagram for the calculation of a set of unknown values is given as Figure 3. To obtain a convergence check on the iterative procedure, the momentum equation for each cell is written as a residue.

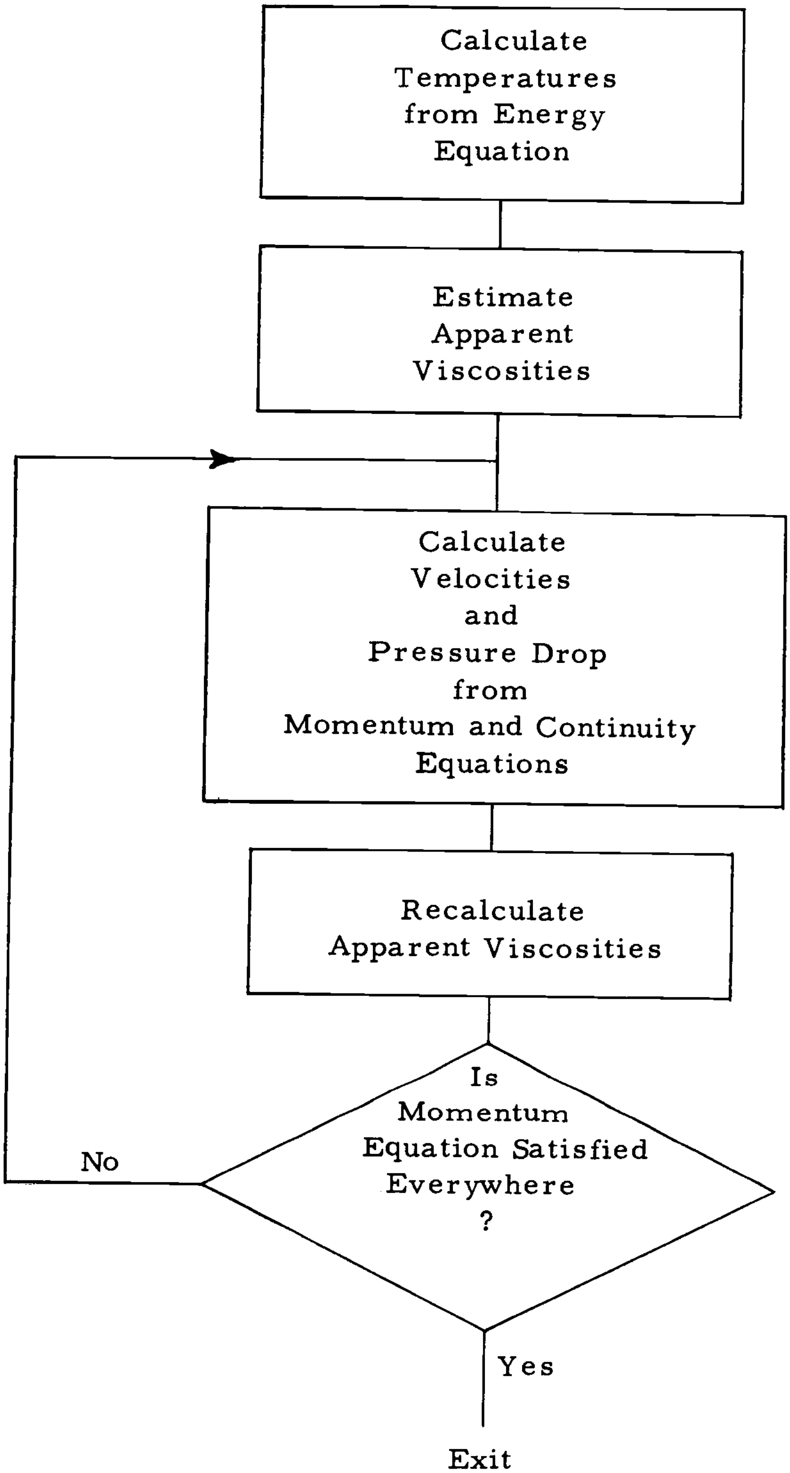

Figure 3. Simplified flow diagram.

Initial and Boundary Conditions

The inlet (initial) conditions are assumed to be uniform temperature and fully developed velocity. For a power-law fluid the fully developed velocity profile, in dimensionless form, is given by (40, p. 62)

$$U = \frac{3n+1}{n+1}\left[1 - (2R)^{\frac{n+1}{n}}\right] .$$

(Substitution of unity for n of course gives the familiar parabolic velocity distribution for a Newtonian fluid.)

The velocity boundary conditions are dictated by the assumptions of no slip at an impervious wall and symmetry about the pipe axis. In equation form the velocity boundary conditions are

$$U = 0 \text{ and } V = 0 \text{ at the wall}$$

and

$$U(-R) = U(+R) \text{ and } V = 0 \text{ at the centerline.}$$

For the grid system used, the application of the boundary conditions for V is direct (see Figure 3), but since U is not defined at the wall or the centerline, some other means must be used to apply the boundary condition on U. For the condition at the wall the artificial row of cells outside the wall is used; the value of U for the cell outside is given the negative of the value of U for the first cell inside the wall. Thus the arithmetic average of the two satisfies the no slip condition, that $U = 0$, at the wall.

For the centerline condition the velocity in the artificial cell beyond the centerline is given the same value as the velocity at the first cell inside the centerline boundary. In this way the symmetry about the centerline is preserved.

The temperature or heat-flux condition at the wall is handled in a way which allows variation in the direction of flow by storing the appropriate value of wall temperature or heat flux. At any pipe cross-section the wall boundary condition is implemented by specifying the relationship between the temperature in the artificial cell outside the wall and the first cell inside the wall. For the case where wall temperature is known, the temperature of the cell outside is specified so that the arithmetic average of the two temperatures on each side of the wall is the same as the known wall temperature. For the case where heat flux is known, the temperature in the artificial cell outside the wall is given a value which causes the appropriate value of the temperature gradient to exist at the wall. Dimensionless heat flux is defined as follows:

$$\text{Flux} \equiv \frac{\dot{q}}{A} \frac{D}{kt_i} = \left(\frac{\partial T}{\partial R}\right)_{\text{at wall}}$$

The centerline temperature boundary condition is based on symmetry about the pipe axis; the temperature in the cell beyond the centerline is given the same value as the temperature of the first cell inside the centerline.

Convergence

A priori determination of convergence for the complicated partial differential equations of change encountered in this investigation is impossible. The non-linear character of the partial differential equations and the necessity for simultaneous solution of the energy and momentum equations makes the convergence determination far beyond the realm of present-day theoretical development. The approach used here is to establish, as nearly as is presently possible, that the two necessary conditions of consistency and stability are met. Consistency (i. e., the discretization error approaches zero as the mesh is refined) of the numerical procedure for each of the partial differential equations is demonstrated in Appendix II where the discretization error in each case is shown to be $O(\Delta X^2) + O(\Delta R^2)$. The Crank-Nicolson representation (37, p. 17) for the second partial derivatives is used for its stability features. For a simpler equation

$$\frac{\partial Q}{\partial X} = \frac{\partial^2 Q}{\partial R^2}$$

the Crank-Nicolson scheme is stable for all types of boundary conditions encountered here and any ratio of ΔX to ΔR (37, p. 60 - 70). The demonstrated consistency and the stability feature of the Crank-Nicolson approach along with the excellent agreement of the calculated results with some known analytical solutions constitute the basis for faith in the convergence of the numerical solution which is used.

Special Computing Features

In this section some special computing features are discussed. The features described serve to improve resolution in certain regions, hasten convergence with the uniform wall temperature boundary condition, and to enhance accuracy for calculating mean temperatures.

The regions where the most severe changes occur are expected to be near the wall and near the inlet. To improve resolution in those regions, the computer program allows use of non-uniform mesh size in both the R and the X directions. To accomplish the finer mesh size near the wall, first the pipe radius is uniformly divided into a number of increments. Some of the increments nearest the wall are then further divided into even smaller subdivisions. This procedure provides high resolution near the wall and at the same time keeps the number of simultaneous equations relatively small to conserve computer time and to keep the effect of roundoff within acceptable limits in solving the set of energy or momentum equations.

To provide high resolution near the inlet, the size of the X increment is increased from an initially very small value to a considerably larger size by an exponential function:

$$\Delta X = \Delta X_{small} + (\Delta X_{large} - \Delta X_{small})(1 - e^{-AX}).$$

The use of the small ΔX near the inlet and a larger X increment farther downstream serves to limit the number of X increments needed thus conserving computer time and keeping the accumulated roundoff error small.

The use of the uniform-temperature boundary condition calls for imposing a step change in wall temperature at the inlet. The step change of temperature causes, in turn, some oscillation of the computed temperature profile near the wall. Since a temperature dependent viscosity is considered, hastening the convergence of the temperature to its true value is desirable. The temperature profiles oscillate in pairs: the first two profiles lower than the probable true temperature and the next two higher than the probable true profile (for heating). To hasten the convergence of the temperature, the calculated temperature profile is altered for the third and the fourth X increments; no further alterations are applied. The calculated temperature profile for the third (and fourth) X increment has the general shape shown in Figure 4. A temperature profile with a straight-line slope from the wall more nearly represents the actual temperature distribution (15, p. 287-290). Therefore, a screening procedure is used to detect the inflection of the calculated temperature profile, and a straight line from the inflection to the wall is substituted for the calculated profile (see Figure 4). That is done at the third and fourth X increments only; no further alterations are made downstream from there. Such a procedure to hasten convergence is not needed for the case where the flux is known since the extremely severe step change of temperature boundary condition is not imposed.

Since calculation for heat transfer rates involves the difference in mean temperatures, accurate evaluation of the mean temperature is imperative. In dimensionless variables the mean temperature is defined by an integral:

$$T_{mean} = 8 \int_0^{1/2} TURdR.$$

For accurate evaluation of the integral, an integration procedure based on the assumption that adjacent values of the integrand lie on a parabola (as in Simpson's rule) is used for calculating the mean temperature. Simpson's rule as such is not conveniently used in

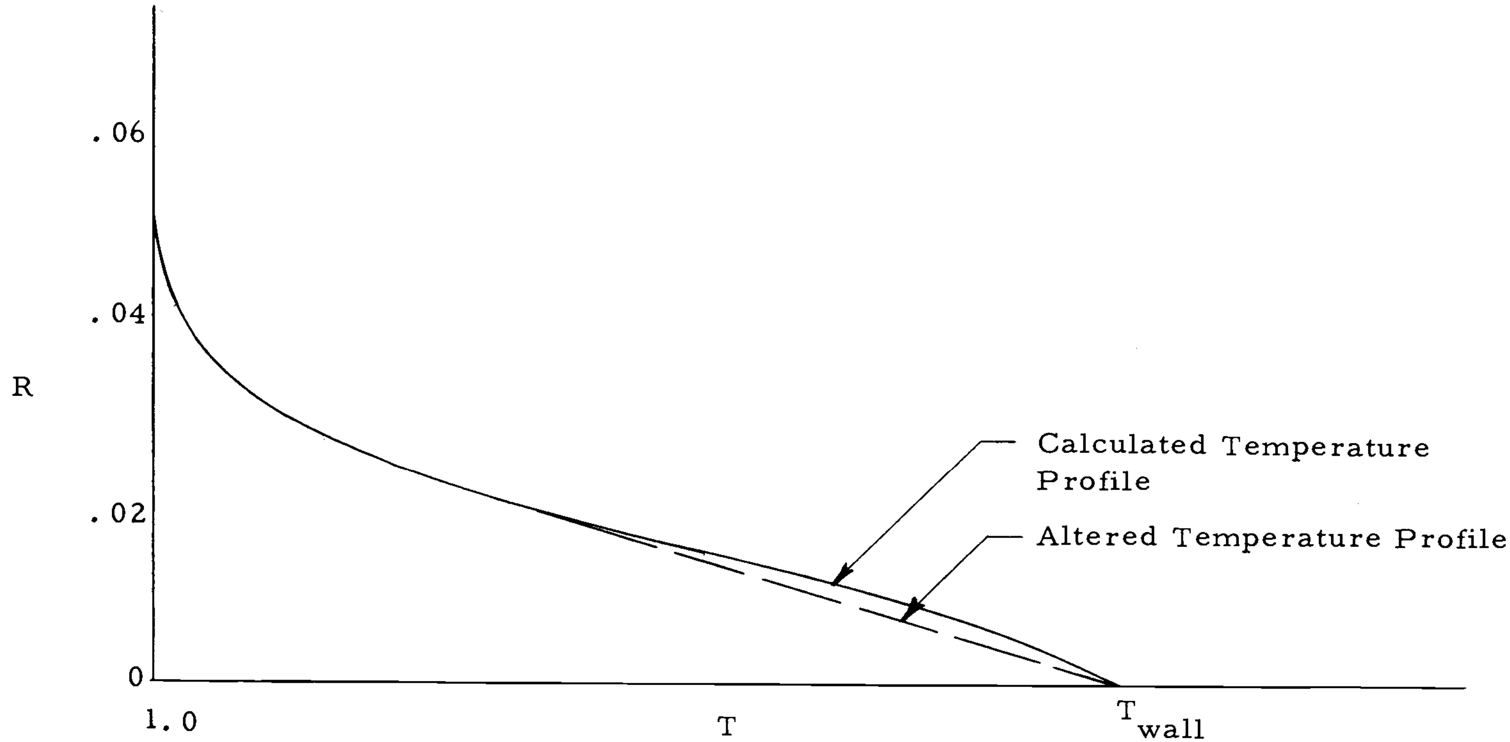

Figure 4. Temperature profile alteration.

this case because of having unequal sizes. The same type integration procedure is used for calculating the mean velocity for monitoring purposes. However, the trapezoidal rule is sufficiently accurate for use in calculating velocities (the continuity equation appended to the momentum equations) and is much more convenient for that purpose.

Results

The results for pipe flow are organized into the following four groups: 1) Checks against known analytical solutions, 2) Results with temperature independent viscosity for a range of the exponent n with uniform heating, 3) Solutions with temperature-dependent viscosity with uniform heating, and 4) Results with temperature-dependent viscosity with sinusoidal heating.

The first check of the results generated by the present program is comparison with the Sellars, Tribus, and Klein (36) analytical solutions for Newtonian flow with a uniform-temperature pipe wall and with uniform heat flux. For the uniform-temperature pipe wall the local and mean Nusselt numbers over the range where comparison is possible are presented in Figure 5. The values of both local and mean Nusselt numbers from the present numerical solution are within one percent of the values from the analytical solution over the range[1] of X from X = 0.014 to X = 0.100. The Nusselt numbers

[1] For clarification of the physical meaning of the values cited for X, one may convert X to the ratio of the distance from the pipe entrance to the pipe diameter. The ratio x/D is obtained by multiply- X by the product of Re and Pr (x/D = XRePr). If one takes Re = 100 and Pr = 1 for illustrative purposes, X = 0.100 is equivalent to x/D = 10. For very viscous Newtonian fluids and for most non-Newtonian flows Pr = 1000 is more nearly typical than is Pr = 1. Then for Re = 100 and Pr = 1000, X = 0.100 corresponds to x/D = 10,000.

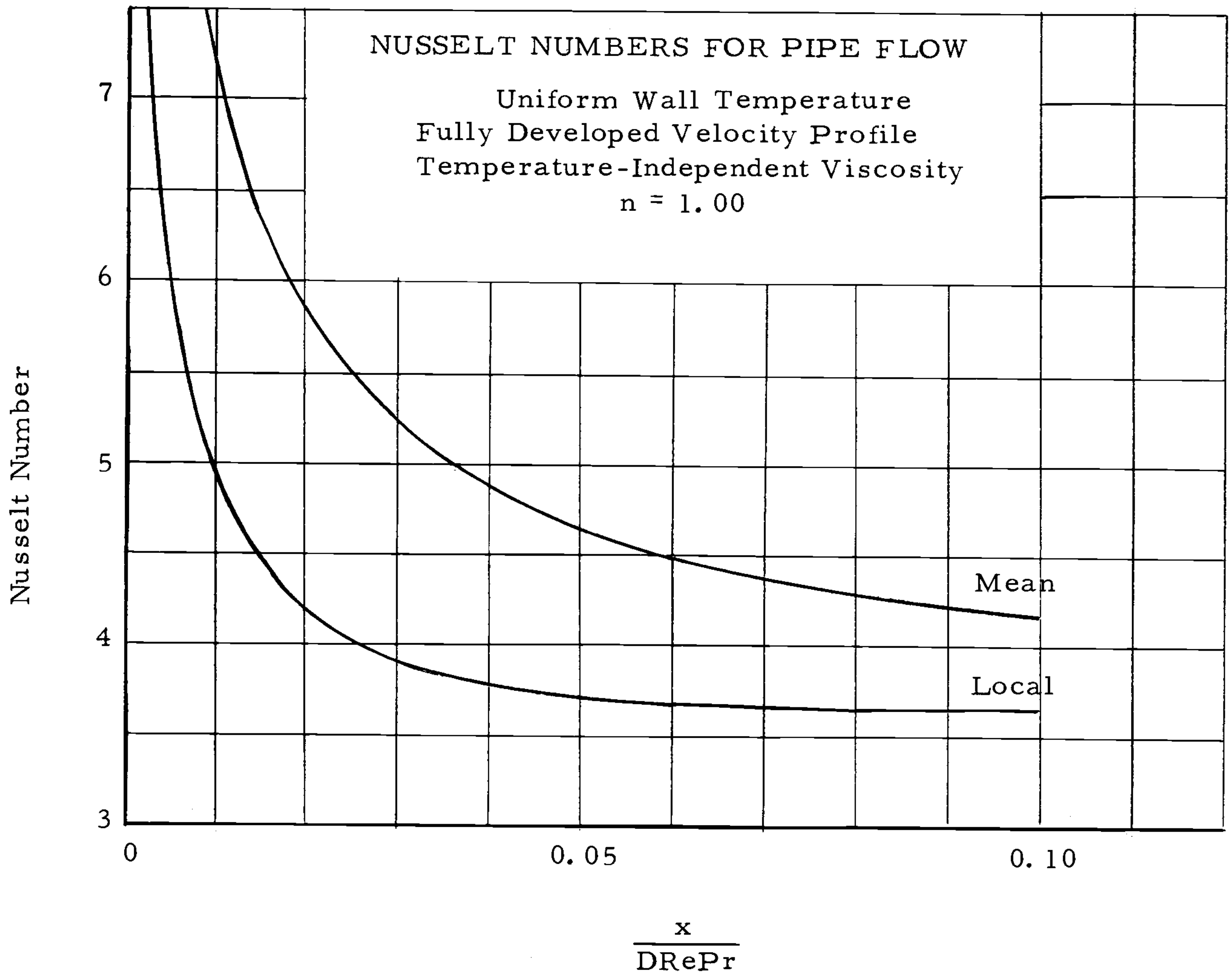

Figure 5. Nusselt numbers for pipe flow with uniform temperature pipe wall - n = 1.00.

from the present solution are slightly higher over that range of X. For uniform heat flux the local Nusselt number is shown in Figure 6 for the range of X where comparison is made. Over the range of X from X = 0.008 to X = 0.100 the values of the local Nusselt number from the solution reported here are within one percent of the values from the Sellars, Tribus, and Klein solution. The Sellars, Tribus, and Klein solution loses accuracy rapidly for smaller values of X because of truncation of the series solution (20, p. 130). Since only five terms were used, comparison is not made for small values of X.

A second check of the present solution is accomplished by comparison with McKillop's (27) results for n = 0.50 with temperature-independent viscosity. For uniform temperature pipe wall the values of local Nusselt number show a mean square difference of 1.2 percent from the values reported by McKillop (27, p. 856). The mean square difference is 0.5 percent for local Nusselt numbers with uniform heat flux. In both cases the values reported by McKillop are in the range from X = 0.0025 to X = 0.075.

Comparison with the results of Christianson and co-workers (6, 7, 8) shows close agreement with their numerical solution for temperature-independent viscosity but large differences for temperature-dependent viscosity. An intuitive argument concerning the shape of the Nusselt number curves seems to support the results of the solution reported here. To make the desired

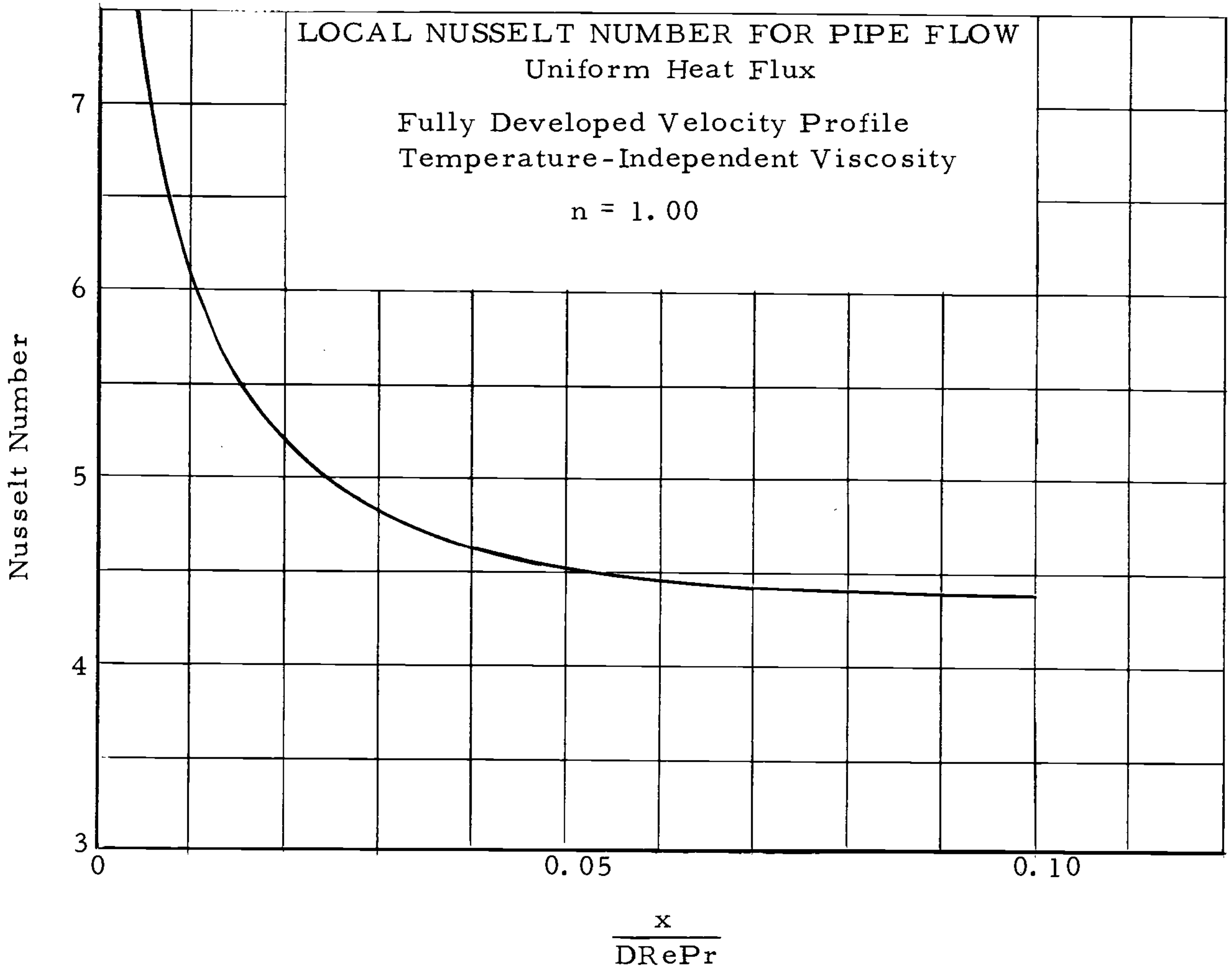

Figure 6. Local Nusselt number for pipe flow with uniform heat flux - n = 1.00.

comparison, the results of the present solution were recast into the form used by Christiansen and co-workers. In their work Graetz number $\left[Gz = \frac{\pi}{4}\frac{1}{X}\right]$ replaces X used here, and the average Nusselt number based on the arithmetic mean temperature difference is used instead of the mean Nusselt number based on the log mean temperature difference. In Figure 7 is shown the average Nusselt number for $n = 1.00$ with $\psi = 0$ (temperature-independent viscosity) and $\psi = 2$ (a case of temperature-dependent viscosity) for uniform temperature pipe wall. For temperature-independent viscosity, the two sets of results compare rather well. The present solution yields average Nusselt number about one percent higher over the range $Gz = 10$ to $Gz = 1000$ ($X = 7.85 \times 10^{-2}$ to $X = 7.85 \times 10^{-4}$). The difference increases from one percent to about four percent in the Graetz number decade from $Gz = 1000$ to $Gz = 10,000$ ($X = 7.85 \times 10^{-4}$ to $X = 7.85 \times 10^{-5}$). For the case of temperature-dependent viscosity comparison is hopeless; at large Graetz number (small X) the average Nusselt number reported by Christiansen and co-workers is considerably greater than the result from the present solution. The following argument concerning the shape of the Nusselt number curves is thought to lend support to the results generated by the present solution. The effect of heating a liquid with temperature-dependent viscosity is a flattening of the velocity profile. Thus one expects the Nusselt number to be increased, compared to the

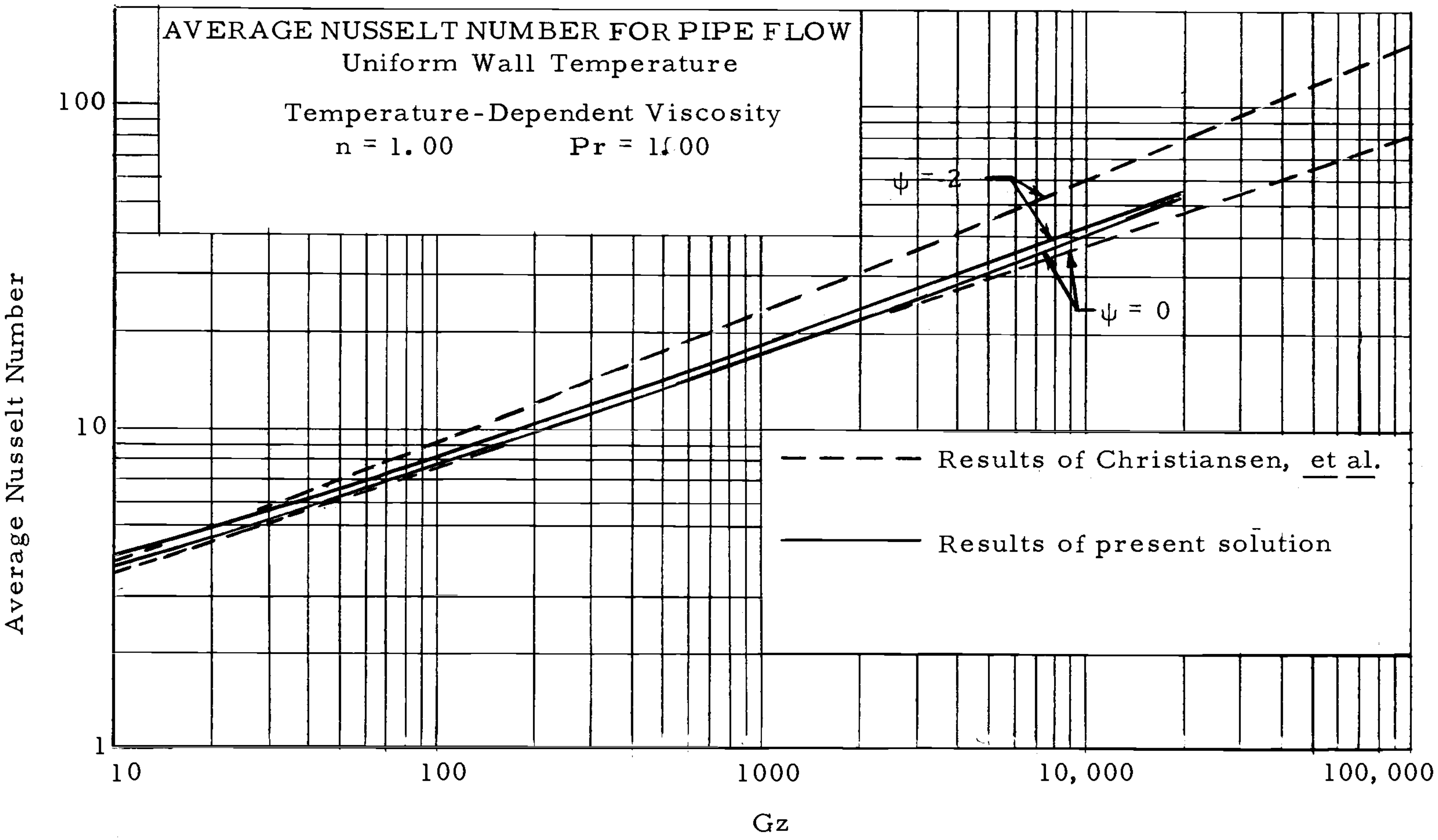

Figure 7. Average Nusselt number for pipe flow with uniform temperature pipe wall - n = 1.00.

Nusselt number for a temperature-independent fluid, as the liquid flows down the pipe. As the temperature of the liquid becomes more nearly uniform, no doubt that trend is reversed as the fully-developed isothermal profile is once again approached. However, the concern here is with the region near the pipe inlet (large values of the Graetz number). Near the inlet of the pipe the Nusselt numbers for the temperature-dependent and the temperature-independent fluids are expected to be approximately equal. The Nusselt number of the fluid with temperature-dependent viscosity is expected to increase, compared to that for the temperature-independent fluid, as the fluid is heated in flowing along the pipe. Of the two solutions shown in Figure 7, only the solution reported here shows that anticipated characteristic. No explanation for the difference in the Nusselt number from the two solutions is presently known.

The local Nusselt number for uniform flux and temperature-independent viscosity is given in Figure 8. Values of Nusselt number are presented for four values of the exponent n. The Nusselt number for Newtonian flow is plotted in the upper portion with the other three values given in the lower portion as ratios of the local Nusselt number to the value of local Nusselt number for Newtonian flow at the same value of X. For $n = 0.25$ the Nusselt number is 19 percent higher than for Newtonian flow near the inlet and 22 percent higher at $X = 0.100$. Values of Nusselt number for $n = 0.50$

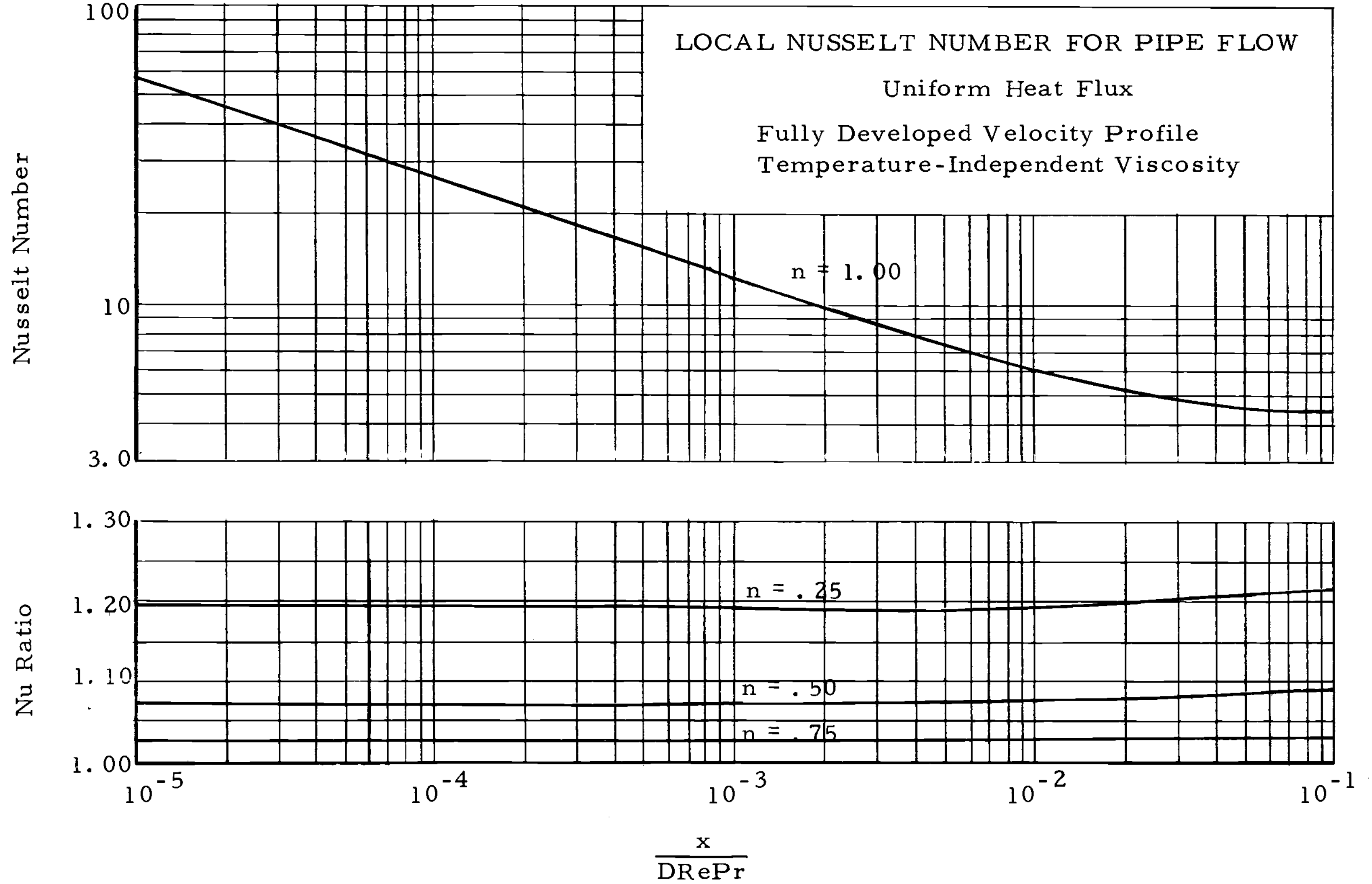

Figure 8. Local Nusselt number for pipe flow with uniform flux n = 0.25, 0.50, 0.75, and 1.00.

and $n = 0.75$, of course showed smaller departure from the values for Newtonian flow.

For temperature-dependent viscosity and uniform heat flux, local Nusselt number and pressure drop are shown in Figures 9 through 16. For the calculations of Figures 9 through 12 the exponent n is unity; Figures 9 and 10 are for dimensionless heat flux equal to 1.00; and Figures 11 and 12 are for dimensionless heat flux equal to 2.00. Consistent with expectations, temperature-dependent viscosity increases the heat transfer rate (Nusselt number) and decreases the pressure drop for situations where heating occurs. For the most severe[2] case checked (Flux = 2.00 and $\Delta H/Rt_i = 10$), the Nusselt number ratio reaches a peak value about 27 percent greater than for the case of temperature-independent viscosity; for that

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[2]The severity of a heating condition is related to the amount of viscosity change caused by the temperature change-temperature dependence combination. Thus high values of heat flux combined with high values of $\Delta H/Rt_i$ are considered as severe heating conditions. To illustrate the physical magnitude implied by a given value of Flux, one may convert Flux to heat flux ($\dot{q}/A$ = Flux kt_i/D) by selecting some representative values for k, t_i, and D. If one takes $k = 0.10$ Btu/hr-ft-F, $t_i = 500$ R, and $D = 2$ inches for illustration sake, the value of $\dot{q}/A = 300$ Flux Btu/hr-ft^2. The effect of a given value of $\Delta H/Rt_i$ is best understood by considering the viscosity change caused by a given change in fluid temperature ($\eta_1/\eta_2 = e^{\Delta H/Rt_i(1/T_1 - 1/T_2)}$ for a fluid with $n = 1$). To illustrate this effect, one may take $t_1 = 500$R and $\Delta H/Rt_i = 10$; for those conditions the viscosity is reduced by a factor of 2.5 when the fluid is heated from 500R to 550R.

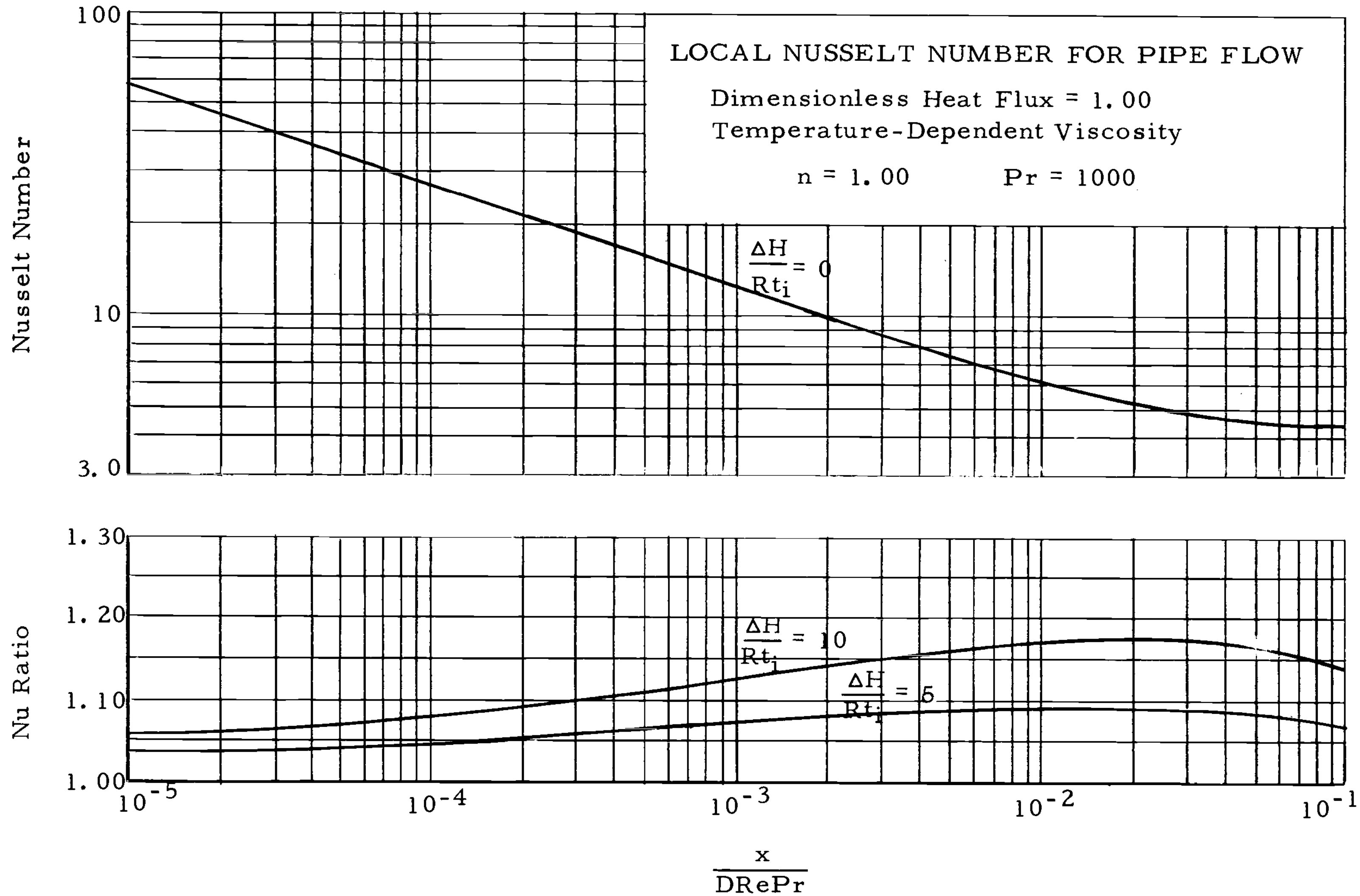

Figure 9. Local Nusselt number for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 1.00.

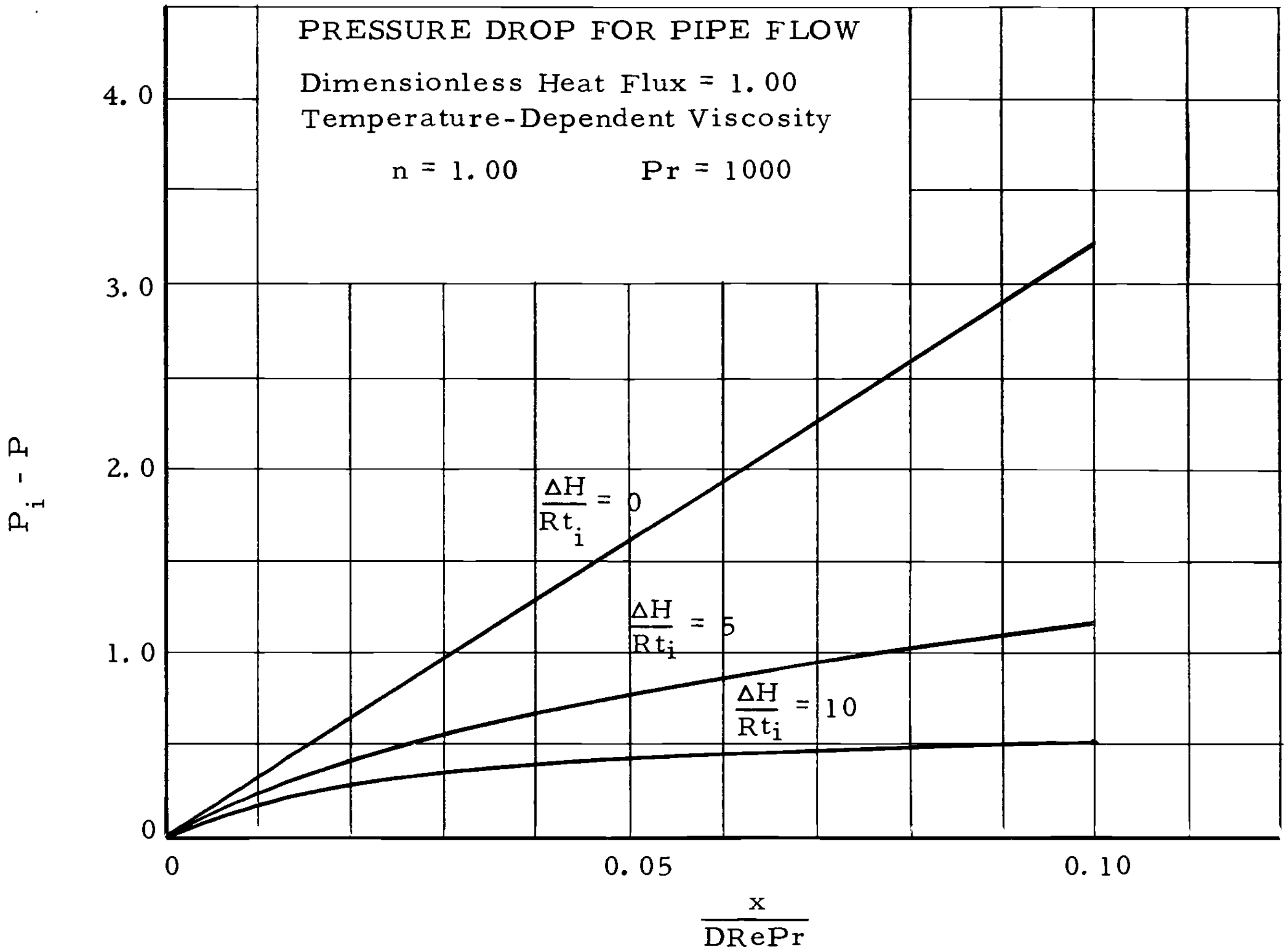

Figure 10. Pressure drop for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 1.00.

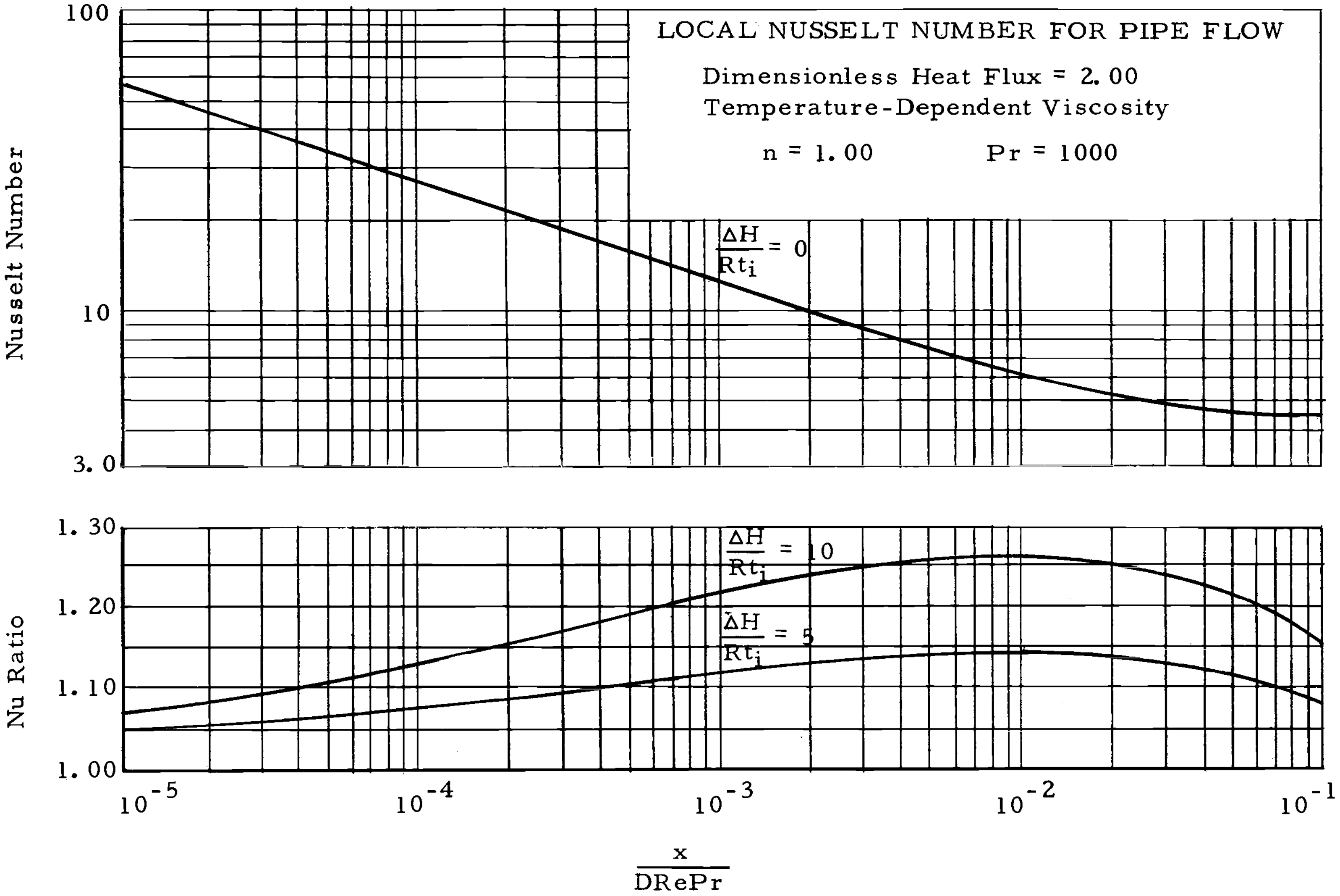

Figure 11. Local Nusselt number for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 1.00.

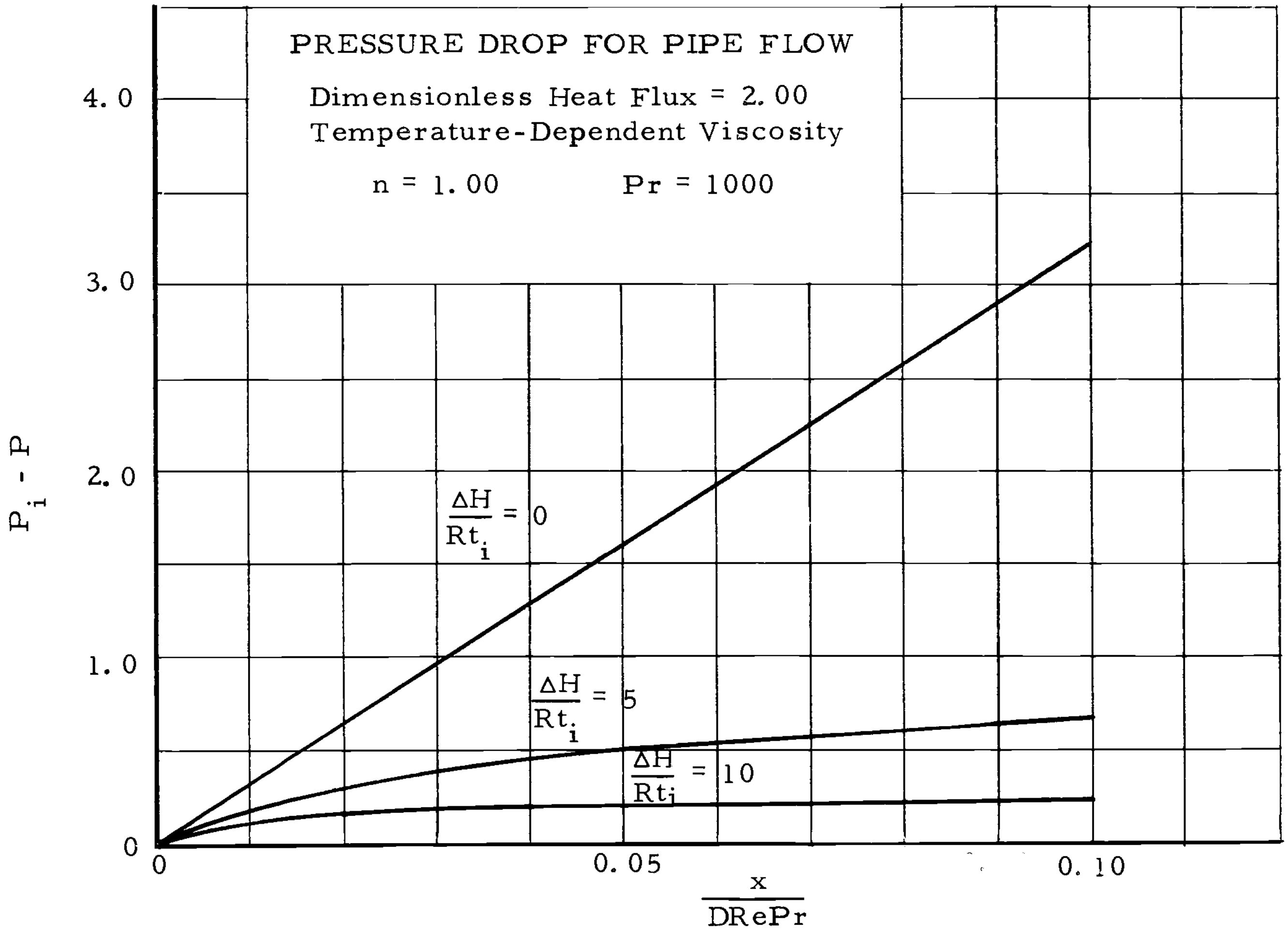

Figure 12. Pressure drop for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 1.00.

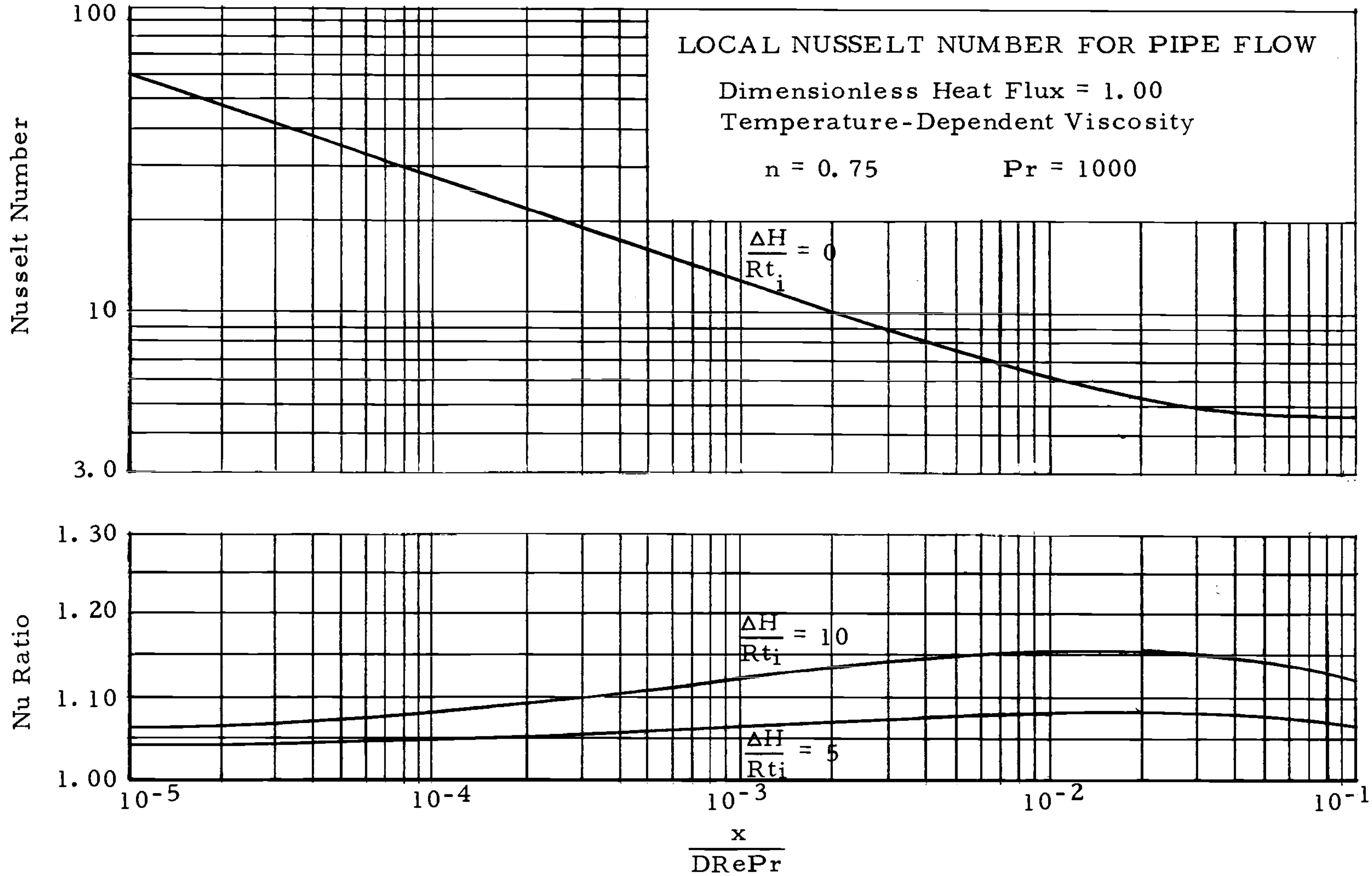

Figure 13. Local Nusselt number for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 0.75.

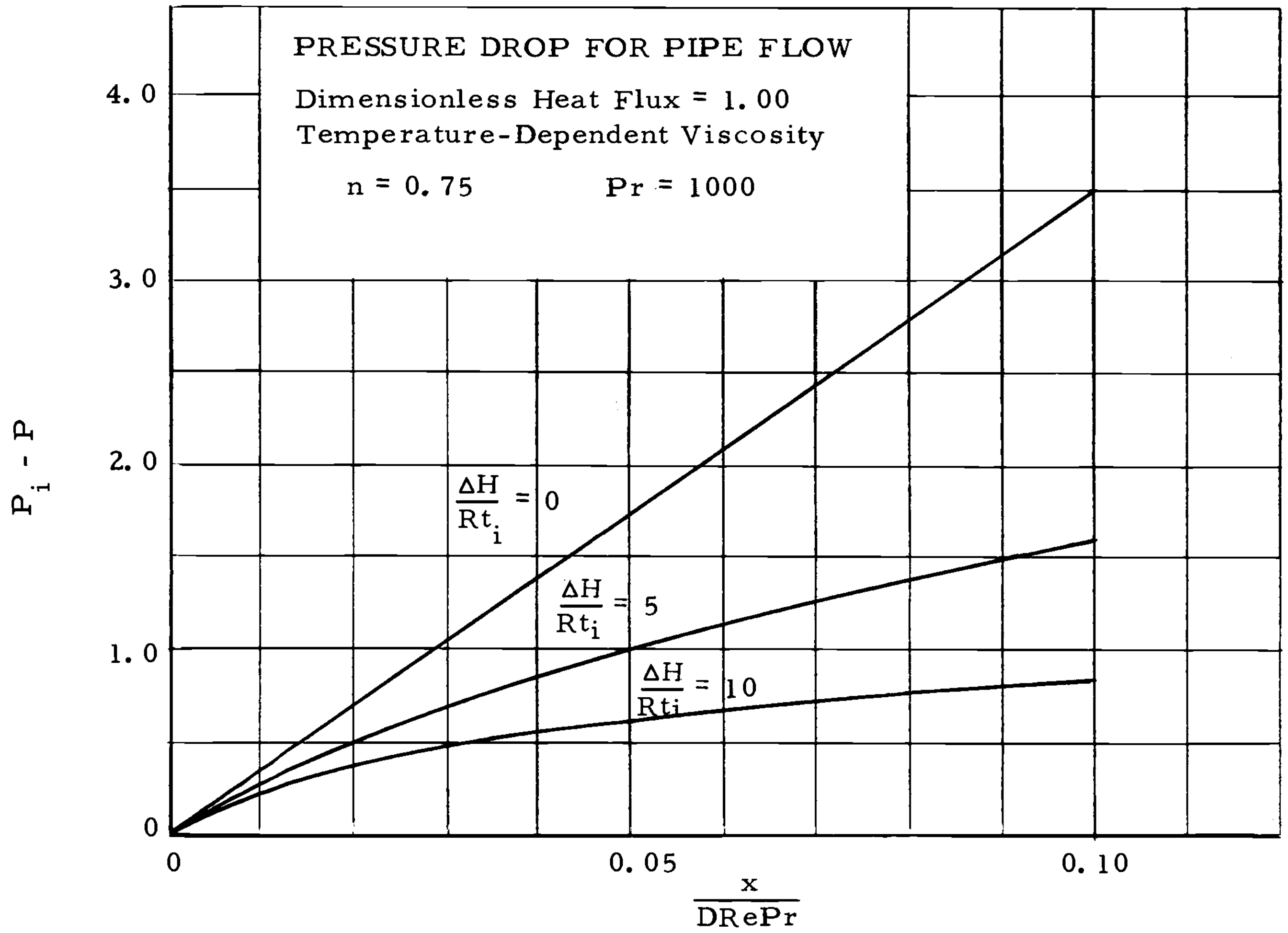

Figure 14. Pressure drop for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 0.75.

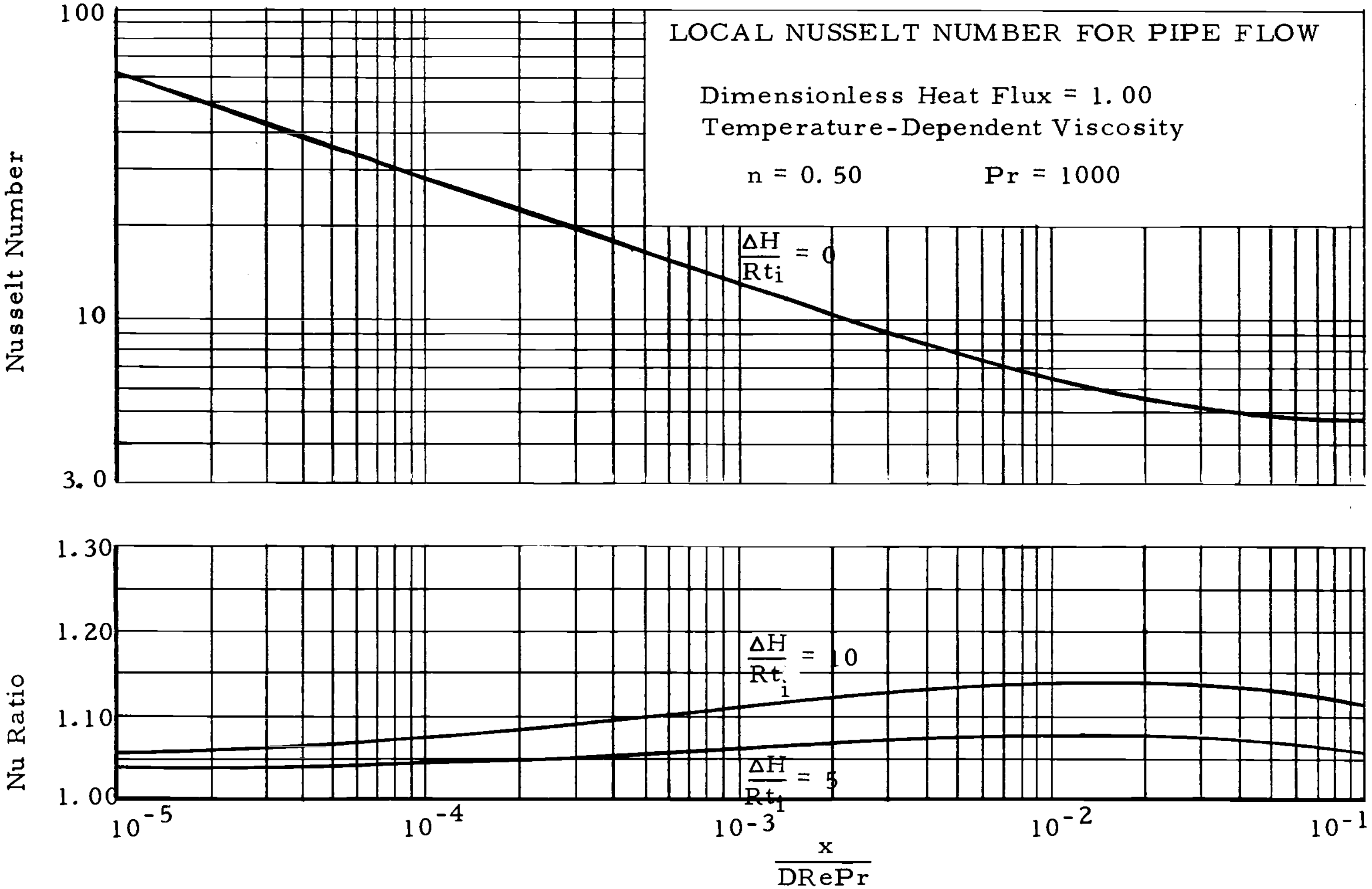

Figure 15. Local Nusselt number for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 0.50.

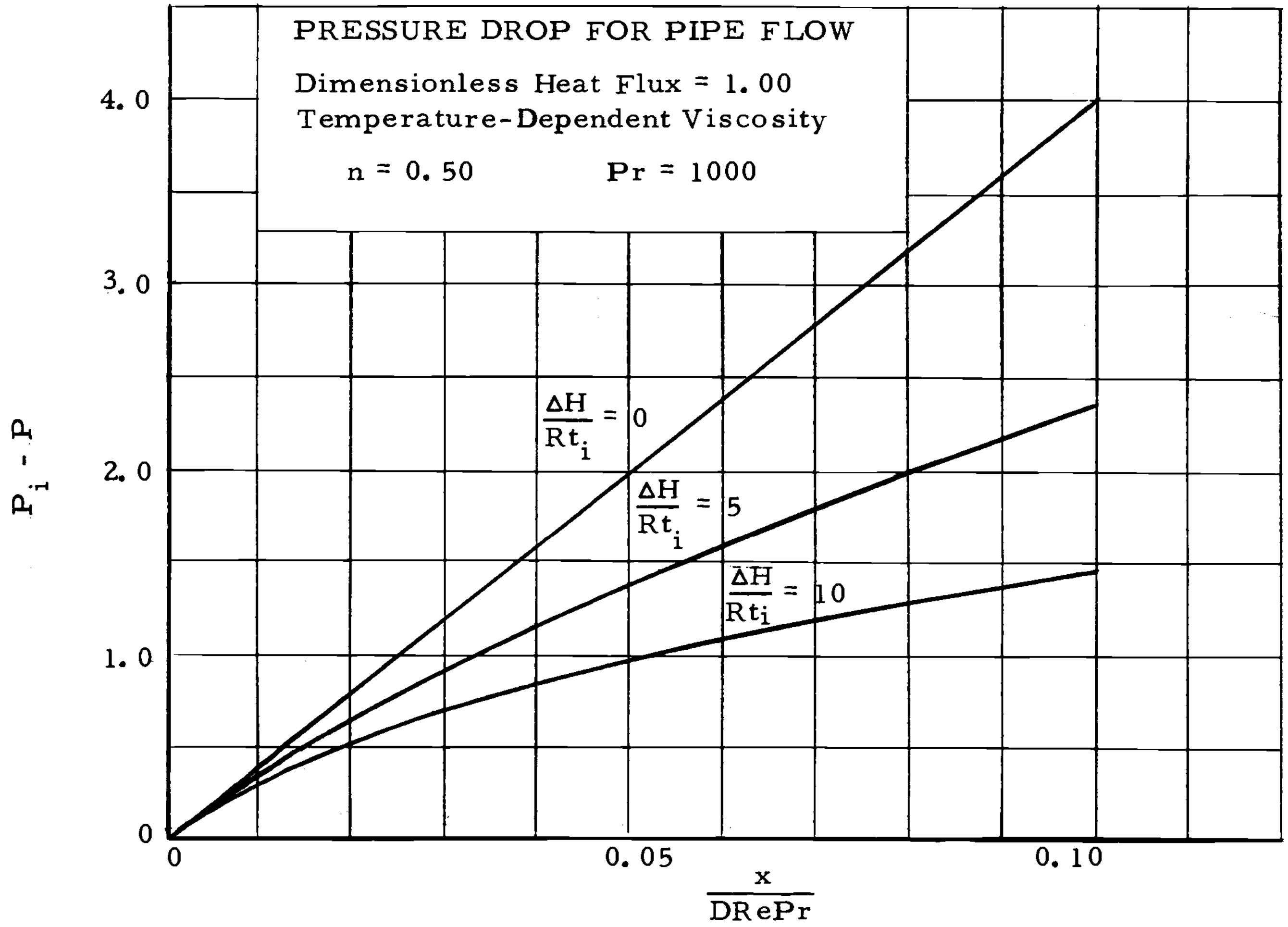

Figure 16. Pressure drop for pipe flow with uniform heat flux and temperature-dependent viscosity - n = 0.50.

same set of conditions the pressure drop from the inlet to $X = 0.100$ is only seven percent as great as for temperature-independent viscosity. Figures 13 through 16 show similar Nusselt number and pressure drop effects for $n = 0.75$ and $n = 0.50$. Since temperature-dependent viscosity causes flattening of the velocity profile for heating, the Nusselt number and pressure drop are affected less for smaller values of the exponent n where the velocity profile is already flattened because of the shear-stress shear-rate relationship. Nevertheless, inspection of Figures 13 through 16 readily shows that sizeable heat transfer rate and pressure drop effects are caused by temperature induced viscosity changes. Some of those effects are summarized below:

n	$\frac{\Delta H}{Rt_i}$	Flux	Peak value of Nusselt number ratio	Pressure drop from inlet to $X = 0.10$ as percent of pressure drop for temperature-independent viscosity
1	5	1	1.09	36
1	10	1	1.18	16
1	5	2	1.14	21
1	10	2	1.27	7
.75	5	1	1.09	46
.75	10	1	1.16	24
.50	5	1	1.08	59
.50	10	1	1.14	36

An interesting and potentially useful example of non-uniform heat flux distribution is the case where the heat flux varies sinusoidally along the pipe. Such a situation could occur in a nuclear reactor (20, p. 140). Figures 17 through 20 show wall temperature, mean temperature, heat flux, and pressure drop for $n = 1.00$ and $n = 0.50$. Since the heat flux is the same in every case, the mean temperature for all cases is the same at any given value of X. As anticipated the wall temperature and pressure drop are lower for temperature-dependent viscosity than for the case where viscosity is independent of temperature.

In discussing the results, the problem of instability of the numerical solution under some conditions must be pointed out for the benefit of any potential user of the present numerical solution. In spite of the efforts made to insure a stable solution, unstable behavior is shown for unfavorable combinations of the parameters. The non-linear nature of the momentum equation and the necessity for coupled solution of the energy and momentum equations make impossible the theoretical determination of an appropriate grid size for stable solution under a given set of parameters. Empirical determination of an appropriate grid size must be employed. Anyone considering use of the present numerical solution is cautioned that such a procedure can be very costly and time-consuming if severe conditions are imposed on the parameters.

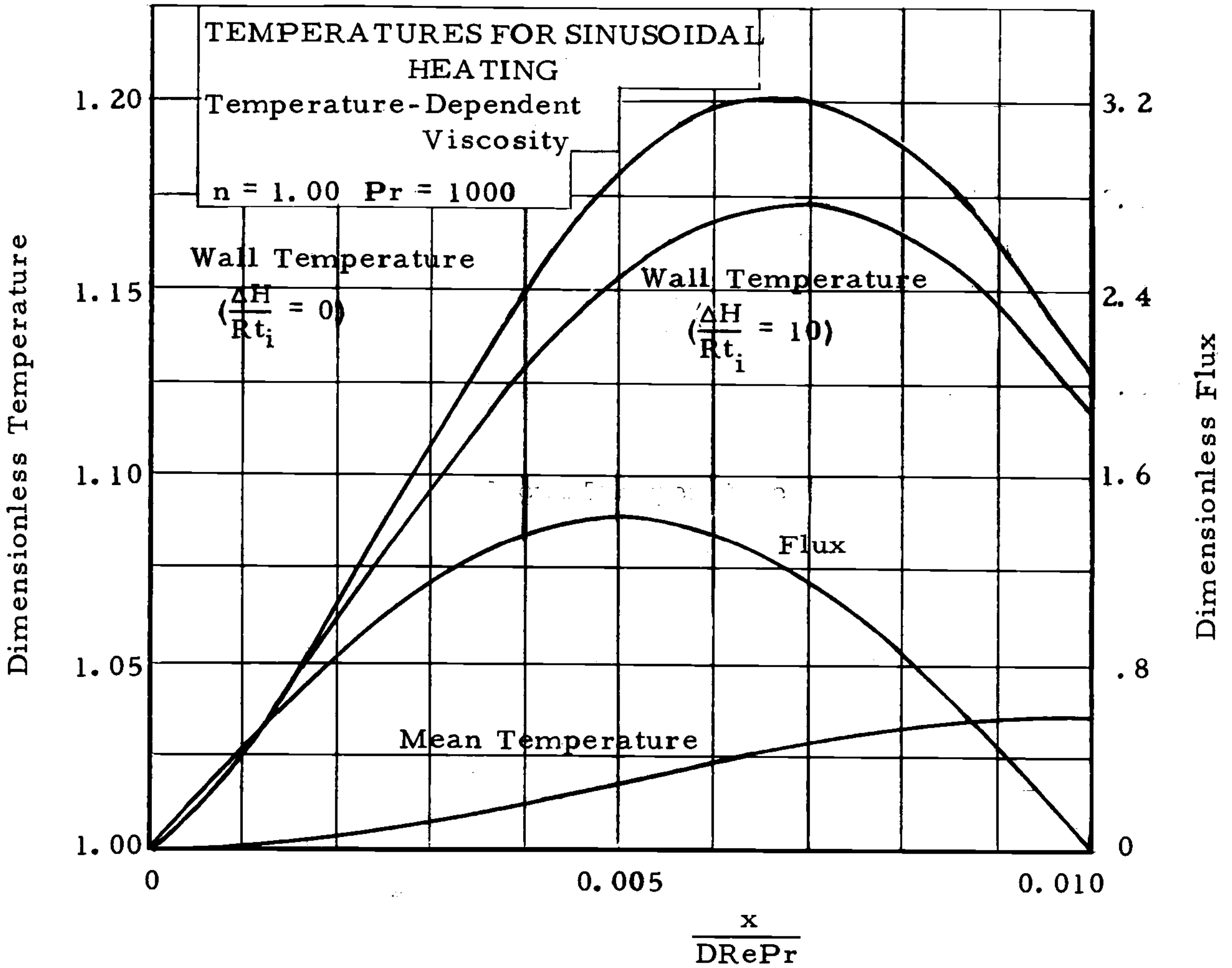

Figure 17. Temperatures for sinusoidal heating - n = 1.00.

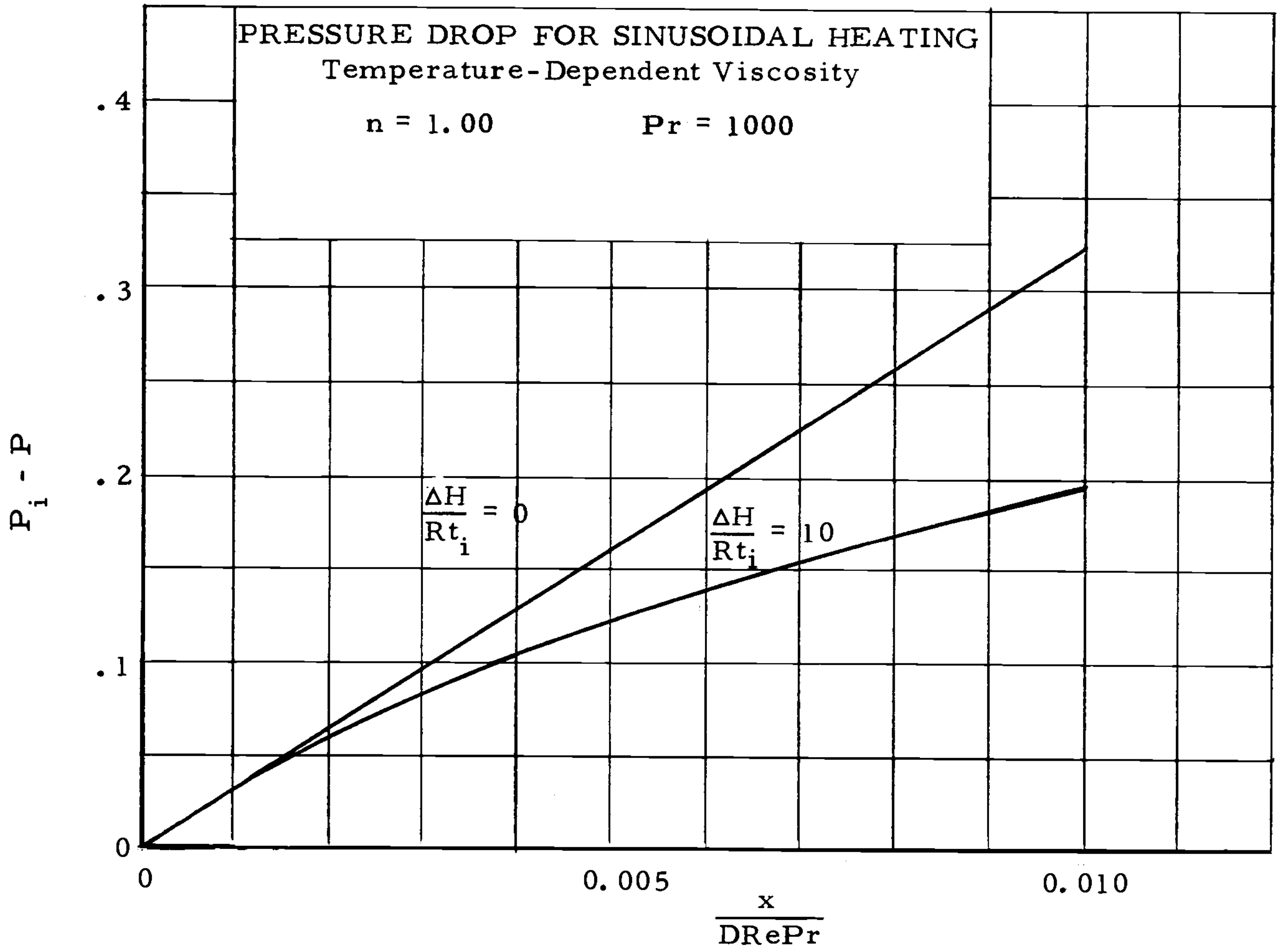

Figure 18. Pressure drop for sinusoidal heating - n = 1.00.

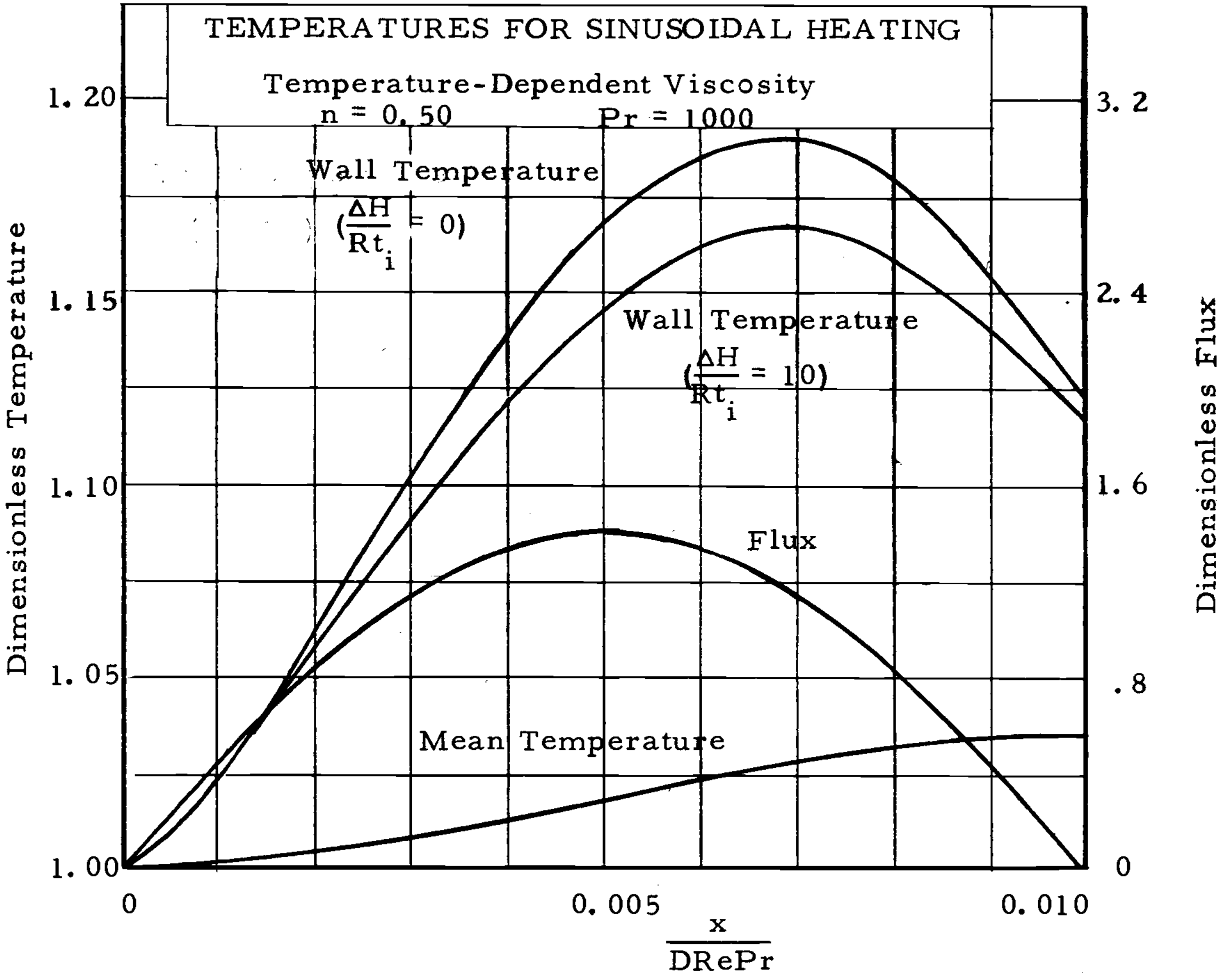

Figure 19. Temperatures for sinusoidal heating - n = 0.50.

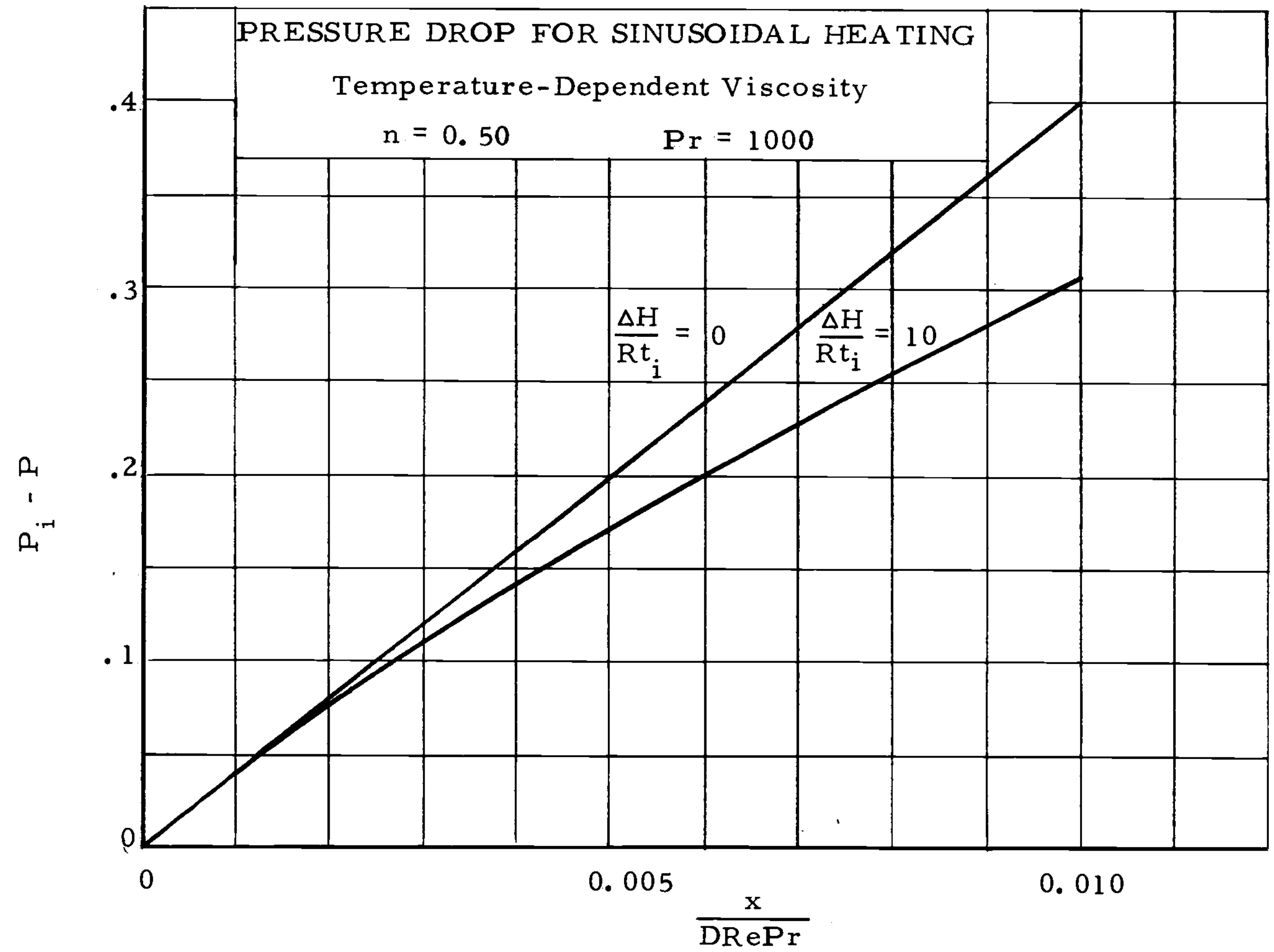

Figure 20. Pressure drop for sinusoidal heating - n = 0. 50.

III. CHANNEL FLOW

Differences from Treatment of Pipe Flow

Since the solution for flow in a channel between two flat, parallel plates is so nearly like that for pipe flow, only the main differences between the two will be discussed.

The equations of change for channel flow of course do not have the terms involving curvature. Justification of the simplified equations from those given by Bird, Stewart, and Lightfoot (3, p. 84, 88, 319) follows the same arguments given in Appendix II for the pipe flow equations. In dimensionless form the equations of change are as follows:

Energy Equation:

$$U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial Y} = \frac{\partial^2 T}{\partial Y^2} + BrS\Phi$$

Momentum Equation:

$$\frac{1}{Pr}\left[U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y}\right] = -\frac{dP}{dX} + S\frac{\partial^2 U}{\partial Y^2} + \frac{\partial S}{\partial Y}\frac{\partial U}{\partial Y}$$

Continuity Equation (Differential Form):

$$\frac{\partial V}{\partial Y} + \frac{\partial U}{\partial X} = 0$$

Continuity Equation (Integral Form):

$$\int_0^1 U dY = 1$$

As is true for pipe flow, the set of equations has two second-order parabolic partial differential equations, and the same type of marching solution is used.

The dimensionless constitutive equation is different from that for pipe flow because of the reference value for apparent viscosity being affected by the lack of curvature of the boundary. A procedure paralleling that used in Appendix II for pipe flow shows that the dimensionless apparent viscosity for channel flow is evaluated as follows:

$$S = e^{n\frac{\Delta H}{Rt_i}\left(\frac{1}{T} - 1\right)} \left[\frac{\Phi}{4\left(\frac{2n+1}{n}\right)^2}\right]^{\frac{n-1}{2}} .$$

The only difference in the grid systems used is that for channel flow no assumption of symmetry is made. Therefore, the grid system is extended all the way across the channel instead of only half way as is done for pipe flow.

The inlet conditions are once again taken as fully developed velocity and uniform temperature. For a power-law fluid the fully developed velocity profile in dimensionless form is given by

$$U = \frac{2n+1}{n+1}\left[1 - |2Y-1|^{\frac{n+1}{n}}\right].$$

This expression is developed from the channel-flow analog of the procedure used by Wilkinson (40, p. 61-63) for pipe flow. (Substitution of unity for n yields the familiar parabolic velocity distribution for Newtonian fluids where the maximum velocity is 50 percent greater than the average velocity.)

To apply the boundary conditions to channel flow, only the wall conditions are used. For the velocity, boundary conditions which apply are $U = 0$ and $V = 0$ at each wall. The wall-temperature or heat-flux boundary conditions are handled independently to allow the two walls to have different temperature or flux conditions.

Results

The results for channel flow are organized into the following four groups: 1) Check against known analytical solutions, 2) Results with temperature-independent viscosity for a range of the exponent n with uniform, symmetrical heating, 3) Solutions with temperature-dependent viscosity for $n = 1$ with uniform, symmetrical heating, and 4) Results with temperature-dependent viscosity for $n = 1$ with non-symmetrical heating.

The principal check of the results generated by the present program is a comparison with the Sellars, Tribus, and Klein (36) analytical solution for Newtonian flow with uniform-temperature walls. Both the local and mean Nusselt numbers over the range where comparison is possible are presented in Figure 21. The values of both local and mean Nusselt numbers from the present numerical solution are within one percent of the values from the analytical solution over the range[3] of Z from Z = 0.006 to Z = 0.0725. The Nusselt numbers from the present solution are slightly higher over that range of Z. The Sellars, Tribus, and Klein solution loses accuracy rapidly for smaller values of Z because of truncation of the series solution (20, p. 130). Since only three terms were used, comparison is not made for small values of Z.

An additional check of the numerical solution is furnished by comparing the local Nusselt number at large Z with the value for a fully-developed temperature profile for the uniform heat flux boundary conditions. For Z greater than Z = 0.055 the local Nusselt number generated by the present solution is within 0.15 percent of the accepted value of N = 8.235 for Newtonian flow (20, p. 117).

The local Nusselt number for uniform flux and temperature-

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[3]Physical interpretation of values cited for Z may be made by converting Z to the ratio of distance from the channel inlet to the distance between the two flat plates. Calculation of the x/L ratio is accomplished by multiplying Z by the product of Re' and Pr (x/L = ZRe'Pr). Then for Re' = 100 and Pr = 1000, Z = 0.0725 corresponds to x/L = 7250.

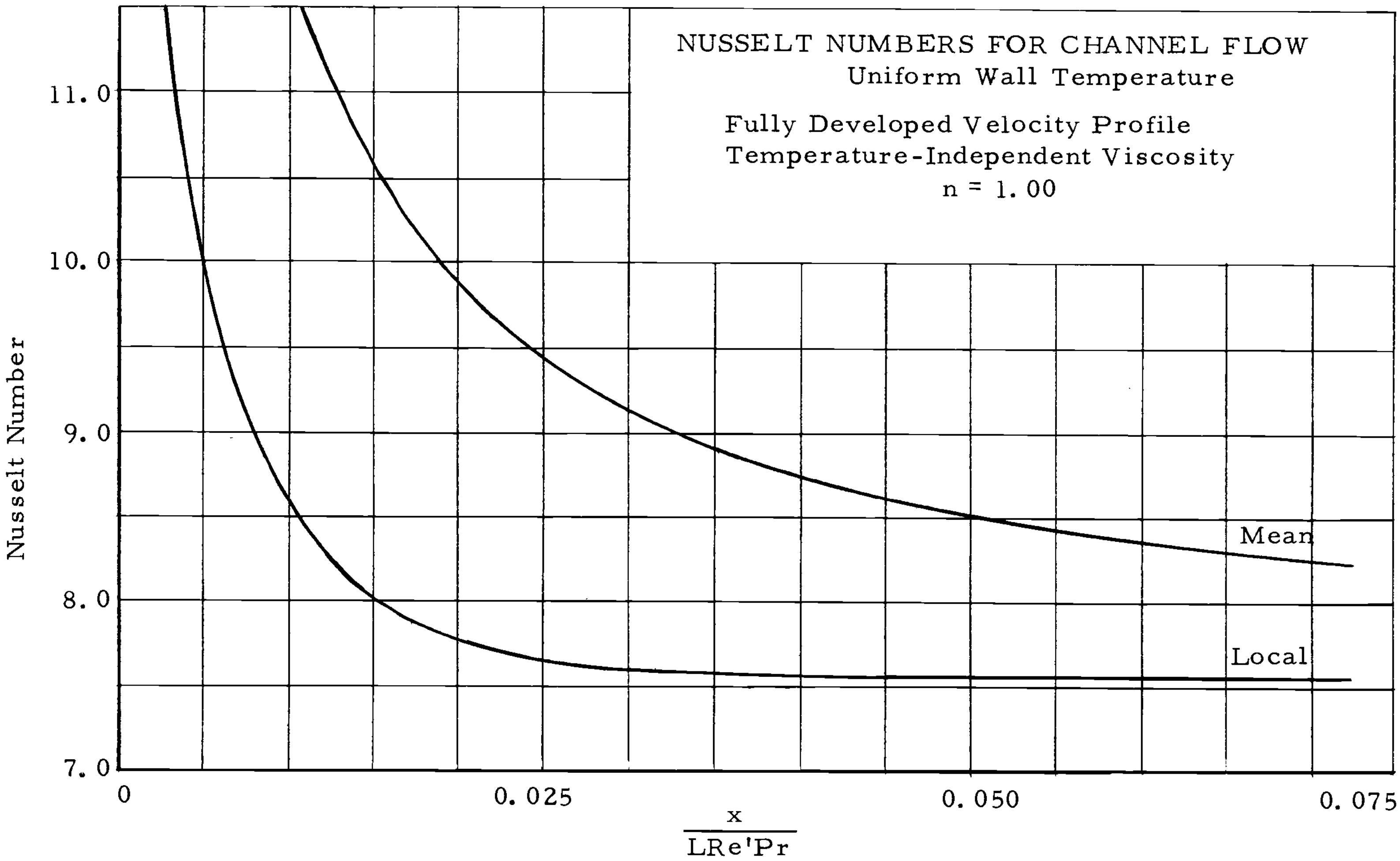

Figure 21. Nusselt numbers for channel flow with uniform temperature walls - n = 1.00.

independent viscosity is given in Figure 22. Values of Nusselt number are presented for four values of the exponent n. The Nusselt number for Newtonian flow is plotted in the upper portion with the other three values given in the lower portion as ratios of the local Nusselt number for Newtonian flow at the same value of $x/(LRe'Pr)$. For $n = 0.25$ the Nusselt number is 25 percent higher than for Newtonian flow near the inlet and 14 percent higher far downstream. Values of Nusselt number for $n = 0.50$ and $n = 0.75$, of course, showed smaller departure from the values for Newtonian flow.

For temperature-dependent viscosity, both Nusselt number and pressure drop are shown in Figures 23 and 24 respectively. For those calculations the exponent n is unity and the heat flux is both symmetrical and uniform. For the conditions of the calculations, the local Nusselt number ratio reaches a peak value about eight percent greater for temperature-dependent viscosity than for the case of temperature-independent viscosity. The pressure drop from the inlet to $x/(LRe'Pr) = 0.0725$ for the temperature-dependent viscosity is only 40 percent of that for the case where viscosity is independent of temperature.

An interesting use can be made of the present numerical solution by allowing the two walls to have different thermal boundary conditions. Figures 25 and 26 show the results of two such calculations. The thermal boundary conditions used in generating

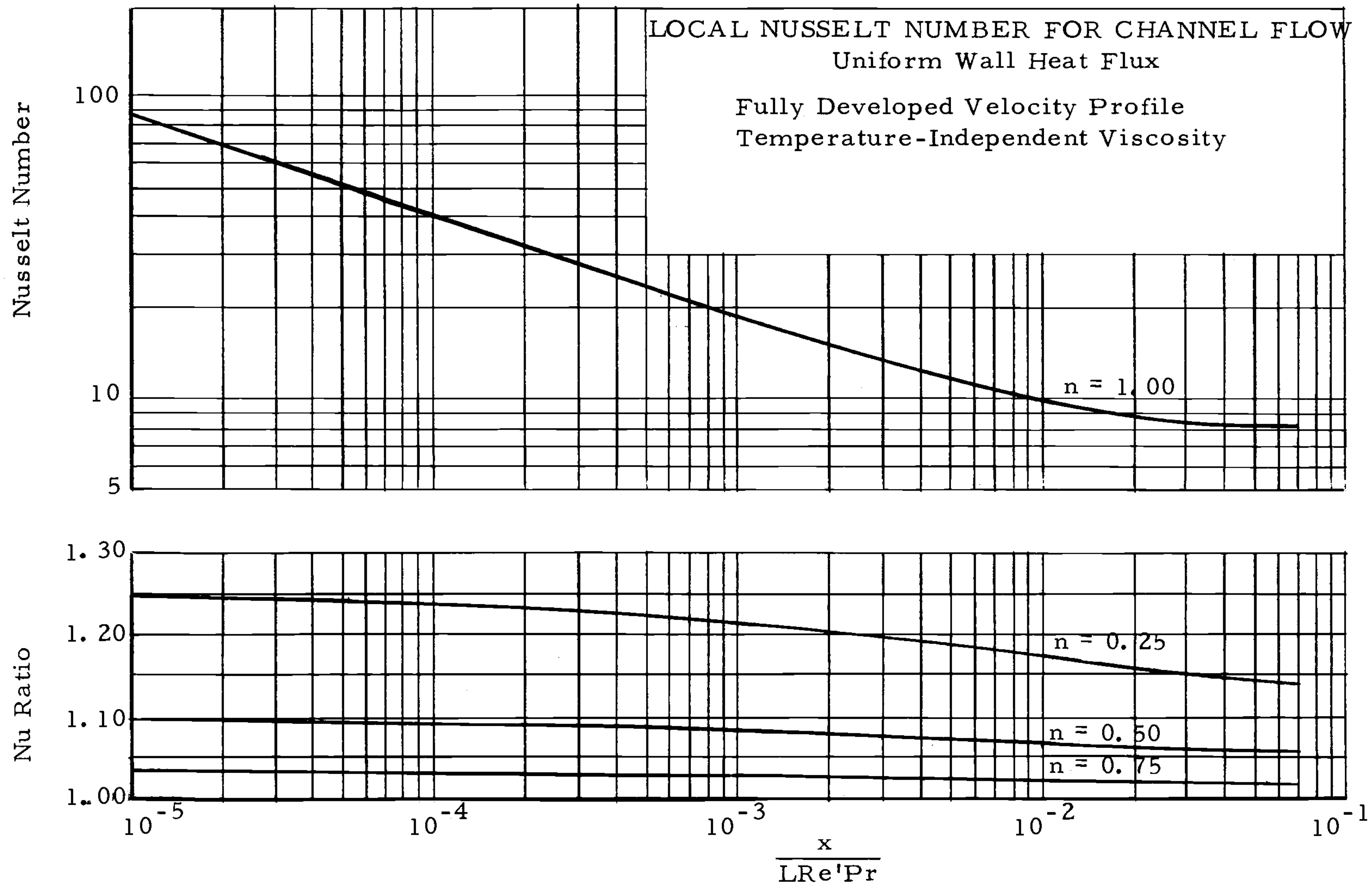

Figure 22. Local Nusselt number for channel flow with uniform wall heat flux n = 0. 25, 0. 50, 0. 75, and 1. 00.

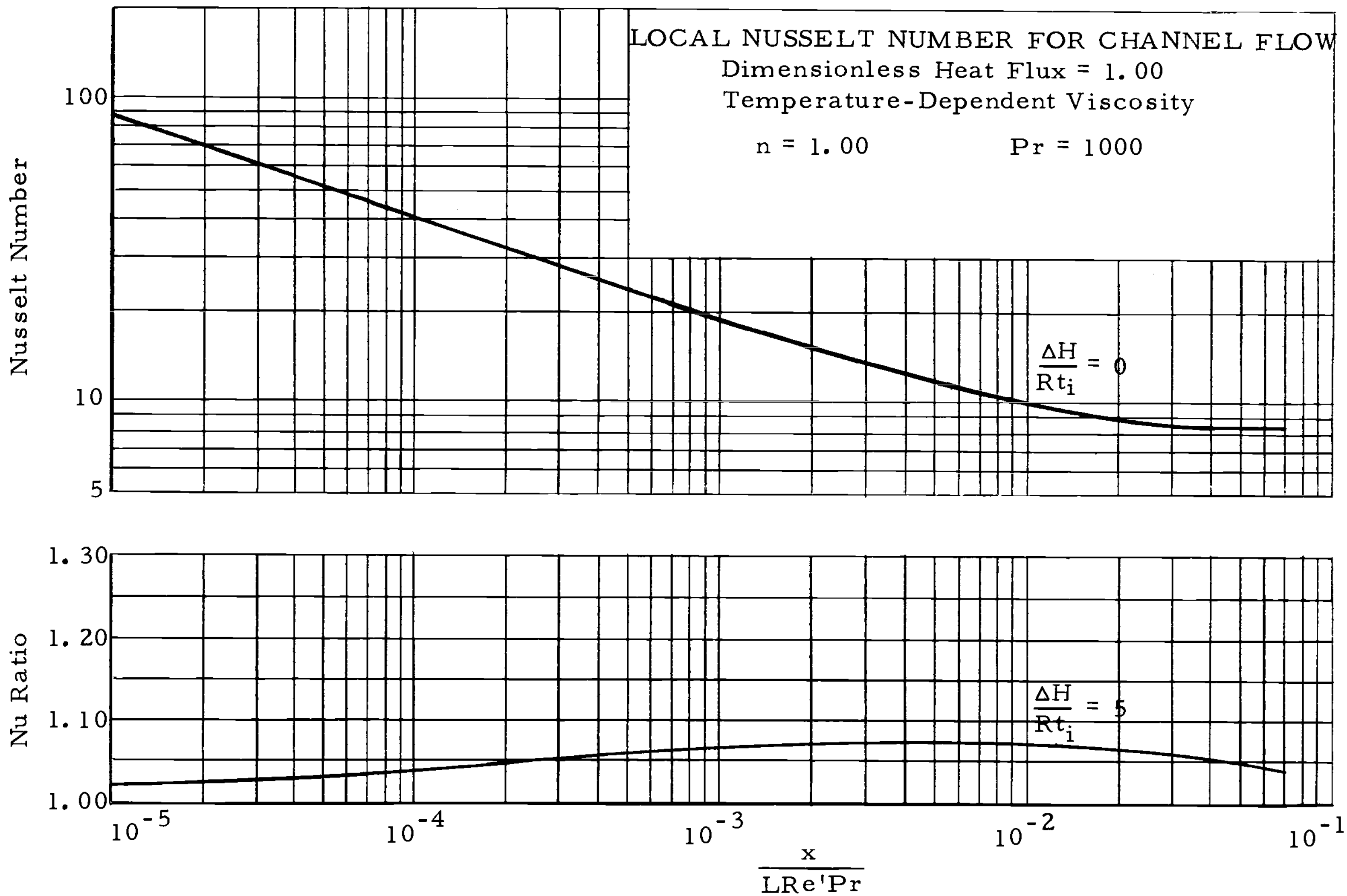

Figure 23. Local Nusselt number for channel flow with uniform wall heat flux and temperature-dependent viscosity - n = 1.00.

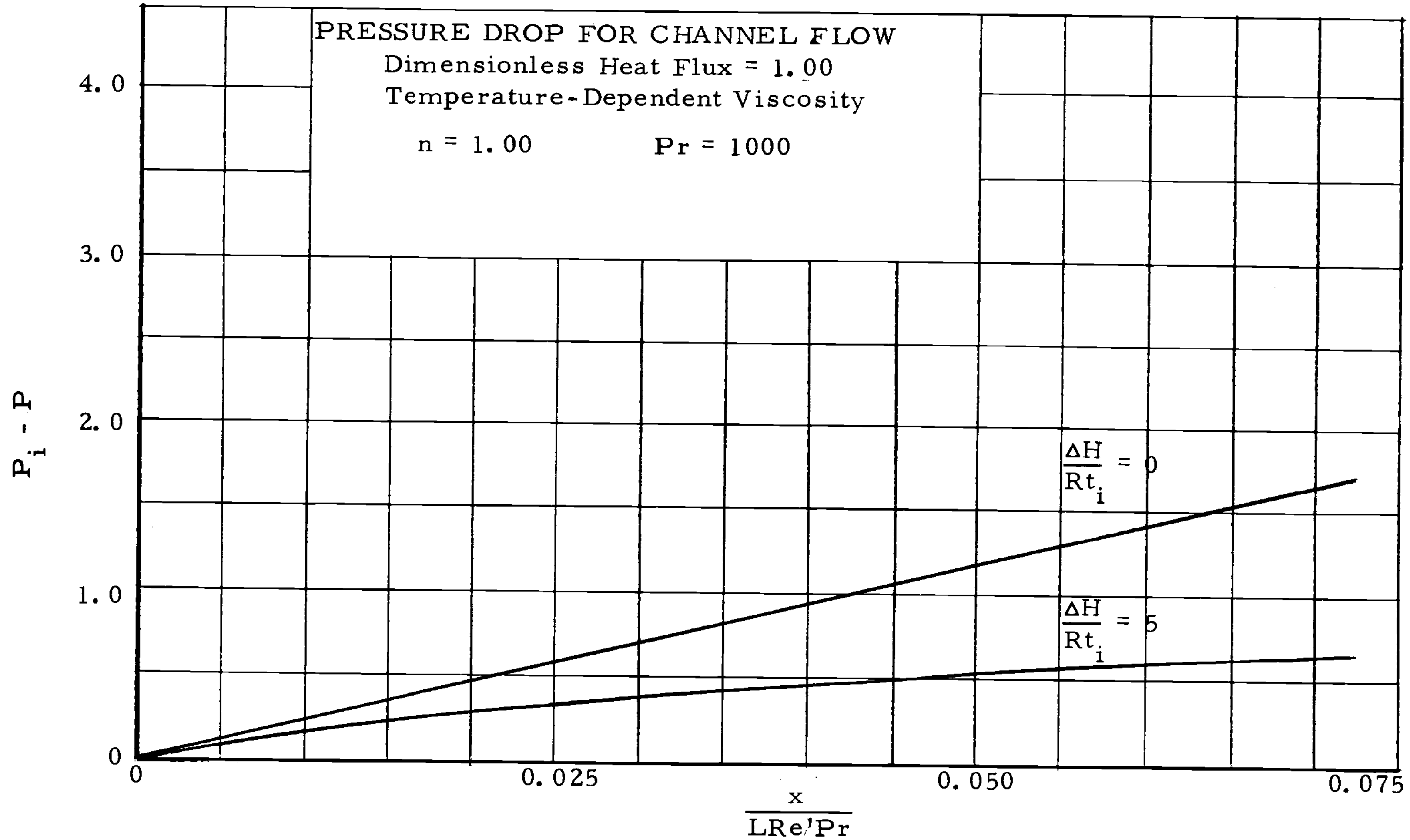

Figure 24. Pressure drop for channel flow with uniform wall heat flux and temperature-dependent viscosity - n = 1.00.

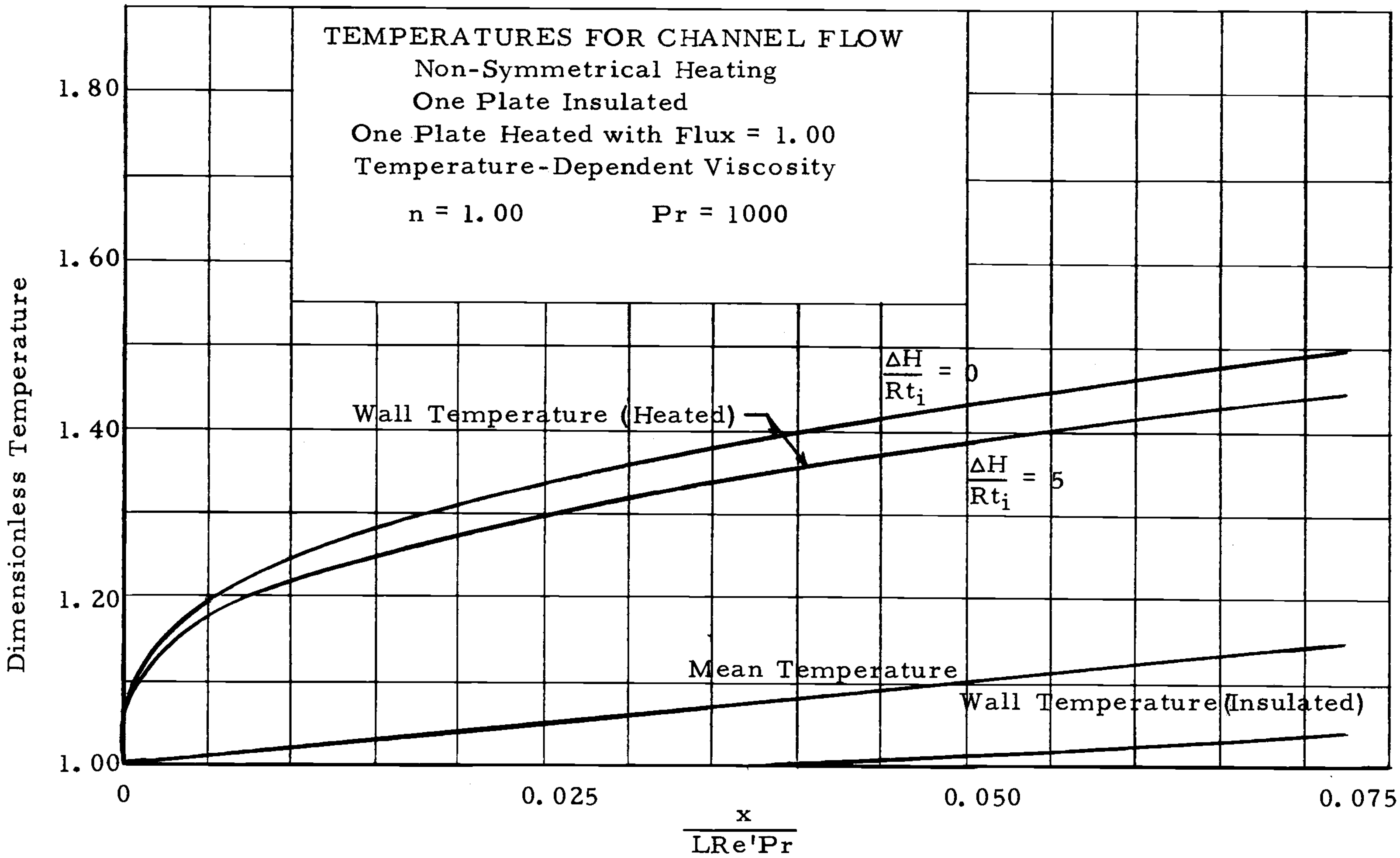

Figure 25. Temperatures for non-symmetrical heating - n = 1.00.

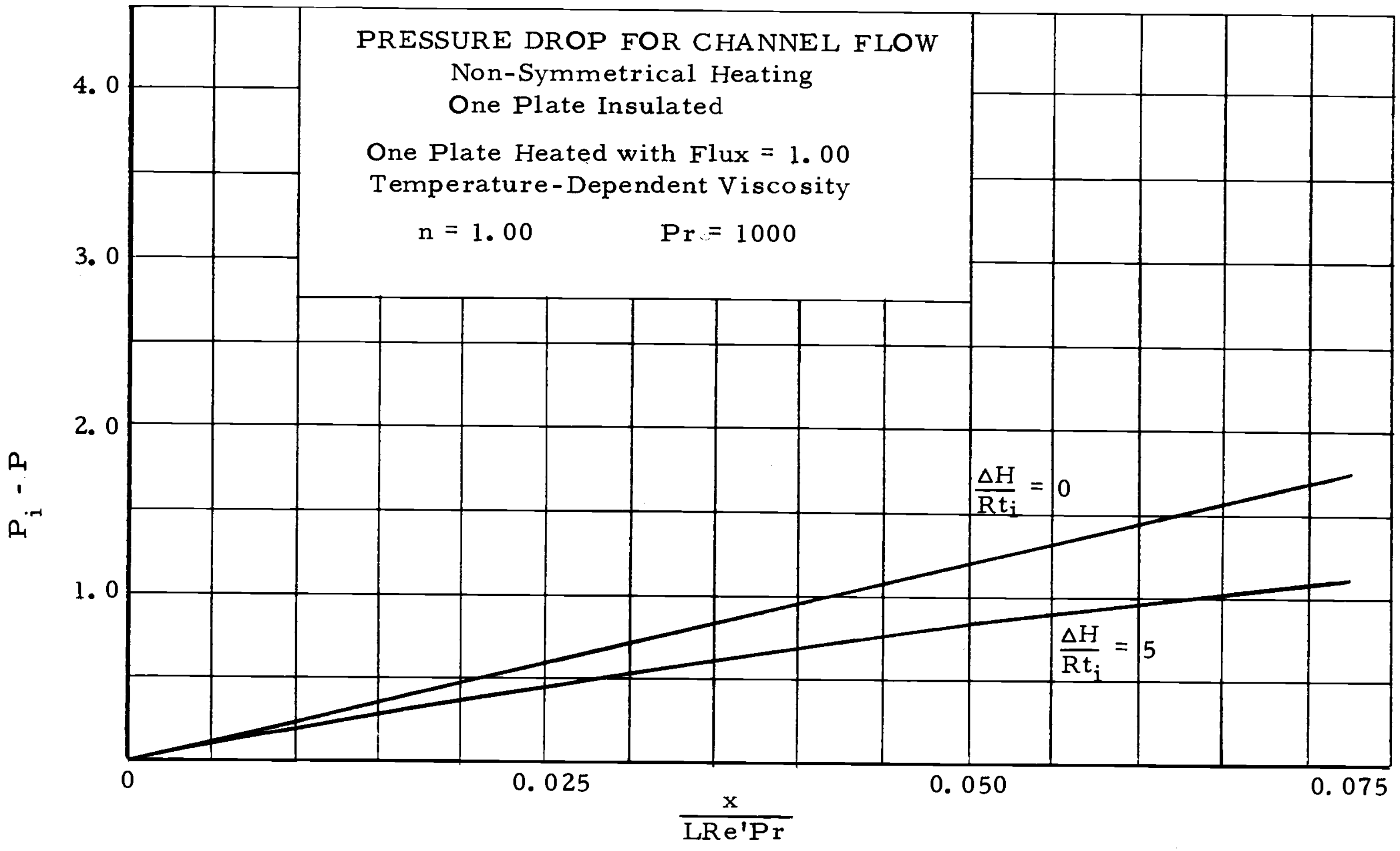

Figure 26. Pressure drop for non-symmetrical heating - n = 1.00.

Figures 25 and 26 call for one wall insulated and one wall uniformly heated. The two fluid conditions are for $n = 1.00$ and temperature-independent viscosity in one case and temperature-dependent viscosity in the other. In Figure 25 are shown the two wall temperatures and the mean temperature. Since the flux has the same value, the mean temperature is the same for both cases. The temperature of the insulated wall is the same in both cases, but the temperature of the heated wall is approximately four percent lower at $x/(LRe'Pr) = 0.0725$ for the temperature-dependent condition used. To convert that to temperature difference instead of dimensionless temperature, one may assume, for sake of illustration, a reasonable inlet temperature of 500°R; with that inlet temperature, the temperature of the heated wall at $x/(LRe'Pr) = 0.0725$ is 750°R for temperature-independent viscosity and 720°R for temperature-dependent viscosity. The pressure drop results in Figure 26 show a large difference because of the temperature-dependent viscosity. The pressure drop from the inlet to $x/(LRe'Pr) = 0.0725$ is approximately 66 percent as great for the temperature-dependent situation as for the case of temperature-independent viscosity.

As is true for pipe flow, unfavorable combinations of the parameters produce an unstable solution. Once again no theoretical basis is known for determination of an appropriate grid for stability; a suitable grid size must be arrived at empirically.

IV. CONCLUSIONS

1. A numerical solution is presented for the coupled energy and momentum equations for laminar flow of temperature-dependent power-law non-Newtonian fluids. Two important geometrical cases are considered: pipe flow and channel flow between two flat, parallel plates. For pipe flow, axially varying wall temperature or heat flux boundary conditions may be handled. Similarly, for channel flow, non-symmetrical and non-uniform thermal boundary conditions may be imposed.

2. For heating of a liquid with temperature-dependent viscosity, the Nusselt number is shown to be greater than for a liquid with temperature-independent viscosity, and the pressure drop is shown to be smaller than for a liquid with no viscosity-temperature dependence. Both the heat transfer and the pressure drop effects of temperature-dependent viscosity are sufficiently large to merit consideration in many design situations.

3. A major problem in applying the present solution is selection of an appropriate grid size to produce a stable solution. Since theoretical criteria for determination of an appropriate grid are not known, the grid size for a stable solution with a given set of conditions must be arrived at empirically.

V. RECOMMENDATIONS FOR FURTHER INVESTIGATION

1. The solution presented is suitable or readily adapted for investigation of a number of important situations which were not covered in this report. Cooling, viscous dissipation, and combined hydrodynamic-thermal entry length problems are a few important applications for which the numerical solution presented here should be suitable. In addition, problems with non-uniform thermal boundary conditions can be realistically solved.

2. As for any analytical solution, careful laboratory checking of the results is recommended.

3. Since selection of a suitable grid size for stable numerical solution must now be done empirically, criteria for selection of an appropriate grid need to be established.

4. An interesting extension of the work reported here is the three-dimensional problem involved in accounting for circumferential variation of the thermal boundary conditions for pipe flow. For example, any application where there is thermal radiation to pipes is likely to cause such circumferential variations.

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APPENDIX I

COMPLETE TOPICAL LISTING OF THE LITERATURE

The numbers used below indicate the corresponding paper listed in the Bibliography.

Geometry

Pipe: 6, 7, 8, 9. 11, 13, 14, 19, 21, 23, 24, 26, 27, 29, 31, 32, 34, 35, 36

Channel: 4, 14, 16, 17, 18, 22, 36, 41

Entry Region

Thermal: 6, 7, 8, 9, 22, 23, 24, 26, 27, 31, 32, 34, 35, 36

Hydrodynamic: 4, 16, 17, 22, 24, 27, 34

Combined: 13, 14, 16, 18, 21, 22, 24, 27, 34, 41

Thermal Boundary Condition

Uniform Temperature: 6, 7, 8, 9, 13, 16, 18, 21, 22, 24, 27, 29, 34, 36, 41

Uniform Heat Flux: 14, 16, 18, 23, 26, 27, 35

Non-Uniform Temperature: 19, 22, 36

Non-Uniform Heat Flux: 19, 31, 32

Temperature Effect on Viscosity

Temperature-Independent: 4, 6, 7, 8, 9, 14, 16, 17, 18, 19, 22, 24, 26, 27, 34, 35, 36, 41

Temperature-Dependent: 6, 7, 8, 13, 22, 23, 24, 29, 34

APPENDIX II

DETAILS OF THE SIMPLIFICATION OF THE DIFFERENTIAL EQUATIONS AND CONVERSION TO NUMERICAL EQUATIONS

Simplification of the Differential Equations

In this section of Appendix II a number of basic assumptions are made, the equations of change subject to those assumptions are given, the equations are further simplified by additional assumptions and approximations, and then the equations are converted to dimensionless form.

The following assumptions allow reduction of the basic equations of change in cylindrical-coordinates as given by Bird, Stewart, and Lightfoot (3, p. 319, p. 83-91) to more concise form:

1. The flow is steady, incompressible, and laminar.
2. Symmetry about the centerline of the pipe exists.
3. Body forces are neglected.
4. The thermal conductivity and specific heat are uniform.

For the preceding conditions to be applicable the governing differential equations which apply to this problem are as follows:

Energy Equation:

$$\rho C_p \left[u\frac{\partial t}{\partial x} + v\frac{\partial t}{\partial r} \right] = k\left[\frac{1}{r} \frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right) + \frac{\partial^2 t}{\partial x^2} \right] + \eta\frac{I_2}{2}$$

Momentum Equations:

$$\rho\left[u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial r}\right] = -\frac{\partial p}{\partial x} - \left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rx}) + \frac{\partial \tau_{xx}}{\partial x}\right]$$

$$\rho\left[u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial r}\right] = -\frac{\partial p}{\partial r} - \left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rr}) + \frac{\partial \tau_{rx}}{\partial x}\right]$$

Continuity Equation:

$$\frac{\partial(rv)}{\partial r} + r\frac{\partial u}{\partial x} = 0$$

The energy equation can be further condensed by assuming that axial diffusion of thermal energy (axial heat conduction) is negligible, i.e.,

$$\frac{\partial^2 t}{\partial x^2} << \frac{\partial^2 t}{\partial r^2} .$$

With that simplification, the energy equation can be written as follows:

$$\rho C_p\left[u\frac{\partial t}{\partial x} + v\frac{\partial t}{\partial r}\right] = k\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right)\right] + \eta\frac{I_2}{2} = k\left[\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r}\right] + \eta\frac{I_2}{2}$$

In reducing the momentum equations to tractable form, uniformity of pressure at any cross-section of the pipe is assumed. Then $\frac{\partial p}{\partial r}$ and all other terms in the r-component of momentum equation are assumed to be negligibly small compared to the terms in the x-component equation. Thus only the x-component of momentum is considered further, and $\frac{\partial p}{\partial x}$ is written as $\frac{dp}{dx}$.

Substitution of the appropriate expressions from Bird, Stewart, and Lightfoot (3, p. 89) for the shear stress components for an incompressible fluid

$$\tau_{rx} = -\eta\left(\frac{\partial u}{\partial r} + \frac{\partial v}{\partial x}\right)$$

and

$$\tau_{xx} = -\eta\left(2\frac{\partial u}{\partial x}\right)$$

into the x-component of momentum equation, differentiation, and grouping of terms produces the following equation:

$$\rho\left[u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial r}\right] = -\frac{dp}{dx} + \eta\left[\frac{\partial^2 u}{\partial r^2} + \frac{\partial^2 u}{\partial x^2}\right] + \frac{\eta}{r}\frac{\partial u}{\partial r}$$

$$+ \frac{\partial \eta}{\partial r}\left[\frac{\partial u}{\partial r} + \frac{\partial v}{\partial x}\right] + 2\frac{\partial \eta}{\partial x}\frac{\partial u}{\partial x}$$

$$+ \eta\frac{\partial}{\partial x}\left[\frac{1}{r}\frac{\partial (rv)}{\partial r} + \frac{\partial u}{\partial x}\right].$$

The operand in the last term is the divergence of velocity which is identically zero for incompressible flow; therefore, the entire last term is identically zero also.

Two other terms may be dropped by an order of magnitude argument. Changes in u are large relative to changes in the smaller transverse velocity v and occur over a distance (with maximum value equal to $\frac{D}{2}$) which is small compared to distance of interest in the axial direction. Thus the assumption is made that

$$\frac{\partial u}{\partial r} >> \frac{\partial v}{\partial x} .$$

Similarly the changes of u in the radial direction are relatively large compared to the changes of u in the axial direction; certainly then the second derivatives in the respective directions are expected to be of different order of magnitude:

$$\frac{\partial^2 u}{\partial r^2} >> \frac{\partial^2 u}{\partial x^2} .$$

In addition the terms $\partial\eta/\partial x$ and $\partial u/\partial x$ are individually small compared to the other terms in the equation; therefore, their product is deleted from the equation. With the simplifications indicated above the resulting momentum equation is

$$\rho[u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial r}] = -\frac{dp}{dx} + \eta\frac{\partial^2 u}{\partial r^2} + \frac{\eta}{r}\frac{\partial u}{\partial r} + \frac{\partial\eta}{\partial r}\frac{\partial u}{\partial r} .$$

To convert the equations of change to dimensionless form, the following set of dimensionless variables is used:

$$X = \frac{x}{DRePr} \qquad\qquad R = \frac{r}{D}$$

$$U = \frac{u}{\overline{u}} \qquad V = \frac{v}{\overline{u}} RePr$$

$$P = \frac{p}{\rho \overline{u}^2 Pr} \qquad S = \frac{\eta}{\eta_i}$$

$$T = \frac{t}{t_i} \qquad \Phi = (\frac{D}{\overline{u}})^2 \frac{I_2}{2}$$

Substitution of the indicated dimensionless variables into the equations of change and reduction to well-known dimensionless parameters produces the set of dimensionless equations of change. In dimensionless form the governing equations are as follows:

Energy Equation:

$$U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial R} = \frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} + BrS\Phi$$

Momentum Equation:

$$\frac{1}{Pr}\left[U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial R}\right] = -\frac{dP}{dX} + S\frac{\partial^2 U}{\partial R^2} + \frac{S}{R}\frac{\partial U}{\partial R} + \frac{\partial S}{\partial R}\frac{\partial U}{\partial R}$$

Continuity Equation:

$$\frac{\partial (RV)}{\partial R} + R\frac{\partial U}{\partial X} = 0$$

The integral form of the continuity equation in dimensional terms is

$$2\pi \int_0^{D_i/2} urdr = \bar{u}\frac{\pi D^2}{4} .$$

Substitution of the appropriate dimensionless variables yields

$$8 \int_0^{1/2} URdR = 1.$$

The term $I_2/2$ (second invariant of the rate of strain matrix) is used in both the calculation of apparent viscosity and in consideration of viscous dissipation. It can be simplified as follows:

$$\frac{I_2}{2} = [\frac{\partial v}{\partial x} + \frac{\partial u}{\partial r}]^2 + 2[(\frac{\partial u}{\partial x})^2 + (\frac{v}{r})^2 + (\frac{\partial v}{\partial r})^2] .$$

As was done for the momentum equation, order of magnitude arguments are used to eliminate some of the terms. The argument to show that

$$\frac{\partial u}{\partial r} >> \frac{\partial v}{\partial x}$$

was given in reducing the momentum equation. Further, changes in the axial direction of the velocity in the direction of flow, are expected to be small compared to changes in the radial direction, and the transverse velocity v is likely to be small enough so that neither its quotient with the radial distance, v/r, nor its derivative in the radial direction are significant compared to $\partial u/\partial r$. By that reasoning one justifies the assumption that

$$(\frac{\partial u}{\partial r})^2 >> 2 [(\frac{\partial u}{\partial x})^2 + (\frac{v}{r})^2 + (\frac{\partial v}{\partial r})^2] .$$

Therefore, a good approximation is obtained by using

$$\frac{I_2}{2} = (\frac{\partial u}{\partial r})^2 .$$

The dimensionless form is denoted by

$$\Phi = (\frac{D}{\bar{u}})^2 \frac{I_2}{2} = (\frac{\partial U}{\partial R})^2 .$$

The constitutive equation

$$\eta = \frac{T}{\dot{\gamma}} = me^{n\frac{\Delta H}{Rt}} \dot{\gamma}^{n-1} = me^{n\frac{\Delta H}{Rt}} (\frac{I_2}{2})^{\frac{n-1}{2}}$$

(6, 7, 8, 3, p. 103) is converted to dimensionless form by dividing by a reference value for the apparent viscosity. The reference value is selected for convenience; for the present investigation the apparent viscosity at the pipe wall and at the inlet temperature was selected and used for the reference value. The reference apparent viscosity is then defined by

$$\eta_i = me^{n\frac{\Delta H}{Rt_i}} (\frac{\partial u}{\partial r})^{n - 1} \text{ at wall}$$

Differentiation of the expression for fully developed velocity (40, p. 62)

$$u = \overline{u}(\frac{3n + 1}{n + 1}) [1 - (\frac{r}{\frac{D}{2}})^{\frac{n + 1}{n}}]$$

and substitution of $r = \frac{D}{2}$ yields

$$\eta_i = me^{n\frac{\Delta H}{Rt_i}} (\frac{2\overline{u}}{D} \frac{3n + 1}{n})^{n - 1} .$$

The dimensionless apparent viscosity is then evaluated as

$$S = \frac{\eta}{\eta_i} = e^{n\frac{\Delta H}{Rt_i}(\frac{1}{T} - 1)} \left[\frac{\sqrt{I_2/2}}{2\frac{\overline{u}}{D} \frac{3n + 1}{n}} \right]^{n - 1}$$

$$= e^{n\frac{\Delta H}{Rt_i}(\frac{1}{T} - 1)} \left[\frac{\Phi}{4(\frac{3n + 1}{n})^2} \right]^{\frac{n - 1}{2}} .$$

<u>Numerical Equations</u>

In this part of Appendix II the numerical equations are written and, concurrently, the consistency of the numerical representations is demonstrated by indicating the magnitude of the discretization error.

The order of the error may be determined by expansion of each term in the numerical representation in a Taylor's series (37, p. 6) although the details for doing so are not shown. The symbol $O(\Delta X^2)$ is used in its conventional sense to mean a remainder with terms having factors of $(\Delta X)^2$ and higher powers of ΔX.

For the dimensionless energy equation

$$U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial R} = \frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} + BrS\Phi$$

the numerical representation is written by taking central differences about the point where $T(2, J)$ is defined (Figure 2). If a quantity is not defined at a point, the arithematic average at the adjacent points is used. The Crank-Nicolson representation for the second derivative is used.

$$\frac{\partial^2 T}{\partial R^2} \approx \frac{1}{2}\left[\frac{T(3, J-1) - 2T(3, J) + T(3, J+1)}{(\Delta R)^2} + \frac{T(1, J-1) - 2T(1, J) + T(1, J+1)}{(\Delta R)^2}\right]$$

$$= \frac{\partial^2 T}{\partial R^2} + O(\Delta X^2) + O(\Delta R^3)$$

$$U \approx \frac{U(2, J) + U(1, J)}{2} = U + O(\Delta X^2)$$

$$\frac{\partial T}{\partial X} \approx \frac{T(3, J) - T(1, J)}{2\Delta X} = \frac{\partial T}{\partial X} + O(\Delta X^2)$$

$$V \approx \frac{V(2, J) + V(2, J - 1)}{2} = V + O(\Delta R^2)$$

$$\frac{\partial T}{\partial R} \approx \frac{T(2, J - 1) - T(2, J + 1)}{2\Delta R} = \frac{\partial T}{\partial R} + O(\Delta R^2)$$

Substitution of the numerical representations into the energy equation yields a set of linear equations in the unknown temperatures $T(3, J)$:

$$T(3, J - 1) - B1(J)T(3, J) + B2(J)T(3, J + 1) = B3(J)$$

The coefficients $B1$, $B2$, and $B3$ are functions of previously-calculated quantities. Solving for the error indicates a discretization error of $O(\Delta X^2) + O(\Delta R^2)$.

For numerical representation of the momentum equation

$$\frac{1}{Pr}\left[U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial R}\right] = -\frac{dP}{dX} + S\frac{\partial^2 U}{\partial R^2} + \frac{S}{R}\frac{\partial U}{\partial R} + \frac{\partial S}{\partial R}\frac{\partial U}{\partial R}$$

the central difference equations are written about the point where $U(2, J)$ is defined.

$$\frac{\partial^2 U}{\partial R^2} \approx \frac{1}{2}\left[\frac{U(3,J-1) - 2U(3,J)+U(3,J+1)}{(\Delta R)^2} + \frac{U(1,J-1) - 2U(1,J)+U(1,J+1)}{(\Delta R)^2}\right]$$

$$= \frac{\partial^2 U}{\partial R^2} + O(\Delta X^2) + O(\Delta R^3)$$

$$\frac{\partial U}{\partial X} \approx \frac{U(3, J) - U(1, J)}{2\Delta X} = \frac{\partial U}{\partial X} + O(\Delta X^2)$$

$$V \approx \frac{1}{4}[V(3, J) + V(2, J) + V(3, J-1) + V(2, J-1)]$$

$$= V + O(\Delta X^2) + O(\Delta R^2)$$

$$\frac{dP}{dX} \approx \frac{\Delta P}{\Delta X} = \frac{dP}{dX} + O(\Delta X^2)$$

$$S \approx \frac{S(3, J) + S(2, J)}{2} = S + O(\Delta X^2)$$

$$\frac{\partial S}{\partial R} \approx \frac{S(2, J-1) + S(3, J-1) - S(2, J+1) - S(3, J+1)}{4\Delta R}$$

$$= \frac{\partial S}{\partial R} + O(\Delta X^2) + O(\Delta R^2)$$

Substitution of the numerical representations into the momentum equation yields a set of pseudo-linear algebraic equations in the unknown velocities and the pressure drop:

$$U(3, J-1) - B1(J)U(3, J) + B2(J)U(3, J+1) - B3(J)\Delta P = B4(J)$$

The equations are not actually linear because the coefficients B1, B2, B3, and B4 contain S(3, J) which is a function of the unknown velocities (via the shear rate) for a non-Newtonian fluid. However, a good estimate of S(3, J) can be made by substituting S(2, J) when calculating the first estimate of the velocities. An iterative solution is formed by calculating S(3, J) from the velocities then recalculating the velocities. Solving for the error in the representation gives a discretization error of $O(\Delta X^2) + O(\Delta R^2)$.

APPENDIX III

ELIMINATION PROCEDURES FOR SOLVING ENERGY AND MOMENTUM EQUATIONS

Energy Equation

The set of simultaneous linear equations derived from the energy equation plus boundary conditions when written in matrix notation is

$$\overline{B}\,\overline{T} = \overline{B3}$$

The terms $\overline{T}$ and $\overline{B3}$ as used here are vectors, and $\overline{B}$ is a tri-diagonal matrix of coefficients. Since $\overline{B}$ is tri-diagonal the solution for the unknown T(3, J) is possible by straight-forward application of the Gauss elimination method. Written out explicitly the set of equations has the following form.

$$-B1(1)T(3,1)+B2(1)T(3,2) = B3(1)$$

$$T(3,1)-B1(2)T(3,2)+B2(2)T(3,3) = B3(2)$$

$$T(3,2)-B1(2)T(3,3)+B2(3)T(3,4) = B3(3)$$

$$\vdots$$

$$T(3,N-2)-B1(N-1)T(3,N-1)+B2(N-1)T(3,N) = B3(N-1)$$

$$T(3,N-1)-B1(N)T(3,N) = B3(N)$$

The elimination procedure is initiated by defining

$$\alpha(1) = -\frac{B2(1)}{B1(1)}$$

and

$$\beta(1) = -\frac{B3(1)}{B1(1)}.$$

For $J > 1$

$$\alpha(J) = -\frac{B2(J)}{B1(J) + \alpha(J-1)}$$

and

$$\beta(J) = -\frac{B3(J) - \beta(J-1)}{B1(J) + \alpha(J-1)}$$

Finally the result is

$$T(3, N) = \beta(N)$$

The other temperatures are then found by back-substitution into the equation

$$T(3, J) = \beta(J) - \alpha(J)T(3, J+1).$$

Momentum Equation

The set of momentum equations with the integral form of the continuity equation appended to it may be written as follows (The continuity equation is written first.):

$$B5(2)R(2)U(3,2)+\ldots \qquad +B5(N-1)R(N-1)U(3,N-1) = 1/8$$

$$-[B1(2)+1]\,U(3,2)+B2(2)U(3,3) \qquad -B3(2)\Delta P = B4(2)$$

$$U(3,2)-B1(3)U(3,3)+B2(3)U(3,4) \qquad -B3(3)\Delta P = B4(3)$$

$$U(3,3)-B1(4)U(3,4)+B2(4)U(3,4)-B3(4)\Delta P = B4(4)$$

$$\vdots$$

$$U(3,N-3)-B1(N-2)U(3,N-2)+B2(N-2)U(3,N-1)-B3(N-2)\Delta P = B4(N-2)$$

$$U(3,N-2)-[B1(N-1)+B2(N-1)]\,U(3,N-1)-B3(N-1)\Delta P = B4(N-1)$$

Application of the elimination method in this case is not so straightforward as it is in solving for temperatures. Not all elimination methods work because of loss of significant figures, and iterative methods give only fair results while using tremendous amounts of computer time. The following elimination method solves the equations far better than iterative methods while using comparatively little computer time.

The procedure actually used redefines the set of B4(J) so that one may solve for

$$\Delta U(J) = U(3,J) - U(2,J)$$

instead of solving for U(3, J).

The set of equations to be solved with that change incorporated is as follows:

$$B5(2)R(2)\Delta U(2)+\ldots \qquad +B5(N-1)R(N-1)\Delta U(N-1) \qquad = 0$$

$$-[B1(2)+1]\,\Delta U(2)+B2(2)\Delta U(3) \qquad -B3(2)\Delta P=B4(2)$$

$$\Delta U(2)-B1(3)\Delta U(3)+B2(3)\Delta U(4) \qquad -B3(3)\Delta P=B4(3)$$

$$\Delta U(3)-B1(4)\Delta U(4)+B2(4)\Delta U(5) \quad -B3(4)\Delta P=B4(4)$$

$$\vdots$$

$$\Delta U(N-3)-B1(N-2)\Delta U(N-2)+B2(N-2)\Delta U(N-1) - B3(N-2)\Delta P=B4(N-2)$$

$$\Delta U(N-2)-[B1(N-1)+B2(N-1)]\,\Delta U(N-1)-B3(N-1)\Delta P=B4(N-1)$$

The elimination procedure is started by defining a set of numbers obtained by dividing the continuity equation by the leading element:

$$\alpha(J) = \frac{B5(J)R(J)}{B5(2)R(2)}$$

for

$$3 \leq J \leq N-1$$

and

$$\alpha(N) = 0.$$

The first momentum equation is then divided by the negative of its first element:

$$\delta(2) = \frac{B2(2)}{B1(2) + 1}$$

$$\gamma(2) = -\frac{B3(2)}{B1(2) + 1}$$

$$\phi(2) = \frac{B4(2)}{B1(2) + 1}$$

That puts the first three equations (the continuity equation and the first two momentum equations) into the following form:

$$\begin{aligned}
&\Delta U(2) + \alpha(3)\Delta U(3) + \ldots + \alpha(N-1)\Delta U(N-1) + \alpha(N)\Delta P = 0 \\
&-\Delta U(2) + \delta(2)\Delta U(3) \qquad\qquad\qquad\qquad + \gamma(2)\Delta P = \phi(2) \\
&\Delta U(2) - B1(3)\Delta U(3) + B2(3)\Delta U(4) \qquad - B3(3)\Delta P = B4(3)
\end{aligned}$$

The second equation is added to each of the other two equations leaving two equations with $\Delta U(2)$ eliminated. The same procedure of dividing by the leading element then reducing the equations is carried out until the result is

$$\Delta U(N-1) + \alpha(N)\Delta P = \sum_{J=2}^{N-2} \phi(J)$$

and

$$-\Delta U(N-1) + \gamma(N-1)\Delta P = \phi(N-1).$$

Then ΔP can be evaluated:

$$\Delta P = \frac{\sum_{J=2}^{N-1} \phi(J)}{\alpha(N) + \gamma(N-1)}$$

Back-substitution for the $\Delta U(J)$ is then begun:

$$\Delta U(N-1) = \gamma(N-1)\Delta P - \phi(N-1)$$

and

$$\Delta U(J) = \gamma(J)\Delta P + \delta(J)\Delta U(J+1) - \phi(J)$$

for

$$N - 2 \leqslant J \leqslant 2.$$

The set of velocities $U(3, J)$ is then obtained by substitution into

$$U(3, J) = \Delta U(J) + U(2, J).$$

APPENDIX IV

FORTRAN PROGRAM FOR PIPE FLOW PROBLEM

FORTRAN PROGRAM FOR PIPE FLOW
CDC 3300

```
      PROGRAM MAIN
      DIMENSION U(3,150),V(3,150),T(3,150),S(3,150),XI202(3,150),
     2FLUX(100 ),B1(150),B2(150),ALPHA(150),BETA(150),B3(150),TBC(100)
     3,      B4(150),B5(150),AF(9,150)
     4,DELTA(150),GAMMA(150),PHI(150),R(150)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DR,E,E2,E3,FLUX,
     2G,ITNO,K,  M,M2,N,NDX,NDRWAL,NTRANS,PR,        R,S,T,TBC,U,V,
     3XI202,XI02R,XN,P,B4,B5,DP,WALLTEMP,      DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3,XNUSS,XNUSSMN,X2
     5,LCARD
  101 FORMAT ( F6.0,     F13.4,F6.0,F6.4,I3,2F8.4,I1)
  201 FORMAT (///5X,2HN=,F8.4,6X,6HDH/RT=,F8.0)
  211 FORMAT (5X,12HPRANDTL NO.=,F8.0,4X,13HBRINKMAN NO.=,F10.4)
  202 FORMAT (5X,10HWALL TEMP=,F10.4)
  204 FORMAT (5X,5HFLUX=,F10.4)
  215 FORMAT (2X,31HITERATION LIMIT REACHED AT NDX=,I5
     2,5X,12HMAX RESIDUE=,E16.6)
      DX=.5E-08
      DDX=4.999995E-03
      A=-115.
C     MAGNITUDE OF A CONTROLS RATE OF INCREASE FOR X INCREMENT
      IPRINT=56
      NDXMX=56
C     IPRINT IS THE NUMBER OF X INCREMENTS BETWEEN PRINTOUTS
      DR=.02
      N=45
      NDRDIV=10
      NDRWAL=2
C     NDRWAL IS THE NUMBER OF R INCREMENTS SUBDIVIDED NEAR THE WALL
C      NDRDIV IS THE NUMBER OF PARTS DR IS BROKEN INTO NEAR THE WALL
      DIV=FLOAT(NDRDIV)
      NTRANS=NDRDIV*NDRWAL
```

```
      ITNMX=20
      G=.001
   75 READ 101,PR,         BRINK,DHRT,XN,K,W1,W2,LCARD
      ITFAIL=0
C     K EQ 1 MEANS FLUX BOUND
C     K EQ 2 MEANS TEMP BOUND
      PRINT 201,XN,DHRT
      PRINT 211,PR,BRINK
C     BOUND COND BELOW IS FOR UNIFORM FLUX OR TEMP
      IF (K .EQ. 1)4,5
    4 PRINT 204,W1
      DO 6 J=1,NDXMX
    6 FLUX(J)=W1
      GO TO 7
    5 PRINT 202,W1
      DO 10 J=1,NDXMX
   10 TBC(J)=W1
    7 CONTINUE
      C=(3.*XN+1.)/(XN+1.)
      E=(XN+1.)/XN
      C2=(3.*XN+1.)/XN
      E2=1./XN
      E3=(XN-1.)/2.
      XI02R=4.*C2**2
      M=N-1
      M2=N-2
      NPRINT=1
      NDX=0
      X=0.
      X2=0.
      DPL=0.
      ITNO=0
      CALL INLTCOND
      DX1=DX
      DX2=DX
      DX3=DX
```

```
      X=DX/2.
      NDX=1
      RESLAST=1000.
   35 CALL TEMPCALC
      CALL SCALC
   36 CALL UANDV
      ITNO=ITNO+1
      CALL SCALC
      RESMX=0.
      DO 43 J=2,M
      VISC=(S(3,J  )+S(2,J  ))/2.
      DUDR=(U(2,J-1)-U(2,J+1))/AF(4,J)
      IF (J .EQ. 2)39,40
   39 DSDR=(S(3,2)-S(3,3)+S(2,2)-S(2,3))*DIV/(2.*DR)
      GO TO 41
   40 DSDR=(S(3,J-1)-S(3,J+1)+S(2,J-1)-S(2,J+1))/(2.*AF(4,J))
   41 RES=ABS(VISC*(U(3,J-1)+U(1,J-1)+B2(J)*(U(3,J+1)+U(1,J+1))
     2-AF(1,J)*(U(3,J)+U(1,J)))/(2.*AF(2,J))
     3+VISC/AF(9,J)*DUDR+DSDR*DUDR-2.*DPA/(DX2+DX3)
     4-U(2,J)*(U(3,J)-U(1,J))/(DX2+DX3)/PR
     5-(V(3,J)+V(2,J)+V(3,J-1)+V(2,J-1))/4.*DUDR/PR)
      IF (RES .GT. RESMX)47,43
   47 RESMX=RES
   43 CONTINUE
      IF (RESMX .LT. .5    .AND. RESLAST .LT. .5
     2.AND. RESMX .LE. RESLAST)42,51
   51 RESLAST=RESMX
      IF (ITNO .LT. ITNMX)36,52
   52 PRINT 215,NDX,RESMX
      IF (ITFAIL .GE. 1)45,50
   50 ITFAIL=ITFAIL+1
   42 CONTINUE
      TM3=U(3,2)*T(3,2)*R(2)*B5(2)*2.+(U(3,2)*T(3,2)*R(2)
     2+U(3,3)*T(3,3)*R(3))*(B5(2)+B5(3))
      DO 95 J=3,M
      Q=(B5(J-1)+B5(J))/2.
```

```
      B=(B5(J+1)+B5(J))/2.
      Z1=U(3,J-1)*R(J-1)*T(3,J-1)
      Z2=U(3,J  )*R(J  )*T(3,J  )
      Z3=U(3,J+1)*R(J+1)*T(3,J+1)
      ZA=(B*(Z1-Z2)+Q*(Z3-Z2))/(Q**2*B+B**2*Q)
      ZB=(B**2*(Z2-Z1)+Q**2*(Z3-Z2))/(Q**2*B+B**2*Q)
      TM3=TM3  +(ZA/3.*(B**3+Q**3)+ZB/2.*(B**2-Q**2)+Z2*(Q+B))*4.
   95 CONTINUE
C     NUSSELT NO CALC BELOW IS FOR NO VISCOUS DISSIPATION
      IF (NDX .EQ. 1)96,97
   97 NM1=NDX-1
      IF (K  .EQ. 1)53,54
   53 WALLTEMP=(T(2,1)+T(2,2))/2.
      XNUSS=FLUX(NM1)      /(WALLTEMP-TM2)
  220 FORMAT (/2X,5HAT X=,E16.6,2X,15HNUSSELT NUMBER=,E15.6,2X
     2,10HMEAN TEMP=,E16.6,2X,10HWALL TEMP=,E16.6)
      PRINT 220,X2,XNUSS,TM2,WALLTEMP
      GO TO 96
   54 CONTINUE
      XNUSS=      ((DX3*TM2+DX2*TM3)/(DX3+DX2)-(DX2*TM1+DX1*TM2)
     2/(DX2+DX1))/(DX2*(TBC(  NM1)-TM2))/4.
C     CALC FOR MEAN NUSS NO FOR UNIFORM WALL TEMP ONLY
      XNUSSMN=      ALOG((TBC(  NM1)-1.)/(TBC(  NM1)-TM2))/(4.*X2)
  217 FORMAT (/2X,5HAT X=,E16.6,2X,15HNUSSELT NUMBER=,E16.6,2X
     2,10HMEAN TEMP=,E16.6,2X,20HMEAN NUSSELT NUMBER=,E16.6)
      PRINT 217,X2,XNUSS,TM2,XNUSSMN
   96 CONTINUE
      IF (NDX .GE. 2)500,501
  500 DELTP=2.*DPL/(DX1+DX2)
  502 FORMAT (2X,2HP=,E16.6,2X,3HDP=,E16.6,2X,6HDP/DX=,E16.5)
      PRINT 502,P,DPL,DELTP
  501 CONTINUE
      DPL=DPA
      P=P+DPA
      IF (NDX .EQ. IPRINT*NPRINT)22,23
   22 CALL OUTPUT
```

```
      NPRINT=NPRINT+1
   23 IF (NDX .LT. NDXMX)60,45
   60 TM1=TM2
      TM2=TM3
      DO 46 J=1,N
      T(1,J)=T(2,J)
      T(2,J)=T(3,J)
      U(1,J)=U(2,J)
      U(2,J)=U(3,J)
      V(1,J)=V(2,J)
      V(2,J)=V(3,J)
      S(1,J)=S(2,J)
      S(2,J)=S(3,J)
      XI202(1,J)=XI202(2,J)
   46 XI202(2,J)=XI202(3,J)
      NDX=NDX+1
      DX1=DX2
      DX2=DX3
      DX3=DX+DDX*(1.-EXPF(A*X))
      X2=X
      X=X+(DX3+DX2)/2.
      ITNO=0
      RESLAST=1000.
      GO TO 35
   45 IF (LCARD .EQ. 0)44,75
   44 CONTINUE
      END

      SUBROUTINE INLTCOND
      DIMENSION U(3,150),V(3,150),T(3,150),S(3,150),XI202(3,150),
     2FLUX(100 ),B1(150),B2(150),ALPHA(150),BETA(150),B3(150),TBC(100)
     3,       B4(150),B5(150),AF(9,150)
     4,DELTA(150),GAMMA(150),PHI(150),R(150)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DR,E,E2,E3,FLUX,
     2G,ITNO,K,   M,M2,N,NDX,NDRWAL,NTRANS,PR,       R,S,T,TBC,U,V,
     3XI202,XIO2R,XN,P,B4,B5,DP,WALLTEMP,      DPA,DX1,DX2,DX3,X,DPDX
```

```
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3,XNUSS,XNUSSMN,X2
     5,LCARD
      DO 1 J=1,N
      V(1,J)=0.
      V(2,J)=0.
      V(3,J)=0.
      T(1,J)=1.
      T(2,J)=1.
    1 T(3,J)=1.
      R(1)=.5+DR/DIV/2.
      DO 2 J=2,M
      IF (J .LE. NTRANS+1)360,361
  360 R(J)=.5-(J-1)*DR/DIV+DR/(2.*DIV)
      B5(J)=DR/DIV
      GO TO 362
  361 R(J)=.5-NDRWAL*DR-(J-1-NTRANS)*DR+DR/2.
      B5(J)=DR
  362 U(1,J)=C*(1.-(2.*R(J))**E)
      U(2,J)=U(1,J)
      U(3,J)=U(1,J)
      XI2O2(1,J)=XIO2R*(2.*R(J))**(2.*E2)
      XI2O2(2,J)=XI2O2(1,J)
      XI2O2(3,J)=XI2O2(1,J)
      ARG2=ABSF(XN-1.)
      IF (ARG2 .LT. .000001)3,9
    3 S(1,J)=1.
      GO TO 5
    9 IF (XI2O2(1,J)    .LT. G*XIO2R)7,4
    7 S(1,J)=G**E3
      GO TO 5
    4 S(1,J)=(2.*R(J))**(1.-E2)
    5 S(2,J)=S(1,J)
      S(3,J)=S(1,J)
    2 CONTINUE
      B5(1)=B5(2)
      B5(N)=B5(M)
```

```
      R(N)=R(M)
      S(1,N)=S(1,M)
      S(2,N)=S(1,M)
      S(3,N)=S(1,M)
      U(1,1)=-U(1,2)
      U(1,N)= U(1,M)
      U(2,1)=-U(1,2)
      U(3,1)=-U(1,2)
      U(2,N)=U(1,M)
      U(3,N)=U(1,M)
      UAVG=2.*U(3,2)*R(2)*B5(2)+(U(3,2)*R(2)+U(3,3)*R(3))*(B5(2)+B5(3))
      DO 620 J=3,M
      A=(B5(J-1)+B5(J))/2.
      B=(B5(J+1)+B5(J))/2.
      Z1=U(3,J-1)*R(J-1)
      Z2=U(3,J  )*R(J  )
      Z3=U(3,J+1)*R(J+1)
      ZA=(B*(Z1-Z2)+A*(Z3-Z2))/(A**2*B+B**2*A)
      ZB=(B**2*(Z2-Z1)+A**2*(Z3-Z2))/(A**2*B+B**2*A)
      UAVG=UAVG+(ZA/3.*(B**3+A**3)+ZB/2.*(B**2-A**2)+Z2*(A+B))*4.
  620 CONTINUE
  221 FORMAT (5X,17HAVERAGE VELOCITY=,E20.10)
      PRINT 221,UAVG
      TM1=1.
      TM2=1.
      TM3=1.
      DPDX=8.*C2
  314 FORMAT (5X,6HDP/DX=,E15.6)
      PRINT 314,DPDX
      P=0.
      DO 600 J=2,M
      IF (J.LE. NTRANS)601,602
  601 AF(1,J)=2.
      AF(2,J)=(DR/DIV)**2
      AF(3,J)=DR/DIV
      AF(4,J)=2.*DR/DIV
```

```
      AF(5,J)=.5
      AF(6,J)=.5
      AF(7,J)=.5
      AF(8,J)=.5
      AF(9,J)=R(J)
      B2(J)=1.
      IF (J .EQ. 2)611,600
  611 AF(2,J)=AF(2,J)*3./4.
      AF(3,J)=AF(3,J)*3./4.
      GO TO 600
  602 IF (J .GE. NTRANS+3)603,604
  603 AF(1,J)=2.
      AF(2,J)=DR**2
      AF(3,J)=DR
      AF(4,J)=2.*DR
      AF(5,J)=.5
      AF(6,J)=.5
      AF(7,J)=.5
      AF(8,J)=.5
      AF(9,J)=R(J)
      B2(J)=1.
      GO TO 600
  604 IF (J .EQ. NTRANS+1)609,610
  609 AF(1,J)=(DIV+3.)/(DIV+1.)
      AF(2,J)=(DIV+3.)*(DR/DIV)**2/4.
      AF(3,J)=DR/DIV
      AF(4,J)=(DIV+3.)*DR/(2.*DIV)
      AF(5,J)=.5
      AF(6,J)=.5
      AF(7,J)=1./(DIV+1.)
      AF(8,J)=DIV/(DIV+1.)
      AF(9,J)=(R(J+1)+R(J-1))/2.
      B2(J)=2./(DIV+1.)
      IF (J .EQ. 2)612,600
  612 AF(2,J)=AF(2,J)*3./4.
      AF(3,J)=AF(3,J)*3./4.
```

```
      GO TO 600
  610 AF(1,J)=(3.*DIV+1.)/(2.*DIV)
      AF(2,J)=(3.*DIV+1.)*(DIV+1.)*(DR/DIV)**2/8.
      AF(3,J)=(DIV+1.)*DR/(2.*DIV)
      AF(4,J)=(3.*DIV+1.)*DR/( 2.*DIV)
      AF(5,J)=1./(DIV+1.)
      AF(6,J)=DIV/(DIV+1.)
      AF(7,J)=.5
      AF(8,J)=.5
      AF(9,J)=(R(J+1)+R(J-1))/2.
      B2(J)=(DIV+1.)/(2.*DIV)
  600 CONTINUE
      RETURN
      END

      SUBROUTINE TEMPCALC
      DIMENSION U(3,150),V(3,150),T(3,150) ,S(3,150),XI202(3,150),
     2FLUX(100 ),B1(150),B2(150),ALPHA(150),BETA(150),B3(150),TBC(100)
     3,      B4(150),B5(150),AF(9,150)
     4,DELTA(150),GAMMA(150),PHI(150),R(150)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DR,E,E2,E3,FLUX,
     2G,ITNO,K,  M,M2,N,NDX,NDRWAL,NTRANS,PR,       R,S,T,TBC,U,V,
     3XI202,XIO2R,XN,P,B4,B5,DP,WALLTEMP,      DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3,XNUSS,XNUSSMN,X2
     5,LCARD
      D1=DX2+(DX1+DX3)/2.
      DO 92 J=2,M
      R1=AF(1,J)
      R2=AF(2,J)
      R4=AF(3,J)
      RAD=AF(9,J)
      B1(J)=R1+R2     *(U(1,J)+U(2,J))/D1
      B3(J)=R4      *(V(2,J)+V(2,J-1))*(T(2,J-1)-T(2,J+1))/2.
     2-2.*R2*BRINK*S(2,J-1)*XI202(2,J-1)-T(1,J-1)-B2(J)*T(1,J+1)
     3+(R1-R2     *(U(1,J)+U(2,J))/D1      )*T(1,J)
     4-R4/RAD *(T(2,J-1)-T(2,J+1))
```

```
   92 CONTINUE
C     T(3,J-1)-B1(J)*T(3,J)+B2(J)*T(3,J+1)=B3(J)
      IF (K .EQ. 1)50,51
   51 B1(1)=-1.
      B2(1)=1.
      B3(1)=2.*TBC(NDX)
      GO TO 52
   50 B1(1)=-1.
      B2(1)=-1.
      B3(1)=DR/DIV    *FLUX(NDX)
   52 CONTINUE
      B1(N)=1.
      B2(N)=0.
      B3(N)=0.
      ALPHA(1)=-(B2(1)/B1(1))
      BETA(1)=-(B3(1)/B1(1))
      DO 93 J=2,N
      ALPHA(J)=B2(J)/(-B1(J)-ALPHA(J-1))
   93 BETA(J)=(B3(J)-BETA(J-1))/(-B1(J)-ALPHA(J-1))
      T(3,N)=BETA(N)
      DO 94 J=1,M
      NMJ=N-J
   94 T(3,NMJ)=BETA(NMJ)-ALPHA(NMJ)*T(3,NMJ+1)
      IF (NDX .EQ. 3 .OR. NDX .EQ. 4)30,31
   30 IF (K .EQ. 2)32,31
   32 SLOPE=ABS(T(3,2)-TBC(   NDX))/(DR/DIV/2.)
      SLPLST=SLOPE
      DO 34 J=3,M
      SLOPE=ABS(T(3,J)-TBC(   NDX))/   (.5-R(J))
      IF (SLOPE .LE. SLPLST)38,39
   39 SLPLST=SLOPE
   34 CONTINUE
   38 J=J-1
      ZREF=.5-R(J)
      TREF=T(3,J)-TBC(NDX)
      J2=J-1
```

```
      DO 43 J=2,J2
   43 T(3,J)=TBC(NDX)+(.5-R(J))/ZREF*TREF
      T(3,1)=2.*TBC(   NDX)-T(3,2)
   31 CONTINUE
      RETURN
      END

      SUBROUTINE SCALC
      DIMENSION U(3,150),V(3,150),T(3,150),S(3,150),XI2O2(3,150),
     2FLUX(100 ),B1(150),B2(150),ALPHA(150),BETA(150),B3(150),TBC(100)
     3,       B4(150),B5(150),AF(9,150)
     4,DELTA(150),GAMMA(150),PHI(150),R(150)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DR,E,E2,E3,FLUX,
     2G,ITNO,K,  M,M2,N,NDX,NDRWAL,NTRANS,PR,       R,S,T,TBC,U,V,
     3XI2O2,XIO2R,XN,P,B4,B5,DP,WALLTEMP,      DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3,XNUSS,XNUSSMN,X2
     5,LCARD
      IF (ITNO .EQ. 0)31,16
   31 DO 32 J=2,M
   32 S(3,J)=S(2,J)*EXPF(DHRT*(1./T(3,J   )-1./T(2,J   ))*XN)
      GO TO 15
   16 I=3
      DO  8 J=2,M
      IF (J .LT. NTRANS+1)383,384
  383 R9=DIV/(2.*DR)
      GO TO 385
  384 IF (J .GE. NTRANS+3)386,387
  386 R9=1./(2.*DR)
      GO TO 385
  387 IF (J .EQ. NTRANS+1)388,389
  388 R9=2.*DIV/(DR*(DIV+3.))
      GO TO 385
  389 R9=2.*DIV/(DR*(3.*DIV+1.))
  385 D4=R9*(U(I,J+1)+U(I-1,J+1)-U(I,J-1)-U(I-1,J-1))/2.
      XI2O2(I,J)=D4**2
      IF (XI2O2(I,J) .LT. G*XIO2R)28,29
```

```
 28 S(I,J)=(EXPF(DHRT*(1./T(I,J  )-1.)*XN))*G**E3
    GO TO 8
 29 S(I,J)=(EXPF(DHRT*(1./T(I,J  )-1.)*XN))*(XI2O2(I,J)/XIO2R)**E3
  8 CONTINUE
 15 CONTINUE
    S(3,N)=S(3,M)
    RETURN
    END

    SUBROUTINE UANDV
    DIMENSION U(3,150),V(3,150),T(3,150),S(3,150),XI2O2(3,150),
   2FLUX(100 ),B1(150),B2(150),ALPHA(150),BETA(150),B3(150),TBC(100)
   3,      B4(150),B5(150),AF(9,150)
   4,DELTA(150),GAMMA(150),PHI(150),R(150)
    COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DR,E,E2,E3,FLUX,
   2G,ITNO,K,  M,M2,N,NDX,NDRWAL,NTRANS,PR,      R,S,T,TBC,U,V,
   3XI2O2,XIO2R,XN,P,B4,B5,DP,WALLTEMP,     DPA,DX1,DX2,DX3,X,DPDX
   4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3,XNUSS,XNUSSMN,X2
   5,LCARD
    D1=(DX2+DX3)/2.
    DO 18 J=2,M
    R1=AF(1,J)
    R2=AF(2,J)
    R3=AF(3,J)
    R4=AF(4,J)
    R5=AF(2,J)/PR
    RAD=AF(9,J)
    IF (J .EQ. 2)615,616
615 DSDR=(S(3,2)-S(3,3)+S(2,2)-S(2,3))*DIV/(2.*DR)
    GO TO 619
616 DSDR=(S(3,J-1)-S(3,J+1)+S(2,J-1)-S(2,J+1))/(2.*R4)
619 VISC=(S(2,J  )+S(3,J  ))/2.
    VEL=(V(3,J)+V(2,J)+V(3,J-1)+V(2,J-1))/4.
    DUDR=(U(2,J-1)-U(2,J+1))/AF(4,J)
    B1(J)=R1+R5*U(2,J)/(VISC*D1)
    B3(J)=2.*R2/(VISC*D1)
```

```
      B4(J)=2.*R5      *VEL*DUDR/VISC-2.*AF(2,J)*DUDR/RAD
     2-2.*AF(2,J)*DSDR*DUDR/VISC
     3-U(1,J-1)+(R1-R5*U(2,J)/(VISC*D1))*U(1,J)-B2(J)*U(1,J+1)
     4-U(2,J-1)+B1(J)*U(2,J)-B2(J)*U(2,J+1)
   18 CONTINUE
C     (U(3,J-1)-U(2,J-1))-B1(J)*(U(3,J)-U(2,J))+B2(J)*(U(3,J+1)-
C     U(2,J+1))-B3(J)*DPA=B4(J)
      DO 910 J=3,M
  910 ALPHA(J)=B5(J)*R(J)/(B5(2)*R(2))
      ALPHA(N)=0.
      PSI=0.
      DELTA(2)=B2(2)/(B1(2)+1.)
      GAMMA(2)=-B3(2)/(B1(2)+1.)
      PHI(2)=B4(2)/(B1(2)+1.)
      DO 911 J=3,M2
      AD=ALPHA(J)+DELTA(J-1)
      BD=B1(J)-DELTA(J-1)
      DO 912 J1=3,M
  912 ALPHA(J1)=ALPHA(J1)/AD
      ALPHA(N)=(ALPHA(N)+GAMMA(J-1))/AD
      PSI=(PSI+PHI(J-1))/AD
      DELTA(J)=B2(J)/BD
      GAMMA(J)=(GAMMA(J-1)-B3(J))/BD
      PHI(J)=PHI(J-1)/BD+B4(J)/BD
  911 PHI(J)=PHI(J-1)/BD+B4(J)/BD
      AD=ALPHA(M)+DELTA(M2)
      BD=(B1(M)-B2(M))-DELTA(M2)
      ALPHA(N)=(ALPHA(N)+GAMMA(M2))/AD
      PSI=(PSI+PHI(M2))/AD
      GAMMA(M)=(GAMMA(M2)-B3(M))/BD
      PHI(M)=PHI(M2)/BD+B4(M)/BD
      DELTA(M)=0.
      DIVS=ALPHA(N)+GAMMA(M)
      DPA=           PHI(M)/DIVS+PSI/DIVS
      BETA(M)=DPA*GAMMA(M)-PHI(M)
C     IN SVANDU BETA(J) EQUALS U(3,J)-U(2,J)
```

```
      U(3,M)=U(2,M)+BETA(M)
      DO 913 J=2,M2
      NMJ=N-J
      NMP=NMJ+1
      BETA(NMJ)=GAMMA(NMJ)*DPA+DELTA(NMJ)*BETA(NMP)-PHI(NMJ)
  913 U(3,NMJ)=U(2,NMJ)+BETA(NMJ)
      U(3,1)=-U(3,2)
      U(3,N)= U(3,M)
      V(3,1)=0.
      V(3,M)=0.
      DO 650 J=2,M2
      Z1=AF(5,J)*R(J)+AF(6,J)*R(J-1)
      Z2=AF(7,J)*R(J+1)+AF(8,J)*R(J)
  650 V(3,J)=Z1/Z2*V(3,J-1)+R(J)*B5(J)/Z2*BETA(J)/DX3
      RETURN
      END

      SUBROUTINE OUTPUT
      DIMENSION U(3,150),V(3,150),T(3,150),S(3,150),XI2O2(3,150),
     2FLUX(100 ),B1(150),B2(150),ALPHA(150),BETA(150),B3(150),TBC(100)
     3,      B4(150),B5(150),AF(9,150)
     4,DELTA(150),GAMMA(150),PHI(150),R(150)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DR,F,E2,E3,FLUX,
     2G,ITNO,K,   M,M2,N,NDX,NDRWAL,NTRANS,PR,       R,S,T,TBC,U,V,
     3XI2O2,XIO2R,XN,P,B4,B5,DP,WALLTEMP,      DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3,XNUSS,XNUSSMN,X2
     5,LCARD
  206 FORMAT (2X,I4,5E22.10)
  207 FORMAT (2X,I4,E22.10,22X,F22.10)
  208 FORMAT (/5X,1HJ,10X,1HU,21X,1HV,21X,1HT,21X,1HS,20X,4HI2/2)
  210 FORMAT (/5X,5HITNO=,I3)
  212 FORMAT (5X,4HNDX=,I4,10X,2HX=,E12.3,10X,3HDX=,E12.3)
  213 FORMAT (5X,9HUAVERAGE=,E20.10)
  214 FORMAT (5X,9HTAVERAGE=,E14.6)
  216 FORMAT (5X,5HP(3)=,E15.6,5X,10HP(3)-P(2)=,E15.6)
      PRINT 208
```

```
      J=1
      PRINT 206,J,U(3,1),V(3,1),T(3,1)
      DO 70 J=2,M
   70 PRINT 206,J,U(3,J),V(3,J),T(3,J),S(3,J   ),XI202(3,J)
      PRINT 207,N,U(3,N),T(3,N)
      UAVG=2.*U(3,2)*R(2)*B5(2)+(U(3,2)*R(2)+U(3,3)*R(3))*(B5(2)+B5(3))
      DO  21 J=3,M
      A=(B5(J-1)+B5(J))/2.
      B=(B5(J+1)+B5(J))/2.
      Z1=U(3,J-1)*R(J-1)
      Z2=U(3,J   )*R(J   )
      Z3=U(3,J+1)*R(J+1)
      ZA=(B*(Z1-Z2)+A*(Z3-Z2))/(A**2*B+B**2*A)
      ZB=(B**2*(Z2-Z1)+A**2*(Z3-Z2))/(A**2*B+B**2*A)
   21 UAVG=UAVG+(ZA/3.*(B**3+A**3)+ZB/2.*(B**2-A**2)+Z2*(A+B))*4.
      PRINT 210,ITNO
      PRINT 212,NDX,X,DX3
      PRINT 213,UAVG
      PRINT 214,TM3
      PRINT 216,P,DPA
      RETURN
      END
         FINIS
```

APPENDIX V

FORTRAN PROGRAM FOR CHANNEL FLOW PROBLEM

FORTRAN PROGRAM FOR CHANNEL FLOW
CDC 3300

```
      PROGRAM MAIN
      DIMENSION U(3,210),V(3,210),T(3,210),S(3,210),XI202(3,210),
     2FLUX(2,90),B1(210),B2(210),ALPHA(210),BETA(210),B3(210),TBC(2, 90)
     3,      B4(210),B5(210),AF(4,210)
     4,DELTA(210),GAMMA(210),PHI(210)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DY,E,E2,E3,FLUX,
     2G,ITNO,K,L,M,M2,N,NDX,NDYWAL,NTRANS,PR,         S,T,TBC,U,V,
     3XI202,XI02R,XN,P,B4,B5,DP,                 DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3
  101 FORMAT ( F6.0,F8.4,F6.0,F6.4,I3,2F8.4,I3,2F8.4,I1)
  201 FORMAT (///5X,2HN=,F8.4,6X,6HDH/RT=,F8.0)
  211 FORMAT (5X,12HPRANDTL NO.=,F8.0,4X,13HBRINKMAN NO.=,F10.4)
  202 FORMAT (5X,12HAT Y=0, TBC=,F10.4)
  203 FORMAT (5X,12HAT Y=1, TBC=,F10.4)
  204 FORMAT (5X,13HAT Y=0, FLUX=,F10.4)
  205 FORMAT (5X,13HAT Y=1, FLUX=,F10.4)
  215 FORMAT (2X,31HITERATION LIMIT REACHED AT NDX=,I5
     2,5X,12HMAX RESIDUE=,E16.6)
      DX=5.E-08
      DDX=4.99995E-03
      A=-115.
      NDXMX=60
      IPRINT=60
C     IPRINT IS THE NUMBER OF X INCREMENTS BETWEEN PRINTOUTS
      DY=.02
      N=88
      NDYDIV=10
      NDYWAL=2
C      NDYDIV IS THE NUMBER OF PARTS DY IS BROKEN INTO NEAR THE WALL
C     NDYWAL IS THE NUMBER OF Y INCREMENTS SUBDIVIDED NEAR THE WALL
      DIV=FLOAT(NDYDIV)
      NTRANS=NDYDIV*NDYWAL
```

```
      ITNMX=20
      G=.001
   75 READ 101,PR,        BRINK,DHRT,XN,K,W1,W2,L,W3,W4,LCARD
      ITFAIL=0
C     K EQ 1 MEANS FLUX BOUND AT Y=0
C     K EQ 2 MEANS TEMP BOUND AT Y=0
C     L EQ 1 MEANS FLUX BOUND AT Y=1
C     L EQ 2 MEANS TEMP BOUND AT Y=1
      PRINT 201,XN,DHRT
      PRINT 211,PR,BRINK
C     BOUND COND BELOW IS FOR UNIFORM FLUX OR TEMP
      IF (K .EQ. 1)4,5
    4 PRINT 204,W1
      DO 6 J=1,NDXMX
    6 FLUX(1,J)=W1
      GO TO 7
    5 PRINT 202,W1
      DO 10 J=1,NDXMX
   10 TBC(1,J)=W1
    7 IF (L .EQ. 1)11,12
   11 PRINT 205,W3
      DO 13 J=1,NDXMX
   13 FLUX(2,J)=W3
      GO TO 3
   12 PRINT 203,W3
      DO 15 J=1,NDXMX
   15 TBC(2,J)=W3
    3 CONTINUE
C     NO CHANGES ARE NEEDED PAST HERE WHEN COMP CONDITIONS ARE CHANGED
      C=(2.*XN+1.)/(XN+1.)
      E=(XN+1.)/XN
      C2=(2.*XN+1.)/XN
      E2=1./XN
      E3=(XN-1.)/2.
      XIO2R=4.*C2*C2
      M=N-1
```

```
      M2=N-2
      NPRINT=1
      NDX=0
      X=0.
      DPL=0.
      ITNO=0
      CALL INLTCOND
      DX1=DX
      DX2=DX
      DX3=DX
      X=DX/2.
      NDX=1
   35 CALL TEMPCALC
      RESLAST=1000.
      CALL SCALC
   36 CALL UANDV
      ITNO=ITNO+1
      CALL SCALC
      RESMX=0.
      DO 43 J=2,M
      VISC=(S(3,J)+S(2,J))/2.
      DUDY=(U(2,J+1)-U(2,J-1))/AF(4,J)
      IF (J .EQ. 2)39,40
   39 DSDY=(S(3,3)-S(3,2)+S(2,3)-S(2,2))*DIV/(2.*DY)
      GO TO 41
   40 IF (J .EQ. M)48,49
   48 DSDY=(S(3,M)-S(3,M2)+S(2,M)-S(2,M2))*DIV/(2.*DY)
      GO TO 41
   49 DSDY=(S(3,J+1)-S(3,J-1)+S(2,J+1)-S(2,J-1))/(2.*AF(4,J))
   41 RES=ABS(VISC*(U(3,J-1)+U(1,J-1)+B2(J)*(U(3,J+1)+U(1,J+1))
     2-AF(1,J)*(U(3,J)+U(1,J)))/(2.*AF(2,J))
     3+DSDY*DUDY-2.*DPA/(DX2+DX3)
     4-U(2,J)*(U(3,J)-U(1,J))/(DX2+DX3)/PR
     5-(V(3,J)+V(2,J)+V(3,J-1)+V(2,J-1))/4.*DUDY/PR)
      IF (RES .GT. RESMX)47,43
   47 RESMX=RES
```

```
   43 CONTINUE
      IF (RESLAST .LT. .5    .AND. RESMX .LE. RESLAST)42,51
   51 RESLAST=RESMX
      IF (ITNO .LT. ITNMX)36,52
   52 PRINT 215,NDX,RESMX
      IF (ITFAIL .GE. 1)45,50
   50 ITFAIL=ITFAIL+1
   42 CONTINUE
      TM3=T(3,2)*U(3,2)*B5(2)/4.+(T(3,2)*U(3,2)+T(3,3)*U(3,3))
     2*(B5(2)+B5(3))/8.
      DO 95 J=3,M2
      Q=(B5(J-1)+B5(J))/2.
      B=(B5(J+1)+B5(J))/2.
      Z1=U(3,J-1)*T(3,J-1)
      Z2=U(3,J)*T(3,J)
      Z3=U(3,J+1)*T(3,J+1)
      ZA=(B*(Z1-Z2)+Q*(Z3-Z2))/(Q**2*B+B**2*Q)
      ZB=(B**2*(Z2-Z1)+Q**2*(Z3-Z2))/(Q**2*B+B**2*Q)
   95 TM3=TM3  +(ZA/3.*(B**3+Q**3)+ZB/2.*(B**2-Q**2)+Z2*(Q+B))/2.
      TM3=TM3+(U(3,M2)*T(3,M2)+T(3,M)*U(3,M))*(B5(M2)+B5(M))/8.
     2+T(3,M)*U(3,M)*B5(M)/4.
C     NUSSELT NO CALC BELOW IS FOR CASE WHERE BOTH PLATES ARE
C     THE SAME TEMPERATURE OR THE SAME HEAT FLUX
      IF (NDX .EQ. 1)96,97
   97 NM1=NDX-1
      X2=X-(DX2+DX3)/2.
      Z=X2/2.
      IF (K  .EQ. 1)71,72
   71 WALLTEMP=(T(2,1)+T(2,2))/2.
      GO TO 96
   72 CONTINUE
      XNUSS=       ((DX3*TM2+DX2*TM3)/(DX3+DX2)-(DX2*TM1+DX1*TM2)
     2/(DX2+DX1))/(DX2*(TBC(1,NM1)-TM2))
C     CALC FOR MEAN NUSS NO FOR UNIFORM WALL TEMP ONLY
      XNUSSMN=1./X2*ALOG((TBC(1,NM1)-1.)/(TBC(1,NM1)-TM2))
  217 FORMAT (/2X,5HAT X=,E16.6,2X,15HNUSSELT NUMBER=,E16.6,2X
```

```
   2,10HMEAN TEMP=,E16.6,2X,20HMEAN NUSSELT NUMBER=,E16.6)
    PRINT 217,Z ,XNUSS,TM2,XNUSSMN
 96 CONTINUE
    IF (NDX .GE. 2)500,501
500 DELTP=2.*DPL/(DX1+DX2)
502 FORMAT (2X,2HP=,E16.6,2X,3HDP=,E16.6,2X,6HDP/DX=,F15.5)
    PRINT 502,P,DPL,DELTP
501 CONTINUE
    DPL=DPA
    P=P+DPA
    IF (NDX .EQ. IPRINT*NPRINT)22,23
 22 CALL OUTPUT
    NPRINT=NPRINT+1
 23 IF (NDX .LT. NDXMX)60,45
 60 TM1=TM2
    TM2=TM3
    DO 46 J=1,N
    T(1,J)=T(2,J)
    T(2,J)=T(3,J)
    U(1,J)=U(2,J)
    U(2,J)=U(3,J)
    V(1,J)=V(2,J)
    V(2,J)=V(3,J)
    S(1,J)=S(2,J)
    S(2,J)=S(3,J)
    XI202(1,J)=XI202(2,J)
 46 XI202(2,J)=XI202(3,J)
    NDX=NDX+1
    DX1=DX2
    DX2=DX3
    DX3=DX+DDX*(1.-EXPF(A*X))
    X=X+(DX3+DX2)/2.
    ITNO=0
    GO TO 35
 45 IF (LCARD .EQ. 0)44,75
 44 CONTINUE
```

```
      END
      SUBROUTINE INLTCOND
      DIMENSION U(3,210),V(3,210),T(3,210),S(3,210),XI2O2(3,210),
     2FLUX(2,90),B1(210),B2(210),ALPHA(210),BETA(210),B3(210),TBC(2, 90)
     3,      B4(210),B5(210),AF(4,210)
     4,DELTA(210),GAMMA(210),PHI(210)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DY,E,E2,E3,FLUX,
     2G,ITNO,K,L,M,M2,N,NDX,NDYWAL,NTRANS,PR,         S,T,TBC,U,V,
     3XI2O2,XIO2R,XN,P,B4,B5,DP,                DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3
      DO 1 J=1,N
      V(1,J)=0.
      V(3,J)=0.
      V(2,J)=0.
      T(1,J)=1.
      T(3,J)=1.
    1 T(2,J)=1.
      DO 2 J=2,M
      IF (J  .LE. NTRANS+1)360,361
  360 Y=(J-1)*DY/DIV-DY/(2.*DIV)
      B5(J)=DY/DIV
      GO TO 362
  361 IF (J  .LE. M-NTRANS)364,363
  364 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
      B5(J)=DY
      GO TO 362
  363 Y=(M2-2*NTRANS+NDYWAL)*DY+(J-1-M2+NTRANS)*DY/DIV-DY/(2.*DIV)
      B5(J)=DY/DIV
  362 ARG=ABSF(2.*Y-1.)
      U(1,J)=C*(1.-ARG**E)
      XI2O2(1,J   )=XIO2R*ARG**(2.*E2)
      XI2O2(2,J   )=XI2O2(1,J)
      XI2O2(3,J   )=XI2O2(1,J)
      ARG2=ABSF(XN-1.)
      IF (ARG2 .LT. .000001)3,9
    3 S(1,J   )=1.
```

```
      GO TO 5
    9 IF (XI2D2(1.J   ) .LT. G*XID2R)7,4
    7 S(1,J   )=G**E3
      GO TO 5
    4 S(1,J   )=ARG**(1.-E2)
    5 S(2,J   )=S(1,J)
      S(3,J   )=S(1,J)
    2 CONTINUE
      B5(1)=B5(2)
      B5(N)=B5(M)
      S(1,N)=S(1,M)
      S(2,N)=S(2,M)
      S(3,N)=S(3,M)
      U(1,1)=-U(1,2)
      U(1,N)=-U(1,M)
      DO 651 J=1,N
      U(2,J)=U(1,J)
  651 U(3,J)=U(1,J)
      UAVG=U(3,2)*B5(2)/4.+(U(3,2)+U(3,3))*(B5(3)+B5(2))/8.
      DO 620 J=3,M2
      A=(B5(J-1)+B5(J))/2.
      B=(B5(J+1)+B5(J))/2.
      Z1=U(3,J-1)
      Z2=U(3,J)
      Z3=U(3,J+1)
      ZA=(B*(Z1-Z2)+A*(Z3-Z2))/(A**2*B+B**2*A)
      ZB=(B**2*(Z2-Z1)+A**2*(Z3-Z2))/(A**2*B+B**2*A)
  620 UAVG=UAVG+(ZA/3.*(B**3+A**3)+ZB/2.*(B**2-A**2)+Z2*(A+B))/2.
      UAVG=UAVG+(U(3,M2)+U(3,M))*(B5(M2)+B5(M))/8.+U(3,M)*B5(M)/4.
  221 FORMAT (5X,17HAVERAGE VELOCITY=,E20.10)
      PRINT 221,UAVG
      TM1=1.
      TM2=1.
      TM3=1.
      DPDX=4.*C2
  314 FORMAT (5X,6HDP/DX=,E15.6)
```

```
      PRINT 314,DPDX
      P=0.
      DO 600 J=2,M
      IF (J.LE. NTRANS .OR. J .GT. N-NTRANS)601,602
  601 AF(1,J)=2.
      AF(2,J)=(DY/DIV)**2
      AF(3,J)=DY/DIV
      AF(4,J)=2.*DY/DIV
      B2(J)=1.
      IF (J .EQ. 2 .OR. J .EQ. M)611,600
  611 AF(2,J)=AF(2,J)*3./4.
      AF(3,J)=AF(3,J)*3./4.
      GO TO 600
  602 IF (J .GE. NTRANS+3 .AND.  J .LE. M2-NTRANS)603,604
  603 AF(1,J)=2.
      AF(2,J)=DY**2
      AF(3,J)=DY
      AF(4,J)=2.*DY
      B2(J)=1.
      GO TO 600
  604 IF (J .EQ. M-NTRANS)605,606
  605 AF(1,J)=(3.*DIV+1.)/(DIV+1.)
      AF(2,J)=(3.*DIV+1.)*DY**2/(4.*DIV)
      AF(3,J)=DY
      AF(4,J)=(3.*DIV+1.)*DY/(2.*DIV)
      B2(J)=2.*DIV/(DIV+1.)
      GO TO 600
  606 IF (J .EQ. N-NTRANS)607,608
  607 AF(1,J)=(DIV+3.)/2.
      AF(2,J)=(DIV+1.)*(DIV+3.)*(DY/DIV)**2/8.
      AF(3,J)=(DIV+1.)*DY/(2.*DIV)
      AF(4,J)=(DIV+3.)*DY/(2.*DIV)
      B2(J)=(DIV+1.)/2.
      IF (J .EQ. M)613,600
  613 AF(2,J)=AF(2,J)*3./4.
      AF(3,J)=AF(3,J)*3./4.
```

```
      GO TO 600
  608 IF (J .EQ. NTRANS+1)609,610
  609 AF(1,J)=(DIV+3.)/(DIV+1.)
      AF(2,J)=(DIV+3.)*(DY/DIV)**2/4.
      AF(3,J)=DY/DIV
      AF(4,J)=(DIV+3.)*DY/(2.*DIV)
      B2(J)=2./(DIV+1.)
      IF (J .EQ. 2)612,600
  612 AF(2,J)=AF(2,J)*3./4.
      AF(3,J)=AF(3,J)*3./4.
      GO TO 600
  610 AF(1,J)=(3.*DIV+1.)/(2.*DIV)
      AF(2,J)=(3.*DIV+1.)*(DIV+1.)*(DY/DIV)**2/8.
      AF(3,J)=(DIV+1.)*DY/(2.*DIV)
      AF(4,J)=(3.*DIV+1.)*DY/(2.*DIV)
      B2(J)=(DIV+1.)/(2.*DIV)
  600 CONTINUE
      RETURN
      END
      SUBROUTINE TEMPCALC
      DIMENSION U(3,210),V(3,210),T(3,210),S(3,210),XI2O2(3,210),
     2FLUX(2,90),B1(210),B2(210),ALPHA(210),BETA(210),B3(210),TBC(2, 90)
     3,      B4(210),B5(210),AF(4,210)
     4,DELTA(210),GAMMA(210),PHI(210)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DY,E,E2,E3,FLUX,
     2G,ITNO,K,L,M,M2,N,NDX,NDYWAL,NTRANS,PR,         S,T,TBC,U,V,
     3XI2O2,XIO2R,XN,P,B4,B5,DP,                DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3
      D1=DX2+(DX1+DX3)/2.
      DO 92 J=2,M
      R1=AF(1,J)
      R2=AF(2,J)
      R4=AF(3,J)
      B1(J)=R1+R2      *(U(1,J)+U(2,J))/D1
      B3(J)=R4      *(V(2,J)+V(2,J-1))*(T(2,J+1)-T(2,J-1))/2.
     2-2.*R2*BRINK*S(2,J   )*XI2O2(2,J   )-T(1,J-1)-B2(J)*T(1,J+1)
```

```
     3+(R1-R2      *(U(1,J)+U(2,J))/D1      )*T(1,J)
   92 CONTINUE
C     T(3,J-1)-B1(J)*T(3,J)+B2(J)*T(3,J+1)=B3(J)
      IF (K .EQ. 1)50,51
   51 B1(1)=-1.
      B2(1)=1.
      B3(1)=2.*TBC(1,NDX)
      GO TO 52
   50 B1(1)=-1.
      B2(1)=-1.
      B3(1)=DY/DIV     *FLUX(1,NDX)
   52 IF (L .EQ. 1)53,54
   54 B1(N)=-1.
      B2(N)=0.
      B3(N)=2.*TBC(2,NDX)
      GO TO 55
   53 B1(N)=1.
      B2(N)=0.
      B3(N)=-(DY/DIV     *FLUX(2,NDX))
   55 CONTINUE
      ALPHA(1)=-(B2(1)/B1(1))
      BETA(1)=-(B3(1)/B1(1))
      DO 93 J=2,N
      ALPHA(J)=B2(J)/(-B1(J)-ALPHA(J-1))
   93 BETA(J)=(B3(J)-BETA(J-1))/(-B1(J)-ALPHA(J-1))
      T(3,N)=BETA(N)
      DO 94 J=1,M
      NMJ=N-J
   94 T(3,NMJ)=BETA(NMJ)-ALPHA(NMJ)*T(3,NMJ+1)
      IF (NDX .EQ. 3 .OR. NDX .EQ. 4)30,31
   30 IF (K .EQ. 2)32,33
   32 SLOPE=ABS(T(3,2)-TBC(1,NDX))/(DY/DIV/2.)
      SLPLST=SLOPE
      NSTOP=N/2
      DO 34 J=3,NSTOP
      IF (J .LE.NTRANS+1)35,36
```

```
35 Y=(J-1)*DY/DIV-DY/(2.*DIV)
   GO TO 37
36 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
37 SLOPE=ABS(T(3,J)-TBC(1,NDX))/Y
   IF (SLOPE .LE. SLPLST)38,39
39 SLPLST=SLOPE
34 CONTINUE
38 J=J-1
   IF (J  .LE.NTRANS+1)40,41
40 Y=(J-1)*DY/DIV-DY/(2.*DIV)
   GO TO 42
41 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
42 YREF=Y
   TREF=T(3,J)-TBC(1,NDX)
   J2=J-1
   DO 43 J=2,J2
   IF (J  .LE. NTRANS+1)44,45
44 Y=(J-1)*DY/DIV-DY/(2.*DIV)
   GO TO 43
45 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
43 T(3,J)=TBC(1,NDX)+Y/YREF*TREF
   T(3,1)=2.*TBC(1,NDX)-T(3,2)
33 IF (L  .EQ. 2)46,31
46 SLOPE=ABS(T(3,M)-TBC(2,NDX))/(DY/DIV/2.)
   SLPLST=SLOPE
   NSTOP=N/2
   DO 48 J=3,NSTOP
   NMJ=N-J+1
   IF (J  .LE. NTRANS+1)60,61
60 Y=(J-1)*DY/DIV-DY/(2.*DIV)
   GO TO 62
61 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
62 SLOPE=ABS(T(3,NMJ)-TBC(2,NDX))/Y
   IF (SLOPE .LE. SLPLST)63,64
64 SLPLST=SLOPE
48 CONTINUE
```

```
63 J=J-1
   IF (J .LE. NTRANS+1)65,66
65 Y=(J-1)*DY/DIV-DY/(2.*DIV)
   GO TO 67
66 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
67 YREF=Y
   NMJ=N-J+1
   TREF=T(3,NMJ)-TBC(2,NDX)
   J2=J-1
   DO 68 J=2,J2
   NMJ=N-J+1
   IF (J .LE. NTRANS+1)69,70
69 Y=(J-1)*DY/DIV-DY/(2.*DIV)
   GO TO 68
70 Y=(NDYWAL+(J-1-NTRANS))*DY-.5*DY
68 T(3,NMJ)=TBC(2,NDX)+Y/YREF*TREF
   T(3,N)=2.*TBC(2,NDX)-T(3,M)
31 CONTINUE
   RETURN
   END
   SUBROUTINE UANDV
   DIMENSION U(3,210),V(3,210),T(3,210),S(3,210),XI202(3,210),
  2FLUX(2,90),B1(210),B2(210),ALPHA(210),BETA(210),B3(210),TBC(2, 90)
  3,      B4(210),B5(210),AF(4,210)
  4,DELTA(210),GAMMA(210),PHI(210)
   COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DY,E,E2,E3,FLUX,
  2G,ITNO,K,L,M,M2,N,NDX,NDYWAL,NTRANS,PR,          S,T,TBC,U,V,
  3XI202,XI02R,XN,P,B4,B5,DP,                DPA,DX1,DX2,DX3,X,DPDX
  4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3
   D1=(DX2+DX3)/2.
   DO 18 J=2,M
   R1=AF(1,J)
   R2=AF(2,J)
   R3=AF(3,J)
   R4=AF(4,J)
   R5=AF(2,J)/PR
```

```
      IF (J .EQ. 2)615,616
  615 DSDY=(S(3,3)-S(3,2)+S(2,3)-S(2,2))*DIV/(2.*DY)
      GO TO 619
  616 IF (J .EQ. M)617,618
  617 DSDY=(S(3,J   )-S(3,J-1)+S(2,J   )-S(2,J-1))*DIV/(2.*DY)
      GO TO 619
  618 DSDY=(S(3,J+1)-S(3,J-1)+S(2,J+1)-S(2,J-1))/(2.*R4)
  619 VISC=(S(2,J)+S(3,J))/2.
      VEL=( V(3,J)+V(2,J)+V(3,J-1)+V(2,J-1))/4.
      DUDY=(U(2,J+1)-U(2,J-1))/AF(4,J)
      B1(J)=R1+R5*U(2,J)/(VISC*D1)
      B3(J)=2.*R2/(VISC*D1)
      B4(J)=2.*R5*VEL*DUDY/VISC
     2-2.*AF(2,J)*DSDY*DUDY/VISC
     3+(R1-R5*U(2,J)/(VISC*D1))*U(1,J)
     4-B2(J)*U(1,J+1)             -U(1,J-1)
     5-U(2,J-1)+B1(J)*U(2,J)-B2(J)*U(2,J+1)
   18 CONTINUE
C     (U(3,J-1)-U(2,J-1))-B1(J)*(U(3,J)-U(2,J))+B2(J)*(U(3,J+1)
C     -U(2,J+1))-B3(J)*DPA=B4(J)
      DO 910 J=3,M
  910 ALPHA(J)=B5(J)/B5(2)
      ALPHA(N)=0.
      RHO=0.
      DELTA(2)=B2(2)/(B1(2)+1.)
      GAMMA(2)=-B3(2)/(B1(2)+1.)
      PHI(2)=B4(2)/(B1(2)+1.)
      DO 911 J=3,M2
      AD=ALPHA(J)+DELTA(J-1)
      BD=B1(J)-DELTA(J-1)
      DO 912 J1=3,M
  912 ALPHA(J1)=ALPHA(J1)/AD
      ALPHA(N)=(ALPHA(N)+GAMMA(J-1))/AD
      RHO=RHO/AD+PHI(J-1)/AD
      DELTA(J)=B2(J)/BD
      GAMMA(J)=(GAMMA(J-1)-B3(J))/BD
```

```
  911 PHI(J)=PHI(J-1)/BD+B4(J)/BD
      AD=ALPHA(M)+DELTA(M2)
      BD=(B1(M)+B2(M))-DELTA(M2)
      ALPHA(N)=(ALPHA(N)+GAMMA(M2))/AD
      RHO=RHO/AD+PHI(M2)/AD
      GAMMA(M)=(GAMMA(M2)-B3(M))/BD
      PHI(M)=PHI(M2)/BD+B4(M)/BD
      DPA=(PHI(M)+RHO)/(ALPHA(N)+GAMMA(M))
      BETA(M)=DPA*GAMMA(M)-PHI(M)
C     IN SVANDU BETA(J) EQUALS U(3,J)-U(2,J)
      U(3,M)=U(2,M)+BETA(M)
      DO 913 J=2,M2
      NMJ=N-J
      NMP=NMJ+1
      BETA(NMJ)=GAMMA(NMJ)*DPA+DELTA(NMJ)*BETA(NMP)-PHI(NMJ)
  913 U(3,NMJ)=U(2,NMJ)+BETA(NMJ)
      U(3,1)=-U(3,2)
      U(3,N)=-U(3,M)
      V(3,1)=0.
      V(3,M)=0.
      DO 650 J=2,M2
  650 V(3,J)=V(3,J-1)+B5(J)*(-BETA(J))/DX3
      RETURN
      END
      SUBROUTINE SCALC
      DIMENSION U(3,210),V(3,210),T(3,210),S(3,210),XI202(3,210),
     2FLUX(2,90),B1(210),B2(210),ALPHA(210),BETA(210),B3(210),TBC(2, 90)
     3,      B4(210),B5(210),AF(4,210)
     4,DELTA(210),GAMMA(210),PHI(210)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DY,E,E2,E3,FLUX,
     2G,ITNO,K,L,M,M2,N,NDX,NDYWAL,NTRANS,PR,          S,T,TBC,U,V,
     3XI202,XI02R,XN,P,B4,B5,DP,                    DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3
      IF (ITNO .EQ. 0)31,16
   31 DO 32 J=2,M
   32 S(3,J)=S(2,J)*EXPF(DHRT*(1./T(3,J  )-1./T(2,J  ))*XN)
```

```
      GO TO 15
   16 I=3
      DO  8 J=2,M
      IF (J .LE. NTRANS .OR. J .GT. N-NTRANS)383,384
  383 R9=DIV/(2.*DY)
      GO TO 385
  384 IF (J .GT. NTRANS+2 .AND. J .LE. M2-NTRANS)386,387
  386 R9=1./(2.*DY)
      GO TO 385
  387 IF (J .EQ. NTRANS+1 .OR. J .EQ. N-NTRANS)388,389
  388 R9=2.*DIV/(DY*(DIV+3.))
      GO TO 385
  389 R9=2.*DIV/(DY*(3.*DIV+1.))
  385 D4=R9*(U(I,J+1)+U(I-1,J+1)-U(I,J-1)-U(I-1,J-1))/2.
      XI2O2(I,J)=D4**2
      IF (XI2O2(I,J) .LT. G*XIO2R)28,29
   28 S(I,J)=(EXPF(DHRT*(1./T(I,J   )-1.)*XN))*G**E3
      GO TO 8
   29 S(I,J)=(EXPF(DHRT*(1./T(I,J   )-1.)*XN))*(XI2O2(I,J)/XIO2R)**E3
    8 CONTINUE
   15 CONTINUE
      RETURN
      END
      SUBROUTINE OUTPUT
      DIMENSION U(3,210),V(3,210),T(3,210),S(3,210),XI2O2(3,210),
     2FLUX(2,90),B1(210),B2(210),ALPHA(210),BETA(210),B3(210),TBC(2, 90)
     3,       B4(210),B5(210),AF(4,210)
     4,DELTA(210),GAMMA(210),PHI(210)
      COMMON ALPHA,B1,B2,B3,BETA,BRINK,C,C2,DHRT,DIV,DX,DY,E,E2,E3,FLUX,
     2G,ITNO,K,L,M,M2,N,NDX,NDYWAL,NTRANS,PR,          S,T,TBC,U,V,
     3XI2O2,XIO2R,XN,P,B4,B5,DP,                DPA,DX1,DX2,DX3,X,DPDX
     4,DELTA,GAMMA,PHI,AF,TM1,TM2,TM3
  206 FORMAT (2X,I4,5E22.10)
  207 FORMAT (2X,I4,E22.10,22X,E22.10)
  208 FORMAT (/5X,1HJ,10X,1HU,21X,1HV,21X,1HT,21X,1HS,20X,4HI2/2)
  210 FORMAT (/5X,5HITNO=,I3)
```

```
212 FORMAT (5X,4HNDX=,I4,10X,2HX=,E12.3,10X,3HDX=,E12.3)
213 FORMAT (5X,9HUAVERAGE=,F20.10)
214 FORMAT (5X,9HTAVERAGE=,E14.6)
216 FORMAT (5X,5HP(3)=,E15.6,5X,10HP(3)-P(2)=,E15.6)
    PRINT 208
    J=1
    PRINT 206,J,U(3,1),V(3,1),T(3,1)
    DO 70 J=2,M
 70 PRINT 206,J,U(3,J),V(3,J),T(3,J),S(3,J  ),XI202(3,J)
    PRINT 207,N,U(3,N),T(3,N)
    UAVG=U(3,2)*B5(2)/4.+(U(3,2)+U(3,3))*(B5(3)+B5(2))/8.
    DO 620 J=3,M2
    A=(B5(J-1)+B5(J))/2.
    B=(B5(J+1)+B5(J))/2.
    Z1=U(3,J-1)
    Z2=U(3,J)
    Z3=U(3,J+1)
    ZA=(B*(Z1-Z2)+A*(Z3-Z2))/(A**2*B+B**2*A)
    ZB=(B**2*(Z2-Z1)+A**2*(Z3-Z2))/(A**2*B+B**2*A)
620 UAVG=UAVG+(ZA/3.*(B**3+A**3)+ZB/2.*(B**2-A**2)+Z2*(A+B))/2.
    UAVG=UAVG+(U(3,M2)+U(3,M))*(B5(M2)+B5(M))/8.+U(3,M)*B5(M)/4.
    PRINT 210,ITNO
    PRINT 212,NDX,X,DX3
    PRINT 213,UAVG
    PRINT 214,TM3
    PRINT 216,P,DPA
    RETURN
    END
       FINIS
```

APPENDIX VI

TABULATED RESULTS

N= 1.0000 DH/RT= 0 PIPE FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
WALL TEMP= 1.2500

X	NU(LOCAL)	NU(MEAN)	P
2.500E-06	7.066E 01	2.725E 02	-1.600E-04
8.124E-06	4.396E 01	8.723E 01	-3.400E-04
1.578E-05	5.164E 01	8.528E 01	-5.849E-04
2.674E-05	3.069E 01	5.851E 01	-9.357E-04
4.235E-05	3.115E 01	5.222E 01	-1.435E-03
6.457E-05	2.431E 01	4.141E 01	-2.145E-03
9.620E-05	2.343E 01	3.695E 01	-3.159E-03
1.412E-04	1.965E 01	3.123E 01	-4.598E-03
2.051E-04	1.806E 01	2.783E 01	-6.644E-03
2.958E-04	1.551E 01	2.414E 01	-9.547E-03
4.243E-04	1.393E 01	2.144E 01	-1.366E-02
6.059E-04	1.210E 01	1.880E 01	-1.947E-02
8.615E-04	1.078E 01	1.666E 01	-2.765E-02
1.219E-03	9.508E 00	1.470E 01	-3.910E-02
1.717E-03	8.518E 00	1.306E 01	-5.504E-02
2.403E-03	7.599E 00	1.161E 01	-7.698E-02
3.336E-03	6.845E 00	1.039E 01	-1.068E-01
4.583E-03	6.187E 00	9.320E 00	-1.467E-01
6.214E-03	5.656E 00	8.425E 00	-1.989E-01
8.293E-03	5.205E 00	7.668E 00	-2.655E-01
1.086E-02	4.839E 00	7.039E 00	-3.477E-01
1.393E-02	4.547E 00	6.517E 00	-4.458E-01
1.747E-02	4.331E 00	6.093E 00	-5.590E-01
2.141E-02	4.163E 00	5.751E 00	-6.852E-01
2.568E-02	4.025E 00	5.474E 00	-8.219E-01
3.020E-02	3.918E 00	5.247E 00	-9.664E-01
3.488E-02	3.849E 00	5.062E 00	-1.115E 00
3.968E-02	3.801E 00	4.912E 00	-1.270E 00
4.456E-02	3.755E 00	4.787E 00	-1.426E 00

4.949E-02	3.720E 00	4.682E 00	-1.584E 00
5.444E-02	3.711E 00	4.593E 00	-1.742E 00
5.941E-02	3.709E 00	4.519E 00	-1.901E 00
6.439E-02	3.691E 00	4.456E 00	-2.061E 00
6.938E-02	3.673E 00	4.399E 00	-2.220E 00
7.438E-02	3.682E 00	4.350E 00	-2.380E 00
7.937E-02	3.697E 00	4.309E 00	-2.540E 00
8.437E-02	3.683E 00	4.272E 00	-2.700E 00
8.937E-02	3.662E 00	4.238E 00	-2.860E 00
9.437E-02	3.679E 00	4.207E 00	-3.020E 00

N= 1.0000 DH/RT= 10 PIPE FLOW
PRANDTL NO.= 1 BRINKMAN NO.= 0
WALL TEMP= 1.2500

X	NU(LOCAL)	NU(MEAN)	P
2.500E-06	6.781E 01	2.725E 02	4.147E-04
8.124E-06	4.678E 01	8.329E 01	1.647E-03
1.578E-05	5.803E 01	8.876E 01	2.884E-03
2.674E-05	3.418E 01	6.112E 01	3.806E-03
4.235E-05	3.387E 01	5.594E 01	4.806E-03
6.457E-05	2.593E 01	4.379E 01	5.223E-03
9.620E-05	2.571E 01	3.967E 01	8.062E-03
1.412E-04	2.102E 01	3.344E 01	1.003E-02
2.051E-04	1.886E 01	2.985E 01	1.222E-02
2.958E-04	1.573E 01	2.554E 01	1.494E-02
4.243E-04	1.438E 01	2.256E 01	1.827E-02
6.059E-04	1.271E 01	1.971E 01	2.193E-02
8.615E-04	1.139E 01	1.754E 01	2.585E-02
1.219E-03	9.950E 00	1.544E 01	3.013E-02
1.717E-03	8.984E 00	1.372E 01	3.463E-02
2.403E-03	8.096E 00	1.222E 01	3.862E-02
3.336E-03	7.323E 00	1.097E 01	4.153E-02
4.583E-03	6.607E 00	9.861E 00	4.281E-02
6.214E-03	6.062E 00	8.934E 00	4.169E-02
8.293E-03	5.623E 00	8.148E 00	3.722E-02
1.086E-02	5.265E 00	7.511E 00	2.862E-02
1.393E-02	4.957E 00	6.975E 00	1.548E-02
1.747E-02	4.733E 00	6.542E 00	-2.112E-03
2.141E-02	4.572E 00	6.189E 00	-2.350E-02
2.568E-02	4.446E 00	5.911E 00	-4.806E-02
3.020E-02	4.319E 00	5.679E 00	-7.535E-02
3.488E-02	4.222E 00	5.489E 00	-1.045E-01
3.968E-02	4.170E 00	5.329E 00	-1.344E-01
4.456E-02	4.140E 00	5.202E 00	-1.648E-01

4.949E-02	4.083E 00	5.093E 00	-1.961E-01
5.444E-02	4.035E 00	4.998E 00	-2.276E-01
5.941E-02	4.031E 00	4.915E 00	-2.586E-01
6.439E-02	4.040E 00	4.848E 00	-2.892E-01
6.938E-02	3.998E 00	4.788E 00	-3.203E-01
7.438E-02	3.955E 00	4.733E 00	-3.514E-01
7.937E-02	3.971E 00	4.683E 00	-3.814E-01
8.437E-02	3.999E 00	4.643E 00	-4.110E-01
8.937E-02	3.952E 00	4.606E 00	-4.411E-01
9.437E-02	3.903E 00	4.569E 00	-4.712E-01

XN=1.00 DH/RT=0. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.193E 02	1.003E 00	1.000E 00	-1.600E-06
8.219E-08	4.073E 02	1.003E 00	1.000E 00	-3.430E-06
1.630E-07	2.219E 02	1.005E 00	1.000E 00	-6.016E-06
2.835E-07	1.970E 02	1.005E 00	1.000E 00	-9.872E-06
4.619E-07	1.717E 02	1.006E 00	1.000E 00	-1.558E-05
7.261E-07	1.527E 02	1.007E 00	1.000E 00	-2.404E-05
1.118E-06	1.237E 02	1.008E 00	1.000E 00	-3.657E-05
1.698E-06	1.081E 02	1.010E 00	1.000E 00	-5.513E-05
2.557E-06	9.619E 01	1.011E 00	1.000E 00	-8.263E-05
3.830E-06	8.461E 01	1.012E 00	1.000E 00	-1.234E-04
5.716E-06	7.190E 01	1.014E 00	1.000E 00	-1.837E-04
8.510E-06	6.272E 01	1.016E 00	1.000E 00	-2.731E-04
1.265E-05	5.563E 01	1.018E 00	1.000E 00	-4.055E-04
1.878E-05	4.879E 01	1.021E 00	1.000E 00	-6.017E-04
2.785E-05	4.208E 01	1.024E 00	1.000E 00	-8.921E-04
4.129E-05	3.672E 01	1.028E 00	1.000E 00	-1.322E-03
6.118E-05	3.242E 01	1.031E 00	1.001E 00	-1.959E-03
9.060E-05	2.845E 01	1.036E 00	1.001E 00	-2.900E-03
1.341E-04	2.474E 01	1.041E 00	1.001E 00	-4.292E-03
1.983E-04	2.165E 01	1.047E 00	1.001E 00	-6.347E-03
2.930E-04	1.907E 01	1.054E 00	1.001E 00	-9.376E-03
4.322E-04	1.673E 01	1.062E 00	1.002E 00	-1.383E-02
6.363E-04	1.459E 01	1.071E 00	1.003E 00	-2.036E-02
9.340E-04	1.278E 01	1.082E 00	1.004E 00	-2.989E-02
1.365E-03	1.129E 01	1.094E 00	1.006E 00	-4.368E-02
1.983E-03	9.997E 00	1.108E 00	1.008E 00	-6.345E-02
2.856E-03	8.870E 00	1.124E 00	1.012E 00	-9.139E-02
4.066E-03	7.929E 00	1.143E 00	1.017E 00	-1.301E-01

5.699E-03	7.171E 00	1.163E 00	1.023E 00	-1.824E-01
7.835E-03	6.552E 00	1.184E 00	1.032E 00	-2.507E-01
1.052E-02	6.041E 00	1.208E 00	1.042E 00	-3.367E-01
1.376E-02	5.635E 00	1.233E 00	1.055E 00	-4.403E-01
1.750E-02	5.330E 00	1.258E 00	1.070E 00	-5.600E-01
2.165E-02	5.103E 00	1.283E 00	1.087E 00	-6.929E-01
2.611E-02	4.924E 00	1.308E 00	1.105E 00	-8.355E-01
3.078E-02	4.784E 00	1.333E 00	1.124E 00	-9.850E-01
3.558E-02	4.683E 00	1.356E 00	1.143E 00	-1.139E 00
4.047E-02	4.614E 00	1.379E 00	1.162E 00	-1.295E 00
4.540E-02	4.557E 00	1.402E 00	1.182E 00	-1.453E 00
5.037E-02	4.507E 00	1.424E 00	1.202E 00	-1.612E 00
5.535E-02	4.472E 00	1.446E 00	1.222E 00	-1.771E 00
6.033E-02	4.453E 00	1.467E 00	1.242E 00	-1.931E 00
6.533E-02	4.436E 00	1.487E 00	1.262E 00	-2.090E 00
7.032E-02	4.416E 00	1.509E 00	1.282E 00	-2.250E 00
7.532E-02	4.401E 00	1.529E 00	1.302E 00	-2.410E 00
8.032E-02	4.398E 00	1.549E 00	1.322E 00	-2.570E 00
8.532E-02	4.395E 00	1.570E 00	1.342E 00	-2.730E 00
9.032E-02	4.385E 00	1.590E 00	1.362E 00	-2.890E 00
9.532E-02	4.376E 00	1.611E 00	1.382E 00	-3.050E 00

XN=1.00 DH/RT=5. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.193E 02	1.003E 00	1.000E 00	-1.591E-06
8.219E-08	4.095E 02	1.003E 00	1.000E 00	-3.399E-06
1.630E-07	2.231E 02	1.005E 00	1.000E 00	-5.955E-06
2.835E-07	1.983E 02	1.005E 00	1.000E 00	-9.758E-06
4.619E-07	1.728E 02	1.006E 00	1.000E 00	-1.539E-05
7.261E-07	1.539E 02	1.007E 00	1.000E 00	-2.374E-05
1.118E-06	1.247E 02	1.008E 00	1.000E 00	-3.611E-05
1.698E-06	1.092E 02	1.009E 00	1.000E 00	-5.441E-05
2.557E-06	9.733E 01	1.011E 00	1.000E 00	-8.152E-05
3.830E-06	8.567E 01	1.012E 00	1.000E 00	-1.217E-04
5.716E-06	7.287E 01	1.014E 00	1.000E 00	-1.811E-04
8.510E-06	6.377E 01	1.016E 00	1.000E 00	-2.691E-04
1.265E-05	5.672E 01	1.018E 00	1.000E 00	-3.993E-04
1.878E-05	4.981E 01	1.020E 00	1.000E 00	-5.919E-04
2.785E-05	4.304E 01	1.024E 00	1.000E 00	-8.767E-04
4.129E-05	3.772E 01	1.027E 00	1.000E 00	-1.297E-03
6.118E-05	3.343E 01	1.030E 00	1.001E 00	-1.918E-03
9.060E-05	2.941E 01	1.035E 00	1.001E 00	-2.833E-03
1.341E-04	2.565E 01	1.040E 00	1.001E 00	-4.178E-03
1.983E-04	2.254E 01	1.045E 00	1.001E 00	-6.148E-03
2.930E-04	1.995E 01	1.052E 00	1.001E 00	-9.023E-03
4.322E-04	1.758E 01	1.059E 00	1.002E 00	-1.320E-02
6.363E-04	1.541E 01	1.068E 00	1.003E 00	-1.921E-02
9.340E-04	1.358E 01	1.078E 00	1.004E 00	-2.779E-02
1.365E-03	1.206E 01	1.089E 00	1.005E 00	-3.988E-02
1.983E-03	1.072E 01	1.101E 00	1.008E 00	-5.663E-02
2.856E-03	9.556E 00	1.116E 00	1.012E 00	-7.933E-02
4.066E-03	8.581E 00	1.133E 00	1.017E 00	-1.092E-01

5.699E-03	7.791E 00	1.151E 00	1.023E 00	-1.473E-01
7.835E-03	7.137E 00	1.172E 00	1.032E 00	-1.938E-01
1.052E-02	6.589E 00	1.194E 00	1.042E 00	-2.481E-01
1.376E-02	6.154E 00	1.218E 00	1.055E 00	-3.085E-01
1.750E-02	5.832E 00	1.242E 00	1.070E 00	-3.727E-01
2.165E-02	5.583E 00	1.266E 00	1.087E 00	-4.382E-01
2.611E-02	5.383E 00	1.290E 00	1.105E 00	-5.030E-01
3.078E-02	5.230E 00	1.315E 00	1.123E 00	-5.658E-01
3.558E-02	5.119E 00	1.338E 00	1.143E 00	-6.255E-01
4.047E-02	5.039E 00	1.361E 00	1.162E 00	-6.822E-01
4.540E-02	4.970E 00	1.383E 00	1.182E 00	-7.356E-01
5.037E-02	4.909E 00	1.406E 00	1.202E 00	-7.860E-01
5.535E-02	4.869E 00	1.427E 00	1.222E 00	-8.334E-01
6.033E-02	4.842E 00	1.448E 00	1.242E 00	-8.782E-01
6.533E-02	4.813E 00	1.470E 00	1.262E 00	-9.206E-01
7.032E-02	4.783E 00	1.491E 00	1.282E 00	-9.607E-01
7.532E-02	4.762E 00	1.512E 00	1.302E 00	-9.987E-01
8.032E-02	4.754E 00	1.532E 00	1.322E 00	-1.035E 00
8.532E-02	4.740E 00	1.553E 00	1.342E 00	-1.069E 00
9.032E-02	4.718E 00	1.574E 00	1.362E 00	-1.102E 00
9.532E-02	4.706E 00	1.595E 00	1.382E 00	-1.133E 00

XN=1.00   DH/RT=10.   PIPE FLOW
FLUX=1.   BRINKMAN NO.=0.   PRANDTL NO.=1000.
DXS=5.E-08   DXL=5.E-03   A=-115.
DR=.02   NDRDIV=10   NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.193E 02	1.003E 00	1.000E 00	-1.582E-06
8.219E-08	4.118E 02	1.003E 00	1.000E 00	-3.368E-06
1.630E-07	2.243E 02	1.005E 00	1.000E 00	-5.894E-06
2.835E-07	1.996E 02	1.005E 00	1.000E 00	-9.646E-06
4.619E-07	1.739E 02	1.006E 00	1.000E 00	-1.520E-05
7.261E-07	1.550E 02	1.007E 00	1.000E 00	-2.345E-05
1.118E-06	1.256E 02	1.008E 00	1.000E 00	-3.566E-05
1.698E-06	1.103E 02	1.009E 00	1.000E 00	-5.371E-05
2.557E-06	9.845E 01	1.010E 00	1.000E 00	-8.043E-05
3.830E-06	8.671E 01	1.012E 00	1.000E 00	-1.200E-04
5.716E-06	7.383E 01	1.014E 00	1.000E 00	-1.786E-04
8.510E-06	6.481E 01	1.016E 00	1.000E 00	-2.652E-04
1.265E-05	5.778E 01	1.018E 00	1.000E 00	-3.932E-04
1.878E-05	5.080E 01	1.020E 00	1.000E 00	-5.825E-04
2.785E-05	4.398E 01	1.023E 00	1.000E 00	-8.619E-04
4.129E-05	3.869E 01	1.026E 00	1.000E 00	-1.274E-03
6.118E-05	3.441E 01	1.030E 00	1.001E 00	-1.880E-03
9.060E-05	3.032E 01	1.034E 00	1.001E 00	-2.770E-03
1.341E-04	2.651E 01	1.039E 00	1.001E 00	-4.071E-03
1.983E-04	2.341E 01	1.044E 00	1.001E 00	-5.963E-03
2.930E-04	2.080E 01	1.049E 00	1.001E 00	-8.699E-03
4.322E-04	1.837E 01	1.056E 00	1.002E 00	-1.262E-02
6.363E-04	1.616E 01	1.065E 00	1.003E 00	-1.818E-02
9.340E-04	1.431E 01	1.074E 00	1.004E 00	-2.595E-02
1.365E-03	1.276E 01	1.084E 00	1.005E 00	-3.663E-02
1.983E-03	1.137E 01	1.096E 00	1.008E 00	-5.096E-02
2.856E-03	1.016E 01	1.110E 00	1.011E 00	-6.960E-02
4.066E-03	9.158E 00	1.125E 00	1.015E 00	-9.296E-02

5.699E-03	8.333E 00	1.143E 00	1.023E 00	-1.212E-01
7.835E-03	7.639E 00	1.162E 00	1.031E 00	-1.534E-01
1.052E-02	7.061E 00	1.184E 00	1.042E 00	-1.882E-01
1.376E-02	6.608E 00	1.206E 00	1.055E 00	-2.242E-01
1.750E-02	6.269E 00	1.230E 00	1.070E 00	-2.595E-01
2.165E-02	5.996E 00	1.254E 00	1.087E 00	-2.925E-01
2.611E-02	5.774E 00	1.278E 00	1.105E 00	-3.227E-01
3.078E-02	5.623E 00	1.301E 00	1.123E 00	-3.498E-01
3.558E-02	5.506E 00	1.325E 00	1.143E 00	-3.737E-01
4.047E-02	5.405E 00	1.348E 00	1.162E 00	-3.947E-01
4.540E-02	5.318E 00	1.370E 00	1.182E 00	-4.131E-01
5.037E-02	5.266E 00	1.392E 00	1.202E 00	-4.296E-01
5.535E-02	5.232E 00	1.413E 00	1.222E 00	-4.441E-01
6.033E-02	5.173E 00	1.436E 00	1.243E 00	-4.569E-01
6.533E-02	5.126E 00	1.457E 00	1.262E 00	-4.684E-01
7.032E-02	5.111E 00	1.478E 00	1.282E 00	-4.787E-01
7.532E-02	5.107E 00	1.498E 00	1.302E 00	-4.880E-01
8.032E-02	5.063E 00	1.520E 00	1.322E 00	-4.963E-01
8.532E-02	5.012E 00	1.541E 00	1.342E 00	-5.038E-01
9.032E-02	5.019E 00	1.561E 00	1.361E 00	-5.107E-01
9.532E-02	5.034E 00	1.581E 00	1.383E 00	-5.170E-01

XN=1.00 DH/RT=5. PIPE FLOW
FLUX=2. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	3.970E 02	1.005E 00	1.000E 00	-1.583E-06
8.219E-08	3.903E 02	1.005E 00	1.000E 00	-3.368E-06
1.630E-07	2.178E 02	1.009E 00	1.000E 00	-5.894E-06
2.835E-07	1.944E 02	1.011E 00	1.000E 00	-9.645E-06
4.619E-07	1.699E 02	1.012E 00	1.000E 00	-1.520E-05
7.261E-07	1.519E 02	1.013E 00	1.000E 00	-2.345E-05
1.118E-06	1.236E 02	1.016E 00	1.000E 00	-3.567E-05
1.698E-06	1.087E 02	1.019E 00	1.000E 00	-5.371E-05
2.557E-06	9.715E 01	1.021E 00	1.000E 00	-8.045E-05
3.830E-06	8.569E 01	1.024E 00	1.000E 00	-1.201E-04
5.716E-06	7.308E 01	1.028E 00	1.000E 00	-1.786E-04
8.510E-06	6.422E 01	1.031E 00	1.000E 00	-2.652E-04
1.265E-05	5.730E 01	1.035E 00	1.000E 00	-3.933E-04
1.878E-05	5.043E 01	1.040E 00	1.000E 00	-5.827E-04
2.785E-05	4.369E 01	1.046E 00	1.001E 00	-8.623E-04
4.129E-05	3.845E 01	1.053E 00	1.001E 00	-1.274E-03
6.118E-05	3.420E 01	1.059E 00	1.001E 00	-1.881E-03
9.060E-05	3.015E 01	1.067E 00	1.001E 00	-2.772E-03
1.341E-04	2.637E 01	1.077E 00	1.001E 00	-4.075E-03
1.983E-04	2.328E 01	1.088E 00	1.002E 00	-5.971E-03
2.930E-04	2.069E 01	1.099E 00	1.003E 00	-8.714E-03
4.322E-04	1.827E 01	1.113E 00	1.004E 00	-1.265E-02
6.363E-04	1.607E 01	1.130E 00	1.005E 00	-1.825E-02
9.340E-04	1.422E 01	1.148E 00	1.008E 00	-2.608E-02
1.365E-03	1.267E 01	1.169E 00	1.011E 00	-3.687E-02
1.983E-03	1.128E 01	1.193E 00	1.016E 00	-5.144E-02
2.856E-03	1.007E 01	1.222E 00	1.023E 00	-7.051E-02
4.066E-03	9.051E 00	1.254E 00	1.033E 00	-9.466E-02

5.699E-03	8.215E 00	1.289E 00	1.046E 00	-1.242E-01
7.835E-03	7.515E 00	1.329E 00	1.063E 00	-1.585E-01
1.052E-02	6.920E 00	1.373E 00	1.084E 00	-1.964E-01
1.376E-02	6.451E 00	1.420E 00	1.110E 00	-2.367E-01
1.750E-02	6.102E 00	1.468E 00	1.140E 00	-2.775E-01
2.165E-02	5.817E 00	1.517E 00	1.173E 00	-3.169E-01
2.611E-02	5.593E 00	1.567E 00	1.209E 00	-3.544E-01
3.078E-02	5.425E 00	1.615E 00	1.246E 00	-3.893E-01
3.558E-02	5.294E 00	1.663E 00	1.285E 00	-4.215E-01
4.047E-02	5.200E 00	1.709E 00	1.324E 00	-4.510E-01
4.540E-02	5.110E 00	1.755E 00	1.363E 00	-4.781E-01
5.037E-02	5.043E 00	1.800E 00	1.404E 00	-5.031E-01
5.535E-02	4.993E 00	1.843E 00	1.443E 00	-5.262E-01
6.033E-02	4.948E 00	1.888E 00	1.484E 00	-5.475E-01
6.533E-02	4.913E 00	1.931E 00	1.523E 00	-5.674E-01
7.032E-02	4.871E 00	1.973E 00	1.563E 00	-5.860E-01
7.532E-02	4.848E 00	2.016E 00	1.603E 00	-6.034E-01
8.032E-02	4.827E 00	2.058E 00	1.643E 00	-6.197E-01
8.532E-02	4.799E 00	2.100E 00	1.684E 00	-6.351E-01
9.032E-02	4.780E 00	2.142E 00	1.723E 00	-6.497E-01
9.532E-02	4.760E 00	2.183E 00	1.763E 00	-6.634E-01

XN=1.00 DH/RT=10. PIPE FLOW
FLUX=2. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-09 DXL=5.E-03 A=-115.
DR=.005 NDRDIV=1 NDRWAL=1

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-09	3.909E 02	1.005E 00	1.000E 00	-1.591E-07
8.219E-09	3.905E 02	1.005E 00	1.000E 00	-3.396E-07
1.630E-08	3.656E 02	1.005E 00	1.000E 00	-5.937E-07
2.835E-08	3.554E 02	1.006E 00	1.000E 00	-9.680E-07
4.619E-08	3.234E 02	1.006E 00	1.000E 00	-1.520E-06
7.262E-08	3.010E 02	1.007E 00	1.000E 00	-2.332E-06
1.118E-07	2.645E 02	1.008E 00	1.000E 00	-3.530E-06
1.698E-07	2.352E 02	1.009E 00	1.000E 00	-5.294E-06
2.557E-07	2.020E 02	1.010E 00	1.000E 00	-7.897E-06
3.831E-07	1.756E 02	1.011E 00	1.000E 00	-1.175E-05
5.717E-07	1.516E 02	1.013E 00	1.000E 00	-1.744E-05
8.512E-07	1.331E 02	1.015E 00	1.000E 00	-2.588E-05
1.265E-06	1.175E 02	1.017E 00	1.000E 00	-3.840E-05
1.879E-06	1.044E 02	1.019E 00	1.000E 00	-5.695E-05
2.787E-06	9.258E 01	1.022E 00	1.000E 00	-8.441E-05
4.134E-06	8.198E 01	1.024E 00	1.000E 00	-1.250E-04
6.128E-06	7.247E 01	1.028E 00	1.000E 00	-1.851E-04
9.083E-06	6.415E 01	1.031E 00	1.000E 00	-2.739E-04
1.346E-05	5.679E 01	1.035E 00	1.000E 00	-4.050E-04
1.994E-05	5.026E 01	1.040E 00	1.000E 00	-5.983E-04
2.954E-05	4.449E 01	1.045E 00	1.000E 00	-8.830E-04
4.375E-05	3.941E 01	1.051E 00	1.000E 00	-1.301E-03
6.478E-05	3.493E 01	1.058E 00	1.001E 00	-1.913E-03
9.588E-05	3.096E 01	1.065E 00	1.001E 00	-2.805E-03
1.419E-04	2.746E 01	1.074E 00	1.001E 00	-4.094E-03
2.097E-04	2.438E 01	1.084E 00	1.002E 00	-5.943E-03
3.098E-04	2.166E 01	1.095E 00	1.003E 00	-8.565E-03
4.568E-04	1.925E 01	1.108E 00	1.004E 00	-1.223E-02

6.723E-04	1.713E 01	1.122E 00	1.005E 00	-1.728E-02
9.862E-04	1.528E 01	1.139E 00	1.008E 00	-2.405E-02
1.440E-03	1.364E 01	1.158E 00	1.012E 00	-3.293E-02
2.090E-03	1.221E 01	1.181E 00	1.017E 00	-4.417E-02
3.006E-03	1.096E 01	1.207E 00	1.024E 00	-5.775E-02
4.270E-03	9.881E 00	1.237E 00	1.034E 00	-7.344E-02
5.971E-03	8.963E 00	1.271E 00	1.048E 00	-9.073E-02
8.183E-03	8.196E 00	1.309E 00	1.065E 00	-1.084E-01
1.095E-02	7.556E 00	1.352E 00	1.087E 00	-1.256E-01
1.426E-02	7.058E 00	1.397E 00	1.114E 00	-1.417E-01
1.807E-02	6.654E 00	1.444E 00	1.143E 00	-1.557E-01
2.227E-02	6.334E 00	1.493E 00	1.178E 00	-1.676E-01
2.677E-02	6.107E 00	1.540E 00	1.213E 00	-1.776E-01
3.146E-02	5.912E 00	1.588E 00	1.250E 00	-1.859E-01
3.628E-02	5.762E 00	1.637E 00	1.290E 00	-1.927E-01
4.117E-02	5.634E 00	1.684E 00	1.329E 00	-1.983E-01
4.611E-02	5.559E 00	1.728E 00	1.369E 00	-2.031E-01
5.107E-02	5.484E 00	1.770E 00	1.405E 00	-2.071E-01
5.606E-02	5.397E 00	1.819E 00	1.448E 00	-2.105E-01
6.104E-02	5.330E 00	1.863E 00	1.488E 00	-2.133E-01
6.604E-02	5.296E 00	1.906E 00	1.529E 00	-2.158E-01
7.103E-02	5.288E 00	1.942E 00	1.563E 00	-2.181E-01
7.603E-02	5.213E 00	1.990E 00	1.605E 00	-2.201E-01
8.103E-02	5.154E 00	2.037E 00	1.649E 00	-2.217E-01
8.603E-02	5.128E 00	2.079E 00	1.689E 00	-2.232E-01
9.103E-02	5.160E 00	2.111E 00	1.723E 00	-2.246E-01
9.603E-02	5.115E 00	2.155E 00	1.764E 00	-2.258E-01

XN= .75 DH/RT=0. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.282E 02	1.003E 00	1.000E 00	-1.730E-06
8.219E-08	4.163E 02	1.003E 00	1.000E 00	-3.704E-06
1.630E-07	2.271E 02	1.005E 00	1.000E 00	-6.496E-06
2.835E-07	2.016E 02	1.005E 00	1.000E 00	-1.066E-05
4.619E-07	1.759E 02	1.006E 00	1.000E 00	-1.684E-05
7.261E-07	1.566E 02	1.007E 00	1.000E 00	-2.601E-05
1.118E-06	1.268E 02	1.008E 00	1.000E 00	-3.959E-05
1.698E-06	1.108E 02	1.009E 00	1.000E 00	-5.972E-05
2.557E-06	9.864E 01	1.010E 00	1.000E 00	-8.953E-05
3.830E-06	8.680E 01	1.012E 00	1.000E 00	-1.337E-04
5.716E-06	7.378E 01	1.014E 00	1.000E 00	-1.991E-04
8.510E-06	6.435E 01	1.016E 00	1.000E 00	-2.960E-04
1.265E-05	5.707E 01	1.018E 00	1.000E 00	-4.395E-04
1.878E-05	5.007E 01	1.020E 00	1.000E 00	-6.520E-04
2.785E-05	4.319E 01	1.024E 00	1.000E 00	-9.667E-04
4.129E-05	3.768E 01	1.027E 00	1.000E 00	-1.433E-03
6.118E-05	3.326E 01	1.031E 00	1.000E 00	-2.122E-03
9.060E-05	2.918E 01	1.035E 00	1.001E 00	-3.142E-03
1.341E-04	2.538E 01	1.040E 00	1.001E 00	-4.650E-03
1.983E-04	2.220E 01	1.046E 00	1.001E 00	-6.875E-03
2.930E-04	1.956E 01	1.053E 00	1.001E 00	-1.016E-02
4.322E-04	1.717E 01	1.060E 00	1.002E 00	-1.499E-02
6.363E-04	1.498E 01	1.070E 00	1.003E 00	-2.206E-02
9.340E-04	1.312E 01	1.080E 00	1.004E 00	-3.238E-02
1.365E-03	1.158E 01	1.092E 00	1.005E 00	-4.733E-02
1.983E-03	1.026E 01	1.106E 00	1.008E 00	-6.875E-02
2.856E-03	9.100E 00	1.122E 00	1.012E 00	-9.902E-02
4.066E-03	8.136E 00	1.139E 00	1.017E 00	-1.410E-01

5.699E-03	7.357E 00	1.159E 00	1.023E 00	-1.976E-01
7.835E-03	6.722E 00	1.180E 00	1.032E 00	-2.715E-01
1.052E-02	6.200E 00	1.204E 00	1.042E 00	-3.648E-01
1.376E-02	5.786E 00	1.228E 00	1.055E 00	-4.771E-01
1.750E-02	5.475E 00	1.253E 00	1.070E 00	-6.068E-01
2.165E-02	5.243E 00	1.278E 00	1.087E 00	-7.507E-01
2.611E-02	5.062E 00	1.302E 00	1.105E 00	-9.054E-01
3.078E-02	4.920E 00	1.327E 00	1.124E 00	-1.067E 00
3.558E-02	4.817E 00	1.350E 00	1.143E 00	-1.234E 00
4.047E-02	4.748E 00	1.373E 00	1.162E 00	-1.403E 00
4.540E-02	4.692E 00	1.395E 00	1.182E 00	-1.574E 00
5.037E-02	4.642E 00	1.418E 00	1.202E 00	-1.746E 00
5.535E-02	4.606E 00	1.439E 00	1.222E 00	-1.919E 00
6.033E-02	4.587E 00	1.460E 00	1.242E 00	-2.092E 00
6.533E-02	4.573E 00	1.481E 00	1.262E 00	-2.265E 00
7.032E-02	4.552E 00	1.502E 00	1.282E 00	-2.438E 00
7.532E-02	4.534E 00	1.522E 00	1.302E 00	-2.611E 00
8.032E-02	4.532E 00	1.543E 00	1.322E 00	-2.785E 00
8.532E-02	4.535E 00	1.563E 00	1.342E 00	-2.958E 00
9.032E-02	4.524E 00	1.583E 00	1.362E 00	-3.132E 00
9.532E-02	4.509E 00	1.604E 00	1.382E 00	-3.305E 00

XN= .75 DH/RT=5. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.282E 02	1.003E 00	1.000E 00	-1.721E-06
8.219E-08	4.181E 02	1.003E 00	1.000E 00	-3.676E-06
1.630E-07	2.282E 02	1.005E 00	1.000E 00	-6.437E-06
2.835E-07	2.030E 02	1.005E 00	1.000E 00	-1.055E-05
4.619E-07	1.769E 02	1.006E 00	1.000E 00	-1.666E-05
7.261E-07	1.577E 02	1.007E 00	1.000E 00	-2.574E-05
1.118E-06	1.278E 02	1.008E 00	1.000E 00	-3.918E-05
1.698E-06	1.120E 02	1.009E 00	1.000E 00	-5.908E-05
2.557E-06	9.976E 01	1.010E 00	1.000E 00	-8.854E-05
3.830E-06	8.786E 01	1.012E 00	1.000E 00	-1.322E-04
5.716E-06	7.474E 01	1.014E 00	1.000E 00	-1.968E-04
8.510E-06	6.537E 01	1.016E 00	1.000E 00	-2.925E-04
1.265E-05	5.814E 01	1.018E 00	1.000E 00	-4.340E-04
1.878E-05	5.110E 01	1.020E 00	1.000E 00	-6.435E-04
2.785E-05	4.415E 01	1.023E 00	1.000E 00	-9.534E-04
4.129E-05	3.864E 01	1.026E 00	1.000E 00	-1.411E-03
6.118E-05	3.425E 01	1.030E 00	1.001E 00	-2.088E-03
9.060E-05	3.015E 01	1.034E 00	1.001E 00	-3.085E-03
1.341E-04	2.628E 01	1.039E 00	1.001E 00	-4.554E-03
1.983E-04	2.308E 01	1.044E 00	1.001E 00	-6.710E-03
2.930E-04	2.043E 01	1.050E 00	1.001E 00	-9.863E-03
4.322E-04	1.801E 01	1.057E 00	1.002E 00	-1.445E-02
6.363E-04	1.578E 01	1.066E 00	1.003E 00	-2.110E-02
9.340E-04	1.389E 01	1.076E 00	1.004E 00	-3.063E-02
1.365E-03	1.233E 01	1.087E 00	1.005E 00	-4.415E-02
1.983E-03	1.097E 01	1.099E 00	1.008E 00	-6.303E-02
2.856E-03	9.769E 00	1.114E 00	1.012E 00	-8.888E-02
4.066E-03	8.764E 00	1.131E 00	1.017E 00	-1.234E-01

5.699E-03	7.956E 00	1.149E 00	1.023E 00	-1.679E-01
7.835E-03	7.289E 00	1.169E 00	1.032E 00	-2.232E-01
1.052E-02	6.730E 00	1.191E 00	1.042E 00	-2.890E-01
1.376E-02	6.284E 00	1.214E 00	1.055E 00	-3.636E-01
1.750E-02	5.951E 00	1.238E 00	1.070E 00	-4.445E-01
2.165E-02	5.701E 00	1.262E 00	1.087E 00	-5.289E-01
2.611E-02	5.501E 00	1.286E 00	1.105E 00	-6.142E-01
3.078E-02	5.343E 00	1.311E 00	1.123E 00	-6.984E-01
3.558E-02	5.228E 00	1.334E 00	1.143E 00	-7.800E-01
4.047E-02	5.150E 00	1.356E 00	1.162E 00	-8.588E-01
4.540E-02	5.085E 00	1.379E 00	1.182E 00	-9.345E-01
5.037E-02	5.022E 00	1.401E 00	1.202E 00	-1.007E 00
5.535E-02	4.975E 00	1.423E 00	1.222E 00	-1.076E 00
6.033E-02	4.952E 00	1.444E 00	1.242E 00	-1.143E 00
6.533E-02	4.932E 00	1.465E 00	1.262E 00	-1.207E 00
7.032E-02	4.898E 00	1.486E 00	1.282E 00	-1.268E 00
7.532E-02	4.871E 00	1.507E 00	1.302E 00	-1.327E 00
8.032E-02	4.865E 00	1.528E 00	1.322E 00	-1.383E 00
8.532E-02	4.861E 00	1.548E 00	1.342E 00	-1.438E 00
9.032E-02	4.838E 00	1.569E 00	1.362E 00	-1.491E 00
9.532E-02	4.816E 00	1.589E 00	1.382E 00	-1.541E 00

XN= .75 DH/RT=10. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.282E 02	1.003E 00	1.000E 00	-1.712E-06
8.219E-08	4.200E 02	1.003E 00	1.000E 00	-3.648E-06
1.630E-07	2.294E 02	1.005E 00	1.000E 00	-6.379E-06
2.835E-07	2.044E 02	1.005E 00	1.000E 00	-1.045E-05
4.619E-07	1.780E 02	1.006E 00	1.000E 00	-1.649E-05
7.261E-07	1.587E 02	1.007E 00	1.000E 00	-2.548E-05
1.118E-06	1.288E 02	1.008E 00	1.000E 00	-3.878E-05
1.698E-06	1.131E 02	1.009E 00	1.000E 00	-5.844E-05
2.557E-06	1.009E 02	1.010E 00	1.000E 00	-8.755E-05
3.830E-06	8.891E 01	1.012E 00	1.000E 00	-1.307E-04
5.716E-06	7.570E 01	1.013E 00	1.000E 00	-1.946E-04
8.510E-06	6.638E 01	1.015E 00	1.000E 00	-2.890E-04
1.265E-05	5.919E 01	1.017E 00	1.000E 00	-4.287E-04
1.878E-05	5.211E 01	1.020E 00	1.000E 00	-6.354E-04
2.785E-05	4.509E 01	1.023E 00	1.000E 00	-9.406E-04
4.129E-05	3.959E 01	1.026E 00	1.000E 00	-1.391E-03
6.118E-05	3.523E 01	1.029E 00	1.001E 00	-2.055E-03
9.060E-05	3.109E 01	1.033E 00	1.001E 00	-3.032E-03
1.341E-04	2.716E 01	1.038E 00	1.001E 00	-4.464E-03
1.983E-04	2.392E 01	1.043E 00	1.001E 00	-6.554E-03
2.930E-04	2.127E 01	1.048E 00	1.001E 00	-9.589E-03
4.322E-04	1.882E 01	1.055E 00	1.002E 00	-1.397E-02
6.363E-04	1.654E 01	1.063E 00	1.003E 00	-2.023E-02
9.340E-04	1.461E 01	1.072E 00	1.004E 00	-2.907E-02
1.365E-03	1.304E 01	1.082E 00	1.005E 00	-4.136E-02
1.983E-03	1.164E 01	1.094E 00	1.008E 00	-5.812E-02
2.856E-03	1.038E 01	1.108E 00	1.012E 00	-8.038E-02
4.066E-03	9.337E 00	1.124E 00	1.017E 00	-1.090E-01

5.699E-03	8.501E 00	1.141E 00	1.023E 00	-1.444E-01
7.835E-03	7.799E 00	1.160E 00	1.031E 00	-1.862E-01
1.052E-02	7.197E 00	1.181E 00	1.042E 00	-2.333E-01
1.376E-02	6.716E 00	1.204E 00	1.055E 00	-2.836E-01
1.750E-02	6.366E 00	1.227E 00	1.070E 00	-3.349E-01
2.165E-02	6.102E 00	1.250E 00	1.086E 00	-3.853E-01
2.611E-02	5.881E 00	1.275E 00	1.105E 00	-4.332E-01
3.078E-02	5.698E 00	1.299E 00	1.124E 00	-4.775E-01
3.558E-02	5.572E 00	1.322E 00	1.143E 00	-5.180E-01
4.047E-02	5.502E 00	1.344E 00	1.162E 00	-5.554E-01
4.540E-02	5.434E 00	1.366E 00	1.182E 00	-5.899E-01
5.037E-02	5.341E 00	1.389E 00	1.202E 00	-6.209E-01
5.535E-02	5.271E 00	1.412E 00	1.222E 00	-6.487E-01
6.033E-02	5.265E 00	1.432E 00	1.242E 00	-6.745E-01
6.533E-02	5.268E 00	1.451E 00	1.261E 00	-6.989E-01
7.032E-02	5.207E 00	1.473E 00	1.281E 00	-7.211E-01
7.532E-02	5.133E 00	1.497E 00	1.302E 00	-7.410E-01
8.032E-02	5.125E 00	1.518E 00	1.323E 00	-7.595E-01
8.532E-02	5.169E 00	1.535E 00	1.341E 00	-7.771E-01
9.032E-02	5.154E 00	1.554E 00	1.360E 00	-7.938E-01
9.532E-02	5.079E 00	1.579E 00	1.382E 00	-8.089E-01

XN= .50 DH/RT=0. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.462E 02	1.002E 00	1.000E 00	-1.985E-06
8.219E-08	4.346E 02	1.003E 00	1.000E 00	-4.249E-06
1.630E-07	2.372E 02	1.004E 00	1.000E 00	-7.445E-06
2.835E-07	2.106E 02	1.005E 00	1.000E 00	-1.221E-05
4.619E-07	1.839E 02	1.006E 00	1.000E 00	-1.929E-05
7.261E-07	1.639E 02	1.006E 00	1.000E 00	-2.984E-05
1.118E-06	1.330E 02	1.008E 00	1.000E 00	-4.550E-05
1.698E-06	1.162E 02	1.009E 00	1.000E 00	-6.876E-05
2.557E-06	1.033E 02	1.010E 00	1.000E 00	-1.032E-04
3.830E-06	9.092E 01	1.011E 00	1.000E 00	-1.542E-04
5.716E-06	7.740E 01	1.013E 00	1.000E 00	-2.296E-04
8.510E-06	6.748E 01	1.015E 00	1.000E 00	-3.415E-04
1.265E-05	5.980E 01	1.017E 00	1.000E 00	-5.070E-04
1.878E-05	5.243E 01	1.019E 00	1.000E 00	-7.522E-04
2.785E-05	4.527E 01	1.022E 00	1.000E 00	-1.115E-03
4.129E-05	3.949E 01	1.026E 00	1.000E 00	-1.652E-03
6.118E-05	3.484E 01	1.029E 00	1.000E 00	-2.448E-03
9.060E-05	3.056E 01	1.033E 00	1.001E 00	-3.624E-03
1.341E-04	2.658E 01	1.038E 00	1.001E 00	-5.362E-03
1.983E-04	2.324E 01	1.044E 00	1.001E 00	-7.930E-03
2.930E-04	2.048E 01	1.050E 00	1.001E 00	-1.172E-02
4.322E-04	1.798E 01	1.058E 00	1.002E 00	-1.728E-02
6.363E-04	1.569E 01	1.067E 00	1.003E 00	-2.544E-02
9.340E-04	1.374E 01	1.077E 00	1.004E 00	-3.735E-02
1.365E-03	1.213E 01	1.088E 00	1.005E 00	-5.459E-02
1.983E-03	1.073E 01	1.101E 00	1.008E 00	-7.927E-02
2.856E-03	9.520E 00	1.117E 00	1.012E 00	-1.142E-01
4.066E-03	8.513E 00	1.134E 00	1.01[illegible]E 00	-1.626E-01

5.699E-03	7.698E 00	1.153E 00	1.023E 00	-2.278E-01
7.835E-03	7.034E 00	1.174E 00	1.032E 00	-3.132E-01
1.052E-02	6.490E 00	1.196E 00	1.042E 00	-4.207E-01
1.376E-02	6.060E 00	1.220E 00	1.055E 00	-5.502E-01
1.750E-02	5.736E 00	1.245E 00	1.070E 00	-6.997E-01
2.165E-02	5.496E 00	1.269E 00	1.087E 00	-8.658E-01
2.611E-02	5.310E 00	1.293E 00	1.105E 00	-1.044E 00
3.078E-02	5.163E 00	1.317E 00	1.124E 00	-1.231E 00
3.558E-02	5.060E 00	1.340E 00	1.143E 00	-1.423E 00
4.047E-02	4.990E 00	1.363E 00	1.162E 00	-1.618E 00
4.540E-02	4.931E 00	1.385E 00	1.182E 00	-1.815E 00
5.037E-02	4.880E 00	1.407E 00	1.202E 00	-2.014E 00
5.535E-02	4.848E 00	1.428E 00	1.222E 00	-2.213E 00
6.033E-02	4.830E 00	1.449E 00	1.242E 00	-2.412E 00
6.533E-02	4.811E 00	1.470E 00	1.262E 00	-2.612E 00
7.032E-02	4.792E 00	1.491E 00	1.282E 00	-2.812E 00
7.532E-02	4.779E 00	1.511E 00	1.302E 00	-3.012E 00
8.032E-02	4.776E 00	1.531E 00	1.322E 00	-3.211E 00
8.532E-02	4.773E 00	1.552E 00	1.342E 00	-3.411E 00
9.032E-02	4.763E 00	1.572E 00	1.362E 00	-3.611E 00
9.532E-02	4.756E 00	1.592E 00	1.382E 00	-3.811E 00

XN= .50 DH/RT=5. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.462E 02	1.002E 00	1.000E 00	-1.978E-06
8.219E-08	4.359E 02	1.003E 00	1.000E 00	-4.225E-06
1.630E-07	2.382E 02	1.004E 00	1.000E 00	-7.392E-06
2.835E-07	2.120E 02	1.005E 00	1.000E 00	-1.211E-05
4.619E-07	1.849E 02	1.006E 00	1.000E 00	-1.913E-05
7.261E-07	1.650E 02	1.006E 00	1.000E 00	-2.960E-05
1.118E-06	1.339E 02	1.008E 00	1.000E 00	-4.514E-05
1.698E-06	1.172E 02	1.009E 00	1.000E 00	-6.820E-05
2.557E-06	1.044E 02	1.010E 00	1.000E 00	-1.023E-04
3.830E-06	9.200E 01	1.011E 00	1.000E 00	-1.529E-04
5.716E-06	7.836E 01	1.013E 00	1.000E 00	-2.277E-04
8.510E-06	6.845E 01	1.015E 00	1.000E 00	-3.385E-04
1.265E-05	6.081E 01	1.017E 00	1.000E 00	-5.024E-04
1.878E-05	5.346E 01	1.019E 00	1.000E 00	-7.452E-04
2.785E-05	4.624E 01	1.022E 00	1.000E 00	-1.104E-03
4.129E-05	4.044E 01	1.025E 00	1.000E 00	-1.635E-03
6.118E-05	3.579E 01	1.028E 00	1.000E 00	-2.420E-03
9.060E-05	3.150E 01	1.032E 00	1.001E 00	-3.579E-03
1.341E-04	2.748E 01	1.037E 00	1.001E 00	-5.284E-03
1.983E-04	2.410E 01	1.043E 00	1.001E 00	-7.796E-03
2.930E-04	2.132E 01	1.048E 00	1.001E 00	-1.148E-02
4.322E-04	1.879E 01	1.055E 00	1.002E 00	-1.686E-02
6.363E-04	1.647E 01	1.064E 00	1.003E 00	-2.467E-02
9.340E-04	1.448E 01	1.073E 00	1.004E 00	-3.594E-02
1.365E-03	1.284E 01	1.084E 00	1.006E 00	-5.204E-02
1.983E-03	1.141E 01	1.096E 00	1.008E 00	-7.467E-02
2.856E-03	1.016E 01	1.110E 00	1.012E 00	-1.060E-01
4.066E-03	9.113E 00	1.126E 00	1.017E 00	-1.484E-01

5.699E-03	8.262E 00	1.144E 00	1.023E 00	-2.038E-01
7.835E-03	7.562E 00	1.164E 00	1.032E 00	-2.739E-01
1.052E-02	6.986E 00	1.185E 00	1.042E 00	-3.589E-01
1.376E-02	6.523E 00	1.208E 00	1.055E 00	-4.571E-01
1.750E-02	6.174E 00	1.232E 00	1.070E 00	-5.658E-01
2.165E-02	5.917E 00	1.256E 00	1.087E 00	-6.819E-01
2.611E-02	5.710E 00	1.280E 00	1.105E 00	-8.012E-01
3.078E-02	5.543E 00	1.304E 00	1.123E 00	-9.209E-01
3.558E-02	5.434E 00	1.327E 00	1.143E 00	-1.040E 00
4.047E-02	5.356E 00	1.349E 00	1.162E 00	-1.157E 00
4.540E-02	5.280E 00	1.371E 00	1.182E 00	-1.271E 00
5.037E-02	5.220E 00	1.394E 00	1.202E 00	-1.382E 00
5.535E-02	5.184E 00	1.415E 00	1.222E 00	-1.490E 00
6.033E-02	5.156E 00	1.436E 00	1.242E 00	-1.595E 00
6.533E-02	5.125E 00	1.457E 00	1.262E 00	-1.697E 00
7.032E-02	5.103E 00	1.478E 00	1.282E 00	-1.797E 00
7.532E-02	5.084E 00	1.499E 00	1.302E 00	-1.894E 00
8.032E-02	5.068E 00	1.519E 00	1.322E 00	-1.988E 00
8.532E-02	5.057E 00	1.540E 00	1.342E 00	-2.080E 00
9.032E-02	5.047E 00	1.560E 00	1.362E 00	-2.170E 00
9.532E-02	5.032E 00	1.581E 00	1.382E 00	-2.258E 00

XN= .50 DH/RT=10. PIPE FLOW
FLUX=1. BRINKMAN NO.=0. PRANDTL NO.=1000.
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-08	4.454E 02	1.002E 00	1.000E 00	-1.971E-06
8.219E-08	4.362E 02	1.003E 00	1.000E 00	-4.200E-06
1.630E-07	2.391E 02	1.004E 00	1.000E 00	-7.337E-06
2.835E-07	2.135E 02	1.005E 00	1.000E 00	-1.201E-05
4.619E-07	1.860E 02	1.006E 00	1.000E 00	-1.896E-05
7.261E-07	1.659E 02	1.006E 00	1.000E 00	-2.935E-05
1.118E-06	1.347E 02	1.008E 00	1.000E 00	-4.477E-05
1.698E-06	1.183E 02	1.009E 00	1.000E 00	-6.763E-05
2.557E-06	1.055E 02	1.010E 00	1.000E 00	-1.014E-04
3.830E-06	9.305E 01	1.011E 00	1.000E 00	-1.516E-04
5.716E-06	7.929E 01	1.013E 00	1.000E 00	-2.257E-04
8.510E-06	6.939E 01	1.015E 00	1.000E 00	-3.355E-04
1.265E-05	6.181E 01	1.016E 00	1.000E 00	-4.979E-04
1.878E-05	5.447E 01	1.019E 00	1.000E 00	-7.383E-04
2.785E-05	4.718E 01	1.022E 00	1.000E 00	-1.094E-03
4.129E-05	4.135E 01	1.025E 00	1.000E 00	-1.618E-03
6.118E-05	3.671E 01	1.028E 00	1.000E 00	-2.393E-03
9.060E-05	3.241E 01	1.031E 00	1.001E 00	-3.535E-03
1.341E-04	2.834E 01	1.036E 00	1.001E 00	-5.211E-03
1.983E-04	2.493E 01	1.041E 00	1.001E 00	-7.669E-03
2.930E-04	2.211E 01	1.047E 00	1.001E 00	-1.126E-02
4.322E-04	1.956E 01	1.053E 00	1.002E 00	-1.646E-02
6.363E-04	1.719E 01	1.061E 00	1.003E 00	-2.396E-02
9.340E-04	1.517E 01	1.070E 00	1.004E 00	-3.467E-02
1.365E-03	1.349E 01	1.080E 00	1.005E 00	-4.975E-02
1.983E-03	1.203E 01	1.091E 00	1.008E 00	-7.059E-02
2.856E-03	1.073E 01	1.105E 00	1.012E 00	-9.893E-02
4.066E-03	9.641E 00	1.120E 00	1.016E 00	-1.363E-01

5.699E-03	8.758E 00	1.137E 00	1.023E 00	-1.835E-01
7.835E-03	8.025E 00	1.156E 00	1.031E 00	-2.415E-01
1.052E-02	7.420E 00	1.177E 00	1.042E 00	-3.095E-01
1.376E-02	6.935E 00	1.199E 00	1.055E 00	-3.844E-01
1.750E-02	6.558E 00	1.223E 00	1.070E 00	-4.641E-01
2.165E-02	6.272E 00	1.246E 00	1.087E 00	-5.459E-01
2.611E-02	6.055E 00	1.270E 00	1.105E 00	-6.261E-01
3.078E-02	5.891E 00	1.293E 00	1.124E 00	-7.038E-01
3.558E-02	5.768E 00	1.316E 00	1.143E 00	-7.789E-01
4.047E-02	5.667E 00	1.339E 00	1.162E 00	-8.493E-01
4.540E-02	5.581E 00	1.361E 00	1.182E 00	-9.146E-01
5.037E-02	5.508E 00	1.384E 00	1.202E 00	-9.769E-01
5.535E-02	5.468E 00	1.405E 00	1.222E 00	-1.037E 00
6.033E-02	5.463E 00	1.425E 00	1.242E 00	-1.092E 00
6.533E-02	5.439E 00	1.447E 00	1.263E 00	-1.145E 00
7.032E-02	5.362E 00	1.469E 00	1.283E 00	-1.195E 00
7.532E-02	5.289E 00	1.491E 00	1.302E 00	-1.242E 00
8.032E-02	5.304E 00	1.510E 00	1.321E 00	-1.286E 00
8.532E-02	5.363E 00	1.529E 00	1.342E 00	-1.329E 00
9.032E-02	5.367E 00	1.549E 00	1.362E 00	-1.371E 00
9.532E-02	5.276E 00	1.572E 00	1.383E 00	-1.410E 00

XN= .25 PIPE FLOW
FULLY-DEV. VELOCITY AND UNIFORM FLUX=1.0
DXS=5.E-09 DXL=5.E-03 A=-115.
DR=.005 NDRDIV=1 NDRWAL=1

X	NU(LOCAL)	T(WALL)	T(MEAN)	P
2.500E-09	3.951E 02	1.003E 00	1.000E 00	-2.800E-07
8.219E-09	3.947E 02	1.003E 00	1.000E 00	-6.002E-07
1.630E-08	3.795E 02	1.003E 00	1.000E 00	-1.053E-06
2.835E-08	3.724E 02	1.003E 00	1.000E 00	-1.728E-06
4.619E-08	3.503E 02	1.003E 00	1.000E 00	-2.725E-06
7.262E-08	3.329E 02	1.003E 00	1.000E 00	-4.206E-06
1.118E-07	3.027E 02	1.003E 00	1.000E 00	-6.399E-06
1.698E-07	2.752E 02	1.004E 00	1.000E 00	-9.648E-06
2.557E-07	2.408E 02	1.004E 00	1.000E 00	-1.446E-05
3.831E-07	2.102E 02	1.005E 00	1.000E 00	-2.159E-05
5.717E-07	1.802E 02	1.006E 00	1.000E 00	-3.216E-05
8.512E-07	1.557E 02	1.006E 00	1.000E 00	-4.781E-05
1.265E-06	1.351E 02	1.007E 00	1.000E 00	-7.099E-05
1.879E-06	1.188E 02	1.008E 00	1.000E 00	-1.053E-04
2.787E-06	1.050E 02	1.010E 00	1.000E 00	-1.562E-04
4.134E-06	9.295E 01	1.011E 00	1.000E 00	-2.316E-04
6.128E-06	8.184E 01	1.012E 00	1.000E 00	-3.433E-04
9.083E-06	7.191E 01	1.014E 00	1.000E 00	-5.088E-04
1.346E-05	6.318E 01	1.016E 00	1.000E 00	-7.538E-04
1.994E-05	5.554E 01	1.018E 00	1.000E 00	-1.117E-03
2.954E-05	4.874E 01	1.021E 00	1.000E 00	-1.654E-03
4.375E-05	4.271E 01	1.024E 00	1.000E 00	-2.450E-03
6.478E-05	3.742E 01	1.027E 00	1.000E 00	-3.628E-03
9.588E-05	3.280E 01	1.031E 00	1.000E 00	-5.369E-03
1.419E-04	2.873E 01	1.035E 00	1.001E 00	-7.944E-03
2.097E-04	2.515E 01	1.041E 00	1.001E 00	-1.174E-02
3.098E-04	2.203E 01	1.047E 00	1.001E 00	-1.735E-02
4.568E-04	1.932E 01	1.054E 00	1.002E 00	-2.558E-02

6.723E-04	1.696E 01	1.062E 00	1.003E 00	-3.765E-02
9.862E-04	1.492E 01	1.071E 00	1.004E 00	-5.523E-02
1.440E-03	1.316E 01	1.082E 00	1.005E 00	-8.065E-02
2.090E-03	1.165E 01	1.094E 00	1.008E 00	-1.170E-01
3.006E-03	1.038E 01	1.108E 00	1.012E 00	-1.683E-01
4.270E-03	9.303E 00	1.125E 00	1.017E 00	-2.391E-01
5.971E-03	8.416E 00	1.143E 00	1.024E 00	-3.344E-01
8.183E-03	7.697E 00	1.163E 00	1.033E 00	-4.582E-01
1.095E-02	7.123E 00	1.184E 00	1.044E 00	-6.132E-01
1.426E-02	6.674E 00	1.207E 00	1.057E 00	-7.988E-01
1.807E-02	6.329E 00	1.230E 00	1.072E 00	-1.012E 00
2.227E-02	6.070E 00	1.254E 00	1.089E 00	-1.247E 00
2.677E-02	5.877E 00	1.277E 00	1.107E 00	-1.499E 00
3.146E-02	5.734E 00	1.300E 00	1.125E 00	-1.762E 00
3.628E-02	5.627E 00	1.323E 00	1.145E 00	-2.031E 00
4.117E-02	5.548E 00	1.345E 00	1.165E 00	-2.305E 00
4.611E-02	5.490E 00	1.366E 00	1.184E 00	-2.582E 00
5.107E-02	5.447E 00	1.388E 00	1.204E 00	-2.860E 00
5.606E-02	5.414E 00	1.409E 00	1.224E 00	-3.139E 00
6.104E-02	5.390E 00	1.429E 00	1.244E 00	-3.418E 00
6.604E-02	5.372E 00	1.450E 00	1.264E 00	-3.698E 00
7.103E-02	5.359E 00	1.470E 00	1.284E 00	-3.978E 00
7.603E-02	5.348E 00	1.491E 00	1.304E 00	-4.258E 00
8.103E-02	5.340E 00	1.511E 00	1.324E 00	-4.538E 00
8.603E-02	5.335E 00	1.531E 00	1.344E 00	-4.818E 00
9.103E-02	5.331E 00	1.551E 00	1.364E 00	-5.098E 00
9.603E-02	5.328E 00	1.571E 00	1.384E 00	-5.378E 00

N= 1.0000 DH/RT= 0 PIPE FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
FLUX= 1.4142 SIN(100*PI*X)
DXS=5.E-08 DXL=5.E-04 A=-4600.
DR=.02 NORDIV=10 NDRWAL=2

X	FLUX	T(WALL)	T(MEAN)	P
2.500E-08	1.111E-05	1.000E 00	1.000E 00	-1.600E-06
1.037E-07	4.609E-05	1.000E 00	1.000E 00	-4.120E-06
3.018E-07	1.341E-04	1.000E 00	1.000E 00	-1.046E-05
8.178E-07	3.633E-04	1.000E 00	1.000E 00	-2.697E-05
2.153E-06	9.566E-04	1.000E 00	1.000E 00	-6.970E-05
5.605E-06	2.490E-03	1.000E 00	1.000E 00	-1.802E-04
1.448E-05	6.434E-03	1.000E 00	1.000E 00	-4.642E-04
3.700E-05	1.644E-02	1.000E 00	1.000E 00	-1.185E-03
9.229E-05	4.100E-02	1.001E 00	1.000E 00	-2.954E-03
2.179E-04	9.675E-02	1.003E 00	1.000E 00	-6.975E-03
4.627E-04	2.049E-01	1.009E 00	1.000E 00	-1.481E-02
8.412E-04	3.694E-01	1.021E 00	1.001E 00	-2.692E-02
1.306E-03	5.642E-01	1.038E 00	1.002E 00	-4.180E-02
1.800E-03	7.579E-01	1.058E 00	1.003E 00	-5.761E-02
2.300E-03	9.351E-01	1.079E 00	1.005E 00	-7.359E-02
2.800E-03	1.090E 00	1.100E 00	1.007E 00	-8.959E-02
3.300E-03	1.217E 00	1.121E 00	1.009E 00	-1.056E-01
3.800E-03	1.315E 00	1.140E 00	1.012E 00	-1.215E-01
4.300E-03	1.380E 00	1.158E 00	1.014E 00	-1.376E-01
4.800E-03	1.411E 00	1.173E 00	1.017E 00	-1.536E-01
5.300E-03	1.408E 00	1.185E 00	1.020E 00	-1.696E-01
5.800E-03	1.370E 00	1.194E 00	1.023E 00	-1.856E-01
6.300E-03	1.298E 00	1.199E 00	1.025E 00	-2.016E-01
6.800E-03	1.194E 00	1.201E 00	1.028E 00	-2.175E-01
7.300E-03	1.061E 00	1.198E 00	1.030E 00	-2.335E-01
7.800E-03	9.015E-01	1.192E 00	1.032E 00	-2.495E-01
8.300E-03	7.200E-01	1.182E 00	1.034E 00	-2.656E-01

8.800E-03	5.207E-01	1.169E 00	1.035E 00	-2.815E-01
9.300E-03	3.086E-01	1.153E 00	1.035E 00	-2.976E-01
9.800E-03	8.893E-02	1.134E 00	1.035E 00	-3.136E-01
1.030E-02	0	1.119E 00	1.035E 00	-3.296E-01
1.080E-02	0	1.109E 00	1.035E 00	-3.456E-01
1.130E-02	0	1.102E 00	1.035E 00	-3.616E-01
1.180E-02	0	1.097E 00	1.035E 00	-3.776E-01

N= 1.0000 DH/RT= 10 PIPE FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
FLUX= 1.4142 SIN(100*PI*X)
DXS=5.E-08 DXL=5.E-04 A=-4600.
DR=.02 NDRDIV=10 NDRWAL=2

X	FLUX	T(WALL)	T(MEAN)	P
2.500E-08	1.111E-05	1.000E 00	1.000E 00	-1.600E-06
1.037E-07	4.609E-05	1.000E 00	1.000E 00	-4.120E-06
3.018E-07	1.341E-04	1.000E 00	1.000E 00	-1.046E-05
8.178E-07	3.633E-04	1.000E 00	1.000E 00	-2.697E-05
2.153E-06	9.566E-04	1.000E 00	1.000E 00	-6.970E-05
5.605E-06	2.490E-03	1.000E 00	1.000E 00	-1.802E-04
1.448E-05	6.434E-03	1.000E 00	1.000E 00	-4.642E-04
3.700E-05	1.644E-02	1.000E 00	1.000E 00	-1.185E-03
9.229E-05	4.100E-02	1.001E 00	1.000E 00	-2.952E-03
2.179E-04	9.675E-02	1.003E 00	1.000E 00	-6.960E-03
4.627E-04	2.049E-01	1.009E 00	1.000E 00	-1.471E-02
8.412E-04	3.694E-01	1.021E 00	1.001E 00	-2.645E-02
1.306E-03	5.642E-01	1.036E 00	1.002E 00	-4.029E-02
1.800E-03	7.579E-01	1.054E 00	1.003E 00	-5.410E-02
2.300E-03	9.351E-01	1.072E 00	1.005E 00	-6.711E-02
2.800E-03	1.090E 00	1.090E 00	1.007E 00	-7.925E-02
3.300E-03	1.217E 00	1.107E 00	1.009E 00	-9.049E-02
3.800E-03	1.315E 00	1.122E 00	1.012E 00	-1.009E-01
4.300E-03	1.380E 00	1.136E 00	1.014E 00	-1.105E-01
4.800E-03	1.411E 00	1.148E 00	1.017E 00	-1.195E-01
5.300E-03	1.408E 00	1.158E 00	1.020E 00	-1.279E-01
5.800E-03	1.370E 00	1.165E 00	1.022E 00	-1.358E-01
6.300E-03	1.298E 00	1.170E 00	1.025E 00	-1.433E-01
6.800E-03	1.194E 00	1.172E 00	1.028E 00	-1.506E-01
7.300E-03	1.061E 00	1.172E 00	1.030E 00	-1.575E-01
7.800E-03	9.015E-01	1.168E 00	1.032E 00	-1.643E-01
8.300E-03	7.200E-01	1.160E 00	1.033E 00	-1.712E-01

8.800E-03	5.207E-01	1.150E 00	1.034E 00	-1.780E-01
9.300E-03	3.086E-01	1.138E 00	1.035E 00	-1.848E-01
9.800E-03	8.893E-02	1.121E 00	1.035E 00	-1.919E-01
1.030E-02	0	1.109E 00	1.036E 00	-1.994E-01
1.080E-02	0	1.100E 00	1.035E 00	-2.070E-01
1.130E-02	0	1.094E 00	1.036E 00	-2.147E-01
1.180E-02	0	1.090E 00	1.035E 00	-2.228E-01

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N=    .5000        DH/RT=         0       PIPE FLOW
PRANDTL NO.=      1000      BRINKMAN NO.=             0
FLUX=     1.4142 SIN(100*PI*X)
DXS=5.E-08       DXL=5.E-04       A=-4600.
DR=.02        NDRDIV=10       NDRWAL=2
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X	FLUX	T(WALL)	T(MEAN)	P
2.500E-08	1.111E-05	1.000E 00	1.000E 00	-1.985E-06
1.037E-07	4.609E-05	1.000E 00	1.000E 00	-5.102E-06
3.018E-07	1.341E-04	1.000E 00	1.000E 00	-1.294E-05
8.178E-07	3.633E-04	1.000E 00	1.000E 00	-3.350E-05
2.153E-06	9.566E-04	1.000E 00	1.000E 00	-8.685E-05
5.605E-06	2.490E-03	1.000E 00	1.000E 00	-2.251E-04
1.448E-05	6.434E-03	1.000E 00	1.000E 00	-5.809E-04
3.700E-05	1.644E-02	1.000E 00	1.000E 00	-1.480E-03
9.229E-05	4.100E-02	1.001E 00	1.000E 00	-3.685E-03
2.179E-04	9.675E-02	1.003E 00	1.000E 00	-8.745E-03
4.627E-04	2.049E-01	1.009E 00	1.000E 00	-1.846E-02
8.412E-04	3.694E-01	1.020E 00	1.001E 00	-3.364E-02
1.306E-03	5.642E-01	1.035E 00	1.002E 00	-5.224E-02
1.800E-03	7.579E-01	1.054E 00	1.003E 00	-7.199E-02
2.300E-03	9.351E-01	1.074E 00	1.005E 00	-9.195E-02
2.800E-03	1.090E 00	1.094E 00	1.007E 00	-1.119E-01
3.300E-03	1.217E 00	1.113E 00	1.009E 00	-1.320E-01
3.800E-03	1.315E 00	1.131E 00	1.011E 00	-1.519E-01
4.300E-03	1.380E 00	1.148E 00	1.014E 00	-1.719E-01
4.800E-03	1.411E 00	1.162E 00	1.017E 00	-1.919E-01
5.300E-03	1.408E 00	1.174E 00	1.020E 00	-2.119E-01
5.800E-03	1.370E 00	1.182E 00	1.022E 00	-2.319E-01
6.300E-03	1.298E 00	1.187E 00	1.025E 00	-2.519E-01
6.800E-03	1.194E 00	1.189E 00	1.028E 00	-2.719E-01
7.300E-03	1.061E 00	1.187E 00	1.030E 00	-2.918E-01
7.800E-03	9.015E-01	1.181E 00	1.032E 00	-3.119E-01
8.300E-03	7.200E-01	1.172E 00	1.033E 00	-3.319E-01

8.800E-03	5.207E-01	1.160E 00	1.035E 00	-3.518E-01
9.300E-03	3.086E-01	1.144E 00	1.035E 00	-3.718E-01
9.800E-03	8.893E-02	1.127E 00	1.035E 00	-3.918E-01
1.030E-02	0	1.113E 00	1.036E 00	-4.118E-01
1.080E-02	0	1.104E 00	1.036E 00	-4.317E-01
1.130E-02	0	1.097E 00	1.036E 00	-4.518E-01
1.180E-02	0	1.093E 00	1.036E 00	-4.718E-01

N= .5000 DH/RT= 10 PIPE FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
FLUX= 1.4142 SIN(100*PI*X)
DXS=5.E-08 DXL=5.E-04 A=-4600.
DR=.02 NDRDIV=10 NDRWAL=2

X	FLUX	T(WALL)	T(MEAN)	P
2.500E-08	1.111E-05	1.000E 00	1.000E 00	-1.985E-06
1.037E-07	4.609E-05	1.000E 00	1.000E 00	-5.102E-06
3.018E-07	1.341E-04	1.000E 00	1.000E 00	-1.294E-05
8.178E-07	3.633E-04	1.000E 00	1.000E 00	-3.350E-05
2.153E-06	9.566E-04	1.000E 00	1.000E 00	-8.686E-05
5.605E-06	2.490E-03	1.000E 00	1.000E 00	-2.251E-04
1.448E-05	6.434E-03	1.000E 00	1.000E 00	-5.809E-04
3.700E-05	1.644E-02	1.000E 00	1.000E 00	-1.480E-03
9.229E-05	4.100E-02	1.001E 00	1.000E 00	-3.684E-03
2.179E-04	9.675E-02	1.003E 00	1.000E 00	-8.733E-03
4.627E-04	2.049E-01	1.009E 00	1.000E 00	-1.838E-02
8.412E-04	3.694E-01	1.019E 00	1.001E 00	-3.329E-02
1.306E-03	5.642E-01	1.034E 00	1.002E 00	-5.116E-02
1.800E-03	7.579E-01	1.051E 00	1.003E 00	-6.956E-02
2.300E-03	9.351E-01	1.068E 00	1.005E 00	-8.752E-02
2.800E-03	1.090E 00	1.085E 00	1.007E 00	-1.048E-01
3.300E-03	1.217E 00	1.101E 00	1.009E 00	-1.217E-01
3.800E-03	1.315E 00	1.117E 00	1.012E 00	-1.374E-01
4.300E-03	1.380E 00	1.131E 00	1.015E 00	-1.528E-01
4.800E-03	1.411E 00	1.141E 00	1.017E 00	-1.678E-01
5.300E-03	1.408E 00	1.151E 00	1.020E 00	-1.819E-01
5.800E-03	1.370E 00	1.158E 00	1.022E 00	-1.961E-01
6.300E-03	1.298E 00	1.164E 00	1.025E 00	-2.097E-01
6.800E-03	1.194E 00	1.167E 00	1.028E 00	-2.226E-01
7.300E-03	1.061E 00	1.165E 00	1.030E 00	-2.353E-01
7.800E-03	9.015E-01	1.160E 00	1.032E 00	-2.485E-01
8.300E-03	7.200E-01	1.153E 00	1.032E 00	-2.620E-01

8.800E-03	5.207E-01	1.145E 00	1.034E 00	-2.745E-01
9.300E-03	3.086E-01	1.134E 00	1.037E 00	-2.871E-01
9.800E-03	8.893E-02	1.117E 00	1.035E 00	-3.001E-01
1.030E-02	0	1.106E 00	1.035E 00	-3.139E-01
1.080E-02	0	1.097E 00	1.035E 00	-3.283E-01
1.130E-02	0	1.092E 00	1.036E 00	-3.421E-01
1.180E-02	0	1.087E 00	1.037E 00	-3.554E-01

N= 1.0000 DH/RT= 0 CHANNEL FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
AT Y=0, FLUX= 1.0000
AT Y=1, FLUX= 1.0000
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

Z	NU(LOCAL)	T(WALL)	T(MEAN)	P
1.250E-08	6.872E 02	1.003E 00	1.000E 00	-6.000E-07
4.109E-08	6.720E 02	1.003E 00	1.000E 00	-1.286E-06
8.150E-08	3.832E 02	1.005E 00	1.000E 00	-2.256E-06
1.417E-07	3.428E 02	1.006E 00	1.000E 00	-3.702E-06
2.309E-07	3.005E 02	1.007E 00	1.000E 00	-5.842E-06
3.631E-07	2.686E 02	1.007E 00	1.000E 00	-9.014E-06
5.588E-07	2.190E 02	1.009E 00	1.000E 00	-1.371E-05
8.489E-07	1.925E 02	1.010E 00	1.000E 00	-2.067E-05
1.279E-06	1.720E 02	1.012E 00	1.000E 00	-3.099E-05
1.915E-06	1.518E 02	1.013E 00	1.000E 00	-4.626E-05
2.858E-06	1.295E 02	1.015E 00	1.000E 00	-6.889E-05
4.255E-06	1.135E 02	1.018E 00	1.000E 00	-1.024E-04
6.324E-06	1.011E 02	1.020E 00	1.000E 00	-1.521E-04
9.389E-06	8.888E 01	1.023E 00	1.000E 00	-2.256E-04
1.393E-05	7.688E 01	1.026E 00	1.000E 00	-3.345E-04
2.065E-05	6.742E 01	1.030E 00	1.000E 00	-4.958E-04
3.059E-05	5.980E 01	1.034E 00	1.000E 00	-7.344E-04
4.530E-05	5.264E 01	1.038E 00	1.000E 00	-1.087E-03
6.704E-05	4.592E 01	1.044E 00	1.000E 00	-1.609E-03
9.915E-05	4.035E 01	1.050E 00	1.000E 00	-2.380E-03
1.465E-04	3.566E 01	1.057E 00	1.001E 00	-3.516E-03
2.161E-04	3.135E 01	1.065E 00	1.001E 00	-5.187E-03
3.182E-04	2.744E 01	1.074E 00	1.001E 00	-7.636E-03
4.670E-04	2.417E 01	1.085E 00	1.002E 00	-1.121E-02
6.825E-04	2.146E 01	1.096E 00	1.003E 00	-1.638E-02
9.915E-04	1.906E 01	1.109E 00	1.004E 00	-2.380E-02

1.428E-03	1.696E 01	1.124E 00	1.006E 00	-3.427E-02
2.033E-03	1.522E 01	1.140E 00	1.008E 00	-4.879E-02
2.850E-03	1.381E 01	1.156E 00	1.011E 00	-6.839E-02
3.917E-03	1.262E 01	1.174E 00	1.016E 00	-9.402E-02
5.261E-03	1.162E 01	1.193E 00	1.021E 00	-1.263E-01
6.880E-03	1.085E 01	1.212E 00	1.028E 00	-1.651E-01
8.751E-03	1.026E 01	1.230E 00	1.035E 00	-2.100E-01
1.083E-02	9.790E 00	1.248E 00	1.043E 00	-2.598E-01
1.306E-02	9.413E 00	1.265E 00	1.052E 00	-3.133E-01
1.539E-02	9.134E 00	1.281E 00	1.062E 00	-3.694E-01
1.779E-02	8.935E 00	1.295E 00	1.071E 00	-4.270E-01
2.023E-02	8.776E 00	1.309E 00	1.081E 00	-4.856E-01
2.270E-02	8.641E 00	1.322E 00	1.091E 00	-5.448E-01
2.518E-02	8.544E 00	1.335E 00	1.101E 00	-6.044E-01
2.767E-02	8.483E 00	1.347E 00	1.111E 00	-6.641E-01
3.017E-02	8.429E 00	1.358E 00	1.121E 00	-7.240E-01
3.266E-02	8.375E 00	1.370E 00	1.131E 00	-7.839E-01
3.516E-02	8.339E 00	1.381E 00	1.141E 00	-8.439E-01
3.766E-02	8.324E 00	1.391E 00	1.151E 00	-9.039E-01
4.016E-02	8.307E 00	1.402E 00	1.161E 00	-9.638E-01
4.266E-02	8.280E 00	1.412E 00	1.171E 00	-1.024E 00
4.516E-02	8.266E 00	1.423E 00	1.181E 00	-1.084E 00
4.766E-02	8.268E 00	1.433E 00	1.191E 00	-1.144E 00
5.016E-02	8.263E 00	1.443E 00	1.201E 00	-1.204E 00
5.266E-02	8.246E 00	1.453E 00	1.211E 00	-1.264E 00
5.516E-02	8.240E 00	1.463E 00	1.221E 00	-1.324E 00
5.766E-02	8.247E 00	1.473E 00	1.231E 00	-1.384E 00
6.016E-02	8.247E 00	1.483E 00	1.241E 00	-1.444E 00
6.266E-02	8.234E 00	1.494E 00	1.251E 00	-1.504E 00
6.516E-02	8.230E 00	1.504E 00	1.261E 00	-1.564E 00
6.766E-02	8.239E 00	1.514E 00	1.271E 00	-1.624E 00
7.016E-02	8.241E 00	1.523E 00	1.281E 00	-1.684E 00
7.266E-02	8.229E 00	1.534E 00	1.291E 00	-1.744E 00

N= 1.0000 DH/RT= 5 CHANNEL FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
AT Y=0, FLUX= 1.0000
AT Y=1, FLUX= 1.0000
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

Z	NU(LOCAL)	T(WALL)	T(MEAN)	P
1.250E-08	6.872E 02	1.003E 00	1.000E 00	-5.948E-07
4.109E-08	6.757E 02	1.003E 00	1.000E 00	-1.266E-06
8.150E-08	3.853E 02	1.005E 00	1.000E 00	-2.218E-06
1.417E-07	3.451E 02	1.006E 00	1.000E 00	-3.633E-06
2.309E-07	3.025E 02	1.007E 00	1.000E 00	-5.729E-06
3.631E-07	2.708E 02	1.007E 00	1.000E 00	-8.844E-06
5.588E-07	2.208E 02	1.009E 00	1.000E 00	-1.345E-05
8.489E-07	1.946E 02	1.010E 00	1.000E 00	-2.028E-05
1.279E-06	1.742E 02	1.011E 00	1.000E 00	-3.039E-05
1.915E-06	1.539E 02	1.013E 00	1.000E 00	-4.539E-05
2.858E-06	1.314E 02	1.015E 00	1.000E 00	-6.760E-05
4.255E-06	1.155E 02	1.017E 00	1.000E 00	-1.005E-04
6.324E-06	1.032E 02	1.019E 00	1.000E 00	-1.492E-04
9.389E-06	9.085E 01	1.022E 00	1.000E 00	-2.213E-04
1.393E-05	7.876E 01	1.025E 00	1.000E 00	-3.279E-04
2.065E-05	6.936E 01	1.029E 00	1.000E 00	-4.856E-04
3.059E-05	6.176E 01	1.033E 00	1.000E 00	-7.185E-04
4.530E-05	5.448E 01	1.037E 00	1.000E 00	-1.062E-03
6.704E-05	4.767E 01	1.042E 00	1.000E 00	-1.567E-03
9.915E-05	4.209E 01	1.048E 00	1.000E 00	-2.308E-03
1.465E-04	3.739E 01	1.054E 00	1.001E 00	-3.392E-03
2.161E-04	3.300E 01	1.061E 00	1.001E 00	-4.966E-03
3.182E-04	2.900E 01	1.070E 00	1.001E 00	-7.241E-03
4.670E-04	2.569E 01	1.080E 00	1.002E 00	-1.050E-02
6.825E-04	2.291E 01	1.090E 00	1.003E 00	-1.510E-02
9.915E-04	2.041E 01	1.102E 00	1.004E 00	-2.152E-02

1.428E-03	1.821E 01	1.116E 00	1.006E 00	-3.028E-02
2.033E-03	1.640E 01	1.130E 00	1.008E 00	-4.193E-02
2.850E-03	1.490E 01	1.146E 00	1.011E 00	-5.695E-02
3.917E-03	1.362E 01	1.163E 00	1.015E 00	-7.554E-02
5.261E-03	1.254E 01	1.181E 00	1.021E 00	-9.761E-02
6.880E-03	1.171E 01	1.198E 00	1.028E 00	-1.227E-01
8.751E-03	1.106E 01	1.216E 00	1.035E 00	-1.499E-01
1.083E-02	1.053E 01	1.233E 00	1.043E 00	-1.782E-01
1.306E-02	1.011E 01	1.250E 00	1.052E 00	-2.070E-01
1.539E-02	9.797E 00	1.266E 00	1.062E 00	-2.355E-01
1.779E-02	9.568E 00	1.280E 00	1.071E 00	-2.634E-01
2.023E-02	9.372E 00	1.294E 00	1.081E 00	-2.903E-01
2.270E-02	9.214E 00	1.308E 00	1.091E 00	-3.164E-01
2.518E-02	9.108E 00	1.320E 00	1.101E 00	-3.416E-01
2.767E-02	9.029E 00	1.332E 00	1.111E 00	-3.658E-01
3.017E-02	8.946E 00	1.344E 00	1.121E 00	-3.891E-01
3.266E-02	8.879E 00	1.356E 00	1.131E 00	-4.116E-01
3.516E-02	8.849E 00	1.366E 00	1.140E 00	-4.334E-01
3.766E-02	8.822E 00	1.377E 00	1.150E 00	-4.546E-01
4.016E-02	8.771E 00	1.389E 00	1.161E 00	-4.748E-01
4.266E-02	8.735E 00	1.400E 00	1.171E 00	-4.945E-01
4.516E-02	8.741E 00	1.409E 00	1.180E 00	-5.137E-01
4.766E-02	8.736E 00	1.419E 00	1.190E 00	-5.325E-01
5.016E-02	8.687E 00	1.431E 00	1.201E 00	-5.503E-01
5.266E-02	8.656E 00	1.442E 00	1.211E 00	-5.676E-01
5.516E-02	8.690E 00	1.450E 00	1.220E 00	-5.848E-01
5.766E-02	8.702E 00	1.460E 00	1.230E 00	-6.016E-01
6.016E-02	8.639E 00	1.473E 00	1.241E 00	-6.175E-01
6.266E-02	8.596E 00	1.485E 00	1.252E 00	-6.328E-01
6.516E-02	8.661E 00	1.491E 00	1.260E 00	-6.482E-01
6.766E-02	8.695E 00	1.499E 00	1.269E 00	-6.635E-01
7.016E-02	8.609E 00	1.514E 00	1.281E 00	-6.777E-01
7.266E-02	8.534E 00	1.527E 00	1.293E 00	-6.913E-01

N= .7500 DH/RT= 0 CHANNEL FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
AT Y=0, FLUX= 1.0000
AT Y=1, FLUX= 1.0000
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

Z	NU(LOCAL)	T(WALL)	T(MEAN)	P
1.250E-08	7.110E 02	1.003E 00	1.000E 00	-6.647E-07
4.109E-08	6.954E 02	1.003E 00	1.000E 00	-1.422E-06
8.150E-08	3.962E 02	1.005E 00	1.000E 00	-2.494E-06
1.417E-07	3.545E 02	1.006E 00	1.000E 00	-4.096E-06
2.309E-07	3.111E 02	1.006E 00	1.000E 00	-6.473E-06
3.631E-07	2.781E 02	1.007E 00	1.000E 00	-1.000E-05
5.588E-07	2.266E 02	1.009E 00	1.000E 00	-1.523E-05
8.489E-07	1.992E 02	1.010E 00	1.000E 00	-2.298E-05
1.279E-06	1.781E 02	1.011E 00	1.000E 00	-3.444E-05
1.915E-06	1.572E 02	1.013E 00	1.000E 00	-5.143E-05
2.858E-06	1.340E 02	1.015E 00	1.000E 00	-7.658E-05
4.255E-06	1.174E 02	1.017E 00	1.000E 00	-1.138E-04
6.324E-06	1.046E 02	1.019E 00	1.000E 00	-1.690E-04
9.389E-06	9.197E 01	1.022E 00	1.000E 00	-2.507E-04
1.393E-05	7.954E 01	1.025E 00	1.000E 00	-3.717E-04
2.065E-05	6.973E 01	1.029E 00	1.000E 00	-5.508E-04
3.059E-05	6.183E 01	1.032E 00	1.000E 00	-8.159E-04
4.530E-05	5.441E 01	1.037E 00	1.000E 00	-1.208E-03
6.704E-05	4.746E 01	1.042E 00	1.000E 00	-1.788E-03
9.915E-05	4.169E 01	1.048E 00	1.000E 00	-2.644E-03
1.465E-04	3.685E 01	1.055E 00	1.001E 00	-3.906E-03
2.161E-04	3.240E 01	1.063E 00	1.001E 00	-5.762E-03
3.182E-04	2.835E 01	1.072E 00	1.001E 00	-8.482E-03
4.670E-04	2.496E 01	1.082E 00	1.002E 00	-1.245E-02
6.825E-04	2.214E 01	1.093E 00	1.003E 00	-1.820E-02
9.915E-04	1.965E 01	1.106E 00	1.004E 00	-2.643E-02

1.428E-03	1.748E 01	1.120E 00	1.006E 00	-3.807E-02
2.033E-03	1.568E 01	1.136E 00	1.008E 00	-5.419E-02
2.850E-03	1.421E 01	1.152E 00	1.011E 00	-7.597E-02
3.917E-03	1.298E 01	1.170E 00	1.015E 00	-1.044E-01
5.261E-03	1.195E 01	1.188E 00	1.021E 00	-1.402E-01
6.880E-03	1.115E 01	1.207E 00	1.028E 00	-1.834E-01
8.751E-03	1.054E 01	1.225E 00	1.035E 00	-2.333E-01
1.083E-02	1.005E 01	1.242E 00	1.043E 00	-2.886E-01
1.306E-02	9.661E 00	1.259E 00	1.052E 00	-3.481E-01
1.539E-02	9.371E 00	1.275E 00	1.062E 00	-4.103E-01
1.779E-02	9.163E 00	1.290E 00	1.071E 00	-4.743E-01
2.023E-02	8.997E 00	1.303E 00	1.081E 00	-5.395E-01
2.270E-02	8.856E 00	1.317E 00	1.091E 00	-6.052E-01
2.518E-02	8.755E 00	1.329E 00	1.101E 00	-6.714E-01
2.767E-02	8.690E 00	1.341E 00	1.111E 00	-7.378E-01
3.017E-02	8.633E 00	1.352E 00	1.121E 00	-8.042E-01
3.266E-02	8.577E 00	1.364E 00	1.131E 00	-8.708E-01
3.516E-02	8.539E 00	1.375E 00	1.141E 00	-9.374E-01
3.766E-02	8.523E 00	1.385E 00	1.151E 00	-1.004E 00
4.016E-02	8.504E 00	1.396E 00	1.161E 00	-1.071E 00
4.266E-02	8.477E 00	1.407E 00	1.171E 00	-1.137E 00
4.516E-02	8.462E 00	1.417E 00	1.181E 00	-1.204E 00
4.766E-02	8.462E 00	1.427E 00	1.191E 00	-1.271E 00
5.016E-02	8.457E 00	1.437E 00	1.201E 00	-1.337E 00
5.266E-02	8.440E 00	1.448E 00	1.211E 00	-1.404E 00
5.516E-02	8.433E 00	1.458E 00	1.221E 00	-1.471E 00
5.766E-02	8.440E 00	1.468E 00	1.231E 00	-1.537E 00
6.016E-02	8.439E 00	1.478E 00	1.241E 00	-1.604E 00
6.266E-02	8.426E 00	1.488E 00	1.251E 00	-1.670E 00
6.516E-02	8.422E 00	1.498E 00	1.261E 00	-1.737E 00
6.766E-02	8.432E 00	1.508E 00	1.271E 00	-1.804E 00
7.016E-02	8.433E 00	1.518E 00	1.281E 00	-1.870E 00
7.266E-02	8.421E 00	1.528E 00	1.291E 00	-1.937E 00

N= .5000 CHANNEL FLOW
FULLY-DEV. VELOCITY AND UNIFORM FLUX=1.0
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

Z	NU(LOCAL)	T(WALL)	T(MEAN)	P
1.250E-08	7.537E 02	1.003E 00	1.000E 00	-8.000E-07
4.109E-08	7.370E 02	1.003E 00	1.000E 00	-1.715E-06
8.150E-08	4.197E 02	1.005E 00	1.000E 00	-3.008E-06
1.417E-07	3.754E 02	1.005E 00	1.000E 00	-4.936E-06
2.309E-07	3.294E 02	1.006E 00	1.000E 00	-7.790E-06
3.631E-07	2.947E 02	1.007E 00	1.000E 00	-1.202E-05
5.588E-07	2.404E 02	1.008E 00	1.000E 00	-1.828E-05
8.489E-07	2.112E 02	1.009E 00	1.000E 00	-2.755E-05
1.279E-06	1.888E 02	1.011E 00	1.000E 00	-4.131E-05
1.915E-06	1.666E 02	1.012E 00	1.000E 00	-6.168E-05
2.858E-06	1.422E 02	1.014E 00	1.000E 00	-9.186E-05
4.255E-06	1.246E 02	1.016E 00	1.000E 00	-1.366E-04
6.324E-06	1.108E 02	1.018E 00	1.000E 00	-2.028E-04
9.389E-06	9.748E 01	1.021E 00	1.000E 00	-3.008E-04
1.393E-05	8.431E 01	1.024E 00	1.000E 00	-4.461E-04
2.065E-05	7.387E 01	1.027E 00	1.000E 00	-6.611E-04
3.059E-05	6.545E 01	1.031E 00	1.000E 00	-9.793E-04
4.530E-05	5.757E 01	1.035E 00	1.000E 00	-1.450E-03
6.704E-05	5.020E 01	1.040E 00	1.000E 00	-2.146E-03
9.915E-05	4.410E 01	1.046E 00	1.000E 00	-3.173E-03
1.465E-04	3.898E 01	1.052E 00	1.001E 00	-4.688E-03
2.161E-04	3.426E 01	1.059E 00	1.001E 00	-6.916E-03
3.182E-04	2.997E 01	1.068E 00	1.001E 00	-1.018E-02
4.670E-04	2.636E 01	1.078E 00	1.002E 00	-1.494E-02
6.825E-04	2.336E 01	1.088E 00	1.003E 00	-2.184E-02
9.915E-04	2.072E 01	1.101E 00	1.004E 00	-3.173E-02
1.428E-03	1.841E 01	1.114E 00	1.005E 00	-4.569E-02
2.033E-03	1.649E 01	1.129E 00	1.008E 00	-6.505E-02

2.850E-03	1.494E 01	1.145E 00	1.011E 00	-9.119E-02
3.917E-03	1.363E 01	1.162E 00	1.015E 00	-1.254E-01
5.261E-03	1.254E 01	1.181E 00	1.021E 00	-1.683E-01
6.880E-03	1.168E 01	1.199E 00	1.028E 00	-2.202E-01
8.751E-03	1.103E 01	1.216E 00	1.035E 00	-2.800E-01
1.083E-02	1.051E 01	1.234E 00	1.043E 00	-3.465E-01
1.306E-02	1.009E 01	1.250E 00	1.052E 00	-4.178E-01
1.539E-02	9.784E 00	1.266E 00	1.062E 00	-4.925E-01
1.779E-02	9.561E 00	1.280E 00	1.071E 00	-5.693E-01
2.023E-02	9.382E 00	1.294E 00	1.081E 00	-6.475E-01
2.270E-02	9.230E 00	1.308E 00	1.091E 00	-7.265E-01
2.518E-02	9.120E 00	1.320E 00	1.101E 00	-8.059E-01
2.767E-02	9.048E 00	1.332E 00	1.111E 00	-8.855E-01
3.017E-02	8.987E 00	1.343E 00	1.121E 00	-9.653E-01
3.266E-02	8.926E 00	1.355E 00	1.131E 00	-1.045E 00
3.516E-02	8.884E 00	1.366E 00	1.141E 00	-1.125E 00
3.766E-02	8.865E 00	1.376E 00	1.151E 00	-1.205E 00
4.016E-02	8.844E 00	1.387E 00	1.161E 00	-1.285E 00
4.266E-02	8.814E 00	1.398E 00	1.171E 00	-1.365E 00
4.516E-02	8.798E 00	1.408E 00	1.181E 00	-1.445E 00
4.766E-02	8.797E 00	1.418E 00	1.191E 00	-1.525E 00
5.016E-02	8.790E 00	1.428E 00	1.201E 00	-1.605E 00
5.266E-02	8.773E 00	1.439E 00	1.211E 00	-1.685E 00
5.516E-02	8.765E 00	1.449E 00	1.221E 00	-1.765E 00
5.766E-02	8.771E 00	1.459E 00	1.231E 00	-1.845E 00
6.016E-02	8.770E 00	1.469E 00	1.241E 00	-1.925E 00
6.266E-02	8.757E 00	1.479E 00	1.251E 00	-2.005E 00
6.516E-02	8.753E 00	1.489E 00	1.261E 00	-2.085E 00
6.766E-02	8.762E 00	1.499E 00	1.271E 00	-2.165E 00
7.016E-02	8.763E 00	1.509E 00	1.281E 00	-2.245E 00
7.266E-02	8.751E 00	1.519E 00	1.291E 00	-2.325E 00

N= .2500 CHANNEL FLOW
FULLY-DEV. VELOCITY AND UNIFORM FLUX=1.0
DR=.02 NDRDIV=10 NDRWAL=2
DXS=5.E-08 DXL=5.E-03 A=-115.

Z	NU(LOCAL)	T(WALL)	T(MEAN)	P
1.250E-08	8.589E 02	1.002E 00	1.000E 00	-1.200E-06
4.109E-08	8.398E 02	1.002E 00	1.000E 00	-2.572E-06
8.150E-08	4.777E 02	1.004E 00	1.000E 00	-4.512E-06
1.417E-07	4.269E 02	1.005E 00	1.000E 00	-7.404E-06
2.309E-07	3.739E 02	1.005E 00	1.000E 00	-1.168E-05
3.631E-07	3.351E 02	1.006E 00	1.000E 00	-1.803E-05
5.588E-07	2.745E 02	1.007E 00	1.000E 00	-2.742E-05
8.489E-07	2.410E 02	1.008E 00	1.000E 00	-4.135E-05
1.279E-06	2.147E 02	1.009E 00	1.000E 00	-6.197E-05
1.915E-06	1.897E 02	1.011E 00	1.000E 00	-9.252E-05
2.858E-06	1.622E 02	1.012E 00	1.000E 00	-1.378E-04
4.255E-06	1.420E 02	1.014E 00	1.000E 00	-2.048E-04
6.324E-06	1.261E 02	1.016E 00	1.000E 00	-3.042E-04
9.389E-06	1.109E 02	1.018E 00	1.000E 00	-4.513E-04
1.393E-05	9.598E 01	1.021E 00	1.000E 00	-6.691E-04
2.065E-05	8.399E 01	1.024E 00	1.000E 00	-9.916E-04
3.059E-05	7.425E 01	1.027E 00	1.000E 00	-1.469E-03
4.530E-05	6.522E 01	1.031E 00	1.000E 00	-2.175E-03
6.704E-05	5.684E 01	1.035E 00	1.000E 00	-3.219E-03
9.915E-05	4.987E 01	1.040E 00	1.000E 00	-4.760E-03
1.465E-04	4.403E 01	1.046E 00	1.001E 00	-7.032E-03
2.161E-04	3.870E 01	1.053E 00	1.001E 00	-1.037E-02
3.182E-04	3.384E 01	1.060E 00	1.001E 00	-1.527E-02
4.670E-04	2.972E 01	1.069E 00	1.002E 00	-2.242E-02
6.825E-04	2.625E 01	1.079E 00	1.003E 00	-3.276E-02
9.915E-04	2.322E 01	1.090E 00	1.004E 00	-4.759E-02
1.428E-03	2.058E 01	1.103E 00	1.005E 00	-6.854E-02
2.033E-03	1.839E 01	1.117E 00	1.003E 00	-9.757E-02

2.850E-03	1.660E 01	1.132E 00	1.011E 00	-1.368E-01
3.917E-03	1.510E 01	1.148E 00	1.016E 00	-1.880E-01
5.261E-03	1.386E 01	1.165E 00	1.021E 00	-2.525E-01
6.880E-03	1.288E 01	1.183E 00	1.028E 00	-3.302E-01
8.751E-03	1.213E 01	1.200E 00	1.035E 00	-4.200E-01
1.083E-02	1.153E 01	1.217E 00	1.043E 00	-5.197E-01
1.306E-02	1.105E 01	1.233E 00	1.052E 00	-6.267E-01
1.539E-02	1.069E 01	1.249E 00	1.062E 00	-7.387E-01
1.779E-02	1.043E 01	1.263E 00	1.071E 00	-8.540E-01
2.023E-02	1.022E 01	1.277E 00	1.081E 00	-9.713E-01
2.270E-02	1.004E 01	1.290E 00	1.091E 00	-1.090E 00
2.518E-02	9.910E 00	1.303E 00	1.101E 00	-1.209E 00
2.767E-02	9.820E 00	1.314E 00	1.111E 00	-1.328E 00
3.017E-02	9.745E 00	1.326E 00	1.121E 00	-1.448E 00
3.266E-02	9.673E 00	1.338E 00	1.131E 00	-1.568E 00
3.516E-02	9.623E 00	1.349E 00	1.141E 00	-1.688E 00
3.766E-02	9.595E 00	1.359E 00	1.151E 00	-1.808E 00
4.016E-02	9.568E 00	1.370E 00	1.161E 00	-1.928E 00
4.266E-02	9.534E 00	1.381E 00	1.171E 00	-2.048E 00
4.516E-02	9.513E 00	1.391E 00	1.181E 00	-2.168E 00
4.766E-02	9.508E 00	1.401E 00	1.191E 00	-2.288E 00
5.016E-02	9.499E 00	1.411E 00	1.201E 00	-2.408E 00
5.266E-02	9.480E 00	1.422E 00	1.211E 00	-2.528E 00
5.516E-02	9.471E 00	1.432E 00	1.221E 00	-2.648E 00
5.766E-02	9.474E 00	1.442E 00	1.231E 00	-2.768E 00
6.016E-02	9.472E 00	1.452E 00	1.241E 00	-2.888E 00
6.266E-02	9.459E 00	1.462E 00	1.251E 00	-3.008E 00
6.516E-02	9.454E 00	1.472E 00	1.261E 00	-3.128E 00
6.766E-02	9.461E 00	1.482E 00	1.271E 00	-3.248E 00
7.016E-02	9.462E 00	1.492E 00	1.281E 00	-3.368E 00
7.266E-02	9.451E 00	1.502E 00	1.291E 00	-3.488E 00

N= 1.0000 DH/RT= 0 CHANNEL FLOW
PRANDTL NO.= 1000 BRINKMAN NO.= 0
AT Y=0, FLUX= 1.0000
AT Y=1, FLUX= 0
DXS=5.E-08 DXL=5.E-03 A=-115.
DR=.02 NDRDIV=10 NDRWAL=2

Z	T(MEAN)	T(WALL) (HEATED)	T(WALL) (INSULATED)	P
1.250E-08	1.000E 00	1.003E 00	1.000E 00	-5.000E-07
4.109E-08	1.000E 00	1.003E 00	1.000E-00	-1.286E-06
8.150E-08	1.000E 00	1.005E 00	1.000E 00	-2.256E-06
1.417E-07	1.000E 00	1.006E 00	1.000E 00	-3.702E-06
2.309E-07	1.000E 00	1.007E 00	1.000E 00	-5.842E-06
3.631E-07	1.000E 00	1.007E 00	1.000E 00	-9.014E-06
5.588E-07	1.000E 00	1.009E 00	1.000E-00	-1.371E-05
8.489E-07	1.000E 00	1.010E 00	1.000E 00	-2.067E-05
1.279E-06	1.000E 00	1.012E 00	1.000E-00	-3.099E-05
1.915E-06	1.000E 00	1.013E 00	1.000E 00	-4.625E-05
2.858E-06	1.000E 00	1.015E 00	1.000E-00	-6.889E-05
4.255E-06	1.000E 00	1.018E 00	1.000E-00	-1.024E-04
6.324E-06	1.000E 00	1.020E 00	1.000E 00	-1.521E-04
9.389E-06	1.000E 00	1.023E 00	1.000E 00	-2.256E-04
1.393E-05	1.000E 00	1.026E 00	1.000E 00	-3.345E-04
2.065E-05	1.000E 00	1.030E 00	1.000E 00	-4.958E-04
3.059E-05	1.000E 00	1.034E 00	1.000E-00	-7.344E-04
4.530E-05	1.000E 00	1.038E 00	1.000E 00	-1.087E-03
6.704E-05	1.000E 00	1.044E 00	1.000E 00	-1.609E-03
9.915E-05	1.000E 00	1.050E 00	1.000E 00	-2.380E-03
1.465E-04	1.000E 00	1.057E 00	1.000E 00	-3.515E-03
2.161E-04	1.000E 00	1.065E 00	1.000E 00	-5.187E-03
3.182E-04	1.001E 00	1.074E 00	1.000E 00	-7.636E-03
4.670E-04	1.001E 00	1.085E 00	1.000E 00	-1.121E-02
6.825E-04	1.001E 00	1.096E 00	1.000E 00	-1.638E-02
9.915E-04	1.002E 00	1.109E 00	1.000E 00	-2.380E-02

1.428E-03	1.003E 00	1.124E 00	1.000E 00	-3.427E-02
2.033E-03	1.004E 00	1.140E 00	1.000E 00	-4.879E-02
2.850E-03	1.006E 00	1.156E 00	1.000E 00	-6.839E-02
3.917E-03	1.008E 00	1.174E 00	1.000E 00	-9.402E-02
5.261E-03	1.011E 00	1.193E 00	1.000E 00	-1.263E-01
6.880E-03	1.014E 00	1.212E 00	1.000E 00	-1.651E-01
8.751E-03	1.018E 00	1.230E 00	1.000E 00	-2.100E-01
1.083E-02	1.022E 00	1.248E 00	1.000E 00	-2.598E-01
1.306E-02	1.026E 00	1.265E 00	1.000E 00	-3.133E-01
1.539E-02	1.031E 00	1.281E 00	1.000E 00	-3.694E-01
1.779E-02	1.036E 00	1.295E 00	1.000E 00	-4.270E-01
2.023E-02	1.041E 00	1.309E 00	1.000E 00	-4.856E-01
2.270E-02	1.045E 00	1.322E 00	1.000E 00	-5.448E-01
2.518E-02	1.050E 00	1.334E 00	1.001E 00	-6.044E-01
2.767E-02	1.055E 00	1.345E 00	1.001E 00	-5.641E-01
3.017E-02	1.060E 00	1.356E 00	1.002E 00	-7.240E-01
3.266E-02	1.065E 00	1.367E 00	1.003E 00	-7.839E-01
3.516E-02	1.070E 00	1.377E 00	1.004E 00	-8.439E-01
3.766E-02	1.075E 00	1.386E 00	1.005E 00	-9.039E-01
4.016E-02	1.080E 00	1.395E 00	1.006E 00	-9.638E-01
4.266E-02	1.085E 00	1.405E 00	1.008E 00	-1.024E 00
4.516E-02	1.090E 00	1.413E 00	1.009E 00	-1.084E 00
4.766E-02	1.095E 00	1.421E 00	1.011E 00	-1.144E 00
5.016E-02	1.100E 00	1.429E 00	1.014E 00	-1.204E 00
5.266E-02	1.105E 00	1.437E 00	1.015E 00	-1.264E 00
5.516E-02	1.110E 00	1.445E 00	1.018E 00	-1.324E 00
5.766E-02	1.115E 00	1.452E 00	1.021E 00	-1.384E 00
6.016E-02	1.120E 00	1.460E 00	1.024E 00	-1.444E 00
6.266E-02	1.125E 00	1.467E 00	1.027E 00	-1.504E 00
6.516E-02	1.130E 00	1.474E 00	1.030E 00	-1.564E 00
6.766E-02	1.135E 00	1.481E 00	1.033E 00	-1.624E 00
7.016E-02	1.140E 00	1.487E 00	1.035E 00	-1.684E 00
7.266E-02	1.145E 00	1.494E 00	1.040E 00	-1.744E 00

```
N=   1.0000        DH/RT=          5      CHANNEL FLOW
PRANDTL NO.=       1000     BRINKMAN NO.=            0
AT Y=0, FLUX=       1.0000
AT Y=1, FLUX=            0
DXS=5.E-08       DXL=5.E-03       A=-115.
DR=.02       NDRDIV=10       NDRWAL=2
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Z	NU(LOCAL)	T(WALL)	T(MEAN)	P
1.250E-08	1.000E 00	1.003E 00	1.000E 00	-5.974E-07
4.109E-08	1.000E 00	1.003E 00	1.000E 00	-1.275E-06
8.150E-08	1.000E 00	1.005E 00	1.000E 00	-2.237E-06
1.417E-07	1.000E 00	1.006E 00	1.000E 00	-3.668E-06
2.309E-07	1.000E 00	1.007E 00	1.000E 00	-5.785E-06
3.631E-07	1.000E 00	1.007E 00	1.000E-00	-8.929E-06
5.588E-07	1.000E 00	1.009E 00	1.000E-00	-1.358E-05
8.489E-07	1.000E 00	1.010E 00	1.000E 00	-2.048E-05
1.279E-06	1.000E 00	1.011E 00	1.000E 00	-3.069E-05
1.915E-06	1.000E 00	1.013E 00	1.000E 00	-4.583E-05
2.858E-06	1.000E 00	1.015E 00	1.000E-00	-6.825E-05
4.255E-06	1.000E 00	1.017E 00	1.000E 00	-1.014E-04
6.324E-06	1.000E 00	1.019E 00	1.000E 00	-1.506E-04
9.389E-06	1.000E 00	1.022E 00	1.000E-00	-2.235E-04
1.393E-05	1.000E 00	1.025E 00	1.000E-00	-3.312E-04
2.065E-05	1.000E 00	1.029E 00	1.000E 00	-4.907E-04
3.059E-05	1.000E 00	1.032E 00	1.000E 00	-7.265E-04
4.530E-05	1.000E 00	1.037E 00	1.000E-00	-1.075E-03
6.704E-05	1.000E 00	1.042E 00	1.000E 00	-1.588E-03
9.915E-05	1.000E 00	1.048E 00	1.000E 00	-2.344E-03
1.465E-04	1.000E 00	1.054E 00	1.000E 00	-3.454E-03
2.161E-04	1.000E 00	1.061E 00	1.000E 00	-5.076E-03
3.182E-04	1.001E 00	1.070E 00	1.000E 00	-7.437E-03
4.670E-04	1.001E 00	1.079E 00	1.000E 00	-1.085E-02
6.825E-04	1.001E 00	1.089E 00	1.000E 00	-1.574E-02
9.915E-04	1.002E 00	1.101E 00	1.000E 00	-2.264E-02

1.428E-03	1.003E 00	1.114E 00	1.000E-00	-3.224E-02
2.033E-03	1.004E 00	1.127E 00	1.000E 00	-4.528E-02
2.850E-03	1.006E 00	1.142E 00	1.000E 00	-6.251E-02
3.917E-03	1.008E 00	1.158E 00	1.000E 00	-8.448E-02
5.261E-03	1.011E 00	1.175E 00	1.000E 00	-1.114E-01
6.880E-03	1.014E 00	1.191E 00	1.000E 00	-1.429E-01
8.751E-03	1.018E 00	1.207E 00	1.000E 00	-1.784E-01
1.083E-02	1.022E 00	1.223E 00	1.000E 00	-2.167E-01
1.306E-02	1.026E 00	1.238E 00	1.000E 00	-2.569E-01
1.539E-02	1.031E 00	1.252E 00	1.000E 00	-2.980E-01
1.779E-02	1.036E 00	1.265E 00	1.000E 00	-3.394E-01
2.023E-02	1.041E 00	1.278E 00	1.000E 00	-3.805E-01
2.270E-02	1.046E 00	1.290E 00	1.000E 00	-4.215E-01
2.518E-02	1.050E 00	1.300E 00	1.001E 00	-4.620E-01
2.767E-02	1.055E 00	1.311E 00	1.001E 00	-5.019E-01
3.017E-02	1.061E 00	1.321E 00	1.002E 00	-5.412E-01
3.266E-02	1.066E 00	1.331E 00	1.002E 00	-5.799E-01
3.516E-02	1.070E 00	1.339E 00	1.003E 00	-6.182E-01
3.766E-02	1.075E 00	1.348E 00	1.004E 00	-6.560E-01
4.016E-02	1.081E 00	1.357E 00	1.005E 00	-6.929E-01
4.266E-02	1.086E 00	1.366E 00	1.007E 00	-7.293E-01
4.516E-02	1.089E 00	1.372E 00	1.009E 00	-7.655E-01
4.766E-02	1.095E 00	1.379E 00	1.011E 00	-8.012E-01
5.016E-02	1.102E 00	1.390E 00	1.013E 00	-8.358E-01
5.266E-02	1.107E 00	1.398E 00	1.015E 00	-8.698E-01
5.516E-02	1.108E 00	1.401E 00	1.017E 00	-9.040E-01
5.766E-02	1.113E 00	1.407E 00	1.020E 00	-9.378E-01
6.016E-02	1.124E 00	1.420E 00	1.023E 00	-9.699E-01
6.266E-02	1.129E 00	1.429E 00	1.025E 00	-1.001E 00
6.516E-02	1.126E 00	1.426E 00	1.029E 00	-1.034E 00
6.766E-02	1.129E 00	1.429E 00	1.032E 00	-1.066E 00
7.016E-02	1.147E 00	1.448E 00	1.035E 00	-1.096E 00
7.266E-02	1.154E 00	1.463E 00	1.037E 00	-1.124E 00