FREE CONVECTION HEAT TRANSFER TO NON-NEWTONIAN RHEOLOGICAL DILATANT FLUIDS FROM A HORIZONTAL CYLINDER

A Dissertation
Presented to
the Faculty of the Graduate School
University of Missouri-Columbia

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

---

by
Chong Bo Kim
August 1975

Dr. David E. Wollersheim Dissertation Supervisor

The undersigned, appointed by the Dean of the Graduate Faculty, have examined a thesis entitled

FREE CONVECTION HEAT TRANSFER TO NON-NEWTONIAN RHEOLOGICAL DILATANT FLUIDS FROM A HORIZONTAL CYLINDER

presented by Chong Bo Kim

a candidate for the degree of Doctor of Philosophy

and hereby certify that in their opinion it is worthy of acceptance.

[redacted]

David E. Wollersheim

[redacted]

John B. Miles

[redacted]

FREE CONVECTION HEAT TRANSFER TO NON-NEWTONIAN RHEOLOGICAL DILATANT FLUIDS FROM A HORIZONTAL CYLINDER

Chong Bo Kim

Dr. David E. Wollersheim Dissertation Supervisor

ABSTRACT

The object of this study is to investigate the laminar free convection heat transfer between a horizontal cylinder and non-Newtonian, rheological dilatant fluids. Surface boundary conditions considered are constant heat flux and isothermal.

The cylindrical model employed in this investigation consisted of twenty aluminum segments each independently heated by resistance strips bonded to the interior surface. Concentrated corn starch suspensions in aqueous sucrose solutions are utilized as dilatant fluids in the experiment. Theoretical integral solutions are provided for power-law non-Newtonian fluids. Experimental free convection results are also compared with the integral solutions.

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation and gratitude to Dr. David E. Wollersheim for his valuable supervision, interest, and encouragement during the investigation and preparation of this paper.

Appreciation is also expressed to his advisory committee and Dr. J. Lloyd Sutterby for their assistance and valuable suggestions for this investigation. The effort of Mrs. Susan Davis is also greatly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C_p	specific heat, Btu/lbm-°F
d	diameter, ft
E_{rms}	root mean square voltage, volt
E(t)	arbitrary voltage, volt
f	dimensionless velocity
g	gravitational acceleration, ft/sec^2
h_{avg}	average free convection coefficient, $Btu/hr\text{-}ft^2\text{-}°F$
h_x	local free convection coefficient, $Btu/hr\text{-}ft^2\text{-}°F$
k	thermal conductivity, $Btu/hr\text{-}ft^2\text{-}°F$
K	consistency index, $lbm/ft\text{-}(sec)^{2-n}$
L	length, ft
M	torque, lb_f-ft
m	mass fraction
n	flow behavior index
P	power
q	heat flux, $Btu/hr\text{-}ft^2$
q_o	surface heat flux, $Btu/hr\text{-}ft^2$
Q_{Genx}	local heat generation rate, Btu/hr
r	radius, ft
r_c	thermocouple radius, ft
r_i	inner radius, ft
r_o	outer radius, ft
R_{strip}	resistance of strip, ohm
t	time, sec
T	temperature, °F
T_s	surface temperature, °F

T_∞	bulk fluid temperature, °F
u	velocity in x direction, ft/sec
U_x	arbitrary velocity dependent on x, ft/sec
v	velocity in y direction, ft/sec
x	coordinate parallel to the surface
x^+	dimensionless coordinate parallel to the surface
y	coordinate normal to the surface
α	thermal diffusivity, ft^2/hr
β	coefficient of thermal expansion, 1/°F
δ	boundary layer thickness, ft
δ^+	dimensionless boundary layer thickness
ρ	density, lbm/ft^3
μ	absolute viscosity, lbm/ft-sec
θ	dimensionless temperature
τ	shear stress, lb_f/ft^2
ϕ	circumferential angle, radian
η	dimensionless variable
ω	angular velocity, radian/sec

<u>Subscripts</u>

a	apparent
avg	average
c	thermocouple
e	equivalent
i	inner
o	outer
s	surface
T	total

x	local
∞	bulk
1	aqueous sucrose solution
2	corn starch

Dimensionless Groups and Functions

N_{Gr}	Grashof number
N_{Gr_A}	Acrivos' Grashof number
$N^+_{Gr_C}$	Chen's Grashof number
$N^+_{Gr_K}$	Kim's Grashof number
$N^+_{Gr_T}$	Tien's Grashof number
N_{Gr_T}	Tien's Grashof number
N_{Pr}	Prandtl number
N_{Pr_A}	Acrivos' Prandtl number
N_{Pr_C}	Chen's Prandtl number
N_{Pr_K}	Kim's Prandtl number
N_{Pr_T}	Tien's Prandtl number
$(N_{Nu})_{avg}$	Average Nusselt number
$(N_{Nu_r})_{avg}$	Average Nusselt number based on radius
$(N_{Nu_d})_{avg}$	Average Nusselt number based on diameter
$(N_{Nu})_r$	Nusselt number based on radius
N_{Nu_x}	Local Nusselt number
$(N_{Nu_x})_r$	Local Nusselt number based on radius
$A(n)$	Acrivos' function
C_n	Chen's function
$C_1(n)$	Tien's function
$C_2(n)$	Tien's function

$F(\eta)$	Similarity function
$G(\eta)$	Gentry's function
$g(\tau)$	arbitrary function for shear stress
$K(\eta)$	Kim's function
$M_1(\eta)$	Tien's function
$M_2(\eta)$	Tien's function
$R(\eta)$	Reilly's function
$\phi(\eta)$	dimensionless velocity profile
$\theta(\eta)$	dimensionless temperature profile

CHAPTER I

INTRODUCTION

Useful engineering studies which deal with transport processes in non-Newtonian fluids are receiving increased attention from varied technical areas which include the chemical process industry, aerospace and defense interests, nuclear reactor developers, bioengineering, and environmental sciences. Naturally, heat transfer problems involving such non-Newtonian fluids become very important. Therefore, it is evident that an understanding of heat transfer to non-Newtonian fluids may give good predictions to the problems encountered.

The heat transfer between a body surface and a motionless fluid is one of the most naturally occurring physical phenomena. Free convection heat transfer occurs whenever a body is placed in a fluid at a higher or a lower temperature than that of the body. Free convection motion transfers internal energy stored in the fluid is essentially the same manner as forced convection. However the intensity of the mixing motion is generally less in free convection, and consequently the heat transfer coefficients are lower than in forced convection. Although free convection heat transfer coefficients are relatively low, many devices including nuclear power application depend largely on this mode of heat transfer for cooling.

Investigations dealing with free convection heat transfer to non-Newtonian fluids have been considerably fewer in number than to Newtonian fluids. Most analytical works for non-Newtonian fluids have been concerned with laminar flow, because turbulence is less tractable in non-Newtonian fluids. Fortunately laminar flow is very important in free convection to non-Newtonian fluids and the leading edge is not a serious source of distrubance. An exact evaluation of the heat transfer for force convection from the boundary layer is usually very difficult. The problem has been solved for simple geometries, such as a vertical flat plate and a horizontal cylinder.

Studies dealing with laminar free convection heat transfer to non-Newtonian fluids have been reported by several investigators. Theoretical studies on free convection to power-law fluids have been presented in the form of similarity solutions for an isothermal two dimensional body(1), similarity solutions for constant heat flux-vertical flat plates(2), integral solutions for isothermal and constant heat flux-vertical flat plates(3), and integral solutions for isothermal horizontal cylinders(4). Experimental investigations also have been reported in the cases of isothermal vertical flat plates(5,6), constant heat flux-vertical flat plates(7), and isothermal horizontal cylinders(4). The results of the experimental work generally seem to agree with theoretical predictions. However, the use of a power-law model for non-Newtonian natural convection seems justifiable at least for engineering purposes. However, all of the above experimental work, without exception, has used only pseudoplastic fluids for non-Newtonian fluids. Although the majority of non-Newtonian fluids are pseudoplastic, it is evident that further investigations using other non-Newtonian (such as dilatant) fluids are desirable.

1.1 Scope of the Investigation

The object of this study is to investigate laminar free convection heat transfer between a horizontal cylinder and dilatant fluids.

Surface boundary conditions considered are both isothermal and constant heat flux. Concentrated corn starch suspensions in aqueous sucrose solutions are utilized as dilatant fluids in the experiment, since they exhibit rheological dilatancy uniformly in a range of high concentrations. Theoretical solutions for natural convection heat transfer from a horizontal cylinder with constant heat flux surface conditions to power-law, non-Newtonian fluids are provided by using an integral technique.

Experimental local free convection results for the isothermal and constant heat flux-surface conditions, expressed in dimensionless forms, are compared with the approximate integral solutions. Average free convection results are also obtained by integrating the local values. Besides getting the heat transfer rates to determine the Nusselt number, it is also necessary to see whether test fluids exhibit similar rheological behavior under natural flow conditions as those observed in a rotational viscometer.

Next, non-Newtonian fluid classification and fundamentals of laminar free convection heat transfer to non-Newtonian fluids will be discussed.

1.2 Non-Newtonian Fluids

There are fluids that do not obey the simple relationship between shear stress and rate of shear strain given by the linear relationship for a Newtonian fluid. These fluids have been given the general name non-Newtonian fluids and many common fluids are non-Newtonian. Although the properties of non-Newtonian fluids do not lend themselves to the elegant and precise analysis that has been developed for Newtonian fluids, the flow of non-Newtonian fluids does possess some interesting useful characteristics. These materials are commonly classified into three broad groups. The simplest of these is the time independent non-Newtonian fluids in which the rate of shear at a given point is solely dependent upon the instantaneous shear stress at that point. Time dependent non-Newtonian fluids have more complex shearing stress-strain rate relationships. In these fluids, the shear rate is a function of 'oth magnitude and the duration of shear and possible of the time lapse between consecutive application of shear stress. In viscoelastic fluids, shear strain as well as strain rate are related in some way to shear stress. Unlike a truly viscous fluid, some of the energy of deformation of a viscoelastic fluid may be recoverable as it is in the deformation of an elastic solid. Such materials possess properties of both fluids and elastic solids.

For the time independent non-Newtonian fluid, Newtonian fluid is simply a special case and thus is also termed as being purely a viscous non-Newtonian fluid. The majority of the non-Newtonian fluids that we encounter probably fall into this category, and in some cases flow of fluids not in this category, such as time dependent fluids, may be approximated in this category for simple cases. The time independent non-Newtonian fluids have been commonly represented by three distinct types as shown in Figure (1.1). These are

1) Bingham plastics, curve A
2) Pseudoplastic fluids, curve B
3) Dilatant fluids, curve C

The Newtonian fluids are indicated by straight lines as shown by line D.

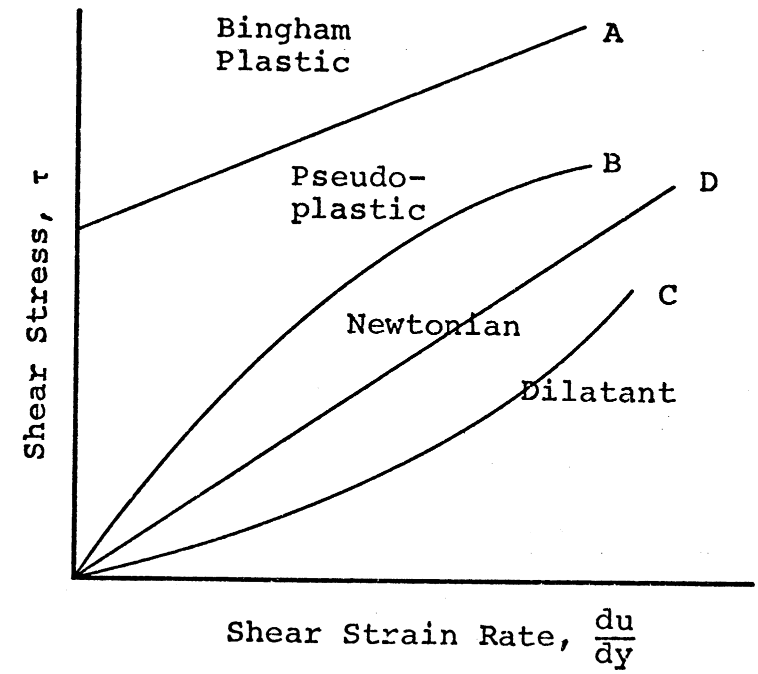

Figure (1.1) Typical Shear Stress-Strain Rate Relationship for Non-Newtonian Fluids

Bingham Plastics

Bingham plastics exhibit a yield stress at zero shear rate, followed by a straight line relationship between shear stress and shear rate. The characteristics of these fluids are defined by two constants, the yield stress τ_y which is the stress that must be exceeded for flow to begin, and the viscosity μ_p which is the slope of the straight line portion of curve A in Figure (1.1). The equation for a Bingham plastic is then,

$$\tau = \tau_y + \mu_p \frac{\partial u}{\partial y} \tag{1.1}$$

Pseudoplastic Fluids

Pseudoplastic fluids as well as dilatant fluids do not have a yield stress. The pseudoplastic fluid is also characterized by a progressively decreasing slope of shear stress versus shear rate. This slope has been defined as apparent viscosity.

$$\mu_a = \tau / \frac{\partial u}{\partial y} \tag{1.2}$$

There are a number of empirical relations that have been used to describe pseudoplastic behavior. The most convenient of these is the power law model due to Ostwald-de Waele. It is written as

$$\tau = K \left(\frac{\partial u}{\partial y}\right)^n \quad \text{where } n < 1 \tag{1.3}$$

K and n are constant for a particular fluid. K is a measure of the consistency of the fluid and n is a measure of how the fluid deviates from a Newtonian fluid. Defining apparent viscosity as equation (1.2), Equation (1.3) gives

$$\mu_a = K \left(\frac{\partial u}{\partial y}\right)^{n-1} \tag{1.4}$$

However, the flow curve B in Figure (1.1) for pseudoplastic fluids is characterized by linearity at very low and very high shear rates.[17,18]

Dilatant Fluids

Dilatant fluids are similar to pseudoplastic fluids in having no yield stress. They differ from pseudoplastic fluids in that the apparent viscosity increases with increasing shear rate. As with the pseudoplastic fluids, they may be represented by the power law model where the exponent n is greater than unity. Two phenomena have been observed with dilatant materials. Volumetric dilatancy denotes an increase in total volume under shear, whereas rheological dilatancy refers to an increase in apparent viscosity with increasing shear rate.

It is this latter which is more usually associated with dilatant fluids. Like behavior of pseudoplastic fluids, dilatant fluids are not dilatant rheologically at all shear rates. In many solid suspensions at low shearing stresses, Newtonian behavior occurs due to absence of sufficient forces to affect the particle size. In the range of slightly increased shearing stresses, the slope of the curve progressively increases. The imposed shearing forces may break up loosely-bonded structures formed by groups of particles.[19]

Since dilatant fluids are employed as test fluids in the present investigation, related literature for the dilatant behavior of fluids will be presented in Chapter II.

1.3 Fundamentals of Free Convection Heat Transfer to Non-Newtonian Fluids

The fluid velocities in free convection currents are generally low, but the characteristics of the flow in the vicinity of the heat transfer surface are similar to those in forced convection.[20,21,22] The fluid velocities near the surface and at the interface of a boundary layer are zero. Although the velocity profile is different from that observed in forced convection in the vicinity of the surface, the characteristics of both types of boundary layer are known to be similar.

The differential form of the general equation governing heat transfer by convection can be written as

$$dq = h_x(T_s - T_\infty)\, dA \qquad (1.5)$$

The reason for writing this equation for a differential area dA is that, in free convection, the heat transfer coefficient h_x is not uniform over a surface. Therefore, a local value of h_x is distinguished from an average value of h_{avg} obtained by averaging h_x over the entire surface. The temperatures, T_s and T_∞ refer to body surface temperature and bulk fluid temperature. Another equation for the surface heat flux may be expressed by the basic Fourier law,

$$dq = -k\ dA\ (\frac{\partial T}{\partial y})_{y=0} \tag{1.6}$$

where k is the thermal conductivity of the fluid and $(\frac{dT}{dy})_{y=0}$ refers to temperature gradient in the fluid at the body surface. By equating Equations (1.5) and (1.6), the local heat transfer coefficient can be defined as

$$h_x = \frac{dq}{(T_s - T_\infty)dA} = \frac{-k(\frac{dT}{dy})_{y=0}}{T_s - T_\infty} \tag{1.7}$$

To obtain the governing differential equations for laminar free convection, boundary layer theory concepts are employed. The boundary layer phenomenon considered in this investigation is limited to the steady and two dimensional case. With a power-law fluid assumption the differential equations which govern the conservation of mass, momentum, and energy within the boundary layer appear (1), respectively, as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1.8}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = g\beta\ (T - T_\infty)\sin\phi + \frac{K}{\rho}\ \frac{\partial}{\partial y}(\left|\frac{\partial u}{\partial y}\right|^{n-1}\ \frac{\partial u}{\partial y}) \tag{1.9}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p}\ \frac{\partial^2 T}{\partial y^2} \tag{1.10}$$

where β denotes the volume expansion coefficient. Constant properties have been assumed, except for the density in the buoyancy term. For a first approximation the frictional dissipation term in the energy equation is neglected. The system of coordinates is displayed in Figure (1.2).

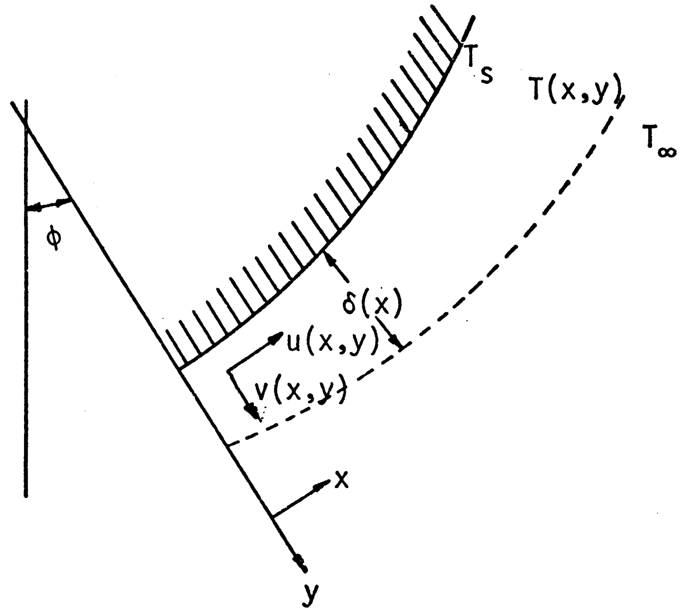

Figure (1.2). Free Convection Boundary Layer

The boundary conditions specify that the temperature or heat flux is a function of x at y=0, and is zero at infinity. The velocity components are zero at y=0 and infinity. The partial derivatives of temperature and velocity with respect to y are also zero at infinity. The boundary conditions for velocity differ from their forced convection counterpart, and have the effect that the velocity and temperature profiles are quite different in shape. Velocity changes from zero through a maximum to zero again, whereas temperature varies monotonically from maximum to zero.

In most of the analytical work it is convenient to non-dimensionlize the variables, and this can be done in many ways. A common device is to allot special symbols to the basic variables which can be reserved for the dimensionless variables in which the greater part of the analysis is to be conducted. From dimensional analysis of free convection to a non-Newtonian fluid, it is often convenient to define generalized Grashof and Prandtl numbers according to corresponding boundary conditions.

The peculiarity which distinguishes free convection from forced, is that the equations of momentum and energy are coupled; they cannot be treated separately. The motion is directly caused by the transfer of heat, and has no independent existence. As a consequence, the principle of superposition cannot be used to develop solutions for complicated situations from solutions for simple and idealized cases.

CHAPTER II

REVIEW OF THE LITERATURE

This chapter is devoted to the review of the literature which is related to the present investigation. Free convection heat transfer studies from a two dimensional body to non-Newtonian fluids for both isothermal and constant heat flux-surface conditions and the dilatant behavior of fluids are being considered.

2.1 Laminar Free Convection Heat Transfer to Non-Newtonian Fluids

Boundary layer concepts have been studied by Acrivos[1] and applied to the analysis of laminar free convective heat transfer to power-law fluids from isothermal surfaces of various geometries. Using conventional boundary layer equations and introducing the generalized Grashof and Prandtl numbers used to reduce the boundary layer equations to dimensionless form, Acrivos obtained similarity solutions with the assumption of large Prandtl number. For a vertical flat plate the local and average Nusselt numbers are expressed as

$$N_{Nu_x} = \frac{h_x x}{k} = \theta'(0) \left(\frac{2n+1}{3n+1}\right)^{\frac{n}{3n+1}} N_{Gr_A}^{\frac{1}{2(n+1)}} N_{Pr_A}^{\frac{n}{3n+1}} \left(\frac{x}{L}\right)^{\frac{-n}{3n+1}} \qquad (2.1)$$

where $$N_{Gr_A} = \frac{\rho^2 L^{n+2}[\beta g(T_s - T_\infty)]^{2-n}}{K^2} \qquad (2.2)$$

$$N_{Pr_A} = \frac{\rho C_p}{k} \left(\frac{K}{\rho}\right)^{\frac{2}{n+1}} L^{\frac{1-n}{n+1}} [L\beta g(T_s - T_\infty)]^{\frac{3(n-1)}{2(n+1)}} \qquad (2.3)$$

L denotes the plate height and $\theta'(0)$ is the parameter dependent on the value n. For a horizontal cylinder with the characteristic length L equal to the radius r in both N_{Gr_A} and N_{Pr_A} the local Nusselt number

$(N_{Nu_x})_r = h_x r/k$ was expressed as below:

$$(N_{Nu_x})_r = \frac{-\theta'(0)\left(\frac{2n+1}{3n+1}\right)^{\frac{n}{3n+1}} N_{Gr_A}^{\frac{1}{2(n+1)}} N_{Pr_A}^{\frac{n}{3n+1}} (\sin\phi)^{\frac{1}{2n+1}}}{\left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2n+1}} d\phi\right]^{\frac{n}{3n+1}}} \qquad (2.4)$$

The average Nusselt number $(N_{Nu})_{avg}$ is given by

$$(N_{Nu})_{avg} = A\, N_{Gr_A}^{\frac{1}{2(n+1)}} N_{Pr_A}^{\frac{n}{3n+1}} \qquad (2.5)$$

where the constant A can readily be calculated by integrating the local Nusselt number over the surface and would be expected to be a function of n. Equation (2.5) can be recognized as a generalization to power-law, non-Newtonian fluids of the well-known correlation $(N_{Nu})_{avg} = (N_{Gr}\, N_{Pr})^{1/4}$ for Newtonian substances. Numerical computation shows that A is only slightly affected by the value of n in the range of $1/10 \leqq n \leqq 3/2$, which includes most of the power-law fluids of interest. Numerical values for A are shown in Table (2.1).

Table (2.1) Numerical Values of A for Various Geometries and n(isothermal surface)

	n = 1/10	n = 1/2	n = 1	n = 3/2
Flat Plate	0.60	0.63	0.67	0.71
Horizontal cylinder (L=radius)	0.36	0.38	0.42	0.45
Sphere (L=radius)	0.44	0.45	0.49	0.52
Vertical cone	0.61	0.65	0.71	0.75
Stagnation region of a horizontal cylinder	0.36	0.45	0.54	0.60
Stagnation region of a sphere	0.45	0.55	0.64	0.70

Acrivos suggests that his two-dimensional exact asymptotic solutions are applicable for the range of $N_{Pr_A} > 10$, which is usually the case.

Chen[2] obtained similar solutions for the constant heat flux over the vertical flat plate. Under the assumption that a generalized Prandtl number approaches infinity, Generalized Grashof and Prandtl numbers were again introduced and the local and average Nusselt number results were presented in the following form:

$$N_{Nu_x} = \frac{h_x x}{k} = C_n N_{Gr_C}^{+\,\frac{1}{n+4}} \; N_{Pr_C}^{\frac{n}{3n+2}} \; \left(\frac{x}{L}\right)^{-\frac{2(n+1)}{3n+2}} \tag{2.6}$$

$$(N_{Nu})_{avg} = \frac{h_{avg} L}{k} = C \, N_{Gr_C}^{+\,\frac{1}{n+4}} \; N_{Pr_C}^{\frac{n}{3n+2}} \tag{2.7}$$

where $$N_{Gr_C}^{+} = \left(\frac{\rho}{K}\right)^2 L^4 \left(\frac{g\beta q_o}{k}\right)^{2-n} \tag{2.8}$$

and $$N_{Pr_C} = \left(\frac{\rho C_p}{k}\right) \left(\frac{K}{\rho}\right)^{\frac{5}{n+4}} L^{\frac{2(n-1)}{n+4}} \left[\frac{g\beta q_o}{k}\right]^{\frac{3(n-1)}{n+4}} \tag{2.9}$$

The constant heat flux, q_o, over the flat plate appears in the dimensionless groups. C_n and C are dependent on the flow behavior index n, and expressed as

$$C_n = \frac{1}{(3n+2)^{\frac{n}{3n+2}} \, Z(0)} \tag{2.10}$$

$$C = \frac{(3n+2)^{\frac{2(n+1)}{3n+2}}}{(5n+4) \, Z(0)} \tag{2.11}$$

Z(0) is a parameter and the values for different n are shown in Figure (2.1).

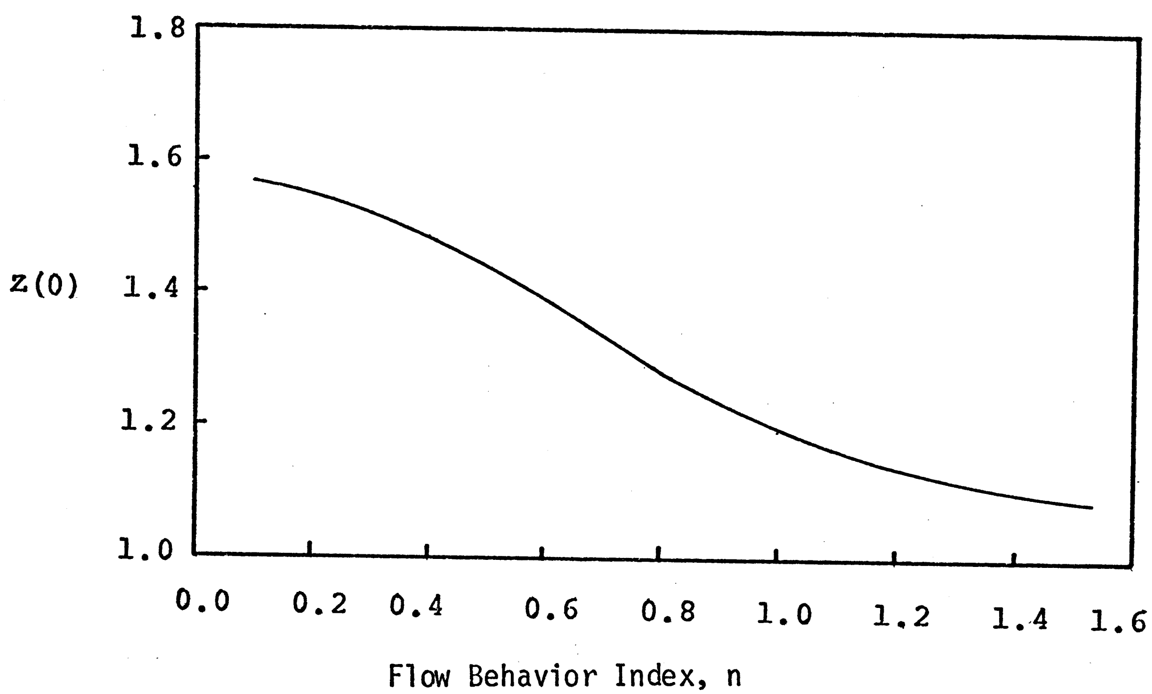

Figure (2.1) Z(0) versus n

Using an integral technique, Tien[3] obtained approximate solutions for laminar natural convection heat transfer between a vertical plate and a power-law fluid with high Prandtl number. The velocity and temperature profiles are assumed to be of the following form:

$$u = u_x[s(\frac{y}{\delta}) \quad e^{-s(\frac{y}{\delta})}] \tag{2.12}$$

$$\theta = \frac{T - T_\infty}{T_s - T_\infty} = (1 + \frac{y}{\delta})\ (1 - \frac{y}{\delta})^3 \tag{2.13}$$

δ is boundary layer thickness, and the constant, s, was chosen to be $\frac{5}{3n}$. For an isothermal flat plate, he obtained the local and average Nusselt number to be

$$N_{Nu_x} = C_1(n)\ N_{Gr_T}^{\frac{1}{3n+1}}\ N_{Pr_T}^{\frac{n}{3n+1}}\ (\frac{x}{L})^{\frac{-n}{3n+1}} \tag{2.14}$$

and

$$(N_{Nu})_{avg} = C_2(n)\, N_{Gr_T}^{\frac{1}{3n+1}}\, N_{Pr_T}^{\frac{n}{3n+1}} \qquad (2.15)$$

where

$$N_{Gr_T} = \frac{g\beta(T_s - T_\infty)\, L^{\frac{n+2}{2-n}}}{(\frac{K}{\rho})^{\frac{2}{2-n}}} \qquad (2.16)$$

$$N_{Pr_T} = \frac{C_p \rho}{k} \left(\frac{K}{\rho}\right)^{\frac{1}{2-n}} L^{\frac{2(n-1)}{n-2}} \qquad (2.17)$$

For a constant flux condition, Nusselt numbers are presented to be

$$N_{Nu_x} = M_1(n)\, N_{Gr_T}^{+\ \frac{1}{3n+1}}\, N_{Pr_T}^{\frac{n}{3n+2}} \left(\frac{x}{L}\right)^{-\frac{n}{3n+2}} \qquad (2.18)$$

and

$$(N_{Nu})_{avg} = M_2(n)\, N_{Gr_T}^{+\ \frac{1}{3n+2}}\, N_{Pr_T}^{\frac{n}{3n+2}} \qquad (2.19)$$

where

$$N_{Gr_T}^{+} = \left(\frac{g\beta q_o}{k}\right) L^{\frac{4}{2-n}} \left(\frac{K}{\rho}\right)^{\frac{2}{n-2}} \qquad (2.20)$$

q_o is the constant heat flux over the flat plate. Numerical values of C_1, C_2, M_1, and M_2 are evaluated based on Tien's velocity and temperature profile expressions and the dependency of the coefficients on n is shown in Figure (2.2).

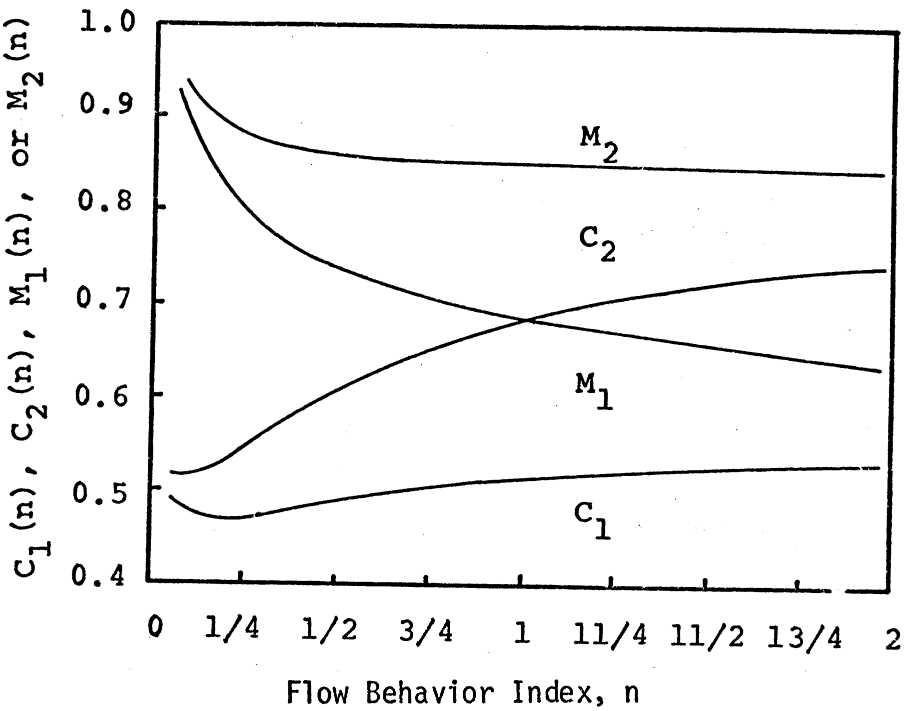

Figure (2.2) Relationships between the coefficients C_1, C_2, M_1, M_2, and n

The agreement between the average Nusselt number and the experimental results from reference (5) appears to be excellent.

Gentry and Wollersheim(4) employed an approximate integral method to get the solution for free convection from an isothermal horizontal cylinder to power-law fluids. With the assumption of high Prandtl number fluid, Gentry utilized Tien's(3) velocity and temperature profile expressions. The local Nusselt number based on the radius was expressed as

$$(N_{Nu_x})_r = \frac{h_x r}{k} = G(n) \left(\frac{2n+1}{3n+1}\right)^{\frac{n}{3n+1}} N_{Gr_A}^{\frac{1}{2(n+1)}} N_{Pr_A}^{\frac{n}{3n+1}} \qquad (2.21)$$

$$(\sin\phi)^{\frac{1}{2n+1}} \left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2n+1}} d\phi\right]^{-\frac{n}{3n+1}}$$

where N_{Gr_A} and N_{Pr_A} are generalized Grashof and Prandtl numbers defined by Acrivos[1]. The flow behavior index-dependent coefficients G(n) are shown in Table (2.2) and compared with the values of θ'(n), which appeared in Acrivos' solutions. Gentry's integral solutions for an isothermal cylinder agree closely with Acrivos' similarity solution results.

Reilly, Tien, and Adelman[5] carried out experimental work for the study of natural convection from an isothermal vertical plate to power-law fluids. The fluid was an aqueous solution of Carbopol which is a carboxy-polymethylene. Three plates of different heights (0.323, 0.656, and 0.989 ft.) were used. Carbopol solutions of two concentrations (0.5% with average flow behavior index n=0.89 and 1.00% solution with n=0.72, were investigated. All physical properties were evaluated at the film temperature. Reilly suggested the following form of average Nusselt number for correlation.

$$(N_{Nu})_{avg} = \frac{h_{avg}\,L}{k} = R(n) \quad [N_{Gr_T} \quad N_{Pr_T}{}^{n}]^{a} \tag{2.22}$$

Table (2.2) The values of G(n) and Comparison with Acrivos' Coefficient θ'(n)

n	G(n)	-θ' (0)
0.1	0.477	0.555
0.2	0.475	0.523
0.3	0.486	0.515
0.4	0.498	0.516
0.5	0.510	0.520
0.6	0.521	0.524
0.7	0.530	0.528

Table (2.2) continued

n	G(n)	$-\theta'(0)$
0.8	0.538	0.534
0.9	0.545	0.537
1.0	0.551	0.540
1.1	0.557	0.546
1.2	0.562	0.550
1.3	0.566	0.555
1.4	0.570	0.559
1.5	0.573	0.562

The experimental results and comparison with Acrivos' solution are shown in Table (2.3).

Table (2.3) Comparisons between Reilly's results and theoretical predictions by Acrivos(1)

Fluid	n (Average)	N_{Pr}	R		a	
			Exp'l	Cal'd	Exp'l	Cal'd
Water	1	5.8-7.76	0.54	0.59	0.25	0.25
0.5% Carbopol	0.891	102-145	0.65	0.665	0.275	0.282
1% Carbopol	0.720	916-2000	0.583	0.618	0.325	0.321

From this comparison it was found that experimentally determined exponents were almost identical with those based on the asymptotic solution. The experimental values of R are approximately 5-10% lower than those predicted by Acrivos. However, this difference is well within the limits of experimental error encountered.

Sharma and Adelman[6] continued the previous experimental work by Reilly with flow behavior index n = 0.20-0.67. The experimental results for three Carbopol solutions were correlated using Acrivos' equation with generalized dimensionless parameters as defined in the original paper. No single correlation including the expression $(N_{Nu})_{avg} = R(N_{Gr_T} N_{Pr_T}{}^n)^a$ which was derived by Reilly was found to accommodate all the experimental data. A satisfactory correlation was found by using the Lorentz equation which is the well-known correlation form for Newtonian fluids. The equation gives the form of

$$(N_{Nu})_{avg} = 0.514(N_{Gr_T} N_{Pr_T})^{0.263} \qquad (2.23)$$

Experimental results have been reported by Dale[7] for a vertical flat plate under constant heat flux conditions. Two vertical flat plates, constructed of thin 302 stainless steel shim stock, were employed. Dimensions for the large plate were 18.5 inches wide by 24 inches high, and for the small plate they were 6.5 inches wide by 12 inches high. The range of the power-law fluid index n was from 0.383 to 1.000. Heating was accomplished by passing alternating current through the thin stainless steel sheets. Temperature profiles were measured and utilized in determining the local surface heat flux. Velocity profiles were obtained by both particle tracking and dye injection techniques. Dale's experimental data were compared with his finite difference computations. His local heat transfer rates were expressed in the following form:

$$N_{Nu_x} = \frac{h_x x}{k} = D(n)\,[N^+_{Gr_T} N_{Pr_T}{}^n]^{\frac{1}{3n+2}} \qquad (2.24)$$

The agreement between Chen's similarity solutions for constant heat flux condition and Dale's experimental results has been reported[2] to be quite good.

Gentry[4] conducted an experimental investigation for the free convection heat transfer from an isothermal horizontal cylinder to power law fluids. Fluids employed included water and four dilute water soluble polymer solutions with fluid index range, 0.66 to 1.00. An electrically heated, employed, and copper-constantan thermocouples were embedded in each test section. Velocity profiles were determined by dye injection technique. All local free convection results were expressed in terms of Acrivos' dimensionless group using radius as a characteristic length dimension. Local free convection data for water appear approximately 10% lower than the similarity and integral solution curves. However, experimental data obtained from the 0.053%, 0.055% and 0.56% solutions agree quite well with similar and integral solution predictions. Local free convection results for the 0.058% solution are approximately 10% to 15% higher than the predicted curve. For correlation a least squares fit of all experimental data was obtained in the following form:

$$(N_{Nu_d})_{avg} = \frac{h_{avg}d}{k} = 1.19\,[(N_{Gr_A})_d\,(N_{Pr_A})_d]^{0.200} \qquad (2.25)$$

where the subscript d denoted that the diameter was taken to be a characteristic length. Average free convection results using diameter as a characteristic dimension in Nusselt, Prandtl and Grashof numbers were also compared with McAdam's correlation[22], $(N_{Nu_d})_{avg} = 0.53\,(N_{Gr}\,N_{Pr})^{0.25}$, for Newtonian fluids. From the comparison with the well-known McAdam's correlation for Newtonian fluids, the average Nusselt number results from the experiment are approximately 5%-15% higher than the McAdam's correlation.

2.2 Rheological Dilatant Behavior of Fluids

Rheological dilatancy refers to an increase in apparent viscosity with increasing shear rate. The flow curve shown in Figure (1.1) is characterized by zero yield stress and may usually be fitted by the power law model with n greater than unity.

The classical experiment demonstrating the dilatant behavior of the fluid was performed by Reynolds[8]. One of the systems which Reynolds considered was sand in water. The sand was placed in a rubber balloon containing a small excess of water over that just necessary to fill the void between the sand grains, and the water level was shown by an attached glass tube. When Reynolds pressed or distorted the balloon the liquid level in the glass tube decreased. Obviously if the sand-water suspension originally had enough water to fill the voids between the sand grains and received more on application of pressure to the system, then the volume of the suspension must have increased, i.e., the system must have dilated.

Freundlick and Roder[9], working with starch-water and quartz-water systems, found that increases in the viscosity of a given system sometimes occurred with increases in shear rate. This was also termed "dilatant" behavior, since Reynolds had also noted similar increases in rigidity upon distortion and volumetric dilation of his systems. From this and related experiments a second definition of dilatancy has arisen: fluids for which a shear stress versus shear rate plot is concave towards the stress axis be termed dilatant. Using particles with diameter between 1.5 and 5 microns, dilatancy was reported only in suspensions containing between 42 and 45% solids by volume. Above and below this range no dilatancy was encountered in either of the two systems studied (starch-water and quartz-water).

Calderbank and Moo-Young[10] also reported rheological dilatancy in corn flour suspension in sugar solution at high concentrations. The experimental results show that these solutions begin to show dilatant behavior under relatively low shear rates.

Verwey and de Boer[11] found that sometimes dilatant behavior occurred only over very narrow concentration ranges in suspensions of metallic particles in organic liquids, although few specific values are given.

Meerman and de Bruijn[12] reported dilatancy in a suspension of glass particles at only 13.8% solids by volume. It suggests that dilatancy may be confined to a narrow range of concentrations. The effects of particle size on dilatancy are somewhat clearer than the above data on concentration effects. Dilatancy was reported for all particle sizes in their 0-50, 50-90, 90-250, 250-500 and 500-700 micron ranges.

Robinson[13] encountered no dilatancy in the rheological sense with particle size in 3-4, 4-10, and 10-30 micron ranges, even with particle concentrations as high as 52% by volume. However, it is possible that he may have missed the phenomenon if it is restricted to as narrow a range of concentrations as indicated above.

Similarly, Vand[14] found no dilatancy in suspensions of 130 micron diameter glass beads, and Ting and Luebbers[15] found no dilatancy in their suspensions of 390 micron diameter glass beads (at concentrations up to about 50% by volume).

Metzner and Whitlock[16] tried to establish the ranges of variables of primary interest in which the phenomena of dilatancy may be observed. Dilatancy in the rheological sense was never obtained in any of the glass bead-suspensions. However, dilatancy was found in the range of approximately 20-45% of titanium dioxide-suspensions by volume in various aqueous solutions whose viscosities ranged from 1 to 42 centipose. As titanium dioxide concentration was increased, non-Newtonian behavior was shown clearly. The particle sizes used were 24-34 micron diameter for glass beads, and 0.2-1.0 micron for titanium dioxide.

The viscosity of the suspending liquids used in studies of dilatancy have not been found to vary over an appreciable range; all studies have been in liquids having viscosity of a few centiposes or less. Freundlich(9) theorized that such low viscosities are probably necessary to bring out the phenomenon.

An explanation of dilatant behavior in solid-suspensions was offered by Reynolds(8). He suggested that the particles in a concentrated suspension will be oriented at rest so that the void space is a minimum. The suspending liquid is just sufficient to fill the voids in this state. The increase in voidage caused by shearing a dilatant material means that the space between particles becomes incompletely filled with liquid. Under these conditions of inadequate lubrication the surfaces of adjacent particles come into direct contact, causing an increase in apparent viscosity with increasing shear rate.

Metzner(16) has proposed a somewhat different tentative hypothesis for the dilatant behavior. He proposed that at sufficiently low shearing stresses Newtonian behavior occurs due to absence of sufficient forces to affect either particle size or concentration. However in the range of slightly increased shearing stresses, the slope of the flow curve in the shear stress-strain rate relationship progressively increases, as shown in Figure (1.1), as the flowing particles progressively decreased in size due to the imposed shearing forces which may break up the loosely bonded structure formed by groups of particles. Progressive decrease in the size of particles decreases not only the excess momentum over that in an adjacent one, but also the total intermolecular forces which account for the momentum transfer. At increasing stresses the system begins to expand volumetrically. Accordingly, entire layers of particles begin to glide over adjacent layers. Figure (2.3) shows schematically that under a shear force particles have no time to fall into voids in adjacent layers and each layer glides over the adjacent one. If particles are suspended in various liquids, the theory also suggests that rheological dilatancy is more likely with low viscosity fluids. The theory also

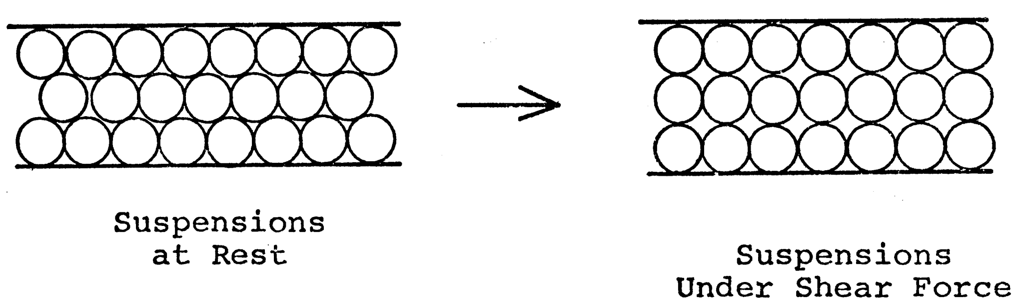

Figure (2.3) Dilatant Behavior of Solid Suspensions in Liquid

suggests that dilatancy occurs at progressively decreasing shear rates as the solids concentration is increased, since the slipping of adjacent layers over one another should be easier to achieve

CHAPTER III
INTEGRAL SOLUTIONS FOR CONSTANT HEAT FLUX SURFACE CONDITIONS

Approximate solutions for laminar natural convection heat transfer between a horizontal cylinder and a power-law, non-Newtonian fluid with high Prandtl number are obtained using an integral method for a case with constant heat flux-surface conditions. Since the similarity solutions are not possible to find for constant flux boundary conditions, the integral technique seems a powerful tool to solve these heat transfer problems for a practical purpose.

With the assumption of high Prandtl number, inertial terms appearing in the momentum equation are neglected. Then generalized Grashof and Prandtl numbers are defined properly through non-dimensional analysis, and velocity and temperature profile expressions are assumed to be utilized in the integral equations to yield the solution form for the local Nusselt number.

The velocity and temperature profile expressions utilized in this analysis were originally proposed by Fujii[23] and Tien[3] for the integral solutions for a vertical plate with constant flux and isothermal boundary conditions. As shown in Chapter II, Tien's results appear to be in excellent agreement with experimental data. Gentry and Wollersheim[4] utilized the same velocity and temperature profile expressions for their isothermal horizontal cylinder to prove that their integral solutions agree quite well with Acrivos'[1] similar solutions as well as with their experimental data. The choice of velocity and temperature profiles used in the integral analysis is somewhat arbitrary and solution accuracy will be improved with good profile assumptions. Using Tien's profiles for a horizontal cylinder with constant heat flux surface condition seems reasonable since these profiles satisfy the imposed boundary conditions of the present problem. Integral solution results will be compared with the experimental data in Chapter VII.

3.1 Boundary Layer Equations and Boundary Conditions

As shown in Chapter I, the governing differential equations for laminar free convection to power-law fluids are given as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1.8}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = g\beta(T-T_\infty)\sin\phi + \frac{K}{\rho}\frac{\partial}{\partial y}\left(\frac{\partial u}{\partial y}\left|\frac{\partial u}{\partial y}\right|^{n-1}\right) \tag{1.9}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} \tag{1.10}$$

where the symbols have the usual meanings and β is defined by

$$\rho_\infty/\rho = 1 + \beta(T - T_\infty) \tag{3.1}$$

Assuming constant properties except the density in the buoyancy term is usually permissible to a first approximation, and the frictional dissipation term in the energy equation is neglected. The system of coordinates of the flow past a two-dimensional horizontal cylinder is shown in Figure (3.1). For a constant heat flux-horizontal cylinder, the boundary conditions are

$$u = v = 0, \quad -k\left(\frac{\partial T}{\partial y}\right)_{y=0} = q_o \text{ at } y=0 \tag{3.2}$$

$$u = 0, \; T = T_\infty \text{ at } y=\infty \tag{3.3}$$

$$u = 0, \; T = T_\infty \text{ at } x=0 \tag{3.4}$$

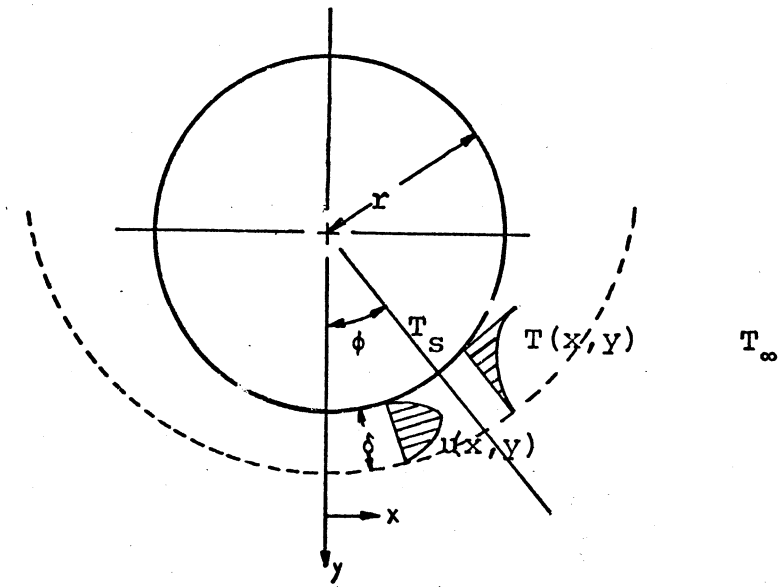

Figure (3.1) Configuration of Coordinates for Flow Over a Horizontal Cylinder

3.2 Integral Equations

The governing differential Equations (1.8-10) are integrated to have the desired integral forms, and the dimensionless temperature expression θ is introduced for convenience.

$$\theta = \frac{T - T_\infty}{T_s - T_\infty} \tag{3.5}$$

Integration of the momentum Equation (1.9) from y=0 to y=∞ gives the following integral equation.

$$\int_{y=0}^{\infty} (u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y})dy = g\beta(T_s - T_\infty)\sin\phi \int_{y=0}^{\infty} \theta dy$$

$$+ \frac{K}{\rho}\int_{y=0}^{\infty} \frac{\partial}{\partial y}(\frac{\partial u}{\partial y} \left|\frac{\partial u}{\partial y}\right|^{n-1}) \, dy \tag{3.6}$$

Similarly, the energy Equation (1.10) gives the integral equation of

$$\int_{y=0}^{\infty} (u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y})dy = \alpha \int_{y=0}^{\infty} \frac{\partial}{\partial y} (\frac{\partial\theta}{\partial y})\, dy \qquad (3.7)$$

Also, by integrating the continuity Equation (1.8), the expression for v is obtained to be

$$v = - \int_{y=0}^{y} (\frac{\partial u}{\partial x})\, dy \qquad (3.8)$$

Substituting the above expression for v into the momentum and energy equations, the equations to be solved are reduced to two coupled integral equations.

$$\frac{d}{dx} \int_{y=0}^{\infty} u^2 dy = g\beta(T_s - T_\infty)\sin\phi \int_{y=0}^{\infty} \theta dy - \frac{K}{\rho}(\frac{\partial u}{\partial y})^n_{y=0} \qquad (3.9)$$

$$\frac{d}{dx} \int_{y=0}^{\infty} u\theta dy = -\alpha(\frac{\partial\theta}{\partial y})_{y=0} \qquad (3.10)$$

Following Fujii's expression(23), the velocity and temperature profiles are assumed to be of the following form:

$$u = u_x \; f(\eta) \qquad (3.11)$$

$$\theta = \theta\; (\eta) \qquad (3.12)$$

u_x and boundary layer thickness δ are assumed to be functions of x only, and the dimensionless variable η is expressed in terms of coordinate y and boundary layer thickness $\delta(x)$.

$$\eta = \frac{y}{\delta\;(x)} \qquad (3.13)$$

Differentiations of u and θ with respect to y give

$$\frac{\partial u}{\partial y} = u_x \frac{\partial f}{\partial \eta} \frac{\partial \eta}{\partial y} = \frac{u_x}{\delta} f'\;(\eta) \qquad (3.14)$$

$$\frac{\partial\theta}{\partial y} = \frac{\partial\theta}{\partial\eta}\ \frac{\partial\eta}{\partial y} = \frac{1}{\delta}\,\theta'\ (\eta) \tag{3.15}$$

and the boundary condition (3.2) can be expressed in terms of η and θ as follows:

$$q_o = \frac{-k(T_S-T_\infty)\ \theta'\ (0)}{\delta}$$

or

$$(T_S-T_\infty) = -\ \frac{q_o\ \delta}{k\theta'\ (0)} \tag{3.16}$$

Now, substitution of Equations (3.11-16) into the two coupled integral momentum and energy equations (3.9-10) gives

$$A\frac{d}{dx}\ (u_x{}^2\delta) = Bg\beta\delta\frac{q_o\delta}{Ek}\ \sin\phi -\ C(\frac{K}{\rho})\ (\frac{u_x{}^n}{\delta^n}) \tag{3.17}$$

$$D\frac{d}{dx}\ (u_x\delta) = E\ \frac{\alpha}{\delta} \tag{3.18}$$

where

$$A = \int_0^\infty f^2\ (\eta)d\eta \tag{3.19}$$

$$B = \int_0^\infty \theta\ \ (\eta)d\eta \tag{3.20}$$

$$C = (f'\ (0))^n \tag{3.21}$$

$$D = \int_0^\infty f\ (\eta)\ \theta\ (\eta)d\eta \tag{3.22}$$

$$E = -\theta'\ (0) \tag{3.23}$$

By simple integration and applying boundary conditions (3.4), Equation (3.18) yields

$$u_x = \frac{E\alpha}{D\delta}\int_0^x \frac{dx}{\delta} \tag{3.24}$$

and substituting the above equation into Equation (3.17) gives

$$\frac{d}{dx}\left[\frac{1}{\delta}\left(\int_0^x \frac{dx}{\delta}\right)^2\right] = \left[\frac{BD^2 g\beta q_o}{AE^3 k\alpha^2}\right]\delta^2 \sin\phi - \left[\frac{CD^2 E^n K\alpha^n}{AD^n E^2 \rho\alpha^2}\right] \frac{\left(\int_0^x \frac{dx}{\delta}\right)^n}{\delta^{2n}} \tag{3.25}$$

For convenience, the following dimensionless quantities are defined as

$$x^+ = \frac{x}{r} \tag{3.26}$$

$$\delta^+ = \frac{\delta}{r} \tag{3.27}$$

By using these dimensionless variables, Equation (3.25) can be written as

$$\frac{d}{dx^+}\left[\frac{1}{\delta^+}\left(\int_0^{x^+} \frac{dx^+}{\delta^+}\right)^2\right] = \left[\frac{BD^2}{AE^3}\right]\left[\frac{r^4 q_o g\beta}{k\alpha^2}\right] \delta^{+2} \sin\phi$$

$$-\left[\frac{CD^{2-n}}{AE^{2-n}}\right]\left[\frac{K\alpha^{n-2}}{\rho r^{2(n-1)}}\right] \frac{\left[\int_0^{x^+} \frac{dx^+}{\delta^+}\right]^n}{\delta^{+2n}} \tag{3.28}$$

The generalized Grashof and Prandtl numbers are defined as

$$N_{Pr_K} = \frac{\rho C_p}{k}\left(\frac{K}{\rho}\right)^{\frac{2}{n+1}} r^{\frac{2(n-1)}{n+1}} \left[\frac{g\beta q_o}{k}\right]^{\frac{3(n-1)}{2(n+1)}} \tag{3.29}$$

$$N^+_{Gr_K} = \left(\frac{\rho}{K}\right)^2 r^4 \left[\frac{g\beta q_o}{k}\right]^{2-n} \tag{3.30}$$

Equation (3.28) can be written in terms of these dimensionless variables.

$$\frac{d}{dx^+}\left[\frac{1}{\delta^+}\left(\int_0^{x^+} \frac{dx^+}{\delta^+}\right)^2\right] = \left(\frac{BD^2}{AE^3}\right)\left[N^+_{Gr_K}{}^{\frac{2}{n+1}} N_{Pr_K}{}^2\right]\delta^{+2} \sin\phi$$

$$-\left(\frac{CD^{2-n}}{AE^{2-n}}\right)\left[N^+_{Gr_K}{}^{\frac{3(1-n)}{2(n+1)}} N_{Pr_K}{}^{2-n}\right] \frac{\left(\int_0^{x^+} \frac{dx^+}{\delta^+}\right)^n}{\delta^{+2n}}$$

or

$$\frac{1}{N_{Pr_K}} \frac{d}{dx^+}\left[\frac{1}{\delta^+}\left(\int_0^{x^+}\frac{dx^+}{\delta^+}\right)^2\right] = \left(\frac{BD^2}{AE^3}\right)\left[N^+_{Gr_K}{}^{\frac{2}{n+1}} N_{Pr_K}\right]\delta^{+2}\sin\phi$$

$$-\left(\frac{CD^{2-n}}{AE^{2-n}}\right)\left[N^+_{Gr_K}{}^{\frac{3(1-n)}{2(n+1)}} N_{Pr_K}{}^{1-n}\right]\frac{\left(\int_0^{x^+}\frac{dx^+}{\delta^+}\right)^n}{\delta^{+2n}} \qquad (3.31)$$

The terms on the left hand side of Equation (3.31) can be ignored for substances with large Prandtl numbers. The limitation imposed by this simplification should not severely restrict the usefulness of the results since most of the non-Newtonian fluids commonly encountered are highly viscous and have relatively large Prandtl numbers. Therefore, with the assumption of high Prandtl number, Equation (3.31) reduces to be

$$\frac{BD^2}{AE^3}\left[N^+_{Gr_K}{}^{\frac{2}{n+1}} N_{Pr_K}\right]\delta^{+2}\sin\phi = \frac{CD^{2-n}}{AE^{2-n}}\left[N^+_{Gr_K}{}^{\frac{3(1-n)}{2(n+1)}} N_{Pr_K}{}^{1-n}\right]\frac{\left(\int_0^{x^+}\frac{dx^+}{\delta^+}\right)^n}{\delta^{+2n}}$$

or

$$\int_0^x \frac{dx}{\delta} = K_1 \, \delta^{\frac{2(n+1)}{n}} (\sin\phi)^{\frac{1}{n}} \qquad (3.32)$$

where

$$K_1 = \left(\frac{B^{\frac{1}{n}} D}{C^{\frac{1}{n}} E^{\frac{n+1}{n}}}\right)\left[\frac{N^+_{Pr_K}{}^{\frac{3n+1}{2n(n+1)}} N_{Pr_K}}{r^{\frac{2(n+1)}{n}}}\right] \qquad (3.33)$$

Differentiating both sides of Equation (3.32) with respect to x gives

$$\frac{1}{\delta} = K_1 \left[\frac{2(n+1)}{n} (\sin\phi)\delta^{\frac{n+2}{n}} \frac{d\delta}{dx} + \frac{1}{n} \delta^{\frac{2(n+1)}{n}} (\sin\phi)^{\frac{1-n}{n}} (\cos\phi)\frac{d\phi}{dx}\right]$$

(3.34)

For convenience, Equation (3.34) is rewritten as

$$\frac{1}{K_1} = (\sin\phi)^{\frac{1}{n}} \delta \frac{d}{dx}(\delta)^{\frac{2(n+1)}{n}} + \delta^{\frac{3n+2}{n}} \frac{d}{dx} (\sin\phi)^{\frac{1}{n}}$$

or

$$\frac{1}{K_1} = \frac{2(n+1)}{3n+2} (\sin\phi)^{\frac{1}{n}} \frac{d}{dx} (\delta^{\frac{3n+2}{n}}) + \frac{1}{n}(\sin\phi)^{\frac{1-n}{n}} (\cos\phi)\, \delta^{\frac{3n+2}{n}} \frac{d\phi}{dx} \qquad (3.35)$$

Considering coordinates for a horizontal cylinder,

$$\frac{d\phi}{dx} = \frac{1}{r} \qquad (3.36)$$

the above expressions for ϕ and x, Equation (3.35) can be expressed in terms of ϕ only instead of x.

$$\frac{d}{d\phi} (\delta^{\frac{3n+2}{n}}) + \frac{3n+2}{2n(n+1)} \cot\phi\, (\delta^{\frac{3n+2}{n}}) = \frac{3n+2}{2(n+1)} \left[\frac{r}{K_1(\sin\phi)^{\frac{1}{n}}}\right] \qquad (3.37)$$

The above equation is recognized as a linear, first order-ordinary differential equation. Therefore, the solution for the differential equation is

$$\delta^{\frac{3n+2}{n}} = \frac{1}{(\sin\phi)^{\frac{3n+2}{2(n+1)}}} \int_{\phi=0}^{\phi} \frac{3n+2}{2(n+1)} \left[\frac{r}{K_1(\sin\phi)^{\frac{1}{n}}}\right] (\sin\phi)^{\frac{3n+2}{2n(n+1)}} d\phi$$

$$= \frac{3n+2}{2(n+1)} \left[\frac{r}{K_1(\sin\phi)^{\frac{3n+2}{2n(n+1)}}}\right] \left[\int_{\phi=0}^{\phi} \frac{1}{(\sin\phi)^{\frac{1}{2(n+1)}}} d\phi\right]$$

(3.38)

The expression of the boundary layer thickness is written as

$$\delta(\phi) = \left[\frac{3n+2}{2(n+1)}\right]^{\frac{n}{3n+2}} \left[\frac{r}{K_1^{\frac{n}{3n+2}} (\sin\phi)^{\frac{1}{2(n+1)}}}\right]$$

$$\left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2(n+1)}} \, d\phi\right]^{\frac{n}{3n+2}} \tag{3.39}$$

Including the expression of K_1 from Equation (3.33), the expression for δ becomes

$$\delta(\phi) = \left[\frac{3n+2}{2(n+1)}\right]^{\frac{n}{3n+2}} \left[\frac{CE^{n+1}}{BD^n}\right]^{\frac{1}{3n+2}} \left[\frac{r}{N_{Gr_K}^{+\frac{3n+1}{2(n+1)(3n+2)}} \, N_{Pr_K}^{\frac{n}{3n+2}}}\right]$$

$$\frac{\left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2(n+1)}} \, d\phi\right]^{\frac{n}{3n+2}}}{(\sin\phi)^{\frac{1}{2(n+1)}}} \tag{3.40}$$

3.3 Velocity and Temperature Profiles

Once the specific expressions for f and θ are known, the parameters, A,B,C,D, and E defined in Equation (3.19) to (3.23) can be readily evaluated. Following Tien's proposed profiles for a flat plate, the velocity and temperature profiles are assumed to be

$$f(\eta) = s\eta \, e^{-s\eta} \qquad \text{for } 0 < \eta < \infty \tag{3.41}$$

$$\theta(\eta) = (1+\eta)(1-\eta)^3 \qquad \text{for } 0 < \eta < 1$$
$$= 0 \qquad \text{for } 1 < \eta < \infty \tag{3.42}$$

where $s = \frac{5}{3n}$ (3.43)

These profiles satisfy the imposed boundary conditions for the present problem. It can be seen that $f = 0$ at $\eta = 0$, $f = 0$ as $\eta \to \infty$, $\theta = 1$ at $\eta = 0$, and $\theta \to 0$ as $\eta \to \infty$.

Combining Equation (3.19) to (3.23) with Equation (3.41) to (3.43), the parameters, A,B,C,D, and E give

$$A = \int_{\eta=0}^{\infty} s^2\eta^2 e^{-2s}\, d\eta = \frac{1}{4s} = \frac{3}{20}n \tag{3.44}$$

$$B = \int_{\eta=0}^{1} (1+\eta)(1-\eta)^3\, d\eta = \frac{3}{10} \tag{3.45}$$

$$C = s^n(e^{-s\eta} - s\eta e^{-s\eta})^n_{\eta=0} = s^n = (\frac{5}{3n})^n \tag{3.46}$$

$$D = \int_{\eta=0}^{1} s\eta e^{-s\eta}\, (1+\eta)(1-\eta)^3\, d\eta$$

$$= [\frac{1}{s} - \frac{4}{s^2} + \frac{48}{s^4} - \frac{120}{s^5}] + \frac{12}{e^s}[\frac{1}{s^3} + \frac{6}{s^4} + \frac{10}{s^5}]$$

$$= [\frac{3n}{5} - 4(\frac{3n}{5})^2 + 48(\frac{3n}{5})^4 - 120(\frac{3n}{5})^5]$$

$$+ 12e^{-\frac{5}{3n}}[(\frac{3n}{5})^3 + 6(\frac{3n}{5})^4 + 10(\frac{3n}{5})^5] \tag{3.47}$$

$$E = [4\eta^3 - 6\eta^2 + 2]_{\eta=0} = 2 \tag{3.48}$$

3.4 <u>Nusselt Number Results</u>

Based on radius, the local Nusselt number is defined as

$$(N_{Nu_x})_r = \frac{h_x r}{k} \tag{3.49}$$

and from Equation (1.7) the local heat transfer coefficient is expressed as

$$h_x = \frac{-k\frac{\partial T}{\partial y})_{y=0}}{T_s - T_\infty} = \frac{-k\theta'(0)}{\delta} \qquad (3.50)$$

Substituting Equation (3.50) into Equation (3.49) gives

$$(N_{Nu_x})_r = \frac{-r\theta'(0)}{\delta} = \frac{rE}{\delta} \qquad (3.51)$$

and utilizing the expression for the boundary layer thickness given in Equation (3.40), the local Nusselt number becomes

$$(N_{Nu_x})_r = [\frac{2(n+1)}{3n+2}]^{\frac{n}{3n+2}}[\frac{BD^n E^{2n+1}}{C}]^{\frac{1}{3n+2}} N^{+}_{Gr_K}{}^{\frac{3n+1}{2(n+1)(3n+2)}}$$

$$N_{Pr_K}{}^{\frac{n}{3n+2}} \frac{(\sin\phi)^{\frac{1}{2(n+1)}}}{L\int_{\phi=0}^{\phi}(\sin\phi)^{\frac{1}{2(n+1)}}\, d\phi]^{\frac{n}{3n+2}}} \qquad (3.52)$$

For convenience, the above equation can be rearranged in the following form:

$$\frac{(N_{Nu_x})_r}{N^{+}_{Gr_K}{}^{\frac{3n+1}{2(n+1)(3n+2)}} N_{Pr_K}{}^{\frac{n}{3n+2}}} = K(n) \frac{(\sin\phi)^{\frac{1}{2(n+1)}}}{[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2(n+1)}} d\phi]^{\frac{n}{3n+2}}} \qquad (3.53)$$

where $K(n) = [\frac{2(n+1)}{3n+2}]^{\frac{n}{3n+2}} [\frac{BD^n E^{2n+1}}{C}]^{\frac{1}{3n+2}}$ (3.54)

Since the parameters, B,D,C, and E are expressed in terms of n only, the coefficient K(n) can be readily evaluated with the given flow behavior index n. Numerical values of K(n) versus flow behavior index n are presented in Table (3.1).

Table (3.1) Numerical Values of K(n) versus Flow Behavior Index, n

n	K(n)
0.1	0.657
0.2	0.629
0.3	0.616
0.4	0.609
0.5	0.605
0.6	0.602
0.7	0.599
0.8	0.597
0.9	0.595
1.0	0.594
1.1	0.592
1.2	0.591
1.3	0.590
1.4	0.589
1.5	0.588
1.6	0.587
1.7	0.586
1.8	0.585
1.9	0.585
2.0	0.584

CHAPTER IV

EXPERIMENTAL APPARATUS

The heat transfer apparatus employed in this investigation is essentially the same as that used earlier by Gentry[24]. A cylindrical model was employed for this investigation. This cylindrical model consisted of twenty aluminum segments each independently heated by resistance strips bonded to the interior surface. Due to the symmetry of fluid behavior along the vertical axis, one electrical power supply was used for two corresponding symmetrical test sections. Therefore, ten individual power supplies were used. In each of the ten individually heated segments a copper-constantan thermocouple was embedded to measure the local surface temperature. By measuring local power supply q_o'', local surface temperature T_s, and bulk fluid temperature T_∞, local free convection heat transfer coefficients along the cylinder surface, h_x, can be determined from Equation (1.2). A photograph of the experimental apparatus is shown in Figure (4.1).

4.1 Cylindrical Test Section

The cylindrical test model shown in Figure (4.2) and (4.3) consisted of twenty instrumented aluminum segments. Aluminum was chosen because it has high thermal conductivity, relatively small thermal expansion coefficient, and good machinability. Ten calibrated Omega #TT-T-30 copper-constantan thermocouples were installed at a diameter of 1.806 inches as shown in Figure (4.3). Using the integrated Fourier conduction equation surface temperatures were determined from the thermocouple readings for interior temperatures and local heat flux values.

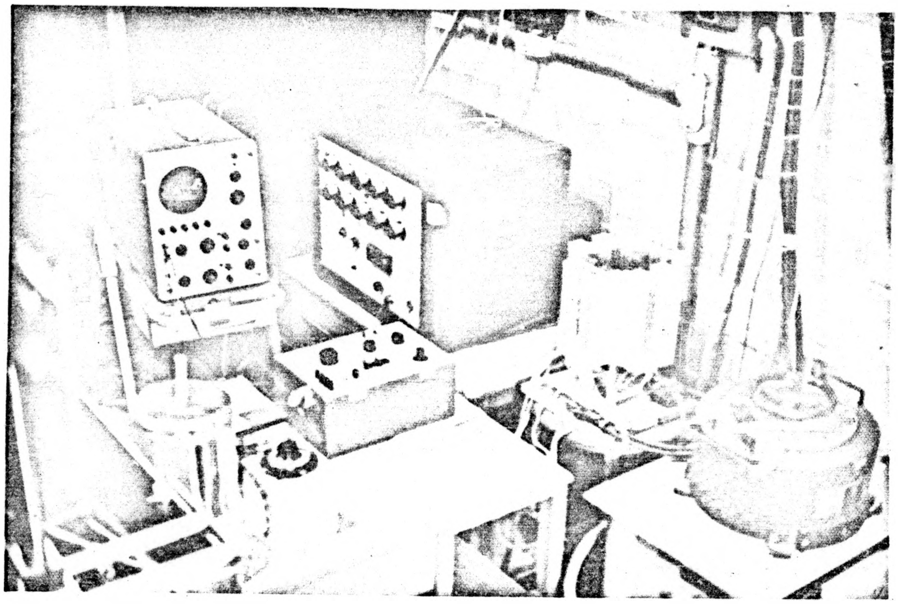

Figure (4.1) Complete Setting of Experimental Apparatus

$$T_S = T_c - Q_{Gen_x} \frac{\ln(\frac{2.034}{1.806})}{\phi k L} \qquad (4.1)$$

Ten sensistors, Texas Instruments #T1-TG-1/8, 120 ohm, were installed in the heater segments. The sensistor has dimensions of 0.105 inch diameter and 0.300 inch long. These solid-state silicon sensistors are used for detectors for the power supply and controller. After all heater segments have been instrumented, they were assembled together by bonding with DOW 732 RTV to the structural frame-terminal board assembly. Power leads consisted of twenty #16 AWG Teflon insulated copper wires and sensistor leads consisted of #24 AWG Teflon insulated copper wire. The interior of the test cylinder was filled with magnesia insulation. Magnesia was used because of its low thermal

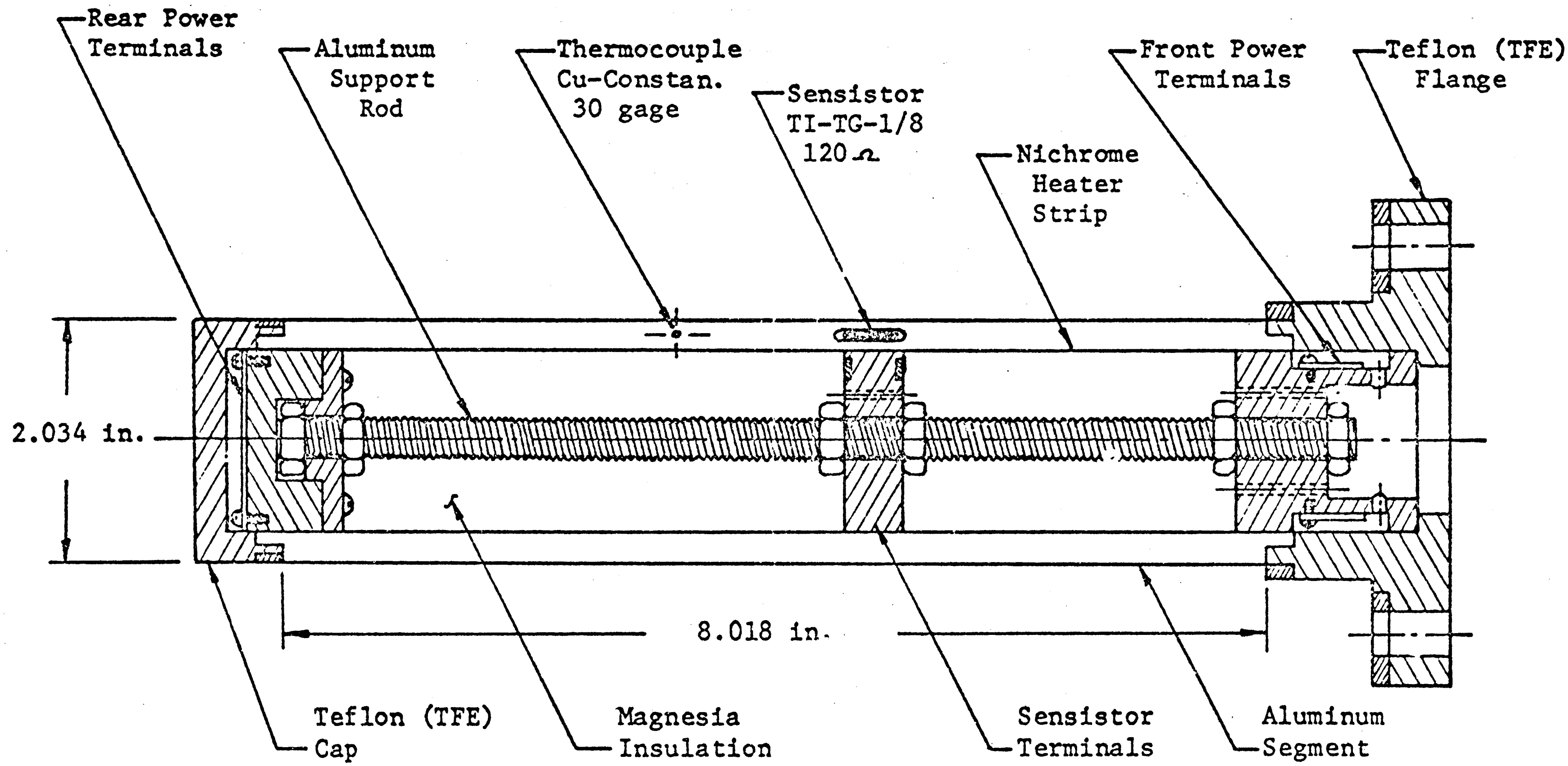

Figure (4.2) Test Section Assembly

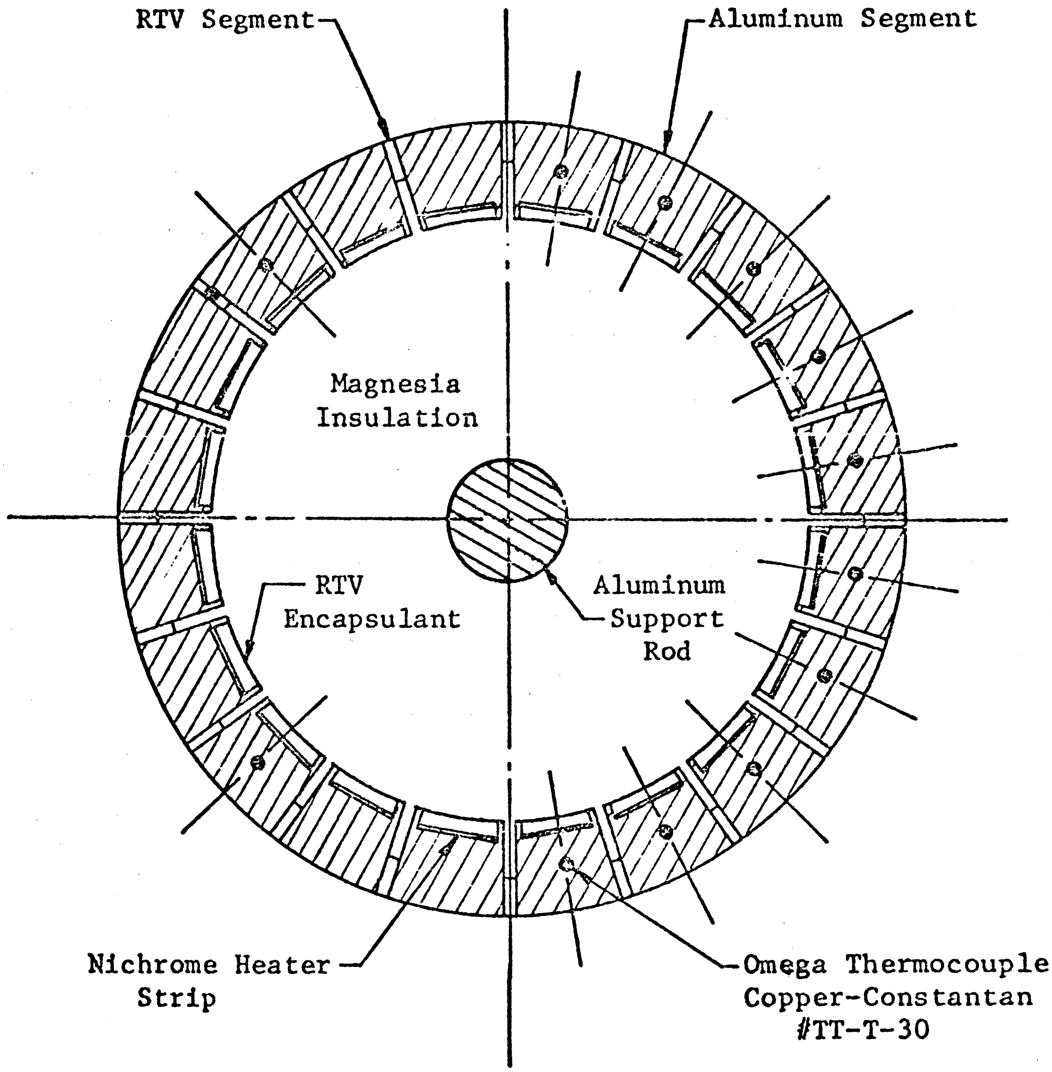

Figure (4.3) Test Cylinder Cross Section conductivity of 0.03 Btu/hr-ft-°F. Assembly was made by sealing the 0.032 inch wide and 1/8 inch deep slots between the reassembled aluminum segments with Dow 732 RTV. Because of its low thermal conductivity of 0.11 Btu/hr-ft-°F, this RTV seal serves as thermal insulation between adjoining aluminum segments.

The final reassembled test section model has 2.034 inches of diameter and 8.018 inches of length. A photograph of the assembled test section model is shown in Figure (4.4).

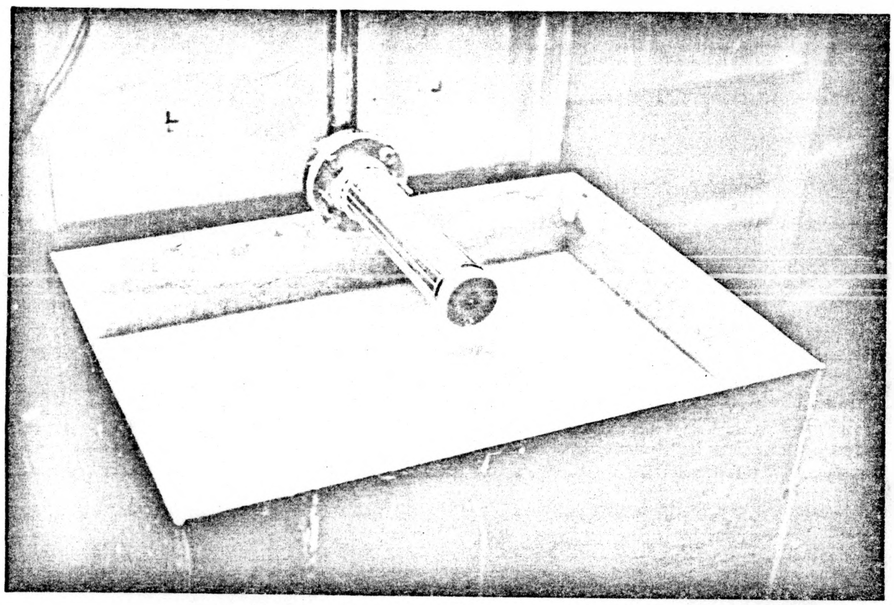

Figure (4.4) Test Section Model

4.2 Electrical Power Supply and Controller

Ten independent sensistor activated electrical power sources were employed in order to supply the power for each of the ten independent segments. Voltage measurements were obtained to determine local heat flux values. Basic components of the power supply and controller are a triac trigger circuit, a voltage measurement circuit, and a sensistor bridge circuit.

A triac is a bi-directional, silicon switch device which may be activated to an on or conducting condition by applying an excitation voltage. This excitation voltage puts the triac in a conducting condition over a time period less than half the 60 Hz sine wave period. As a result, only a portion of the sine wave voltage signal is utilized for heating purposes. Thus control of the power is accomplished by varying the time period that the triac is in the conducting state. Figure (4.5) shows the utilized portion of the sine wave. To obtain greater flexibility of the power supply, the transformer was used to permit selection of the input voltage upon which the triac acted. The effects of different input voltage at a fixed triac trigger point are illustrated in Figure (4.6). For the effective heating, root mean square voltage is defined in the following equation.

$$E_{rms} = [\frac{1}{t} \int_0^t (E(t))^2 dt]^{1/2} \qquad (4.2)$$

The voltmeter system shown in Figure (4.7) was employed to measure the effective rms voltage for triac modified signals. Total voltage drop across each heater strip was imposed across an appropriate resistor, a limiting amplifier, and an incandescent lamp. The limiting amplifier served as an overload protection device for the type 47 lamp, which was rated at 6 volts. The incandescent lamp was enclosed in a light free container along with a vacuum photo-tube, type 868. Light from the incandescent lamp impinged on the vacuum photo-tube cathode surface, producing an emission of electrons from cathode to anode. The electrons received at the anode produced a small change in the anode

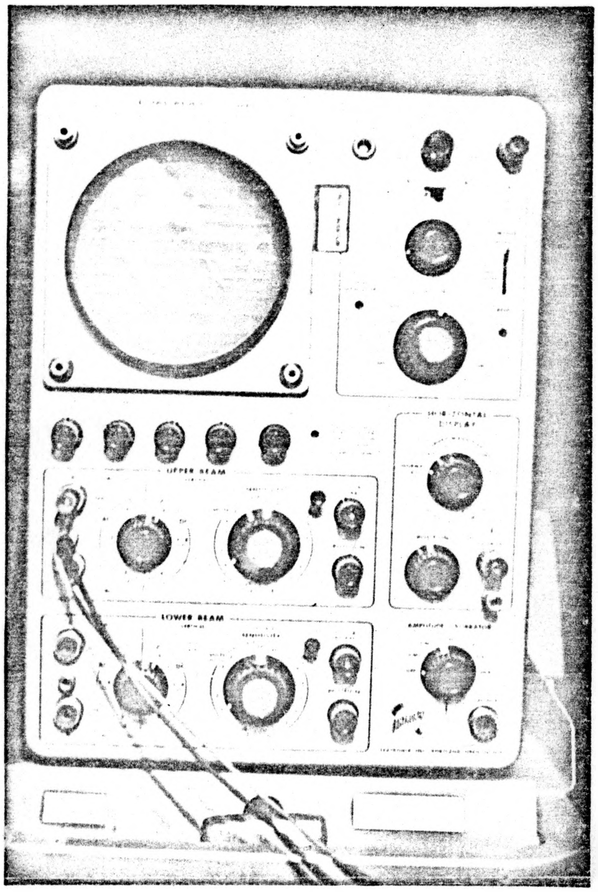

Figure (4.5) Triac Modified Voltage Signal

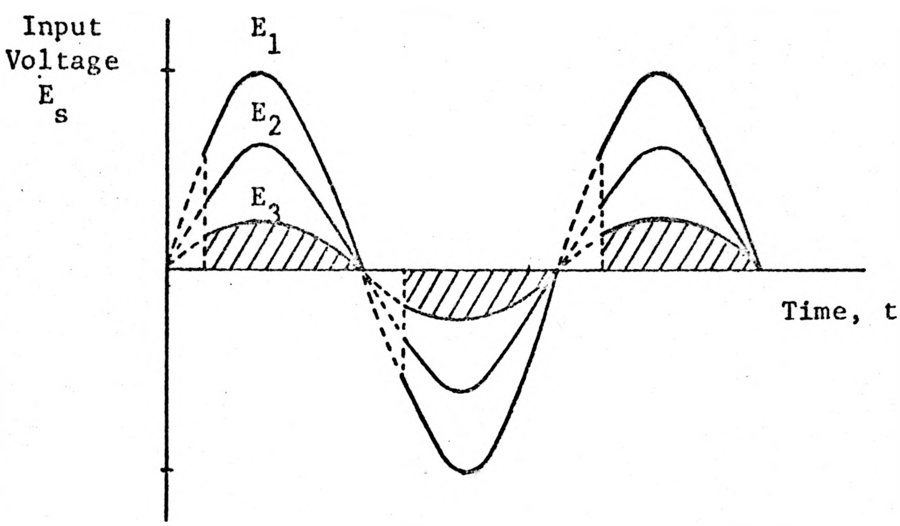

Figure (4.6) Effects of Different Input Voltages

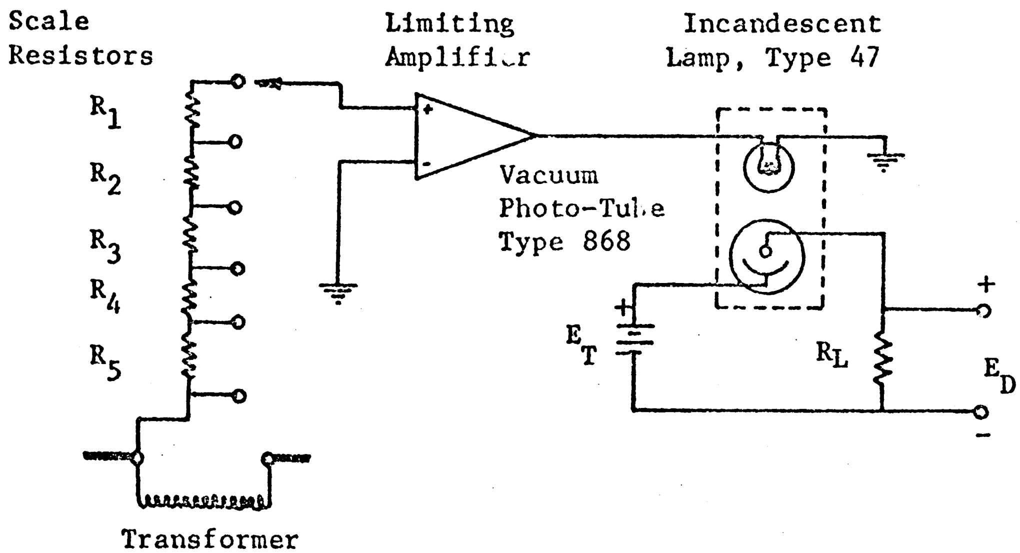

Figure (4.7) Basic Voltmeter Circuit

current. This small change in anode current, which is dependent only on the voltage drop, was detected in the form of a voltage drop across a large coupling resistance R_L. This coupling resistor voltage drop produced a three digit output display on the Weston voltmeter. In the present investigation, two voltage ranges are used to obtain the required voltage. Scale 1 covers the voltage range from 2.50 V to 5.50 V, and scale 2 applies for the voltage range from 5.00 V to 10.00 V. Then local power to each strip was determined by using the resistance values for each nichrome heater strip and the measured rms voltages.

$$\text{Power, } P = \frac{(E_{rms})^2}{R_{strip}} \qquad (4.3)$$

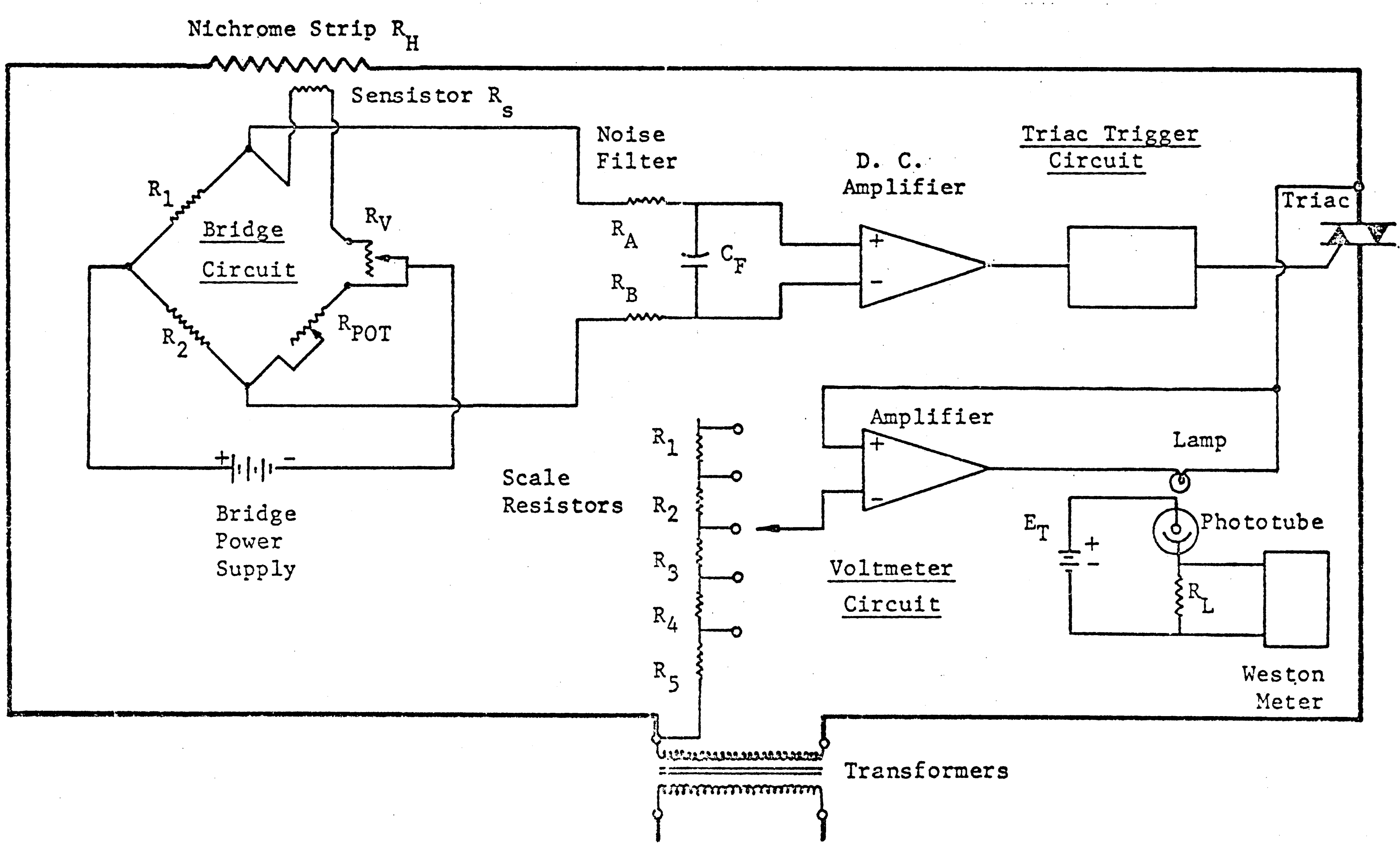

Figure (4.8) Power Supply and Controller Schematic

The activation voltage to the triac circuit is provided by the temperature detection system. The temperature detection system consists of the bridge circuit shown in Figure (4.8). Texas Instruments #T1-TG-1/8, 120 ohm sensistor, a Spectrol Precision Ten Turn Potentiometer #570-246, and a range adjustment resistor R_v. Desired power settings at a fixed input voltage could be made by adjustment of the pot resistance R_{pot}. A variac was used for input voltage adjustment. Therefore, the potentiometers were used only for fine voltage adjustments. Employing resistor R_v, a temperature of 40°F was set to be the minimum temperature at which the triacs could be activated. The photograph of the ten potentiometers, Weston meter, and the voltmeter signal are shown in Figure (4.9).

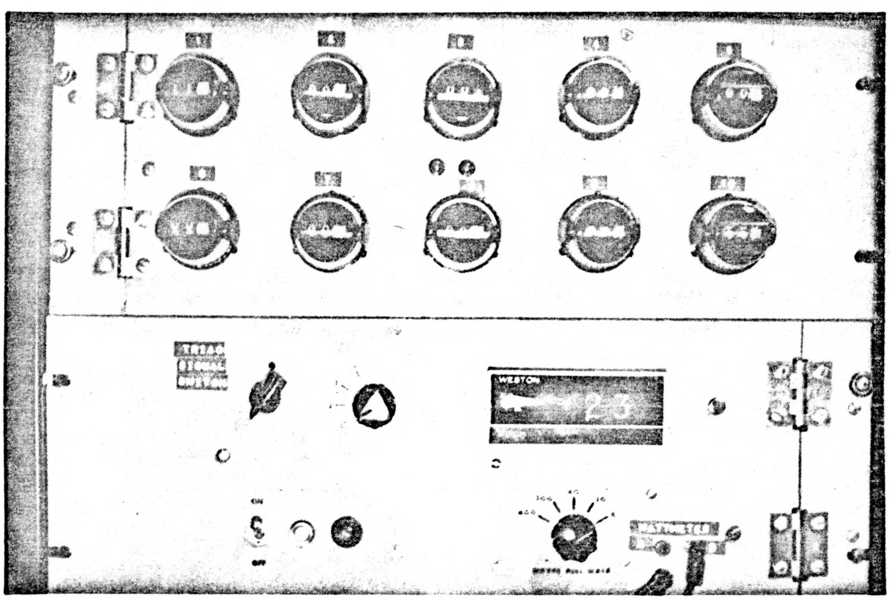

Figure (4.9) Power Supply and Controller Unit

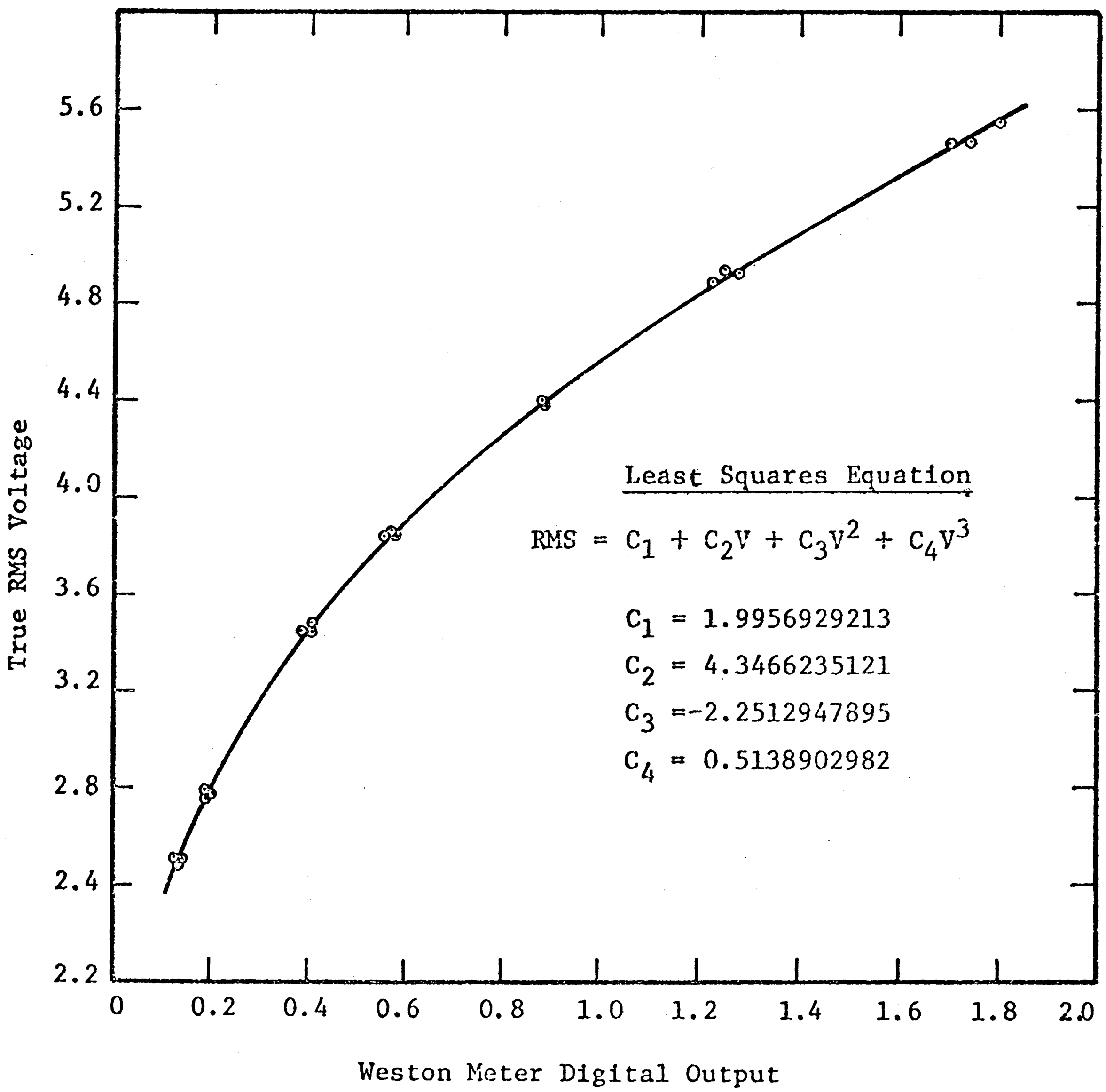

Figure (4.10) Weston Meter Calibration Curve, Scale 1

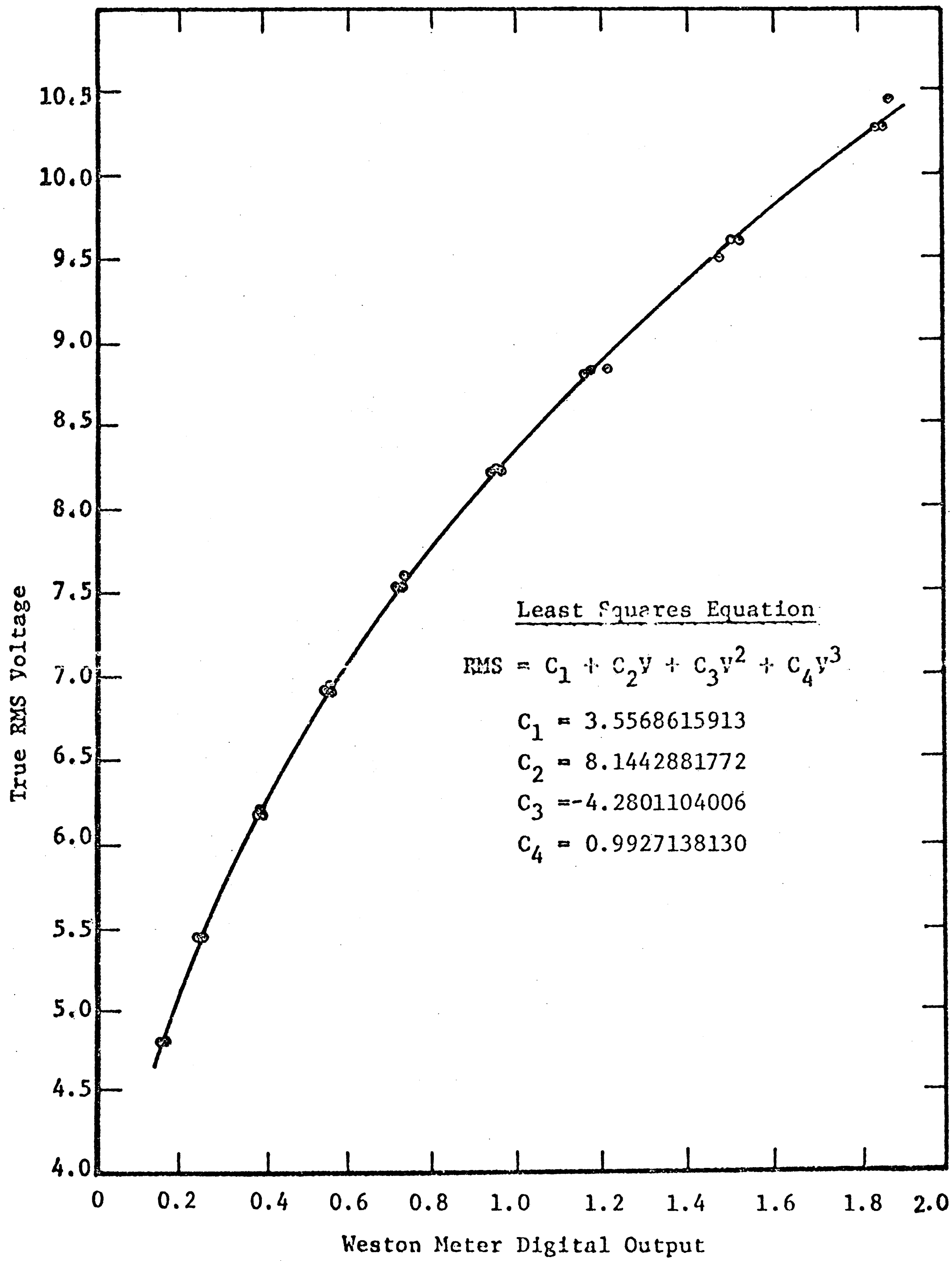

Figure (4.11) Weston Meter Calibration Curve, Scale 2

Calibration of the digital Weston meter was carried out by using two dummy resistors, having resistance of 2.774 ohms and 5.461 ohms and constructed of the same Tophet C nichrome strip material. Voltage measurements were obtained from a pre-calibrated Ballentine true RMS voltmeter, Model #323. The ammeters used were a Westinghouse Model #682166, and a Weston, Model #433. The corresponding calibration curves for scale 1 and 2 are shown in Figure (4.10) and (4.11).

4.3 Temperature Measurement System

Omega TT-T-30, copper-constantan thermocouples were used to measure the temperatures of all test sections. Components in the measurement circuit included a ten point selector switch, an ice point reference junction, and a two channel input Biddle Millivolt Potentiometer. Figure (4.12) shows a typical temperature measurement schematic.

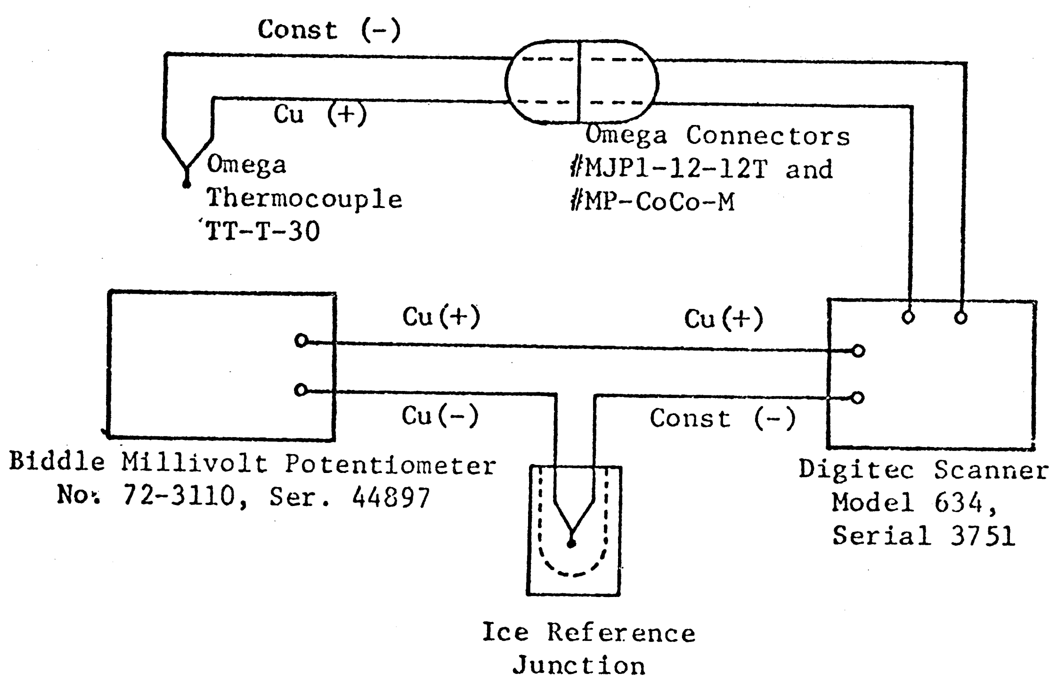

Figure (4.12) Temperature Measurement Schematic

Calibration of all copper-constantan thermocouples shows that the agreement between measured millivolt values at reference thermometer temperatures and National Bureau of Standards, Circular 561 is within 1/2°F.

4.4 Viscometric Apparatus

Rheological properties of the dilatant fluids are determined using a Brookfield Synchro-Lectric Viscometer, Model LVT. Eight rotational speeds, 0.2, 0.6, 1.5, 3, 6, 12, 30, and 60 rpm established the shear rate for a given spindle arrangement. Shear stress was indicated by the torque reading on the rotating scale.

Since the dilatant fluids used in the present investigation have a high viscosity, a two concentric cylinder type of viscometric setting could not be used, because the torque required to rotate the inner cylinder rod was too large to give readings on the Brookfield viscometer. Therefore, it was necessary to increase the gap distance (to decrease the torques) between two cylinders until the torque was readable on the viscometer. It was found that the rotating cylinder in an infinite medium type of viscometric setting was proper in the present investigation. By rotating the cylindrical rod in the middle of the test fluid in a beaker whose radius is much larger than the rotating rod, the walls of the beaker exert no influence on the shearing movement of the fluid. The viscometric apparatus consists of the Brookfield LVT viscometer, a Glass-Col Resistance Heater, Model #71678, a Superior Powerstat Type 116, and a 1500 CC glass beaker, as shown in Figure (4.13). The powerstat supplied voltage necessary to maintain constant temperature conditions in the bath. Before the viscometric data were taken, the fluid was constantly stirred

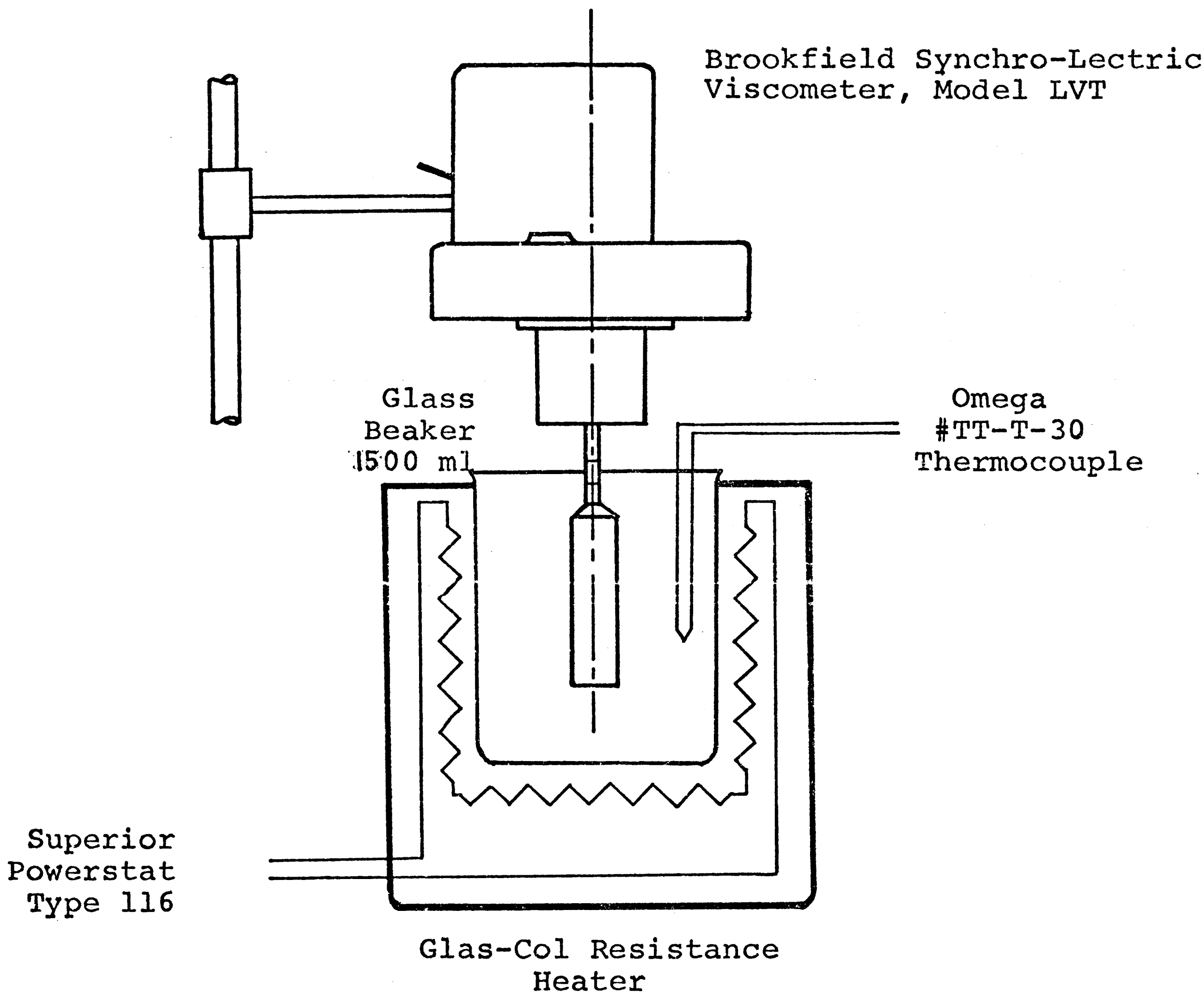

Figure (4.13) Viscometric Apparatus Setting to ensure the uniformity of temperatures in the beaker, and temperatures were measured with an Omega #TT-T-30 copper-constantan thermocouple stationed in the middle of the fluid.

The concentric cylinder viscometer with a bob has length L and radius R_1 and the beaker has radius R_2. The bob rotates with an angular velocity Ω and a torque M exerted on the bob. Under laminar flow the velocity gradient, where the fluid rotates with angular velocity ω, is

$$\frac{du}{dy} = r\frac{d\omega}{dr} \tag{4.5}$$

while the shearing stress is

$$\tau = \frac{M}{2\pi r^2 L_e} \tag{4.6}$$

The term L_e is the equivalent length which accounts for end effects, and can be obtained by calibration with a Newtonian fluid of known viscosity. The flow behavior of a non-Newtonian fluid is defined by the functional relationship between the rate of shear $\frac{du}{dy}$, and the shearing stress τ.

$$\frac{du}{dy} = g(\tau) \tag{4.7}$$

Equation (4.7) becomes in this case

$$r\frac{d\omega}{dr} = g(\tau) \tag{4.8}$$

Further, since $\frac{dr}{r} = -\frac{d\tau}{2\tau}$ from Equation (4.6), Equation (4.8) may be transformed to

$$d\omega = -\frac{1}{2}\,g(\tau)\,\frac{d\tau}{\tau} \tag{4.9}$$

which on integration between the bob where $\omega=\Omega$ and $\tau_1 = M/2\pi R_1^2 L_e$, and the beaker where $\omega = 0$ and $\tau_2 = 0$ gives

$$\Omega = \frac{1}{2}\int_0^{\tau_1} \frac{g(\tau)}{\tau}\, d\tau \qquad (4.10)$$

Differentiation of Equation (4.10) with respect to τ_1 gives

$$g(\tau_1) = \frac{2d\Omega}{d[\ln(\tau_1)]} \qquad (4.11)$$

and combining Equation (4.7) and (4.11), and by the fact that $\Omega = 2\pi N$, where N is rotational speed of the bob,

$$\left(\frac{du}{dy}\right)_1 = \frac{2d\Omega}{d(\ln\tau_1)} = \frac{2d(2\pi N)}{d[\ln(M/2\pi R_1^2 L_e)]}$$

$$= \frac{4\pi dN}{d(\ln M)} = \frac{4\pi[N\ d(\ln N)]}{d(\ln M)}$$

$$= \frac{4\pi N}{\frac{d(\ln M)}{d(\ln N)}} \qquad (4.12)$$

The shear rates at the surface of the rotating cylinder were determined by Equation (4.12). Torque readings and rotational speeds were obtained from the Brookfield LVT cylinder viscometer. Torque values appeared as a percentage of the full scale torque, which was 4.969×10^{-5} ft-lb_f. Then the slope d(ln M)/d(ln N) in Equation (4.12) was readily determined from the plots. It was also necessary to make measurements with more than two beakers of different diameters to insure that the fluid was effectively infinite. Three containers with different diameters (4.65", 6.23", and 12.5" were used to determine the size of the beaker for this purpose. No significant changes in the reading were detected between the three different sizes. Therefore, the beaker whose diameter is 4.65" was employed. Throughout the whole viscometric test, spindle No. 3 (which has a diameter of 0.235", and an effective length of 1.758") was used as a rotating rod.

From these determined shear stress and shear rate values the plot of τ_1 versus $(\frac{du}{dy})_1$ constitutes the flow curve, and flow behavior index n. Consistency index K values are obtained using the power-law model expressed in Equation (1.3).

$$\tau_1 = K \left(\frac{du}{dy}\right)_1^n \qquad (1.3)$$

CHAPTER V

TEST FLUID PREPARATION AND FLUID PROPERTIES

Corn starch suspensions in aqueous sucrose solution were employed as a test fluid to represent a rheological dilatant fluid. In searching for proper dilatant fluids for the present experiment, possible fluids were narrowed down to corn starch suspensions[9,10], and titanium dioxide suspensions[16] in aqueous sucrose solution. As discussed in Chapter II, all the reliable data available on rheological dilatancy indicated that it had been confined to suspensions of particles whose diameter is less than five microns in liquids having viscosities of a few centiposes. Corn starch and titanium dioxide have average diameters of less than 1.0 micron. The aqueous sucrose solutions were used because of their flexibility to obtain desired viscosity and density.

Besides the above considerations the test fluid had to meet the following four requirements.

1. The data of the test fluids must fit the power-law fluid model.
2. The test fluids must show rheological dilatant behavior in the range of low shear rates (approximately 10^{-1} to 10 1/sec) which is encountered at the test section surface during the present free convection experiments.
3. The test fluids must be time-independent.
4. The test fluids must not settle due to gravity during the experiment, i.e., at least for one day.

By measuring viscometric properties from sample fluids with different combinations of particle concentrations and different viscosities of sucrose solutions, it was obvious that corn starch suspensions had advantages over titanium dioxide suspensions. Titanium dioxide suspensions failed to satisfy requirement 2 and 4, while corn starch suspensions seemed to satisfy all of the above requirements. Titanium dioxide suspensions exhibit dilatant behavior only in higher shear rates because of their longer particle sizes, and they settle down faster than corn starch suspensions because of their higher densities.

As shown in Table (5.1) four volume concentrations (38, 39, 41, and 42%) of corn starch suspensions in sucrose solutions were chosen to represent four different dilatant fluids. An aqueous sucrose solution of 50% concentration by weight was used for liquids. This sucrose solution had a viscosity of 8.4 centipose at 85.2°F, and had a density of 1.23 gm/cc. The concentration of sucrose solution was determined by making the density of sucrose solution close to the density of corn starch (1.24 gm/cc) in order to minimize the settling problem for the suspensions.

Table (5.1) Corn Starch Suspensions in Aqueous Sucrose Solution for Test Fluids

Name of Test Fluids	Volume of Corn Starch	Volume of the Aqueous Sucrose Solution
38% CS/SS	612.9 cc (760.0 g)	1000.0 cc
39% CS/SS	639.3 cc (792.7 g)	1000.0 cc
41% CS/SS	694.9 cc (861.7 g)	1000.0 cc
42% CS/SS	723.8 cc (897.5 g)	1000.0 cc

The viscometric tests showed that the dilatant behavior of the fluid was restricted in the range of particle concentrations 36-44% by volume. For the range lower than 36%, the fluid showed pseudoplastic behavior and for the range higher than 44%, the fluid showed behavior of Bingham plastics.

The method of preparation of the test fluids and physical properties of the fluids will be presented in the following section.

5.1 Test Fluid Preparation

The aqueous sucrose solution was obtained by dissolving 1.0 kg of sugar in each of 1.0 kg of water. Therefore, the weight percentage of sugar, A, in the aqueous sucrose solution is

$$A = \frac{\text{weight of sugar}}{\text{weight of sugar + weight of water}} \cdot 100$$

$$= \frac{1.0}{1.0 + 1.0} \cdot 100 = 50.0\% \text{ by weight sugar} \qquad (5.1)$$

The volume fraction x of corn starch in the sugar solution based on the assumption of no change in volume or mixing is expressed as:

$$x = \frac{\text{volume of corn starch}}{\text{volume of corn starch + volume of the sucrose solution}}$$

The important physical properties of the fluids are expressed in terms of temperature, T, and volume fraction, x, of corn starch.

Corn starch was measured to be 17.1 liters (21.104 kg) and mixed up with 27.9 liters of sucrose solution to make 45.0 liters of 38.0% CS/SS solution. To ensure the uniformity of the suspensions, mixing was done using a Lightnin Rotation Mixer, Model S2, for about 30 minutes. The fluid properties were measured before and after heat transfer experiments to ensure the previously measured fluid properties.

After completing the heat transfer experiments for 38% CS/SS solution, 0.564 kg (0.455 l) of corn starch was added to the previous 45.0 liters of 38% CS/SS solution to make 39% CS/SS solution. Again the same procedures were followed to make 41%, 42% CS/SS solutions, i.e., 1.131 kg and 0.566 kg of corn starch were added to 39% and 41% CS/SS solutions after each of the experiments.

5.2 Fluid Properties

5.2.1 Density

Reference (25) shows that the density of 50.0% by weight sucrose solution is 1.23 gm/cc at 70°F and the density of solid corn starch is given by Mohsenin[26] to be 1.24 gm/cc at 75°F. Since the temperature in the actual heat transfer experiment reaches not higher than 110°F, densities can be assumed to be constant in this temperature range without significant errors. Therefore, the density of the test fluids can be expressed as

$$\rho_T = 62.427961[1.24\, x + 1.23\,(1-x)] \quad (lbm/ft^3) \tag{5.3}$$

5.2.2 Specific Heat Capacity

The empirical equation of heat capacity of sucrose solutions between 70°F and 87°F is given by Gucker[27] to be

$$(C_p)_1 = 1.000 - 0.326\, m - 0.0215 m^2 \quad (Btu/lbm\text{-}°F) \tag{5.4}$$

where m is the mass fraction. Comparing the values at 70°F and at 87°F, the heat capacity remains constant. Therefore, assuming constant values in our temperature ranges is quite acceptable. Since m is 0.5 for 50% sucrose solution, the final value becomes

$$(C_p)_1 = 0.8424 \quad (Btu/lbm\text{-}°F) \tag{5.5}$$

The specific heat of corn starch is given by Sprockoff[28] to be

$$(C_p)_2 = 0.3555 \text{ (Btu/lbm-°F)} \qquad (5.6)$$

According to Metzner[29], the total specific heat of solid suspensions in liquids can be expressed as

$$(C_p)_T = m_1(C_p)_1 + m_2(C_p)_2$$

where m_1 = mass fraction of sucrose solution

m_2 = mass fraction of corn starch

Therefore, the final expression for the total specific heat of the test fluid becomes

$$(C_p)_T = \frac{1.23\ (1-x)\ (0.8424) + 1.24\ x\ (0.3555)}{1.23\ (1-x) + 1.24x}$$

$$= \frac{1.038\ (1-x) + 0.441x}{1.23\ (1-x) + 1.24x} \quad \text{(Btu/lbm-°F)} \qquad (5.7)$$

5.2.3 Thermal Expansion Coefficient

The empirical equation for thermal expansion coefficient of 50% sucrose solution was obtained based on the data given by reference (30) in the temperature range of 65°F to 125°F. A second order polynominal was used to express the data points.

$$\beta_1 = \beta_{01}\ [1 + c_1T + c_2T^2] \quad \text{(1/°F)} \qquad (5.8)$$

where $\beta_{01} = 2.14 \times 10^{-4}$

$c_1 = 1.56 \times 10^{-4}$

$c_2 = 5.42 \times 10^{-7}$

and T is temperature in °F.

Blitz, Fisher, and Wunnenberg[31] give a linear equation to express the thermal expansion coefficient for corn starch for temperatures from 0°F to 220°F.

$$\beta_2 = \beta_{02}(1 + \alpha T) \qquad (1/°F) \qquad (5.9)$$

where $\beta_{02} = 1.18 \times 10^{-3}$

$\alpha = 2.14 \times 10^{-4}$

and T is temperature in °F

According to Metzner(29), the total thermal volume expansion coefficient for solid suspensions in liquids can be easily expressed as

$$\beta_T = (1 - x)\beta_1 + x\beta_2 \qquad (1/°F) \qquad (5.10)$$

5.2.4 Thermal Conductivity

Kharbanda's(32) experimental data show that thermal conductivities of a sucrose solution for temperatures from 32°F to 200°F can be expressed as

$$k_1 = [0.358 + 0.0000643T - 0.0000000011T^2](1 - 0.0054w) \quad (Btu/hr\text{-}ft\text{-}°F)$$

where w is weight percentage sugar in the solution, and T is temperature in °F. Therefore, for w=50.0, k_1 becomes

$$k_1 = 0.730[0.358 + 0.0000643T - 0.0000000011T^2] (Btu/hr\text{-}ft\text{-}°F) \qquad (5.11)$$

These values agree quite well with Gillam and Lamm's(33) experimental values.

The thermal conductivity of corn starch was measured by Garrett(34). At 70°F, it gives the value of 0.0107 Btu/hr-ft-°F and with small increase of temperature, the value stays almost constant. Therefore, the thermal conductivity of corn starch for the present investigation was assumed to be

$$k_2 = 0.0107 \quad (Btu/hr\text{-}ft\text{-}°F) \qquad (5.12)$$

Metzner[29] suggests that the conductivity of solid suspensions in liquids may be estimated by the following equation.

$$k_T = \frac{2k_1+k_2-2x(k_1-k_2)}{2k_1+k_2+x(k_1-k_2)} \quad k_1 \tag{5.13}$$

A considerable body of experimental evidence[35,36,37] is available in support of the above predictions.

5.2.5 Consistency Index and Flow Behavior Index Number

Rheological properties of the test fluids were obtained at four different temperatures (70°F, 80°F, 90°F, and 100°F) by using the Brookfield LVT viscometer as shown in Chapter IV, and these values were checked with a Weissenberg Rheogoneometer, Model R18 at 88°F.

Viscometric data presented in Figure (5.1), (5.2), (5.3), and (5.4) appeared to be well represented by a power-law fluid model, since the data fit a straight line on log-log scale. The data taken at 88°F from the rheogoneometer confirm the values of those from the Brookfield viscometer.

Flow behavior index curves and consistency index curves for each of the four concentrations appear as functions of temperature in Figure (5.5) and (5.6). From a least squares fit of experimental data, the following equations for flow behavior index n, and consistency index K were obtained in terms of temperature T in °F.

38% CS/SS solution

$$n(T) = 1.03925526+0.00428745T-0.00003016T^2 \tag{5.14}$$

$$\ln(K(T)) = -0.28868019-0.00691136T-0.00003493T^2 \tag{5.15}$$

39% CS/SS solution

$$n(T) = 1.40231864-0.00284363T-0.00000990T^2 \tag{5.16}$$

$$\ln(K(T)) = 0.13088331-0.1382273T+0.00001358T^2 \tag{5.17}$$

<u>41% CS/SS solution</u>

$$n(T) = 1.40118940+0.00064992T-0.00001006T^2 \quad (5.18)$$

$$\ln(K(T)) = 0.15981980-0.00756106T-0.00001587T^2 \quad (5.19)$$

<u>42% CS/SS solution</u>

$$n(T) = 1.54715146-0.00164812T+0.00000475T^2 \quad (5.20)$$

$$\ln(K(T)) = 0.14652677-0.00432161T-0.00002974T^2 \quad (5.21)$$

Shear rates produced by the viscometer assemblies extended approximately from 0.3 to 10.0 1/sec. As will be discussed later, these viscometric shear rates were representative of the shear rates encountered at the test section surface during free convection experiments. A complete tabulation of viscometric data are shown in Appendix B.

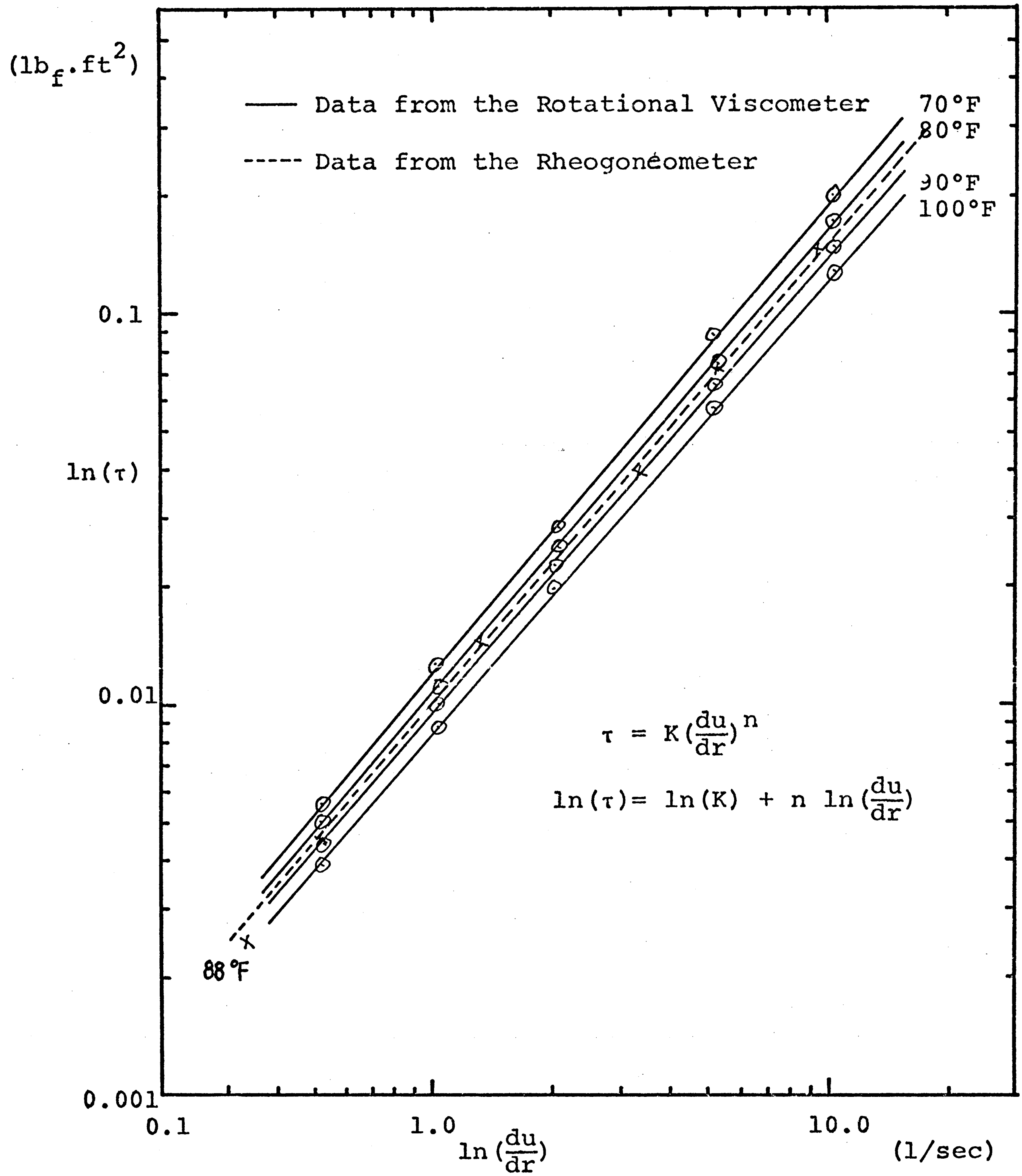

Figure (5.1) Viscometric Data for 38% CS/SS Solution

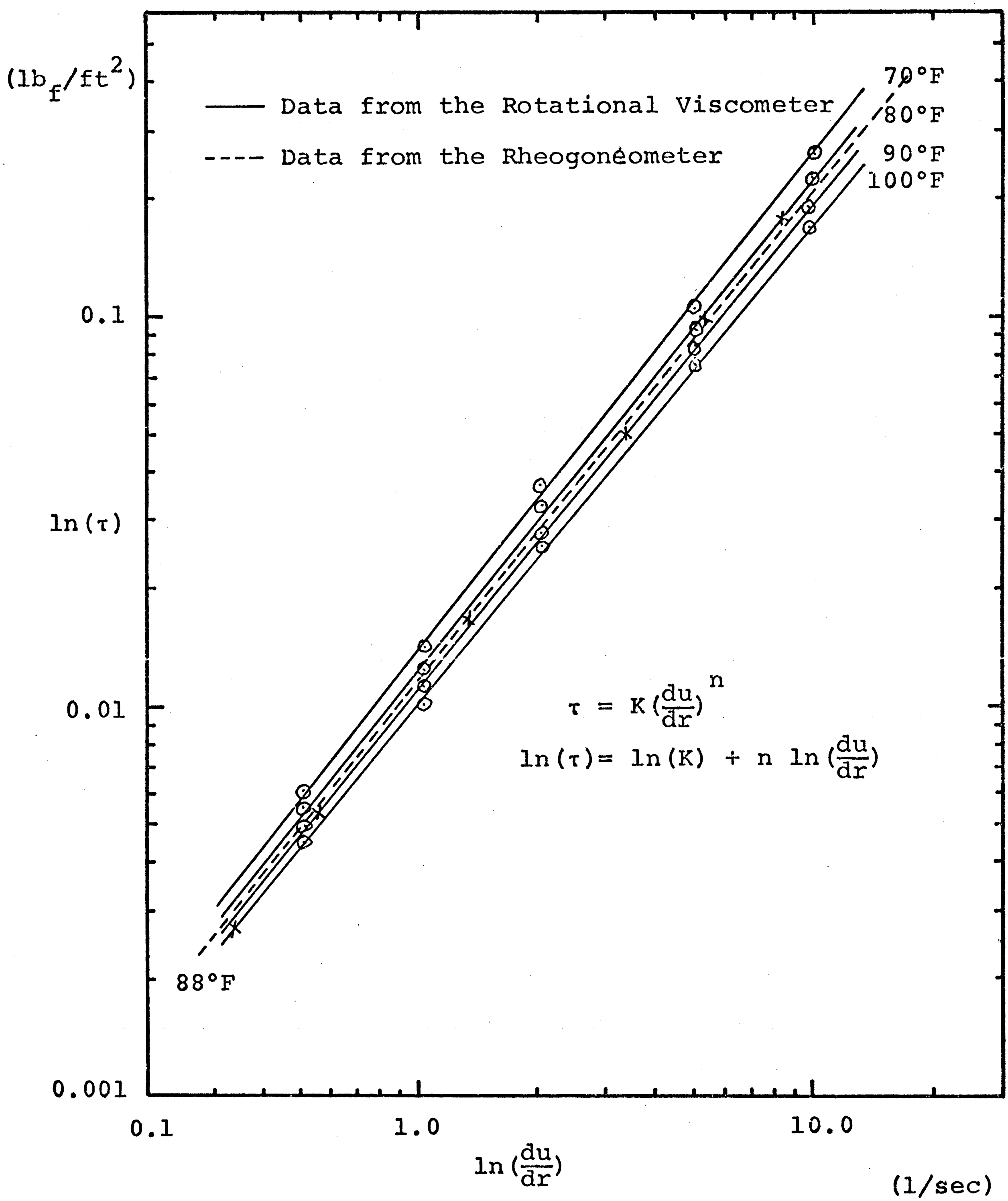

Figure (5.2) Viscometric Data for 39% CS/SS Solution

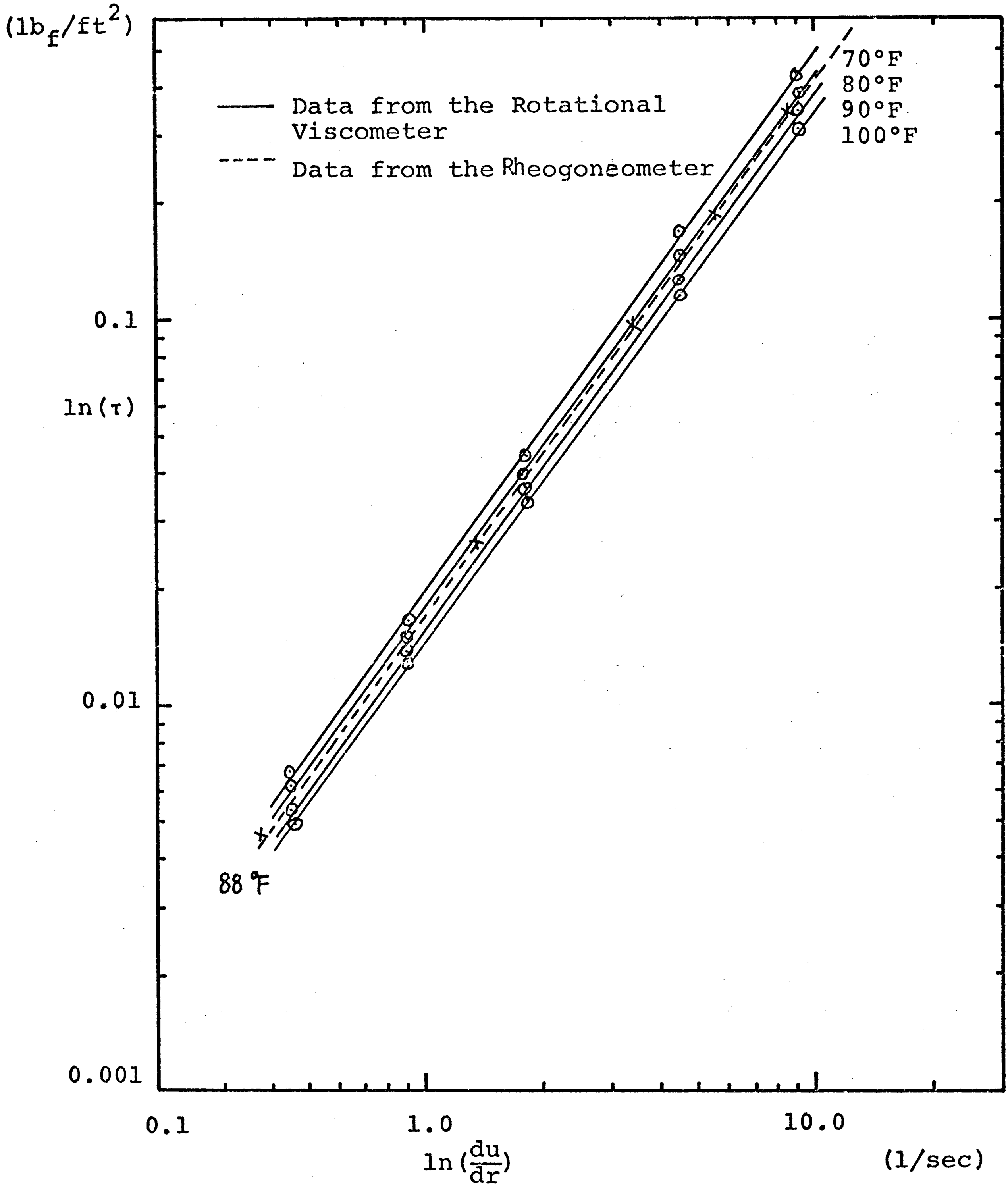

Figure (5.3) Viscometric Data for 41% CS/SS Solution

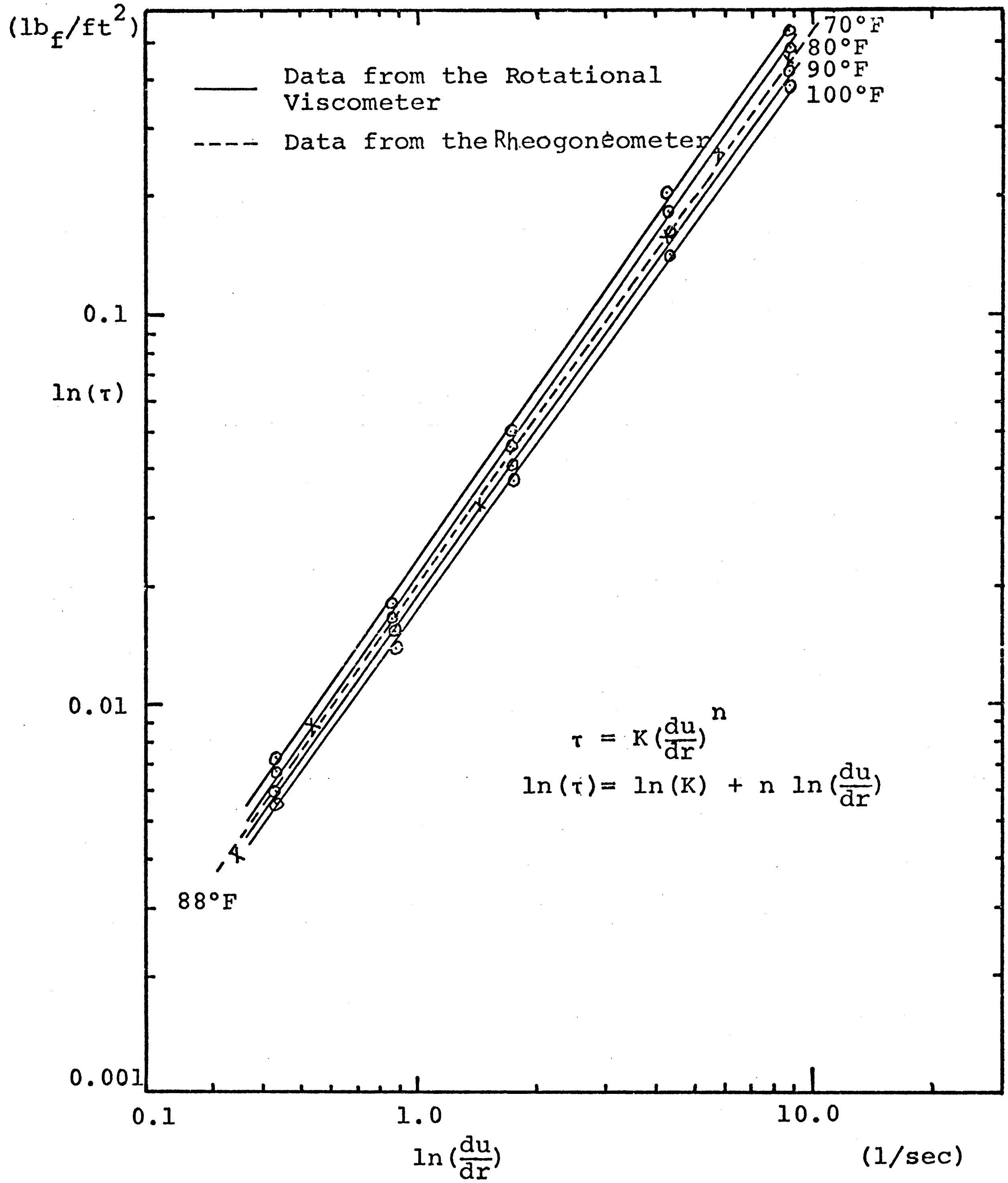

Figure (5.4) Viscometric Data for
42% CS/SS Solution

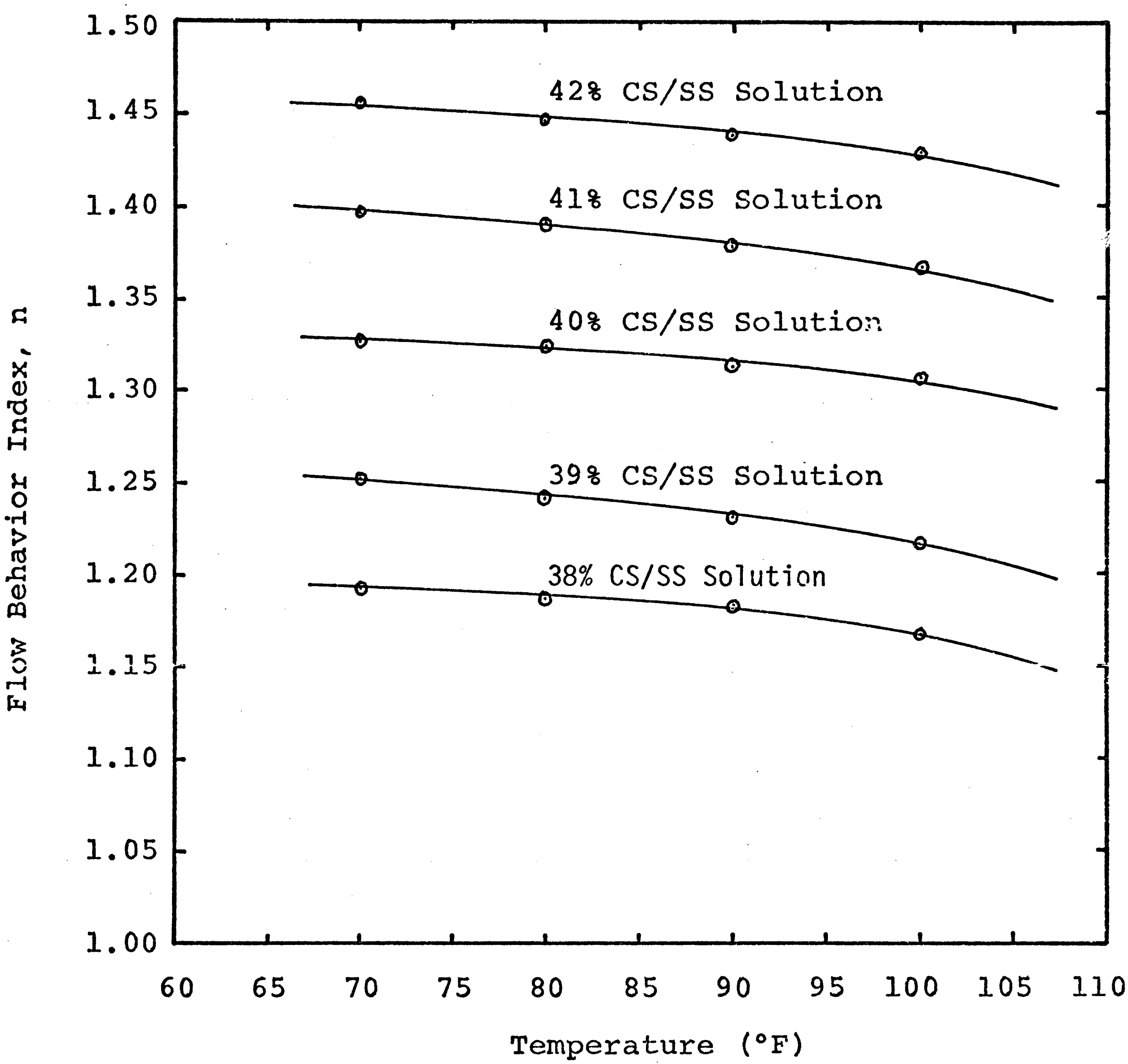

Figure (5.5) Flow Behavior Index, n versus Temperature of Test Fluids

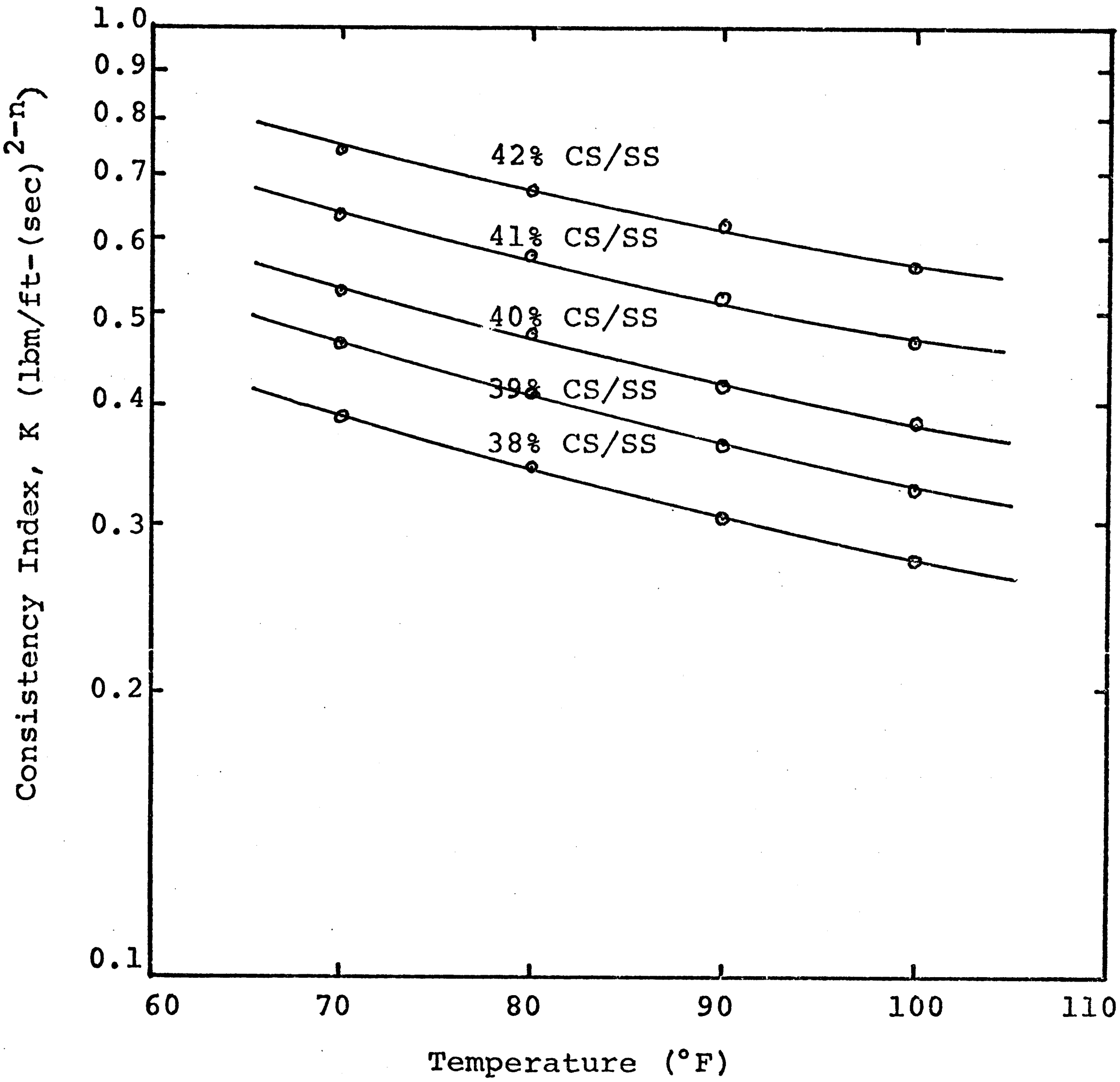

Figure (5.6) Consistency Index, K versus Temperature of Test Fluids

CHAPTER VI

EXPERIMENTAL PROCEDURES

The test fluids were prepared in a 3 ft^3 aluminum container. Before energizing the instrumented test section, a complete electrical check out was needed, since an electrical short would have been destructive to certain power supply and controller circuits. Longitudinal leveling of the test cylinder was accomplished by adjusting a horizontal RTV segment line to the liquid level of the test fluid. Angular positioning was also required to achieve circumferential symmetry of the test section. It was achieved using a Starret Precision Level, #USAF-938-445.

6.1 Free Convection Data Acquisition

At the beginning of each series of runs for 38%, 39%, 41%, and 42% CS/SS solutions, test fluids were first mixed at a moderate speed for about half an hour to assure fluid uniformity. When the test fluid was ready, 250 CC of sample was taken for viscometric measurement to ensure that rheological properties had not been changed. Then the test cylinder was adjusted to set about 3 inches from the bottom, and 8 inches from the top of the surface. A gauze-wrapped swab was then used on the test section to remove any entrapped air bubbles.

In obtaining the desired input voltage level, the power supply was activated and the variac was set. Next, each of the ten-turn potentiometers connected to each of the ten test segments was adjusted gradually to heat the test section to constant flux or isothermal surface condition. In obtaining isothermal surface conditions, the test section thermocouples were continuously monitored to get the desired isothermal temperatures at all segments. Compared with obtaining the isothermal surface conditions, obtaining the constant heat flux-surface conditions were relatively easier, since the desired heat flux conditions were achieved by simply setting up all the potentiometers to one voltage reading on the Weston-voltmeter. A stabilizing period of approximately 30 minutes was needed before initial data were taken. During this stabilizing period, continuous adjustment was needed to stabilize the desired surface condition. The voltmeter signal was also checked using a Taktronic Dual Beam Oscilloscope, Model 520A to ensure that the voltmeter signal was not being topped off by the limiting amplifier on the voltmeter scale being used.

Upon reaching the desired surface conditions, the following set of data was taken

1) Voltmeter readings for the ten test sections
2) Thermocouple readings for the ten test sections
3) Two thermocouple readings for the bulk fluid
4) Two thermometer readings for the bulk fluid

After the above data were taken, the test section surface was again swabbed to ensure that there were no air bubbles entrapped. Then a second set of data was taken following a restabilization period. The average of these two sets was considered to be the representative of the run. After completion of a series of runs, viscometric data were again checked to verify rheological properties.

In this manner, 38% CS/SS solution was used first to get the data for constant heat flux surface conditions and then isothermal surface conditions. After a series of experiments was completed for 38% CS/SS solution, corn starch was added, as shown in Chapter V, to make 39%

CS/SS solution. Similar procedures then were followed for the rest of the fluids to acquire the necessary free convection data.

6.2 Shear Rate Verification

As mentioned in Chapter I, it is also necessary to see whether test fluids exhibit similar rheological behavior under natural flow conditions as those observed in the rotational viscometer, since rheological properties determined by the viscometer were used for the actual flow conditions.

Due to the opaqueness of the test fluid, optical methods of determining the velocity profiles of the flow were impossible. Also, a pitot-tube type of device was not possible to use, since the velocity of the flow in the present experiment was too slow to give a significant reading for a pitot-tube. However, the primary objective of the process was to determine if shear rates under actual flow conditions were indeed within the range of the shear rates obtained by the viscometer. Therefore Acrivos'[1] expression shown in Equation (6.1) was employed to estimate the shear rates at the cylinder surface.

$$\left(\frac{\partial u}{\partial y}\right)_0 = F''(0)\left(\frac{3n+1}{2n+1}\right)^{\frac{1}{3n+1}} \frac{[g\beta r(T_s-T_\infty)]^{1/2}}{r} \frac{(N_{Gr_A})^{\frac{1}{2(n+1)}}}{(N_{Pr_A})^{\frac{1}{3n+1}}}$$

$$(\sin\phi)^{\frac{2}{2n+1}}\left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2n+1}}\, d\phi\right]^{\frac{1}{3n+1}} \qquad (6.1)$$

Figure (6.1) shows the values of F"(0) provided by Acrivos for values of flow behavior index. The possible inaccuracy of the equation was considered permissible because of the nature of the object of shear rate verification.

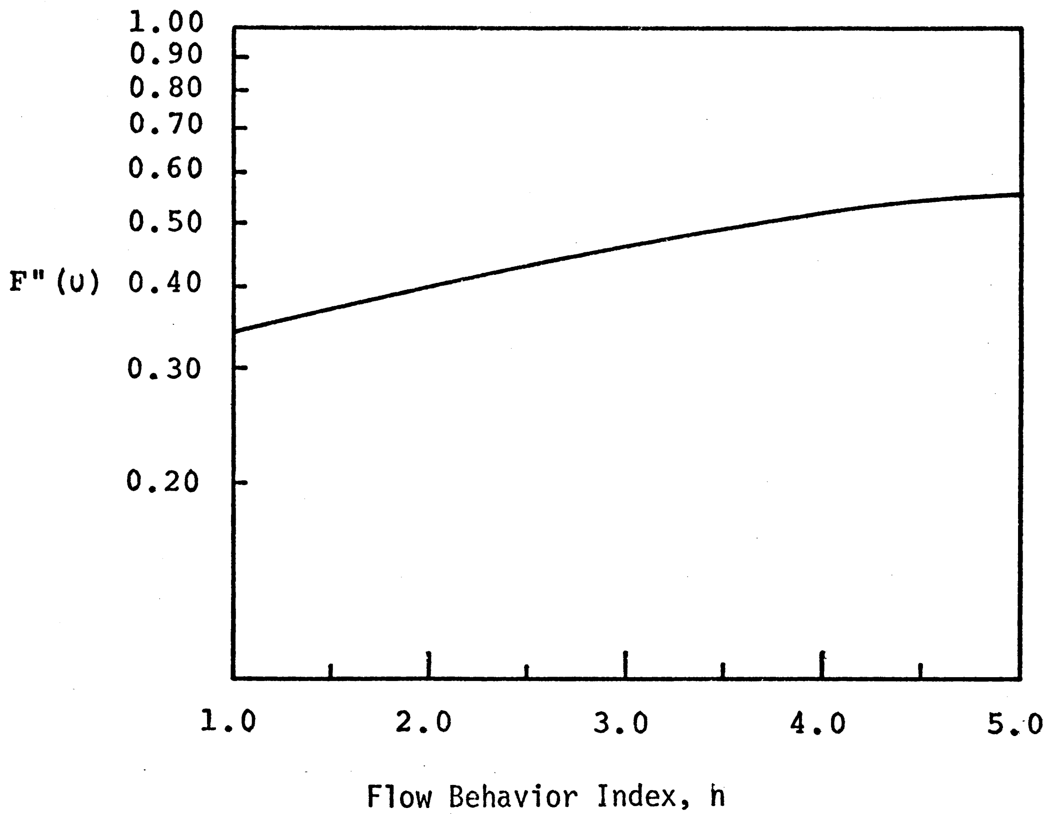

Figure (6.1) F"(0) Versus Flow Behavior Index, n

CHAPTER VII

EXPERIMENTAL RESULTS

Experimental results for both the constant flux and isothermal cases are presented in this chapter. Local free convection data and average free convection values are compared with theoretical solution predictions previously considered in Chapters II and III. The theoretical calculations for estimated shear rates under the actual flow conditions are also presented to ensure the validity of non-Newtonian, dilatant fluid properties as determined by the rotational viscometer.

7.1 Local Free Convection Results

For constant flux surface conditions, six different fluxes (255, 275, 295, 315, 335, and 355 Btu/hr-ft^2) were supplied to the cylinder surfaces and 24 runs were carried out for the experimental results. Local free convection data are expressed in terms of dimensionless groups developed in Chapter III for this case, and the experimental results are compared with integral solution results. For isothermal surface conditions, six different temperature differences (28, 32, 36, 40, 44, and 48°F) were used for each of the four different test fluids. A total of 24 runs were also made for the experimental results. Local free convection data are expressed in terms of Acrivos(1) dimensionless groups and comparisons are made with integral solutions by Gentry and Wollersheim(4). A complete listing of all free convection data is described in Appendix A, and graphical presentations of local free convection results for both constant flux and isothermal cases are shown in Figures (7.1-7.8). The solid lines on the figures represent

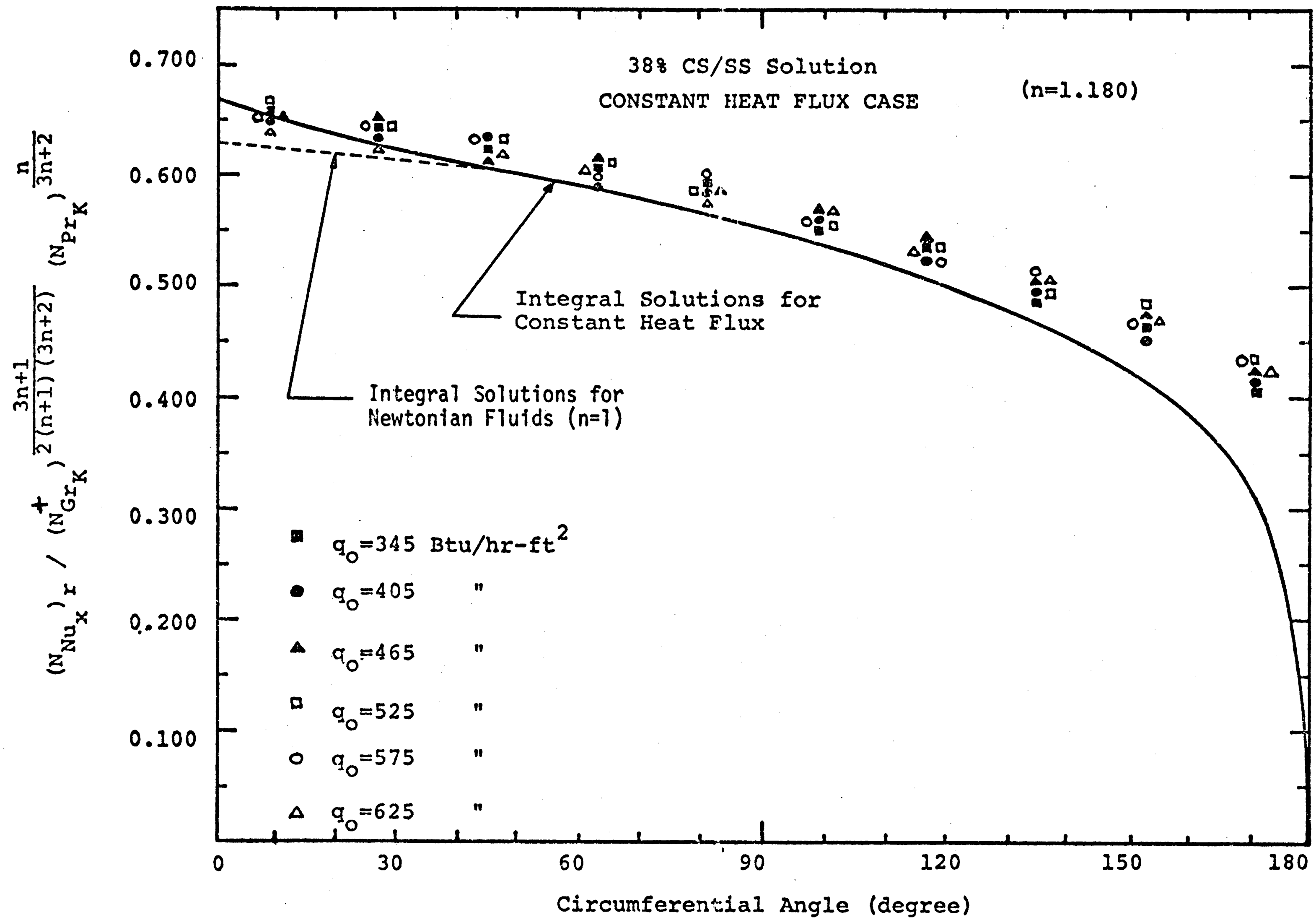

Figure (7.1) Heat Transfer Results for the Constant Heat Flux Case for 38% CS/SS

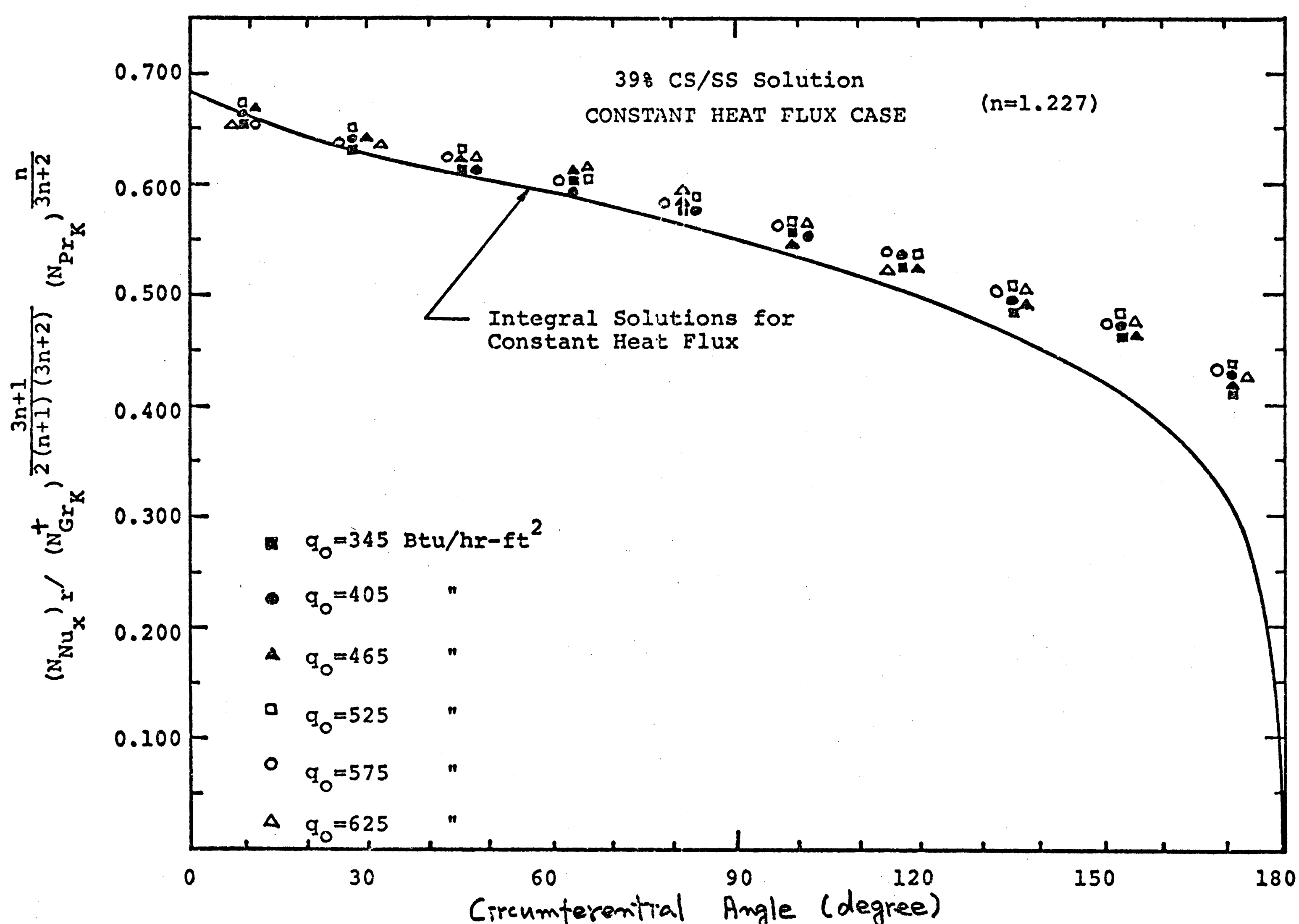

Figure (7.2) Heat Transfer Results for the Constant Heat Flux Case for 39% CS/SS

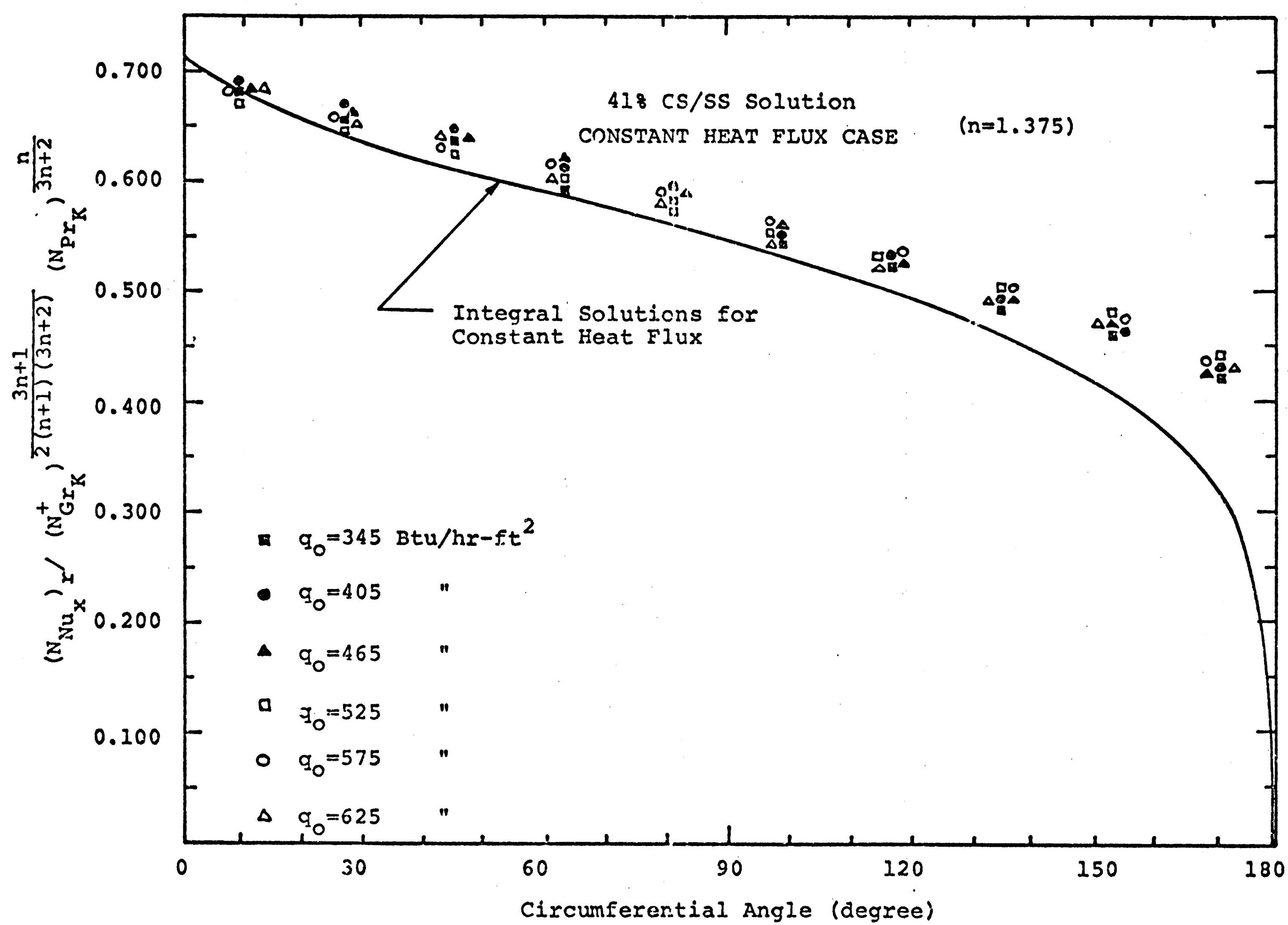

Figure (7.3) Heat Transfer Results for the Constant Heat Flux Case for 41% CS/SS

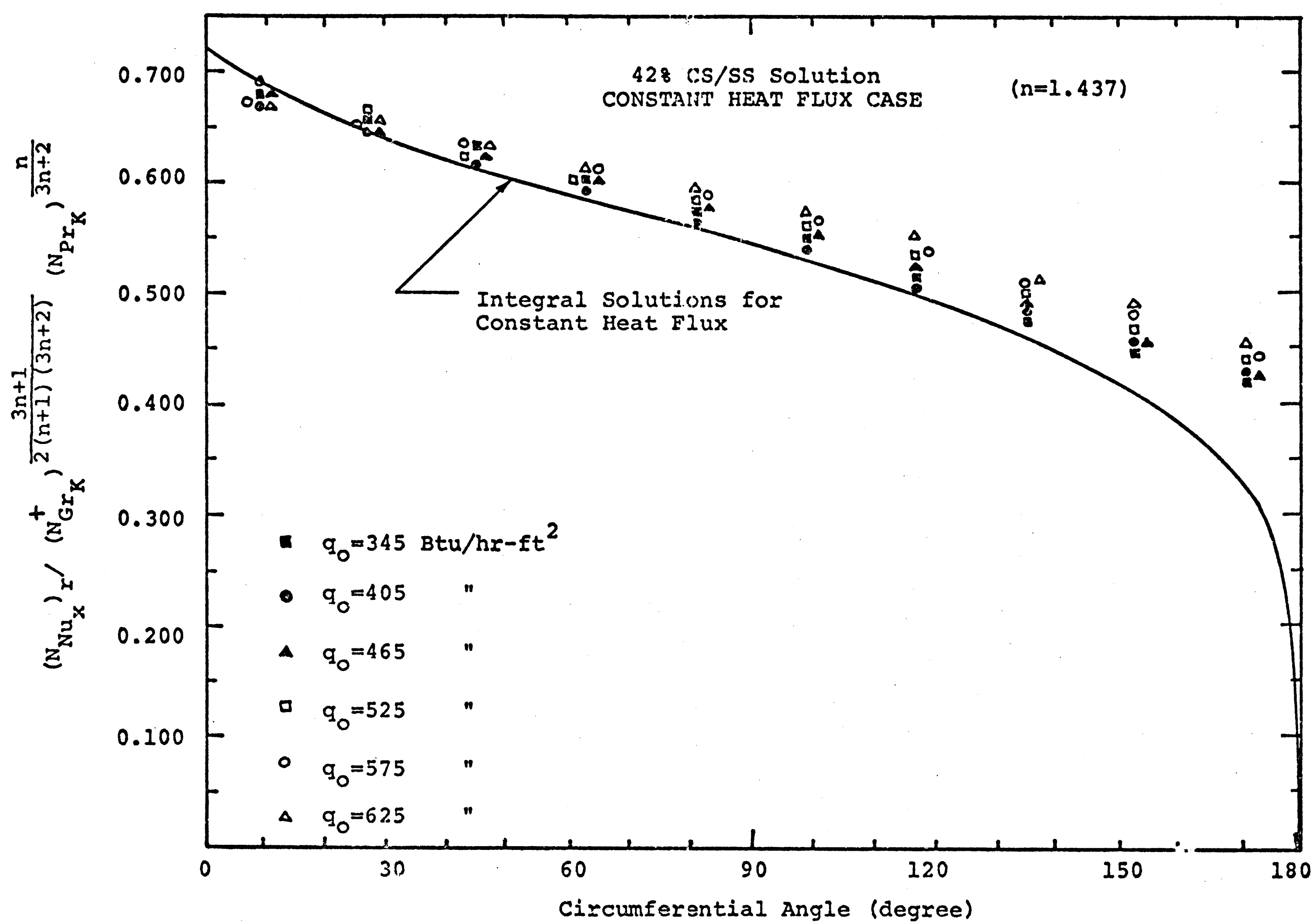

Figure (7.4). Heat Transfer Results for the Constant Flux Case for 42% CS/SS

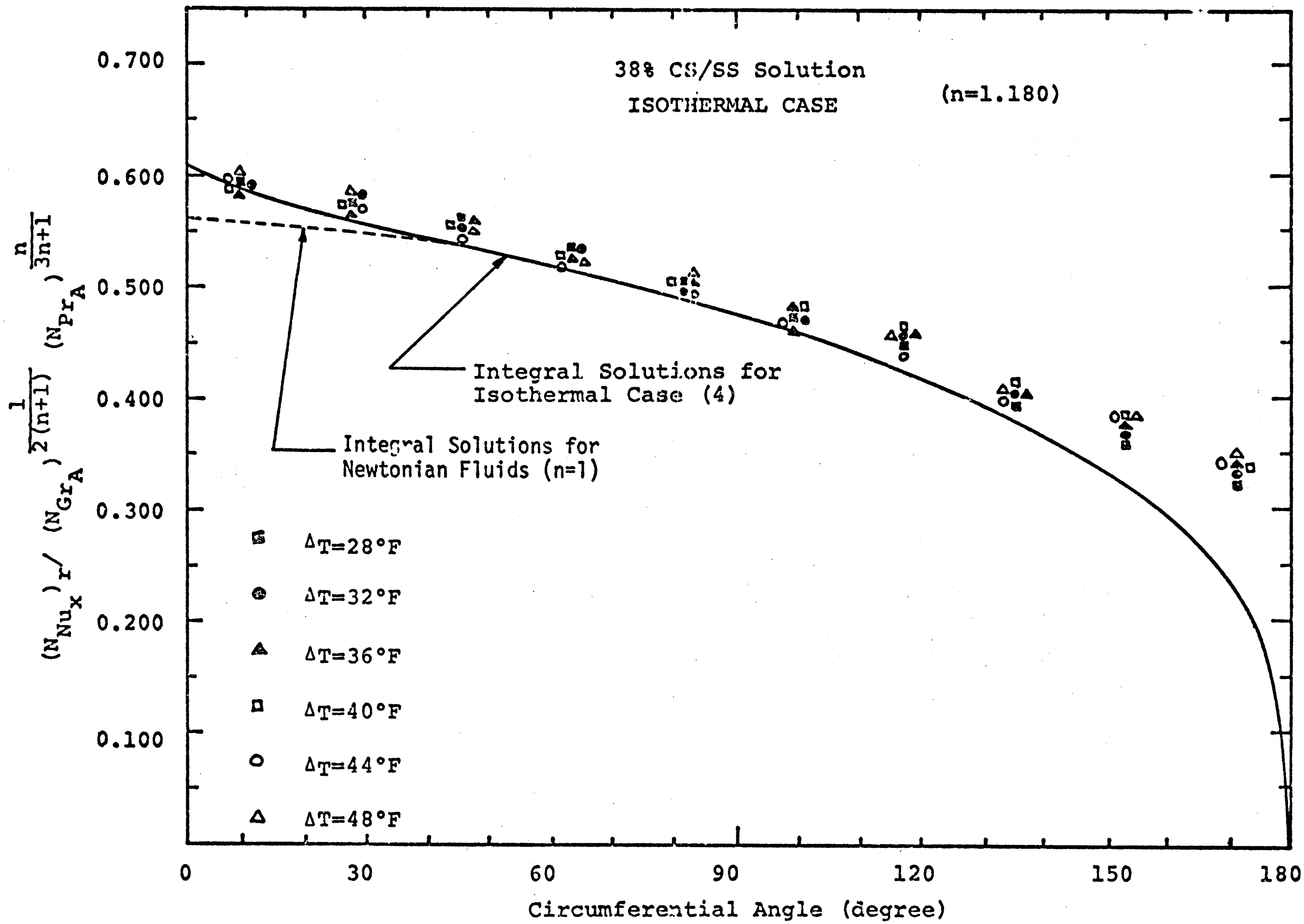

Figure (7.5) Heat Transfer Results for the Isothermal Case for 38% CS/SS

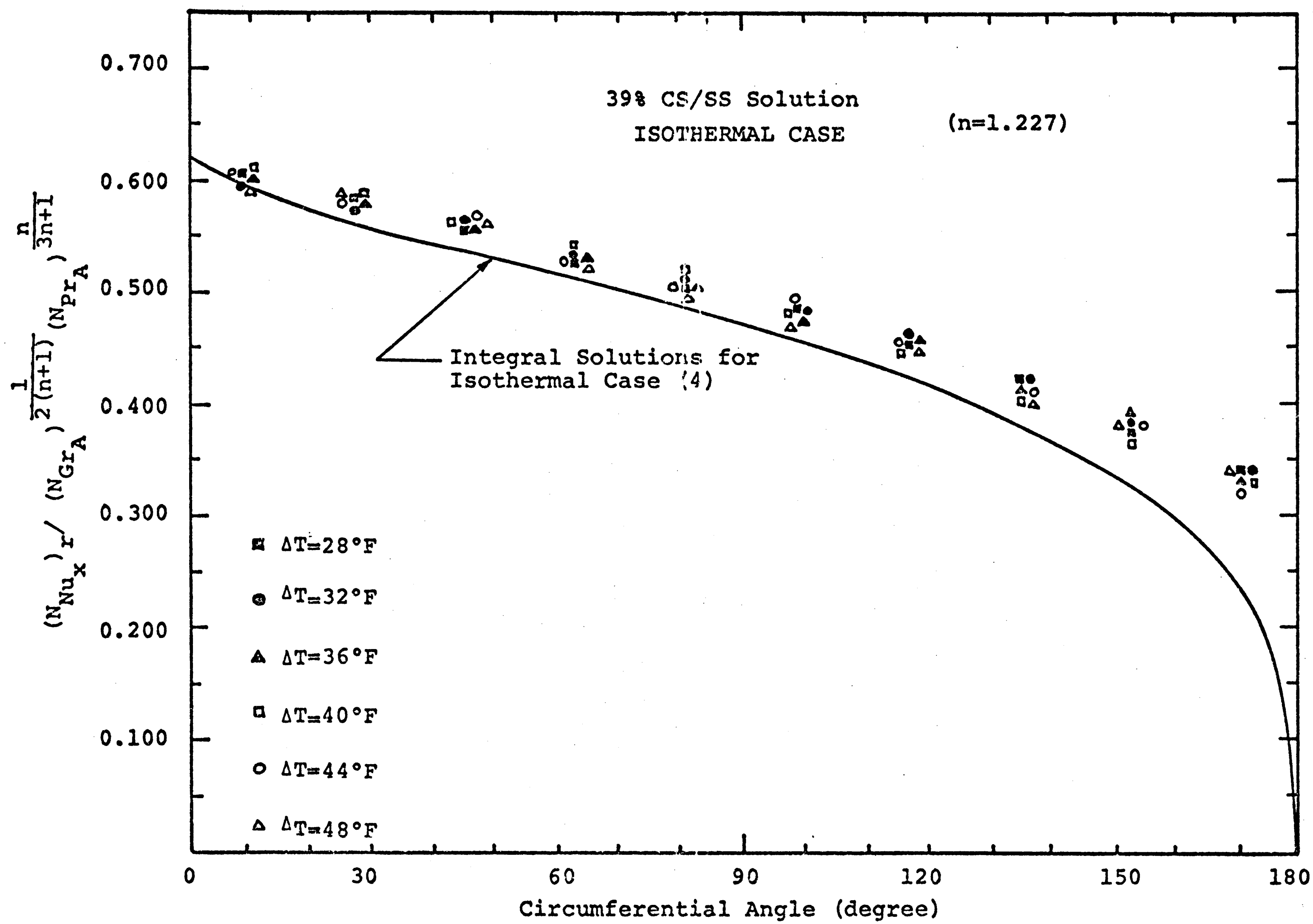

Figure (7.6) Heat Transfer Results for the Isothermal Case for 39% CS/SS

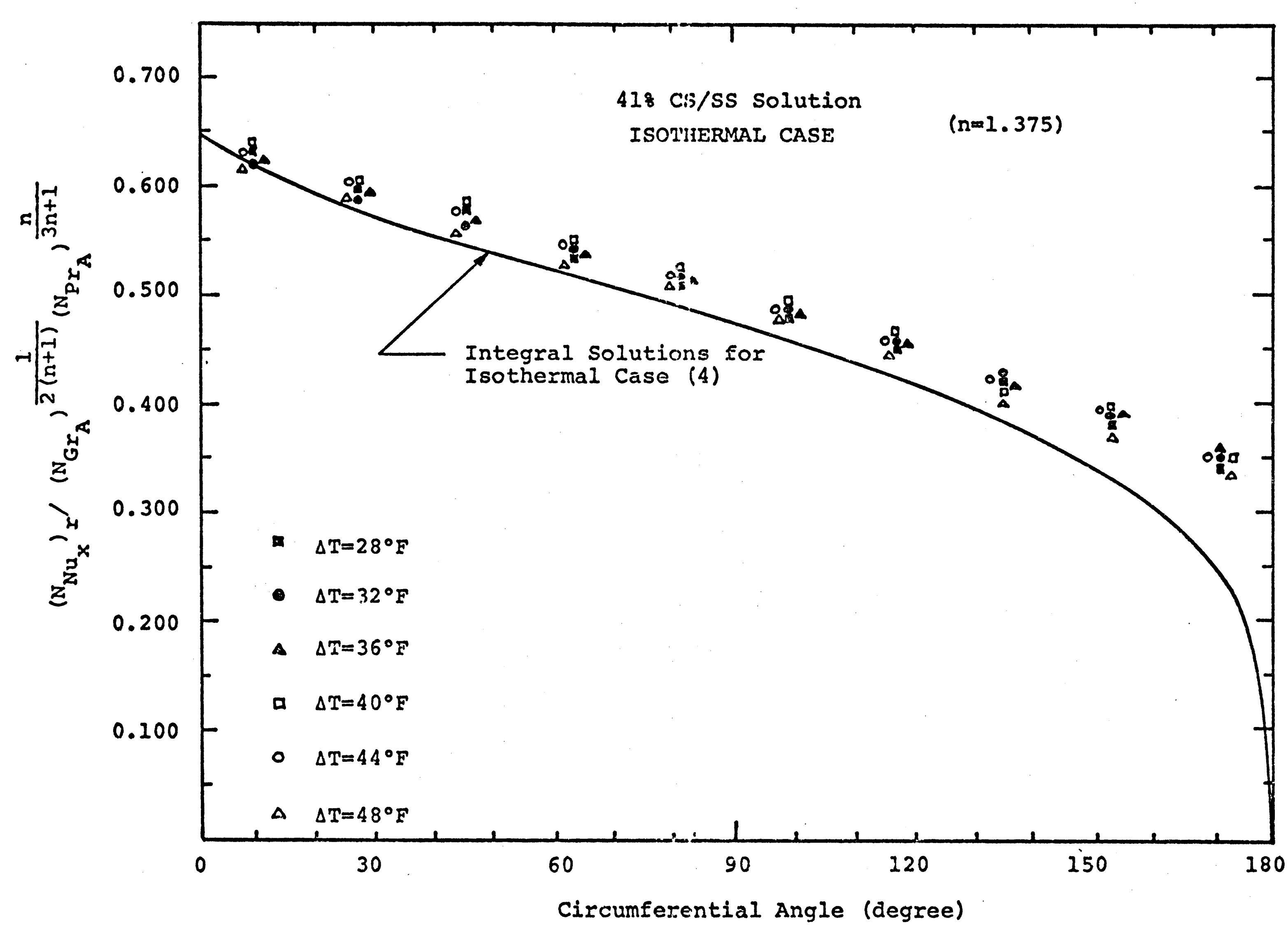

Figure (7.7) Heat Transfer Results for the Isothermal Case for 41% CS/SS

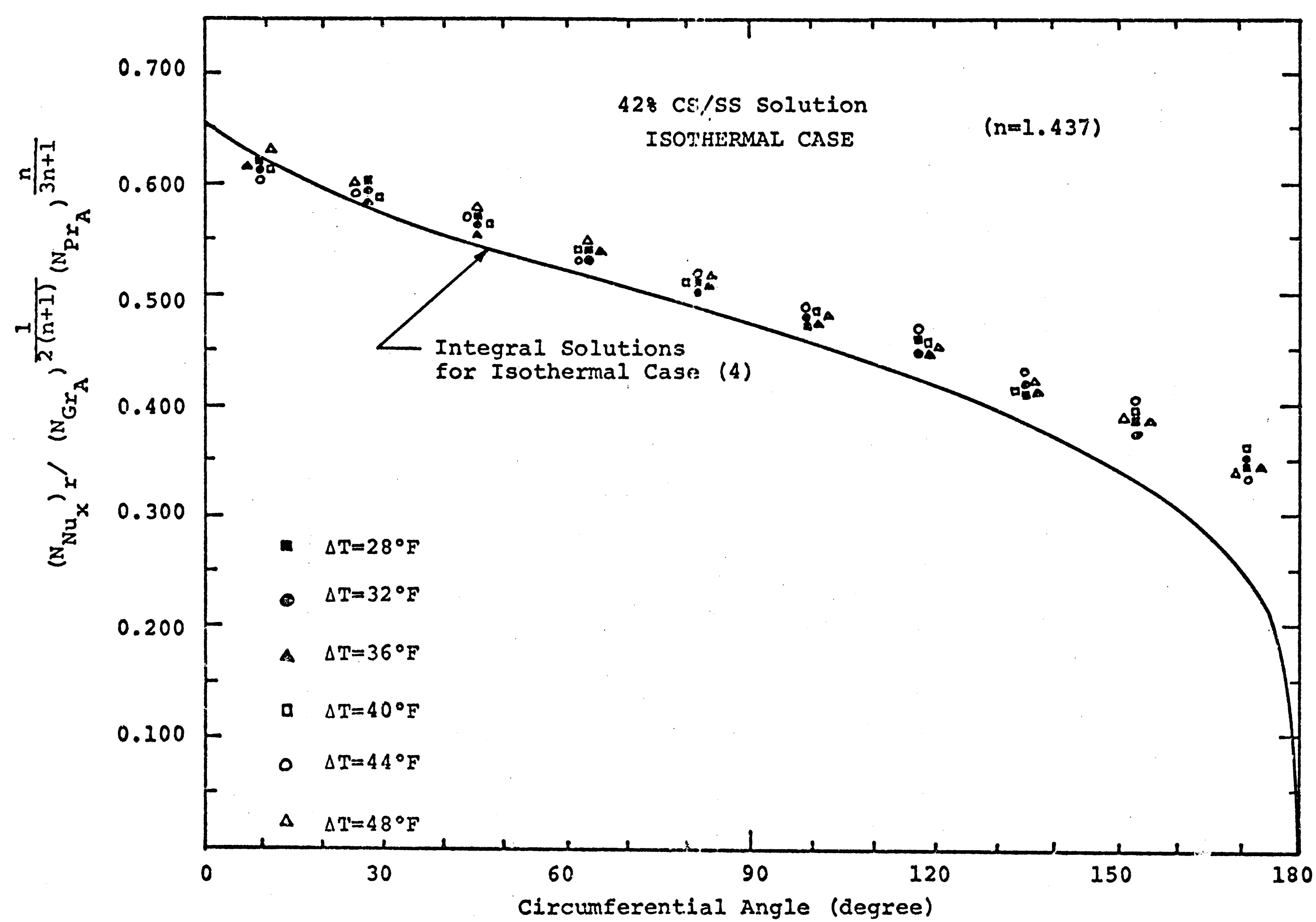

Figure (7.8) Heat Transfer Results for the Isothermal Case for 42% CS/SS

the theoretical solution predictions, and experimental values are provided at angular positions of 9°, 27°, 45°, 63°, 81°, 99°, 117°, 135°, 153°, and 171° measured from the lower stagnation point.

Dimensionless numbers for both cases are expressed as follows:

$$(N_{Nu_x})_r = \frac{h_x r}{r} \qquad (3.49)$$

Dimensionless numbers for the constant flux case by the author:

$$N_{Pr_K} = \left(\frac{\rho C_p}{k}\right)\left(\frac{K}{\rho}\right)^{\frac{2}{n+1}} (r)^{\frac{2(n-1)}{n+1}} \left(\frac{g\beta q_o}{k}\right)^{\frac{3(n-1)}{2(n+1)}} \qquad (3.29)$$

$$N^{+}_{Gr_K} = \left(\frac{\rho}{K}\right)^2 r^4 \left(\frac{g\beta q_o}{k}\right)^{2-n} \qquad (3.30)$$

Dimensionless numbers for the isothermal case by Acrivos[1]:

$$N_{Pr_A} = \left(\frac{\rho C_p}{k}\right) \left(\frac{K}{\rho}\right)^{\frac{2}{n+1}} (r)^{\frac{1-n}{1+n}} \left[g\beta r(T_s - T_\infty)^{\frac{3(n-1)}{2(n+1)}}\right] \qquad (2.3)$$

$$N_{Gr_A} = \left(\frac{\rho}{K}\right)^2 (r)^{n+2} \left[g\beta(T_s - T_\infty)\right]^{2-n} \qquad (2.2)$$

In expressing the experimental results with the above dimensionless groups, all physical property data appearing in dimensionless groups were evaluated at the local film temperature, which is the mean temperature of the cylinder surface and the bulk fluid temperature.

In comparing the experimenta results with theoretical solutions the integral solution results for constant flux case by the author were obtained from

$$(N_{Nu_x})_r = K(n)\, N^{+\,\frac{3n+1}{2(n+1)(3n+2)}}_{Gr_K}\; N_{Pr_K}^{\frac{n}{3n+2}}$$

$$\frac{(\sin\phi)^{\frac{1}{2(n+1)}}}{\left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2(n+1)}}\, d\phi\right]^{\frac{n}{3n+2}}} \tag{3.52}$$

and the integral solutions for the isothermal case obtained by Gentry and Wollersheim[4] were calculated from

$$(N_{Nu_x})_r = G(n)\left(\frac{2n+1}{3n+1}\right)^{\frac{n}{3n+1}} (N_{Gr_A})^{\frac{1}{2(n+1)}} (N_{Pr_A})^{\frac{n}{3n+1}}$$

$$\frac{(\sin\phi)^{\frac{1}{2n+1}}}{\left[\int_{\phi=0}^{\phi} (\sin\phi)^{\frac{1}{2n+1}}\, d\phi\right]^{\frac{n}{3n+1}}} \tag{2.21}$$

For the constant heat flux case, as shown in Figures (7.1-7.4), experimental data for the four different dilatant fluids were higher than the theoretical values, but generally they agree quite well with integral solution predictions for angles smaller than 140°. At angles higher than 140° experimental values for the local free convection coefficients are significantly higher than coefficients from the integral solutions. As shown in Figures (7.5-7.8), experimental values for the isothermal case, again, show good agreement with integral solutions for angles smaller than approximately 140°. At angles higher than 140°, experimental values are higher than coefficients from the integral solutions.

Similar experimental results were reported for pseudoplastic fluids for isothermal conditions[4], and for mineral oil for both constant flux and isothermal conditions[38]. This phenomenon is primarily attributable to boundary layer interaction in the upper stagnation region which is not accounted for in the integral solution. At the upper stagnation region of the cylinder, the natural convection flow from one side of the cylinder interacts with the flow coming from the other side of the cylinder. As a result the integral solutions are not valid as the upper stagnation region is approached.

Comparing the integral solutions for different n values including the Newtonian case (n=1), it was found that the integral solutions are very close to each other, as shown in Figures (7.1-7.8), when they are expressed in dimensionless forms.

7.2 Average Free Convection Results

The average expressions for free convection were obtained by integrating local dimensionless groups over the test section surface. The average experimental Nusselt numbers for the constant flux case appear to be approximately 4% - 8% higher than the theoretical Nusselt numbers, while the average experimental Nusselt numbers for the isothermal case are approximately 3% - 8% higher than the theoretical ones. The average Nusselt number for all experimental data were obtained from a least squares fit to be

Constant Heat Flux Case:

$$(N_{Nu_r})_{avg} = 3.544\ (N^{+}_{Gr_K} N_{Pr_K})^{0.071} \qquad (7.1)$$

and for the

Isothermal Case:

$$(N_{Nu_r})_{avg} = 2.816\ (N_{Gr_A} N_{Pr_A})^{0.103} \qquad (7.2)$$

The above expressions for the average Nusselt number for non-Newtonian, dilatant fluids are useful for design purposes, since the forms are relatively simple to use.

7.3 Shear Rate Verification

Local surface shear rates were calculated for each set of local free convection data by using Equation (6.1) for theoretical velocity gradient expressions. As shown in Appendix A, the range of shear rates encountered under the actual flow condition was from approximately 0.100 to 2.000 1/sec, while the shear rates produced in the rotational viscometer were in the range of approximately 0.100-10.0 1/sec. Therefore, it is safe to assume that test fluids exhibit similar rheological dilatant behavior under natural flow conditions.

7.4 Errors For The Measurements

As mentioned previously, a stabilizing period of approximately 30 minutes was required before the initial data were taken. In most of the cases, without taking a third set of data, it was possible to obtain two representive sets of data with maximum difference of 0.01V in values on the digital Weston meter (approximately 2% error in values). However, during certain runs, voltage fluctuations were as much as 0.02 V. In such cases, another series of data were taken until the voltmeter gave readings within 0.01V error.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Concluding remarks which summarize the results of the present investigation are presented in this chapter. Recommendations are also presented for possible areas of future study.

8.1 Conclusions

The present study has been an attempt to investigate the laminar free convection heat transfer between a horizontal cylinder and rheological dilatant fluids. Surface boundary conditions considered were constant flux and isothermal. Heat transfer data were taken and compared with the theoretical integral solutions. To summarize the results of the present investigation, conclusions are made as follows:

1) Experimental results for dilatant fluids agree quite well with the results from the integral solutions for both constant flux and isothermal surface conditions at angles smaller than approximately 140° measured from the lower stagnation point. At angles higher than 140° experimental values for the local free convection coefficients are significantly higher than coefficients from the integral solutions. Therefore, the integral solutions are not valid as the upper stagnation region is approached. The average experimental Nusselt numbers appear to be approximately 3% - 8% higher than the theoretical Nusselt numbers.

2) The phenomenon which exhibits significantly higher experimental Nusselt numbers at angles larger than 140° may be attributable to boundary layer interaction in the upper stagnation region which is not accounted for in the integral solutions.

3) The experimental results agree quite well with those by Gentry and Wollersheim[4] for pseudoplastic fluids under isothermal surface conditions, and those by Kim, Pontikes, and Wollersheim[12] for mineral oils under constant flux and isothermal surface conditions.

4) Since similiarity solutions are not possible for the constant heat flux case, the integral technique seems a powerful tool to provide approximate theoretical solutions.

5) The integral solutions for different n values including Newtonian fluids (n=1) are very close to each other for both the constant heat flux case and the isothermal case, when they are expressed in dimensionless forms.

8.2 Recommendations

Some areas are recommended to gain more insight of this heat transfer problem. The following are recommendations for future study.

1) The boundary interaction for the upper stagnation region which was not accounted for in the theoretical solution warrants attention for further study to gain more insight into this type of heat transfer problem.

2) The possible turbulent free convection heat transfer in non-Newtonian fluids is also worthy of consideration. Turbulent flow may be achieved by supplying more heat to the surface and by increasing the size of the test model.

3) No theoretical solutions for non-Newtonian fluids such as Bingham plastic fluids, and time dependent fluids have been obtained to date. Future study in this area is recommended by using a proper fluid model.

4) Theoretical solutions with arbitrary temperature distributions along the cylinder surface have not been reported yet. Therefore, further considerations are desirable for arbitrary surface temperature conditions.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Acrivos, A., "A Theoretical Analysis of Laminar Natural Convection Heat Transfer to Non-Newtonian Fluids," A.I.Ch.E. Journal, Vol. 6, Nov. 4, 1960, pl 584.

2. Chen, T. Y., "On the Solution of External Laminar Free Convection to Power Law Fluids," Ph.D. Thesis, University of Missouri-Columbia, Columbia, Missouri, 1971.

3. Tien, C., "Laminar Natural Convection Heat Transfer from Vertical Plate to Power-Law Fluid," Appl. Sci. Res., Vol. 17, 1967, p. 233.

4. Gentry, C. C. and Wollersheim, D. E., "Local Free Convection to Non-Newtonian Fluids from a Horizontal Isothermal Cylinder," J. Heat Transfer, Trans. ASME, Vol. 96, No. 1, 1973, p. 3.

5. Reilly, I. G., Tien, C., and Adelman, M., "Experimental Study of Natural Convection Heat Transfer from a Vertical Plate in a Non-Newtonian Fluid," Can. J. Chem. Eng., Vol. 47, 1965, p. 157.

6. Sharma, K. K., and Adelman, M., "Experimental Study of Natural Convection Heat Transfer from a Vertical Plate in a Non-Newtonian Fluid," Can J. Chem. Eng., Vol. 47, 1969, p. 553.

7. Dale, J. D., "Laminar Free Convection of Non-Newtonian Fluids from a Vertical Flat Plate with Uniform Surface Heat Flux," Ph.D. Thesis, University of Washington, Seattle, Washington, 1969.

8. Reynolds, O., "On the Dilatancy of Media Composed of Rigid Particles in Contact: With Experimental Illustrations," Phil. Mag., Vol. 8, 1885, p. 20.

9. Freundlich, H., and Roder, H. C., "Dilatancy and Its Relation to Thixotrophy," Trans. Faraday Soc., Vol. 34, 1938, p. 308.

10. Calderbank, P. H., and Moo-Young, M. B., "The Prediction of Power Consumption in the Agitation of Non-Newtonian Fluids," Trans, Instr. Chem. Engrs., Vol. 37, 1959.

11. Verwey, E. J. W., and de Boer, J., "Dilatancy," Rec. Trav. Chim., Vol. 57, 1939, p. 383.

12. de Bruijn, H., and Meerman, P. G., Proc. Intern. Rheological Congress (Holland), Vol. II. North Holland Pub. Co., Interscience, New York, 1948, p. 160.

13. Robinson, R. B., "The Effect of Sphere Diameter," J. Phys. and Colloid Chem., Vol. 55, 1951, p. 455.

14. Vand, V., "Experimental Determination of the Viscosity-Concentration Function of Spherical Suspensions," Phys. and Colloid Chem., Vol. 52, 1948. p. 300.

15. Ting, A. P. and Luebbers, R. H., "Viscosity of Suspensions of Spherical and Other Isodimensional Particles in Liquids," A.I.Ch.E. Journal, Vol. 3, No. 1, 1957, p. 111.

16. Metzner, A. B., and Whitlock, M., "Flow Behavior of Concentrated Dilatant Suspensions," Trans. Sci. of Rheology, Vol. II, 1958, p. 239.

17. Fredrickson, A. G., Principles and Applications of Rheology, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1964.

18. Wilkinson, W. K., Non-Newtonian Fluids, Pergamon Press, New York, 1960.

19. Skelland, A. H. P., Non-Newtonian Flow and Heat Transfer, John Wiley and Sons, Inc., 1967.

20. Ede, A. J., "Advances in Free Convection," Advanced in Heat Transfer, Vol. 4, 1973, p. 1.

21. Jakob, M., Heat Transfer, Vol. 1, New York, John Wiley and Sons, Inc., 1962.

22. McAdams, W. H., Heat Transmission, 3rd ed., New York, McGraw-Hill Book Company, Inc., 1954, p. 175.

23. Fujii, T., "Mathematical Analysis of Heat Transfer from a Vertical Flat Surface by Laminar Free Convection," Bull. J.S.M.E., Vol. 2, 1959, p. 363.

24. Gentry, C. C., "Local Free Convection to Non-Newtonian Fluids From a Horizontal, Isothermal Cylinder," Ph.D. Thesis, University of Missouri-Columbia, Columbia, Missouri, 1972.

25. Weast, R. C., and Selby, S. M., Handbook of Chemistry and Physics, 55th ed., The Chemical Rubber Co., Cleveland, 1974-1975, D-231.

26. Mohsenin, N. N., Physical Properties of Plant and Animal Materials, Vol. 1, Gordon and Breach Science Publishers, New York, 1970, p. 55.

27. Gucker, F. T., Pickard, H. B., and Planck, R. W., "A New Microcalorimeter; the Heats of Dilution of Aqueous Solutions of Sucrose at 20^{o} and 30^{o} and their Heat Capacities at 25^{o}," J. Am. Chem. Soc., Vol. 61, 1939, p. 459.

28. Sprockhoff, F., "The Specific Heat and Heat Wetting of Dextrin," Z. Spiritusind, Vol. 45, 1922, p. 217.

29. Metzner, A. B., "Heat Transfer in Non-Newtonian Fluids," Advanced in Heat Transfer, Vol. 2, 1965, p. 357.

30. International Critical Table, Vol. III, McGraw-Hill Book Co., Inc., 1927.

31. Beltz, W., Fisher, W., and Wunnenberg, Z., "The Claim to Uptake of Space of Crystallized Organic Materials," Zeit. Phys. Chem., 1930, p. 13.

32. Kharbanda, O. P., "Chart Quickly Tells Thermal Conductivity of Equeous Sugar Solutions in Wide Temperature-Concentration Range," Food Engr., Feb., 1955, p. 94.

33. Gillam, D. G., and Lamm, O., "Precision Measurements of the Thermal Conductivities of Certain Liquids by the Hot-Wire Method," Acta Chem. Scand., Vol. 9, 1955.

34. Garrett, M. P., "Apparent Thermal Conductivity for Three Types of Structures in Freeze-Dried Food Models," M.S. Thesis, Pennsylvania State Univ., Sept., 1967.

35. Thomas, D. G., "Part I: Physical Properties and Laminar Transport," Ind. Eng. Chem., Vol. 55, No. 11, 1963, p. 18.

36. Jefferson, T. B., Witzell, O. W., and Silbitt, W. L., "Thermal Conductivity of Graphite-Silicone Oil and Graphite-Silicone Oil and Graphite-Water Suspensions," Ind. Eng. Chem., Vol. 50, 1958, p. 1589.

37. Orr, C., and Dalla Valle, J. M., "Heat Transfer Properties of Liquid-Solid Suspensions," Chem. Eng. Propr. Symp. Ser. 50, Vol. 9, 1954, p. 29.

38. Kim, C. B., Pontikes, T. J., and Wollersheim, D. E., "Free Convection Heat Transfer from a Horizontal Cylinder with Isothermal and Constant Heat Flux Surface Conditions," J. Heat Transfer, Trans. ASME, Vol. 97, No. 1, 1975, p. 129.

39. Emery, A. F., Chi, H. W., and Dale, J. D., "Free Convection Through Vertical Plane Layers of Non-Newtonian Power Law Fluids," J. Heat Transfer, Trans. ASME, Vol. 93, No. 2, 1971, p. 164.

40. Acrivos, A., Shah, M. J., and Peterson, E. E., "Momentum and Heat Transfer in Laminar Boundary Layer Flows of Non-Newtonian Fluids Past External Surfaces," A.I.Ch.E. Journal, Vol. 6, No. 2, 1960, p. 312.

41. Shah, M. J., Peterson, E. E., and Acrivos, A., "Heat Transfer from a Cylinder to a Power-Law Non-Newtonian Fluid," A.I.Ch.E. Journal, Vol. 8, No. 4, 1962, p. 542.

42. Tomita, Y., "On the Fundamental Formula of Non-Newtonian Flow," Bull. J.S.M.E., Vol. 2, No. 7, 1959, p. 469.

43. Eckert, E. R. G., and Soehngen, E. E., "Studies on Heat Transfer in Laminar Free Convection with the Zehnder-Mach Interferometer," USAF Air Material Command, Tech. Report No. 5747, Dayton, Ohio, 1948.

44. Braun, W. H., and Heighway, J. E., "An Integral Method for Natural Convection Flows at High and Low Prandtl Numbers," NASA TN D-292, 1960.

45. Hermann, R., "Heat Transfer by Free Convection from Horizontal Cylinders in Diatonic Gases," NACA TM 1366, 1964.

46. Levy, S., "Integral Methods in Natural Convection Flow," J. Appl. Mech., 1955, p. 515.

47. Chiang, T., and Kaye, J., "On Laminar Free Convection from a Horizontal Cylinder," Proc. of the Fourth U.S. National Congress of Applied Mechanics, Vol. 2, University of California, Berkeley, 1962, p. 1213.

48. Granville, P.S., "The Frictional Resistance and Boundary Layer of Flat Plates in Non-Newtonian Fluids," J. Ship Research, October, 1962, p. 43.

49. Eckert, E. R. G., and Drake, R. M., Heat and Mass Transfer, 2nd ed., New York, McGraw-Hill Book Company, Inc., 1959, p. 312.

50. Schlichting, H., Boundary Layer Theory, 6th ed., McGraw-Hill, New York, 1968.

51. Mooney, M., In Rheology, edited by Eirich, F. R., Vol. 2, Academic Press, New York, 1958, p. 207.

52. Johnson, F. A., "The Thermal Conductivity of Aqueous Thoria Suspensions," UKAEA Research Group, Atomic Energy Research Establishment HARWELL. Data of Manuscript, June, 1958, HX 5060(os).

53. Kreiger, I. M., and Maron, S. H., "Direct Determination of the Flow Curves of Non-Newtonian Fluids," J. Appl. Physics, Vol. 23, No. 1, 1952, p. 147.

54. Kreiger, I. M., and Maron, S. H., "Direct Determination of the Flow Curves of Non-Newtonian Fluids. III. Standardized Treatment of Viscometric Data," J. Appl. Physics, Vol. 25, No. 1, 1954, p. 72.

55. Lee, S. Y., and Ames, W. F., "Similarity Solutions for Non-Newtonian Fluids," A.I.Ch.E. Journal, Vol. 12, No. 4, 1966, p. 700.

56. Darfman, A. S., and Vishnevskii, Viki, "Approximate Solutions of the Equations of the Dynamic and Thermal Boundary Layers for Non-Newtonian Fluids with Arbitrary Pressure Gradients and Surface Temperature," Int'l Chem. Eng., Vol. II, No. 3, 1971, p. 377.

57. Christiansen, E. B., and Craig, S. E., Jr., "Heat Transfer to Pseudoplastic Fluids in Laminar Flow," A.I.Ch.E. Journal, Vol. 8, No. 2, 1962, p. 154.

APPENDIX A

FREE CONVECTION HEAT TRANSFER RESULTS

FREE CONVECTION HEAT TRANSFER RESULTS

Nomenclature

TBULK	bulk temperature, °F
DENSITY	density, lbm/ft^3
THERMK	thermal conductivity, Btu/hr-ft-°F
SPHEAT	specific heat, Btu-lbm-°F
BETA	coefficient of thermal expansion, 1/°F
KLBFTHR	consistency index, lbm/ft-(hr)$^{2-n}$
NINDEX	flow behavior index
ANGLE	angle from lower stagnation point, degrees
NUX	local Nusselt number
NUGPD	product of Nusselt number and Grashof number
HX	local heat transfer coefficient, Btu/hr-ft^2-°F
QFLUX	local heat flux, Btu/hr-ft^2
BTUHR	heat transfer rate per segment, Btu/hr
TWALL	local wall temperature, °F
DELT T	wall-to-fluid temperature difference, °F
THETA	Acrivos' constant θ' (0)
FACR	Acrivos' constant F" (0)
KN	Kim's constant
CN	Gentry's constant
NPRK	Kim's Prandtl number form
NGRK	Kim's Grashof number form
NPR	Acrivos' Prandtl number form
NGR	Acrivos' Grashof number form
NUAVG EXPMTL	average experimental Nusselt number
NGRPRK	product of Kim's Grashof and Prandtl numbers
NGRPR	product of Acrivos' Grashof and Prandtl numbers
SHRAVG	average surface shear rate, 1/sec
NUAVG INTGL	average Nusselt number from the integral solutions

```
EVEL 2  ( NOV 72 )                              OS/360  FORTRAN H EXTENDED

QUESTED OPTIONS: OBJECT,NODECK

TIONS IN EFFECT: NAME(MAIN) OPTIMIZE(2) LINECOUNT(58) SIZE(MAX) AUTODBL(NONE)
                 SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT NOGOSTMT NOX

              C
              C      HORIZONTAL CYLINDER DATA REDUCTION
              C
 ISN 0002            REAL MV, MV11, MV12, LENIN, LENFT, LACRIN, LACRFT,
                    1LDIAIN, LDIAFT, KINDEX, NINDEX, NUX, NGR, NPR, NGRPR,
                    2NPRC14, NGRC13, NGPROD, NUGRPR, NUGPAC, NUXACR,
                    3NUGPCW, NUXCW, NGRD, NUAVG, NUADMS, NUEKRT, NUACAV,
                    4NUXINT, NGPDAV, NUGPD, NUGPIN, KAVG, NPRAVG, NGRAVG,
                    5NGPAVG, NUXACD, NUDAVG, NUGPD1, NUGPD2, NUXD, NGRDK,
                    6NPRD, NPRK, NPRD14, NGRD13, NGPD, NAVG, KINAVG,NUAVGI,
                    7NGR2, NGRD2, NPR2, NPRD2, NPRK2, NGRPR2, NGPD2, KN,KNAVG
              C
 ISN 0003            INTEGER RUN, DAY, MO, YR, TIME, NO, NUMBER, CODE,
                    1CASE, SCALE
              C
 ISN 0004            DIMENSION MV(25), SCALE(10), VRDG(10), RMS(10),T(25),
                    1RSTRIP(10), RTOTAL(10), VTOTAL(10), AMPS(10),
                    2WATTS(10), QBTUHR(10), QFLUX(10), TTC(25), TWALL(20),
                    3TFILM(10), HX(10), DEN(10), THERMK(10), BETA(10),
                    4VIS(10), SPHT(10), KINDEX(10), NINDEX(10), NUX(10),
                    5NGR(10), NPR(10), NGRPR(10), NPRC14(10), NGRC13(10),
                    6NGPROD(10), NUGRPR(10), ANGLE(10), NO(10), THETA(10),
                    7FACR(10), PHI(10), FCHEN(10), ANGDEG(10), CN(10),
                    8V(10), NGRD(10), DELT(10), NUXD(10), NGRDK(10),
                    9NPRD(10),NPRK(10), NPRD14(10), NGRD13(10), NGPD(10),
                    1NGR2(10), NGRD2(10), NPR2(10), NPRD2(10), NGRPR2(10),
                    2PRC214(10),PRD214(10),GRC213(10),GRD213(10),
                    3GPROD2(10),NGPD2(10),UGRPR2(10),KN(10),NPRK2(10)
              C
              C      ***** READ INPUT DATA *****
              C
 ISN 0005          1 READ(5,3) RUN,FL,U,ID,CONCEN,CODE,CASE,TBULK
 ISN 0006          3 FORMAT(I2,1X,3A3,F5.1,I2,I2,F5.1)
 ISN 0007            READ(5,5)  (MV(I),I=1,10)
 ISN 0008          5 FORMAT(10F6.3)
 ISN 0009            READ(5,7) (SCALE(I), I=1,10)
 ISN 0010          7 FORMAT(10I2)
 ISN 0011            READ(5,77) (VRDG(I),I=1,10)
 ISN 0012         77 FORMAT(10F5.2)
              C
              C      ***** INTERNAL INPUT DATA *****
              C
 ISN 0013            DODIN = 2.034
 ISN 0014            DIDIN = 1.576
 ISN 0015            DTCIN = 1.806
 ISN 0016            LENIN = 8.000
 ISN 0017            LACRIN = DODIN/2.0
 ISN 0018            WIDTH = 0.168
 ISN 0019            THKIN = 0.002
 ISN 0020            SEGDEG = 18.0
 ISN 0021            SEGRAD = 0.31416
```

```
ISN 0022           GCONST = 32.2 * (3600.0 ** 2.0)
ISN 0023           LENFT = LENIN / 12.0
ISN 0024           LACRFT = LACRIN/12.0
ISN 0025           DODFT = DODIN/12.0
ISN 0026           DIDFT = DIDIN/12.0
ISN 0027           DTCFT = DTCIN/12.0
ISN 0028           GROUP1 = DODIN/DTCIN
ISN 0029           GROUP2 = ALOG(GROUP1)
ISN 0030           GROUP3 = 118.0 * SEGRAD * LENFT
ISN 0031           GROUP4 = GROUP2/GROUP3
ISN 0032           ATOTAL = ((3.1416*DODIN -(20.0*0.03125))*LENIN)/144.0
ISN 0033           ASEGFT = ATOTAL/20.
ISN 0034           SUMKN=0.0
             C
             C     ********** REDUCING LOCAL EXPERIMENTAL DATA *********
             C
ISN 0035            DO 20 I=1,10
ISN 0036           IF(SCALE(I) .GT. 1) GO TO 12
ISN 0038           COF1=  1.9956929213
ISN 0039           COF2=  4.3466235121
ISN 0040           COF3= -2.2512947895
ISN 0041           COF4=  0.5138902982
ISN 0042           GO TO 100
ISN 0043        12 IF(SCALE(I) .GT. 2)  GO TO 14
ISN 0045           COF1=  3.5568615913
ISN 0046           COF2=  8.1442881772
ISN 0047           COF3= -4.2801104006
ISN 0048           COF4=  0.9927138130
ISN 0049           GO TO 100
ISN 0050        14 IF(SCALE(I) .GT.3)  GO TO 16
ISN 0052           COF1=  6.5996029623
ISN 0053           COF2= 12.7208933095
ISN 0054           COF3= -6.1138320465
ISN 0055           COF4=  1.3742775228
ISN 0056           GO TO 100
ISN 0057        16 IF(SCALE(I) .GT. 4)   GO TO 18
ISN 0059           COF1= 11.3320824429
ISN 0060           COF2= 26.0865237549
ISN 0061           COF3=-13.9750489754
ISN 0062           COF4=  3.2743372209
ISN 0063           GO TO 100
ISN 0064        18 COF1= 19.8399731506
ISN 0065           COF2= 47.3033506494
ISN 0066           COF3=-28.4300100730
ISN 0067           COF4=  7.7254385568
ISN 0068       100 Z = COF1 + COF2*VRDG(I) + COF3*VRDG(I)*VRDG(I) + COF4
                  1*VRDG(I)*VRDG(I)*VRDG(I)
ISN 0069           VTOTAL(I) = Z
ISN 0070       125 RSTRIP(1) = 1.162
ISN 0071           RSTRIP(2) = 1.164
ISN 0072           RSTRIP(3) = 1.163
ISN 0073           RSTRIP(4) = 1.160
ISN 0074           RSTRIP(5) = 1.150
ISN 0075           RSTRIP(6) = 1.160
ISN 0076           RSTRIP(7) = 1.155
ISN 0077           RSTRIP(8) = 1.163
```

```
ISN 0078          RSTRIP(9) = 1.166
ISN 0079          RSTRIP(10) = 1.178
ISN 0080          RTOTAL(1) = 2.752
ISN 0081          RTOTAL(2) = 2.761
ISN 0082          RTOTAL(3) = 2.739
ISN 0083          RTOTAL(4) = 2.750
ISN 0084          RTOTAL(5) = 2.750
ISN 0085          RTOTAL(6) = 2.768
ISN 0086          RTOTAL(7) = 2.734
ISN 0087          RTOTAL(8) = 2.791
ISN 0088          RTOTAL(9) = 2.763
ISN 0089          RTOTAL(10) = 2.799
ISN 0090          AMPS(I) = VTOTAL(I)/RTOTAL(I)
ISN 0091          WATTS(I) = RSTRIP(I) * AMPS(I) * AMPS(I)
ISN 0092          QBTUHR(I) = 3.413 * WATTS(I)
ISN 0093          QFLUX(I) = QBTUHR(I)/ASEGFT
ISN 0094          TTC(I) = 32.523355 + 45.531510*MV(I) - 0.820318*MV(I)
                 1*MV(I)
ISN 0095          TWALL(I) = TTC(I) - (QBTUHR(I) * GROUP4)
ISN 0096          TFILM(I) = (TBULK + TWALL(I))/2.0
ISN 0097          DELT(I) = TWALL(I) - TBULK
ISN 0098          HX(I) = QFLUX(I)/(TWALL(I) - TBULK)
ISN 0099          IF(CODE .EQ. 1) GO TO 101
ISN 0101          IF(CODE .EQ. 2) GO TO 102
ISN 0103          IF(CODE .EQ. 3) GO TO 103
ISN 0105          IF(CODE .EQ. 4) GO TO 104
            C
            C     ** PHYSICAL PROPERTY EXPRESSIONS FOR 38.0 % CS/SS SOL **
            C
ISN 0107      101 CCX=CONCEN/100.
ISN 0108          DEN(I)=62.427961*(1.24*CCX+1.23*(1.-CCX))
ISN 0109          TK1=0.73*(0.358+0.0000643*TFILM(I)-0.000000011*
                 1TFILM(I)**2.0)
ISN 0110          TK2=0.0107
ISN 0111          THERMK(I)=TK1*(2.0*TK1+TK2-2.0*CCX*(TK1-TK2))/
                 1(2.0*TK1+TK2+CCX*(TK1-TK2))
ISN 0112          BETA(I)=(1.-CCX)*0.000214*(1.+0.000156*TFILM(I)+
                 10.000000542*TFILM(I)**2.)+CCX*0.001180*(1.+0.000214*
                 2TFILM(I))
ISN 0113          SPHT(I)=(1.038*(1.-CCX)+0.441*CCX)/(1.230*(1.-CCX)
                 1+1.24*CCX)
ISN 0114          NINDEX(I)=1.03925526+0.00428745*TFILM(I)-
                 10.00003016*TFILM(I)**2.0
ISN 0115          V(I)=-0.28868019-0.00691136*TFILM(I)-
                 10.00003493*TFILM(I)**2.0
ISN 0116          VIS(I) = EXP(V(I))
ISN 0117          KINDEX(I) = VIS(I) * (3600.0 **(2.0-NINDEX(I)))
ISN 0118          GO TO 110
            C
            C     ** PHYSICAL PROPERTY EXPRESSIONS FOR 39.0 % CS/SS SOL **
            C
ISN 0119      102 CCX=CONCEN/100.
ISN 0120          DEN(I)=62.427961*(1.24*CCX+1.23*(1.-CCX))
ISN 0121          TK1=0.73*(0.358+0.0000643*TFILM(I)-0.000000011*
                 1TFILM(I)**2.0)
ISN 0122          TK2=0.0107
```

```
 ISN 0123          THERMK(I)=TK1*(2.0*TK1+TK2-2.0*CCX*(TK1-TK2))/
                  1(2.0*TK1+TK2+CCX*(TK1-TK2))
 ISN 0124          BETA(I)=(1.-CCX)*0.000214*(1.+0.000156*TFILM(I)+
                  10.000000542*TFILM(I)**2.)+CCX*0.001180*(1.+0.000214*
                  2TFILM(I))
 ISN 0125          SPHT(I)=(1.038*(1.-CCX)+0.441*CCX)/(1.230*(1.-CCX)
                  1+1.24*CCX)
 ISN 0126          NINDEX(I)=1.40241864-0.00284363*TFILM(I)+
                  10.0000099*TFILM(I)**2.0
 ISN 0127          V(I)=0.13088331-0.01382273*TFILM(I)+
                  10.00001358*TFILM(I)**2.0
 ISN 0128          VIS(I) = EXP(V(I))
 ISN 0129          KINDEX(I) = VIS(I) * (3600.0 **(2.0-NINDEX(I)))
 ISN 0130          GO TO 110
             C
             C     ** PHYSICAL PROPERTY EXPRESSIONS FOR 41.0 % CS/SS SOL **
             C
 ISN 0131      103 CCX=CONCEN/100.
 ISN 0132          DEN(I)=62.427961*(1.24*CCX+1.23*(1.-CCX))
 ISN 0133          TK1=0.73*(0.358+0.0000643*TFILM(I)-0.000000011*
                  1TFILM(I)**2.0)
 ISN 0134          TK2=0.0107
 ISN 0135          THERMK(I)=TK1*(2.0*TK1+TK2-2.0*CCX*(TK1-TK2))/
                  1(2.0*TK1+TK2+CCX*(TK1-TK2))
 ISN 0136          BETA(I)=(1.-CCX)*0.000214*(1.+0.000156*TFILM(I)+
                  10.000000542*TFILM(I)**2.)+CCX*0.001180*(1.+0.000214*
                  2TFILM(I))
 ISN 0137          SPHT(I)=(1.038*(1.-CCX)+0.441*CCX)/(1.230*(1.-CCX)
                  1+1.24*CCX)
 ISN 0138          NINDEX(I)=1.40118940+0.00064992*TFILM(I)-
                  10.00001006*TFILM(I)**2.0
 ISN 0139          V(I)=0.1598198-0.00756106*TFILM(I)-
                  10.00001589*TFILM(I)**2.0
 ISN 0140          VIS(I) = EXP(V(I))
 ISN 0141          KINDEX(I) = VIS(I) * (3600.0 **(2.0-NINDEX(I)))
 ISN 0142          GO TO 110
             C
             C     ** PHYSICAL PROPERTY EXPRESSIONS FOR 42.0 % CS/SS SOL **
             C
 ISN 0143      104 CCX=CONCEN/100.
 ISN 0144          DEN(I)=62.427961*(1.24*CCX+1.23*(1.-CCX))
 ISN 0145          TK1=0.73*(0.358+0.0000643*TFILM(I)-0.000000011*
                  1TFILM(I)**2.0)
 ISN 0146          TK2=0.0107
 ISN 0147          THERMK(I)=TK1*(2.0*TK1+TK2-2.0*CCX*(TK1-TK2))/
                  1(2.0*TK1+TK2+CCX*(TK1-TK2))
 ISN 0148          BETA(I)=(1.-CCX)*0.000214*(1.+0.000156*TFILM(I)+
                  10.000000542*TFILM(I)**2.)+CCX*0.001180*(1.+0.000214*
                  2TFILM(I))
 ISN 0149          SPHT(I)=(1.038*(1.-CCX)+0.441*CCX)/(1.230*(1.-CCX)
                  1+1.24*CCX)
 ISN 0150          NINDEX(I)=1.54715146-0.00164812*TFILM(I)+
                  10.00000475*TFILM(I)**2.0
 ISN 0151          V(I)=0.14652677-0.00432161*TFILM(I)-
                  10.00002974*TFILM(I)**2.0
 ISN 0152          VIS(I) = EXP(V(I))
```

```
 ISN 0153            KINDEX(I) = VIS(I) * (3600.0 **(2.0-NINDEX(I)))
 ISN 0154            GO TO 110
              C
              C
 ISN 0155        110 NUX(I) = (HX(I) * LACRFT)/THERMK(I)
 ISN 0156            NUXD(I) = (HX(I) * DODFT)/THERMK(I)
 ISN 0157            C1 = (DEN(I)/KINDEX(I))**2.0
 ISN 0158            C2 = ((LACRFT) **(NINDEX(I) + 2.0))
 ISN 0159            C3 = GCONST * BETA(I) * (TWALL(I) - TBULK)
 ISN 0160            C4 = C3 **(2.0 - NINDEX(I))
 ISN 0161            NGR(I) = C1 * C2 * C4
 ISN 0162            NGRD(I) = NGR(I) * ((DODFT/LACRFT)**(NINDEX(I) + 2.0))
 ISN 0163            NGRDK(I) = C1 * GCONST * BETA(I) * (DODFT**3.0) *
                    1(TWALL(I) -TBULK)
 ISN 0164            C5 = (DEN(I) * SPHT(I))/THERMK(I)
 ISN 0165            C6 = KINDEX(I)/DEN(I)
 ISN 0166            C7 = 2.0/(NINDEX(I) + 1.0)
 ISN 0167            C8 = C6 ** C7
 ISN 0168            C9 =  (1.0 - NINDEX(I))/(1.0 + NINDEX(I))
 ISN 0169            C10 = LACRFT ** C9
 ISN 0170            CD10 = DODFT ** C9
 ISN 0171            C11 = (3.0 *(NINDEX(I) - 1.0))/(2.0*(1.0 + NINDEX(I)))
 ISN 0172            C12 = (LACRFT * C3) ** C11
 ISN 0173            CD12 = (DODFT * C3) ** C11
 ISN 0174            NPR(I) = C5 * C8 * C10 * C12
 ISN 0175            NPRD(I) = C5*C8*CD10*CD12
 ISN 0176            NPRK(I) = SPHT(I) * KINDEX(I)/THERMK(I)
 ISN 0177            NGRPR(I) = NPR(I) * NGR(I)
 ISN 0178            C13 = 1.0/(2.0 * (NINDEX(I) + 1.0))
 ISN 0179            C14 = NINDEX(I)/(3.0 *NINDEX(I) + 1.0)
 ISN 0180            NPRC14(I) = NPR(I) ** C14
 ISN 0181            NPRD14(I) = NPRD(I) ** C14
 ISN 0182            NGRC13(I) = NGR(I) ** C13
 ISN 0183            NGRD13(I) = NGRD(I) ** C13
 ISN 0184            NGPROD(I) = NPRC14(I) * NGRC13(I)
 ISN 0185            NGPD(I) = NPRD14(I) * NGRD13(I)
 ISN 0186            NUGRPR(I) = NUX(I)/NGPROD(I)
 ISN 0187            ANGLE(I) = 9 *((2*I) - 1)
 ISN 0188            NO(I) = I
 ISN 0189            THETA(I) = -0.49538476 - 0.04645549*NINDEX(I) +
                    10.00153830*NINDEX(I)*NINDEX(I)
 ISN 0190            FACR(I) = 2.29349982 - 2.20172694*NINDEX(I) +
                    10.92576695*NINDEX(I)*NINDEX(I)
 ISN 0191            S = 5.0/(3.0*NINDEX(I))
 ISN 0192            B = 0.30
 ISN 0193            C = (S**NINDEX(I))
 ISN 0194            E = 2.0
 ISN 0195            C25 = 1.0/S
 ISN 0196            C26 = 1.0/(S**2.0)
 ISN 0197            C27 = 1.0/(S**3.0)
 ISN 0198            C28 = 1.0/(S**4.0)
 ISN 0199            C29 = 1.0/(S**5.0)
 ISN 0200            CGR1 = C25 - 4.0*C26 + 48.0*C28 - 120.*C29
 ISN 0201            CGR2 = C27 + 6.0*C28 + 10.0*C29
 ISN 0202            C30 = EXP(S)
 ISN 0203            C31 = 12.0/C30
```

```
ISN 0204          D = CGR1 + C31*CGR2
ISN 0205          CGR3 = (NINDEX(I)) /(3.0*NINDEX(I) + 1.0)
ISN 0206          CGR4 = (2.0*NINDEX(I) + 1.0)/(3.0*NINDEX(I) + 1.0)
ISN 0207          CGR5 = CGR4 ** CGR3
ISN 0208          CGR6 = 1.0/(3.0*NINDEX(I) + 1.0)
ISN 0209          CN(I) = E * ((B/C)**CGR6) * ((D/E)**CGR3)
ISN 0210      120 IF(CASE.EQ.1) GO TO 20
ISN 0212          D1=(DEN(I)/KINDEX(I))**2.0
ISN 0213          D2=LACRFT**4.0
ISN 0214          D3=GCONST*BETA(I)*QFLUX(I)/THERMK(I)
ISN 0215          D4=D3**(2.0-NINDEX(I))
ISN 0216          NGR2(I)=D1*D2*D4
ISN 0217          NGRD2(I)=NGR2(I)*((DODFT/LACRFT)**4.0)
ISN 0218          D5=DEN(I)*SPHT(I)/THERMK(I)
ISN 0219          D6=KINDEX(I)/DEN(I)
ISN 0220          D7=2.0/(NINDEX(I)+1.0)
ISN 0221          D8=D6**D7
ISN 0222          D9=(2.0*(NINDEX(I)-1.0))/(1.0+NINDEX(I))
ISN 0223          D10=LACRFT**D9
ISN 0224          DD10=DODFT**D9
ISN 0225          D11=(3.0*(NINDEX(I)-1.0))/(2.0*(1.0+NINDEX(I)))
ISN 0226          D12=D3**D11
ISN 0227          NPR2(I)=D5*D8*D10*D12
ISN 0228          NPRD2(I)=D5*D8*DD10*D12
ISN 0229          NPRK2(I)=SPHT(I)**KINDEX(I)/THERMK(I)
ISN 0230          NGRPR2(I)=NPR2(I)*NGR2(I)
ISN 0231          D13=(3.0*NINDEX(I)+1.0)/(2.0*(NINDEX(I)+1.0)*
                 1(3.0*NINDEX(I)+2.0))
ISN 0232          D14=NINDEX(I)/(3.0*NINDEX(I)+2.0)
ISN 0233          PRC214(I)=NPR2(I)**D14
ISN 0234          PRD214(I)=NPRD2(I)**D14
ISN 0235          GRC213(I)=NGR2(I)**D13
ISN 0236          GRD213(I)=NGRD2(I)**D13
ISN 0237          GPROD2(I)=PRC214(I)*GRC213(I)
ISN 0238          NGPD2(I)=PRD214(I)*GRD213(I)
ISN 0239          UGRPR2(I)=NUX(I)/GPROD2(I)
ISN 0240      130 DGR3=(NINDEX(I))/(3.0*NINDEX(I)+2.0)
ISN 0241          DGR4=(2.0*NINDEX(I)+2.0)/(3.0*NINDEX(I)+2.0)
ISN 0242          DGR5=DGR4**DGR3
ISN 0243          DGR6=1.0/(3.0*NINDEX(I)+2.0)
ISN 0244          DGR7=2.0*NINDEX(I)+1.0
ISN 0245          DGR8=E**DGR7
ISN 0246          DGR9=NINDEX(I)
ISN 0247          DGR10=D**DGR9
ISN 0248          KN(I)=DGR5*((B*DGR10*DGR8/C)**DGR6)
ISN 0249          SUMKN=SUMKN+KN(I)
ISN 0250       20 CONTINUE
            C
            C     ***** AVERAGE PHYSICAL PROPERTY DETERMINATION *****
            C
ISN 0251          SUMK = 0.0
ISN 0252          SUMDEN = 0.0
ISN 0253          SUMBET = 0.0
ISN 0254          SUMSPH=0.0
ISN 0255          SUMN = 0.0
ISN 0256          SUMKIN = 0.0
```

```
 ISN 0257             SUMTHE = 0.0
 ISN 0258             SUMFAC = 0.0
 ISN 0259             SUMCN = 0.0
 ISN 0260             DO 68 I=1,10
 ISN 0261             SUMK = SUMK + THERMK(I)
 ISN 0262             SUMDEN = SUMDEN + DEN(I)
 ISN 0263             SUMBET = SUMBET + BETA(I)
 ISN 0264             SUMSPH=SUMSPH+SPHT(I)
 ISN 0265             SUMN = SUMN + NINDEX(I)
 ISN 0266             SUMKIN = SUMKIN + KINDEX(I)
 ISN 0267             SUMTHE = SUMTHE + THETA(I)
 ISN 0268             SUMFAC = SUMFAC + FACR(I)
 ISN 0269             SUMCN = SUMCN + CN(I)
 ISN 0270          68 CONTINUE
 ISN 0271             KAVG = SUMK/10.0
 ISN 0272             DENAVG = SUMDEN/10.0
 ISN 0273             BETAVG = SUMBET/10.0
 ISN 0274             SPHAVG=SUMSPH/10.
 ISN 0275             NAVG = SUMN /10.0
 ISN 0276             KINAVG = SUMKIN/10.0
 ISN 0277             THEAVG = SUMTHE/10.0
 ISN 0278             FACAVG = SUMFAC/10.0
 ISN 0279             CNAVG = SUMCN/10.0
 ISN 0280             IF(CASE.EQ.1) GO TO 69
 ISN 0282             KNAVG=SUMKN/10.
                C
                C     ***** WRITE OUTPUT STATEMENTS *****
                C
 ISN 0283          69 WRITE(6,2)
 ISN 0284           2 FORMAT(1H1,////, 21X, 'LOCAL FREE CONVECTION FROM',
                     11X, 'HORIZONTAL CYLINDER'/35X,'TO POWER-LAW FLUIDS'/)
 ISN 0285             IF(CASE.EQ.2) GO TO 222
 ISN 0287             WRITE (6,4) RUN
 ISN 0288           4 FORMAT(31X,'RUN ',I3,'    ISOTHERMAL CASE'//)
 ISN 0289             GO TO 333
 ISN 0290         222 WRITE(6,44) RUN
 ISN 0291          44 FORMAT(31X,'RUN ',I3,'    CONSTANT FLUX CASE'//)
 ISN 0292         333 WRITE(6,6)
 ISN 0293           6 FORMAT(31X,'***** FLUID PROPERTIES *****'/)
 ISN 0294             WRITE(6,8) CONCEN, FL, U,ID, SPHAVG
 ISN 0295           8 FORMAT(16X,'FLUID    = ',F4.1,1X,'%',1X,3A3,12X,
                     1'SPHEAT  = ', F5.3)
 ISN 0296             WRITE(6,22) TBULK, BETAVG
 ISN 0297          22 FORMAT(16X,'TBULK    = ',F5.1,23X,'BETA     = ',F7.5)
 ISN 0298             WRITE(6,24) DENAVG, KINAVG
 ISN 0299          24 FORMAT(16X,'DENSITY = ',F5.2,23X,'KLBFTHR = ',F7.2)
 ISN 0300             WRITE(6,26) KAVG, NAVG
 ISN 0301          26 FORMAT(16X,'THERMK  = ', F5.3, 23X, 'NINDEX  = ',
                     1F5.3//)
 ISN 0302             WRITE(6,28)
 ISN 0303          28 FORMAT(26X, '***** REDUCED EXPERIMENTAL DATA *****'/)
 ISN 0304             WRITE(6,30)
 ISN 0305          30 FORMAT(16X, 'NO', 1X, 'ANGLE', 2X, 'NUX', 3X, 'NUGPD',
                     13X, 'HX', 4X, 'QFLUX', 3X, 'BTUHR', 3X, 'TWALL', 2X,
                     2'DELT T')
 ISN 0306             IF(CASE.EQ.2) GO TO 938
```

```
ISN 0308           WRITE(6,32) (NO(I), ANGLE(I), NUX(I), NUGRPR(I),
                  1HX(I), QFLUX(I), QBTUHR(I), TWALL(I), DELT(I),
                  2I=1,10)
ISN 0309        32 FORMAT(16X, I2, 1X, F4.0, 2X, F5.2, 2X, F5.3, 2X,
                  1F5.1, 2X, F6.0, 2X, F5.1, 3X, F5.1, 2X, F5.1)
ISN 0310           GO TO 140
ISN 0311       938 WRITE(6,32) (NO(I), ANGLE(I), NUX(I), UGRPR2(I),
                  1HX(I), QFLUX(I), QBTUHR(I), TWALL(I), DELT(I),
                  2I=1,10)
ISN 0312       140 IF(CASE.EQ.1) GO TO 141
ISN 0314           WRITE(6,35)
ISN 0315        35 FORMAT(//,21X,'***** INTEGRAL SOLUTIONS FOR CONSTANT',
                  11X,'FLUX *****'/)
ISN 0316           WRITE(6,37)
ISN 0317        37 FORMAT(41X,'INTEGRAL')
ISN 0318           WRITE(6,39) KNAVG
ISN 0319        39 FORMAT (40X,'KN =', F6.3)
ISN 0320           WRITE(6,43)
ISN 0321        43 FORMAT(//26X,'NO',1X,'ANGLE',2X,'NUX',3X,
                  1'NUGPD',4X,'HX',4X,'SHEAR')
ISN 0322           GO TO 142
ISN 0323       141 WRITE(6,34)
ISN 0324        34 FORMAT(//,18X,'***** SIMILAR AND INTEGRAL SOLUTIONS',
                  11X,'FOR ISOTHERMAL *****'/)
ISN 0325           WRITE(6,36)
ISN 0326        36 FORMAT(34X, 'ACRIVOS', 19X, 'INTEGRAL')
ISN 0327           WRITE(6,38) THEAVG, CNAVG
ISN 0328        38 FORMAT(31X, 'THETA=', F7.3, 15X, 'CN =', F6.3)
ISN 0329           WRITE(6,40) FACAVG
ISN 0330        40 FORMAT(31X, 'FACR =', F7.3/)
ISN 0331           WRITE(6,42)
ISN 0332        42 FORMAT(16X, 'NO', 1X, 'ANGLE', 2X, 'NUX', 3X,
                  1'NUGPD', 4X, 'HX', 4X, 'SHEAR', 4X, 'NUX', 3X,
                  2'NUGPD', 4X, 'HX')
             C
             C     ******* SIMILAR AND INTEGRAL SOLUTION RESULTS ******
             C
ISN 0333       142 J=1
ISN 0334           ASUM = 0.0
ISN 0335           ASUM2 = 0.0
ISN 0336           SUMANU = 0.0
ISN 0337           SUMSHR = 0.0
ISN 0338           DEGREE = 0.0
ISN 0339           RAD = 0.0
ISN 0340           SUMNUI = 0.0
ISN 0341           DIVDEG = 0.25
ISN 0342           DIVRAD = 0.01745 * DIVDEG
ISN 0343           DELDEG = DIVDEG/2.0
ISN 0344           DELRAD = DIVRAD/2.0
ISN 0345       150 I = J
ISN 0346           ANGDEG(I) = 9*((2*I) -1)
ISN 0347           C15 = (2.0 * NINDEX(I) + 1.0)/(3.0 * NINDEX(I) + 1.0)
ISN 0348           C16 = (NINDEX(I))/(3.0 * NINDEX(I) + 1.0)
ISN 0349           C17 = 1.0/(2.0 * NINDEX(I) + 1.0)
ISN 0350           D16=NINDEX(I)/(3.0*NINDEX(I)+2.0)
ISN 0351           D17=1.0/(2.0*NINDEX(I)+2.0)
```

```
 ISN 0352            C18 = (3.0 * NINDEX(I) +1.0)/(2.0 * NINDEX(I) + 1.0)
 ISN 0353            C19 = 1.0/(3.0 * NINDEX(I) + 1.0)
 ISN 0354            C20 = C18 ** C19
 ISN 0355            C21 = 1.0/(2.0 *(NINDEX(I) + 1.0))
 ISN 0356            C22 = 2.0/(2.0 * NINDEX(I) + 1.0)
 ISN 0357            C23=(32.2*LACRFT*BETA(I)*(TWALL(I)-TBULK))**0.5
 ISN 0358            C24 = C15 ** C16
 ISN 0359            C32 = 2.0 ** (NINDEX(I)/(2.0*(NINDEX(I) + 1.0)))
 ISN 0360            NUMBER = I
               C
               C     ***** NUMERICAL INTEGRATION BY SIMPSONS RULE *****
               C
               C     VARIABLES:  H=DELRAD,  A=(H/3)*(F1 + 4F2 + F3)
 ISN 0361        160 DEGREE = DEGREE + DIVDEG
 ISN 0362            RAD = RAD + DIVRAD
 ISN 0363            IF(RAD .GT. DIVRAD) GO TO 190
 ISN 0365            FUN1 = 0.0
 ISN 0366            GO TO 192
 ISN 0367        190 FUN1 = (SIN(RAD - DIVRAD))**C17
 ISN 0368        192 FUN2 = (SIN(RAD - DELRAD))**C17
 ISN 0369            FUN3 = (SIN(RAD))**C17
 ISN 0370            AREA = (DELRAD/3.0)*(FUN1 + 4.0*FUN2 + FUN3)
 ISN 0371            ASUM = ASUM + AREA
 ISN 0372            FUN12 = (SIN(RAD-DIVRAD))**D17
 ISN 0373            FUN22 = (SIN(RAD-DELRAD))**D17
 ISN 0374            FUN32 = (SIN(RAD))**D17
 ISN 0375            AREA2 = (DELRAD/3.0)*(FUN12+4.0*FUN22+FUN32)
 ISN 0376            ASUM2 = ASUM2+AREA2
 ISN 0377            IF(DEGREE . EQ. ANGDEG(I)) GO TO 170
 ISN 0379            GO TO 160
 ISN 0380        170 FUN4 = FUN3/(ASUM**C16)
 ISN 0381            FUN42 = FUN32/(ASUM2**D16)
 ISN 0382            FUN5 = (SIN(RAD)**C22)*(ASUM**C19)
 ISN 0383            FUNSHR = (C20 * C23 * (NGR(I)**C21) * FUN5)/
                    1(LACRFT*(NPR(I)**C19))
               C
               C     ----- ACRIVOS QUANTITIES -----
               C
 ISN 0384        161 NUGPAC = (-C24) * FUN4 * THETA(I)
 ISN 0385            NUXACR = NUGPAC * NGPROD(I)
 ISN 0386            NUXACD = NUGPAC * NGPD(I)
 ISN 0387            HXACR = (THERMK(I) * NUXACR)/LACRFT
 ISN 0388            HXACD = NUXACD * THERMK(I)/DODFT
 ISN 0389            SHRACR = FUNSHR * FACR(I)
 ISN 0390            SUMANU = SUMANU + NUXACD
 ISN 0391            SUMSHR = SUMSHR + SHRACR
 ISN 0392            IF(CASE.GT.1) GO TO 171
               C
               C     -----ISOTHERMAL INTEGRAL SOLUTION -----
               C
 ISN 0394        300 NUGPIN = C24 * FUN4 * CN(I)
 ISN 0395            NUXINT = NUGPIN * NGPROD(I)
 ISN 0396            HBARIN = (NUXINT * THERMK(I))/LACRFT
 ISN 0397            SUMNUI = SUMNUI + NUXINT
 ISN 0398            WRITE(6,52) NUMBER, DEGREE, NUXACR, NUGPAC, HXACR,
                    1SHRACR, NUXINT, NUGPIN, HBARIN
```

```
ISN 0399        52 FORMAT(16X,I2, 1X, F4.0, 2X, F5.2, 2X, F5.3, 2X,
                  1F5.1, 2X, F6.3, 3X, F5.2, 2X, F5.3, 2X, F5.1)
ISN 0400           GO TO 172
             C
             C     -----CONSTANT FLUX INTEGRATION SOLUTION-----
ISN 0401       171 UGPIN2 = FUN42*KN(I)
ISN 0402           UXINT2=UGPIN2*GPROD2(I)
ISN 0403           BARIN2=(UXINT2*THERMK(I))/LACRFT
ISN 0404           SUMNUI = SUMNUI + UXINT2
ISN 0405           WRITE(6,53) NUMBER,DEGREE,UXINT2,UGPIN2,BARIN2,SHRACR
ISN 0406        53 FORMAT(26X,I2,1X,F4.0,2X,F5.2,2X,F5.3,2X,F5.1,2X,F6.3)
             C
ISN 0407       172 IF(DEGREE.GE.171.0) GO TO 180
ISN 0409           J = J + 1
ISN 0410           GO TO 150
             C
             C     ************ AVERAGE HEAT TRANSFER RESULTS **********
             C
ISN 0411       180 SUMHX = 0.0
ISN 0412           SUMPR = 0.0
ISN 0413           SUMGR = 0.0
ISN 0414           SUMNU = 0.0
ISN 0415           SUMGPD = 0.0
ISN 0416           IF(CASE.GT.1) GO TO 181
ISN 0418           DO 200 I=1,10
ISN 0419           SUMHX = SUMHX + HX(I)
ISN 0420           SUMNU = SUMNU + NUX(I)
ISN 0421           SUMPR = SUMPR + NPR(I)
ISN 0422           SUMGR = SUMGR + NGR(I)
ISN 0423           SUMGPD = SUMGPD + NGPD(I)
ISN 0424       200 CONTINUE
ISN 0425           GO TO 201
ISN 0426       181 DO 203 I=1,10
ISN 0427           SUMHX=SUMHX+HX(I)
ISN 0428           SUMNU = SUMNU + NUX(I)
ISN 0429           SUMPR = SUMPR + NPR2(I)
ISN 0430           SUMGR = SUMGR + NGR2(I)
ISN 0431           SUMGPD=SUMGPD+NGPD2(I)
ISN 0432       203 CONTINUE
ISN 0433       201 HBAR=SUMHX/10.0
ISN 0434           SHRAVG = SUMSHR/10.0
ISN 0435           NUAVG = SUMNU/10.0
ISN 0436           NGRAVG = SUMGR/10.0
ISN 0437           NPRAVG = SUMPR/10.0
ISN 0438           NGPAVG = NGRAVG * NPRAVG
ISN 0439           NUAVGI = SUMNUI/10.0
ISN 0440           NGPDAV = SUMGPD/10.0
ISN 0441           NUGPD1 = NUDAVG/(NGPAVG ** 0.25)
ISN 0442           NUGPD2 = NUDAVG/NGPDAV
ISN 0443           NUEKRT = 0.4 * NGPDAV
ISN 0444           NUACAV = SUMANU/10.0
ISN 0445           WRITE(6,54)
ISN 0446        54 FORMAT(//,24X,'***** AVERAGE HEAT TRANSFER RESULTS',
                  11X, '*****'/)
ISN 0447           IF(CASE.GT.1) GO TO 207
ISN 0449           WRITE(6,56) NPRAVG, NGRAVG, NUAVG
```

```
ISN 0450         56 FORMAT(16X,'NPRC=',F7.1,9X,'NGRC=',F8.2,5X,
                   1'NUAVG EXPMTL =',F6.2)
ISN 0451            WRITE(6,58) NGPAVG, SHRAVG, NUAVGI
ISN 0452         58 FORMAT(16X,'NGRPRC=',F10.0,4X,'SHRAVG=',F6.3,5X,
                   1'NUAVG INTGRL =',F6.2)
ISN 0453            GO TO 208
ISN 0454        207 WRITE(6,57) NPRAVG,NGRAVG,NUAVG
ISN 0455         57 FORMAT(16X,'NPRK=',F7.1,9X,'NGRK=',F8.2,5X,
                   1'NUAVG EXPMTL =',F6.2)
ISN 0456            WRITE(6,59) NGPAVG,SHRAVG,NUAVGI
ISN 0457         59 FORMAT(16X,'NGRPRK=',F10.0,4X,'SHRAVG=',F6.3,5X,
                   1'NUAVG INTGRL =',F6.2)
ISN 0458        208 IF(RUN.EQ.24) GO TO 701
ISN 0460            GO TO 1
ISN 0461        701 IF(CASE.EQ.1) GO TO 70
ISN 0463            GO TO 1
ISN 0464         70 WRITE(6,72)
ISN 0465         72 FORMAT(1H1)
ISN 0466        210 STOP
ISN 0467            END
```

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 1 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 74.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 252.97
THERMK	= 0.145	NINDEX	= 1.185

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.10	0.661	17.2	348.	5.6	94.2	20.2
2	27.	9.84	0.644	16.8	347.	5.5	94.6	20.6
3	45.	9.59	0.625	16.4	352.	5.6	95.5	21.5
4	63.	9.34	0.610	15.9	348.	5.6	95.8	21.8
5	81.	9.05	0.591	15.4	345.	5.5	96.4	22.4
6	99.	8.47	0.553	14.4	344.	5.5	97.8	23.8
7	117.	8.24	0.535	14.1	351.	5.6	98.9	24.9
8	135.	7.57	0.494	12.9	339.	5.4	100.2	26.2
9	153.	7.05	0.457	12.0	347.	5.6	102.8	28.8
10	171.	6.32	0.410	10.8	341.	5.5	105.6	31.6

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.04	0.657	17.1	0.101
2	27.	9.61	0.629	16.4	0.264
3	45.	9.34	0.609	15.9	0.409
4	63.	9.02	0.589	15.4	0.521
5	81.	8.66	0.566	14.8	0.603
6	99.	8.25	0.539	14.1	0.666
7	117.	7.79	0.506	13.3	0.677
8	135.	7.12	0.465	12.1	0.635
9	153.	6.31	0.409	10.8	0.539
10	171.	4.85	0.314	8.3	0.314

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK= 8879.2	NGRK= 67.81	NUAVG EXPMTL = 8.56
NGRPRK= 602091.	SHRAVG= 0.473	NUAVG INTGRL = 8.10

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 2 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 74.5	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 250.31
THERMK	= 0.145	NINDEX	= 1.183

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.29	0.651	17.6	410.	6.6	97.9	23.4
2	27.	10.15	0.642	17.3	408.	6.5	98.1	23.6
3	45.	10.12	0.638	17.3	415.	6.6	98.5	24.0
4	63.	9.50	0.599	16.2	410.	6.6	99.8	25.3
5	81.	9.34	0.590	15.9	407.	6.5	100.0	25.5
6	99.	8.95	0.565	15.3	405.	6.5	101.0	26.5
7	117.	8.55	0.537	14.6	413.	6.6	102.8	28.3
8	135.	7.90	0.499	13.5	399.	6.4	104.1	29.6
9	153.	7.34	0.460	12.5	409.	6.5	107.1	32.6
10	171.	6.66	0.417	11.4	402.	6.4	109.9	35.4

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.39	0.657	17.7	0.113
2	27.	9.94	0.629	17.0	0.293
3	45.	9.66	0.609	16.5	0.446
4	63.	9.34	0.589	15.9	0.584
5	81.	8.96	0.566	15.3	0.669
6	99.	8.54	0.539	14.6	0.727
7	117.	8.06	0.506	13.8	0.750
8	135.	7.37	0.465	12.6	0.700
9	153.	6.53	0.409	11.2	0.597
10	171.	5.02	0.314	8.6	0.345

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK= 8788.7	NGRK= 82.62	NUAVG EXPMTL = 8.88
NGRPRK= 726102.	SHRAVG= 0.522	NUAVG INTGRL = 8.38

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 3 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 74.5	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 248.82
THERMK	= 0.145	NINDEX	= 1.181

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.70	0.658	18.3	470.	7.5	100.2	25.7
2	27.	10.61	0.654	18.1	468.	7.5	100.3	25.8
3	45.	10.05	0.616	17.2	475.	7.6	102.2	27.7
4	63.	9.98	0.613	17.0	470.	7.5	102.1	27.6
5	81.	9.56	0.588	16.3	466.	7.5	103.0	28.5
6	99.	9.24	0.568	15.8	464.	7.4	103.9	29.4
7	117.	8.88	0.542	15.2	473.	7.6	105.7	31.2
8	135.	8.21	0.504	14.0	457.	7.3	107.1	32.6
9	153.	7.84	0.478	13.4	468.	7.5	109.4	34.9
10	171.	7.01	0.427	12.0	461.	7.4	112.9	38.4

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.67	0.657	18.2	0.122
2	27.	10.21	0.628	17.4	0.314
3	45.	9.94	0.609	17.0	0.497
4	63.	9.59	0.589	16.4	0.624
5	81.	9.22	0.566	15.7	0.730
6	99.	8.78	0.539	15.0	0.787
7	117.	8.29	0.506	14.2	0.810
8	135.	7.57	0.465	12.9	0.756
9	153.	6.71	0.409	11.5	0.631
10	171.	5.16	0.314	8.8	0.369

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=	8752.8	NGRK=	96.32	NUAVG EXPMTL =	9.21
NGRPRK=	843043.	SHRAVG=	0.564	NUAVG INTGRL =	8.61

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 4 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 75.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 247.14
THERMK	= 0.145	NINDEX	= 1.179

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.08	0.666	18.9	526.	8.4	102.8	27.8
2	27.	10.78	0.648	18.4	524.	8.4	103.4	28.4
3	45.	10.58	0.633	18.1	532.	8.5	104.4	29.4
4	63.	10.23	0.613	17.5	526.	8.4	105.1	30.1
5	81.	9.77	0.586	16.7	521.	8.3	106.2	31.2
6	99.	9.23	0.553	15.8	519.	8.3	107.9	32.9
7	117.	9.01	0.537	15.4	530.	8.5	109.4	34.4
8	135.	8.24	0.493	14.1	512.	8.2	111.4	36.4
9	153.	8.01	0.476	13.7	524.	8.4	113.3	38.3
10	171.	7.34	0.436	12.6	516.	8.3	116.1	41.1

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.92	0.656	18.6	0.129
2	27.	10.45	0.628	17.9	0.339
3	45.	10.17	0.609	17.4	0.524
4	63.	9.83	0.589	16.8	0.672
5	81.	9.45	0.566	16.1	0.787
6	99.	9.00	0.539	15.4	0.866
7	117.	8.50	0.506	14.5	0.881
8	135.	7.77	0.465	13.3	0.830
9	153.	6.88	0.409	11.8	0.683
10	171.	5.29	0.314	9.0	0.392

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK= 8613.9	NGRK= 112.25	NUAVG EXPMTL = 9.43
NGRPRK= 966953.	SHRAVG= 0.610	NUAVG INTGRL = 8.83

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 5 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 75.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 246.19
THERMK	= 0.145	NINDEX	= 1.177

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.15	0.657	19.0	579.	9.3	105.4	30.4
2	27.	10.95	0.645	18.7	576.	9.2	105.8	30.8
3	45.	10.67	0.626	18.2	585.	9.4	107.1	32.1
4	63.	10.29	0.605	17.6	578.	9.3	107.9	32.9
5	81.	10.02	0.589	17.1	573.	9.2	108.5	33.5
6	99.	9.53	0.560	16.3	571.	9.1	110.1	35.1
7	117.	9.17	0.535	15.7	583.	9.3	112.2	37.2
8	135.	8.60	0.505	14.7	563.	9.0	113.3	38.3
9	153.	8.01	0.466	13.7	576.	9.2	117.1	42.1
10	171.	6.73	0.389	11.5	567.	9.1	124.3	49.3

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.13	0.656	19.0	0.138
2	27.	10.66	0.628	18.2	0.361
3	45.	10.38	0.609	17.7	0.561
4	63.	10.03	0.589	17.1	0.721
5	81.	9.63	0.566	16.5	0.833
6	99.	9.18	0.539	15.7	0.911
7	117.	8.67	0.506	14.8	0.939
8	135.	7.93	0.465	13.5	0.867
9	153.	7.03	0.409	12.0	0.740
10	171.	5.43	0.314	9.3	0.458

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK= 8495.7	NGRK= 128.03	NUAVG EXPMTL = 9.51
NGRPRK= 1087745.	SHRAVG= 0.653	NUAVG INTGRL = 9.01

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 6 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID = 38.0 % CS/SS SOL
TBULK = 76.0
DENSITY = 77.02
THERMK = 0.145

SPHEAT = 0.657
BETA = 0.00059
KLBFTHR = 245.06
NINDEX = 1.174

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.27	0.651	19.3	627.	10.0	108.6	32.6
2	27.	10.93	0.631	18.7	624.	10.0	109.4	33.4
3	45.	10.75	0.619	18.4	634.	10.1	110.5	34.5
4	63.	10.44	0.602	17.8	627.	10.0	111.1	35.1
5	81.	10.23	0.590	17.5	622.	10.0	111.6	35.6
6	99.	9.79	0.564	16.7	619.	9.9	113.0	37.0
7	117.	9.38	0.537	16.0	632.	10.1	115.4	39.4
8	135.	8.83	0.508	15.1	610.	9.8	116.4	40.4
9	153.	8.23	0.469	14.1	624.	10.0	120.4	44.4
10	171.	7.40	0.421	12.7	615.	9.8	124.6	48.6

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.34	0.655	19.4	0.147
2	27.	10.87	0.628	18.6	0.388
3	45.	10.58	0.609	18.1	0.599
4	63.	10.23	0.589	17.5	0.767
5	81.	9.82	0.567	16.8	0.882
6	99.	9.36	0.539	16.0	0.961
7	117.	8.84	0.506	15.1	0.994
8	135.	8.08	0.465	13.8	0.916
9	153.	7.17	0.409	12.3	0.782
10	171.	5.51	0.314	9.4	0.456

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK= 8300.5 NGRK= 145.88 NUAVG EXPMTL = 9.72
NGRPRK= 1210852. SHRAVG= 0.689 NUAVG INTGRL = 9.18

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 7 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 73.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 208.44
THERMK	= 0.142	NINDEX	= 1.232

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	9.91	0.659	16.6	348.	5.6	94.0	21.0
2	27.	9.61	0.639	16.1	347.	5.5	94.5	21.5
3	45.	9.34	0.619	15.6	352.	5.6	95.5	22.5
4	63.	9.08	0.603	15.2	348.	5.6	95.9	22.9
5	81.	8.66	0.576	14.5	345.	5.5	96.8	23.8
6	99.	8.40	0.558	14.1	344.	5.5	97.4	24.4
7	117.	8.00	0.529	13.4	351.	5.6	99.2	26.2
8	135.	7.37	0.490	12.3	339.	5.4	100.5	27.5
9	153.	6.99	0.462	11.7	347.	5.6	102.6	29.6
10	171.	6.33	0.418	10.6	341.	5.5	105.2	32.2

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.00	0.665	16.7	0.100
2	27.	9.49	0.632	15.9	0.253
3	45.	9.20	0.610	15.4	0.388
4	63.	8.87	0.589	14.8	0.491
5	81.	8.50	0.565	14.2	0.572
6	99.	8.09	0.538	13.5	0.613
7	117.	7.64	0.505	12.8	0.632
8	135.	6.98	0.464	11.7	0.592
9	153.	6.20	0.409	10.4	0.498
10	171.	4.78	0.316	8.0	0.292

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=12081.9	NGRK= 39.81	NUAVG EXPMTL = 8.37
NGRPRK= 481026.	SHRAVG= 0.443	NUAVG INTGRL = 7.98

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 8 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 74.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 207.20
THERMK	= 0.142	NINDEX	= 1.229

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.36	0.667	17.4	410.	6.6	97.7	23.7
2	27.	9.98	0.642	16.7	408.	6.5	98.4	24.4
3	45.	9.59	0.615	16.1	415.	6.6	99.8	25.8
4	63.	9.34	0.599	15.6	410.	6.6	100.2	26.2
5	81.	8.96	0.576	15.0	407.	6.5	101.1	27.1
6	99.	8.65	0.556	14.5	405.	6.5	102.0	28.0
7	117.	8.36	0.535	14.0	413.	6.6	103.5	29.5
8	135.	7.71	0.495	12.9	399.	6.4	104.9	30.9
9	153.	7.35	0.470	12.3	409.	6.5	107.1	33.1
10	171.	6.74	0.431	11.3	402.	6.4	109.6	35.6

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.33	0.665	17.3	0.109
2	27.	9.81	0.631	16.4	0.279
3	45.	9.51	0.610	15.9	0.431
4	63.	9.17	0.589	15.4	0.545
5	81.	8.80	0.565	14.7	0.633
6	99.	8.37	0.538	14.0	0.682
7	117.	7.90	0.505	13.2	0.696
8	135.	7.22	0.464	12.1	0.652
9	153.	6.41	0.409	10.7	0.545
10	171.	4.94	0.316	8.3	0.317

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=11967.2	NGRK= 48.57	NUAVG EXPMTL = 8.70
NGRPRK= 581243.	SHRAVG= 0.489	NUAVG INTGRL = 8.25

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 9 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 74.5	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 206.04
THERMK	= 0.142	NINDEX	= 1.226

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.69	0.669	17.9	470.	7.5	100.7	26.2
2	27.	10.25	0.642	17.2	468.	7.5	101.7	27.2
3	45.	10.01	0.625	16.8	475.	7.6	102.8	28.3
4	63.	9.73	0.608	16.3	470.	7.5	103.3	28.8
5	81.	9.32	0.583	15.6	466.	7.5	104.3	29.8
6	99.	8.80	0.550	14.7	464.	7.4	105.9	31.4
7	117.	8.45	0.525	14.2	473.	7.6	107.9	33.4
8	135.	7.93	0.495	13.3	457.	7.3	108.9	34.4
9	153.	7.48	0.464	12.5	468.	7.5	111.8	37.3
10	171.	6.86	0.425	11.5	461.	7.4	114.6	40.1

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.61	0.665	17.8	0.118
2	27.	10.08	0.631	16.9	0.303
3	45.	9.77	0.610	16.4	0.463
4	63.	9.42	0.589	15.8	0.586
5	81.	9.04	0.565	15.1	0.682
6	99.	8.61	0.538	14.4	0.747
7	117.	8.13	0.505	13.6	0.767
8	135.	7.43	0.464	12.5	0.709
9	153.	6.59	0.409	11.1	0.599
10	171.	5.09	0.316	8.5	0.348

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=11879.8	NGRK= 57.17	NUAVG EXPMTL = 8.95
NGRPRK= 679217.	SHRAVG= 0.532	NUAVG INTGRL = 8.48

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 10 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 75.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 205.01
THERMK	= 0.142	NINDEX	= 1.225

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.87	0.665	18.2	526.	8.4	103.9	28.9
2	27.	10.55	0.646	17.7	524.	8.4	104.6	29.6
3	45.	10.30	0.628	17.3	532.	8.5	105.8	30.8
4	63.	9.88	0.603	16.6	526.	8.4	106.7	31.7
5	81.	9.63	0.588	16.1	521.	8.3	107.3	32.3
6	99.	9.26	0.565	15.5	519.	8.3	108.5	33.5
7	117.	8.84	0.537	14.8	530.	8.5	110.8	35.8
8	135.	8.31	0.507	13.9	512.	8.2	111.7	36.7
9	153.	7.85	0.476	13.2	524.	8.4	114.8	39.8
10	171.	7.12	0.432	11.9	516.	8.3	118.2	43.2

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.85	0.664	18.2	0.127
2	27.	10.31	0.631	17.3	0.323
3	45.	10.00	0.610	16.8	0.494
4	63.	9.65	0.589	16.2	0.633
5	81.	9.25	0.565	15.5	0.727
6	99.	8.81	0.538	14.8	0.785
7	117.	8.32	0.505	13.9	0.811
8	135.	7.60	0.464	12.7	0.748
9	153.	6.75	0.409	11.3	0.632
10	171.	5.21	0.316	8.7	0.371

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=11808.5	NGRK= 65.45	NUAVG EXPMTL = 9.26
NGRPRK= 772869.	SHRAVG= 0.565	NUAVG INTGRL = 8.67

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 11 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 76.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 203.49
THERMK	= 0.142	NINDEX	= 1.222

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.03	0.661	18.5	579.	9.3	107.3	31.3
2	27.	10.68	0.640	17.9	576.	9.2	108.2	32.2
3	45.	10.43	0.623	17.5	585.	9.4	109.4	33.4
4	63.	10.10	0.604	16.9	578.	9.3	110.2	34.2
5	81.	9.67	0.578	16.2	573.	9.2	111.4	35.4
6	99.	9.41	0.563	15.8	571.	9.1	112.2	36.2
7	117.	9.04	0.538	15.2	583.	9.3	114.4	38.4
8	135.	8.46	0.506	14.2	563.	9.0	115.6	39.6
9	153.	8.00	0.475	13.4	576.	9.2	118.9	42.9
10	171.	7.34	0.435	12.3	567.	9.1	122.0	46.0

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.08	0.664	18.6	0.135
2	27.	10.53	0.631	17.7	0.346
3	45.	10.21	0.610	17.1	0.529
4	63.	9.85	0.589	16.5	0.673
5	81.	9.45	0.565	15.9	0.784
6	99.	8.99	0.538	15.1	0.840
7	117.	8.49	0.505	14.2	0.864
8	135.	7.77	0.464	13.0	0.800
9	153.	6.90	0.409	11.6	0.676
10	171.	5.32	0.316	8.9	0.393

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=11613.4	NGRK= 75.11	NUAVG EXPMTL = 9.42
NGRPRK= 872225.	SHRAVG= 0.604	NUAVG INTGRL = 8.86

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 12 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 76.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 202.65
THERMK	= 0.142	NINDEX	= 1.221

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.26	0.664	18.9	627.	10.0	109.2	33.2
2	27.	10.91	0.644	18.3	624.	10.0	110.1	34.1
3	45.	10.63	0.624	17.8	634.	10.1	111.6	35.6
4	63.	10.29	0.605	17.3	627.	10.0	112.3	36.3
5	81.	9.93	0.585	16.7	622.	10.0	113.3	37.3
6	99.	9.56	0.563	16.0	619.	9.9	114.6	38.6
7	117.	9.22	0.539	15.5	632.	10.1	116.8	40.8
8	135.	8.63	0.507	14.5	610.	9.8	118.1	42.1
9	153.	8.04	0.469	13.5	624.	10.0	122.3	46.3
10	171.	7.44	0.434	12.5	615.	9.8	125.2	49.2

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.591

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.25	0.664	18.9	0.141
2	27.	10.70	0.631	17.9	0.361
3	45.	10.38	0.610	17.4	0.555
4	63.	10.01	0.589	16.8	0.706
5	81.	9.61	0.565	16.1	0.817
6	99.	9.15	0.538	15.3	0.883
7	117.	8.63	0.505	14.5	0.906
8	135.	7.90	0.464	13.2	0.840
9	153.	7.02	0.409	11.8	0.718
10	171.	5.41	0.316	9.1	0.415

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=11573.4	NGRK= 82.61	NUAVG EXPMTL = 9.59
NGRPRK= 956106.	SHRAVG= 0.634	NUAVG INTGRL = 9.01

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 13 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 72.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 85.51
THERMK	= 0.137	NINDEX	= 1.384

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.09	0.682	16.3	348.	5.6	93.4	21.4
2	27.	9.71	0.656	15.6	347.	5.5	94.2	22.2
3	45.	9.48	0.639	15.3	352.	5.6	95.0	23.0
4	63.	8.88	0.599	14.3	348.	5.6	96.3	24.3
5	81.	8.61	0.581	13.9	345.	5.5	96.9	24.9
6	99.	8.13	0.549	13.1	344.	5.5	98.2	26.2
7	117.	7.82	0.526	12.6	351.	5.6	99.8	27.8
8	135.	7.22	0.488	11.6	339.	5.4	101.1	29.1
9	153.	6.89	0.463	11.1	347.	5.6	103.2	31.2
10	171.	6.35	0.427	10.2	341.	5.5	105.3	33.3

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.21	0.690	16.4	0.106
2	27.	9.46	0.640	15.2	0.249
3	45.	9.07	0.612	14.6	0.366
4	63.	8.70	0.587	14.0	0.465
5	81.	8.31	0.562	13.4	0.528
6	99.	7.90	0.533	12.7	0.572
7	117.	7.45	0.501	12.0	0.584
8	135.	6.83	0.461	11.0	0.548
9	153.	6.09	0.409	9.8	0.465
10	171.	4.76	0.320	7.7	0.281

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=24019.2	NGRK= 11.43	NUAVG EXPMTL = 8.32
NGRPRK= 274497.	SHRAVG= 0.416	NUAVG INTGRL = 7.88

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 14 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 72.5	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 85.26
THERMK	= 0.137	NINDEX	= 1.381

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.48	0.688	16.9	410.	6.6	96.8	24.3
2	27.	10.21	0.671	16.5	408.	6.5	97.3	24.8
3	45.	9.92	0.649	16.0	415.	6.6	98.4	25.9
4	63.	9.41	0.616	15.2	410.	6.6	99.5	27.0
5	81.	9.10	0.596	14.7	407.	6.5	100.2	27.7
6	99.	8.42	0.551	13.6	405.	6.5	102.3	29.8
7	117.	8.24	0.538	13.3	413.	6.6	103.6	31.1
8	135.	7.63	0.500	12.3	399.	6.4	105.0	32.5
9	153.	7.21	0.470	11.6	409.	6.5	107.6	35.1
10	171.	6.67	0.435	10.8	402.	6.4	109.9	37.4

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.51	0.690	16.9	0.115
2	27.	9.74	0.640	15.7	0.269
3	45.	9.35	0.612	15.1	0.396
4	63.	8.96	0.587	14.4	0.499
5	81.	8.56	0.562	13.8	0.569
6	99.	8.14	0.533	13.1	0.625
7	117.	7.68	0.501	12.4	0.630
8	135.	7.04	0.461	11.4	0.591
9	153.	6.28	0.409	10.1	0.504
10	171.	4.91	0.320	7.9	0.304

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=24409.9	NGRK= 13.34	NUAVG EXPMTL = 8.73
NGRPRK= 325599.	SHRAVG= 0.450	NUAVG INTGRL = 8.12

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 15 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 73.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 85.04
THERMK	= 0.137	NINDEX	= 1.379

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.70	0.685	17.3	470.	7.5	100.2	27.2
2	27.	10.34	0.662	16.7	468.	7.5	101.0	28.0
3	45.	10.02	0.639	16.2	475.	7.6	102.4	29.4
4	63.	9.72	0.621	15.7	470.	7.5	103.0	30.0
5	81.	9.22	0.589	14.9	466.	7.5	104.3	31.3
6	99.	8.73	0.558	14.1	464.	7.4	105.9	32.9
7	117.	8.30	0.528	13.4	473.	7.6	108.3	35.3
8	135.	7.32	0.500	12.6	457.	7.3	109.2	36.2
9	153.	7.39	0.469	11.9	468.	7.5	112.2	39.2
10	171.	6.82	0.433	11.0	461.	7.4	114.8	41.8

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.77	0.689	17.4	0.124
2	27.	9.99	0.640	16.1	0.292
3	45.	9.58	0.612	15.5	0.431
4	63.	9.19	0.587	14.8	0.536
5	81.	8.79	0.562	14.2	0.618
6	99.	8.35	0.534	13.5	0.669
7	117.	7.88	0.501	12.7	0.689
8	135.	7.22	0.461	11.7	0.639
9	153.	6.44	0.409	10.4	0.546
10	171.	5.04	0.320	8.1	0.330

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=24567.0	NGRK= 15.39	NUAVG EXPMTL = 8.91
NGRPRK= 377996.	SHRAVG= 0.487	NUAVG INTGRL = 8.32

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 16 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 74.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 84.86
THERMK	= 0.137	NINDEX	= 1.376

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.81	0.677	17.4	526.	8.4	104.2	30.2
2	27.	10.36	0.649	16.7	524.	8.4	105.3	31.3
3	45.	9.97	0.622	16.1	532.	8.5	107.0	33.0
4	63.	9.61	0.600	15.5	526.	8.4	107.9	33.9
5	81.	9.23	0.577	14.9	521.	8.3	109.0	35.0
6	99.	8.86	0.554	14.3	519.	8.3	110.3	36.3
7	117.	8.59	0.534	13.9	530.	8.5	112.2	38.2
8	135.	8.03	0.502	13.0	512.	8.2	113.5	39.5
9	153.	7.64	0.474	12.3	524.	8.4	116.5	42.5
10	171.	7.15	0.444	11.5	516.	8.3	118.7	44.7

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.00	0.689	17.7	0.133
2	27.	10.21	0.640	16.5	0.315
3	45.	9.80	0.612	15.8	0.469
4	63.	9.40	0.587	15.2	0.585
5	81.	8.99	0.562	14.5	0.670
6	99.	8.54	0.534	13.8	0.719
7	117.	8.06	0.501	13.0	0.732
8	135.	7.39	0.461	11.9	0.682
9	153.	6.59	0.409	10.6	0.580
10	171.	5.15	0.320	8.3	0.347

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=24468.0	NGRK= 17.68	NUAVG EXPMTL = 9.03
NGRPRK= 432690.	SHRAVG= 0.523	NUAVG INTGRL = 8.51

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 17 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 74.5	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 84.80
THERMK	= 0.137	NINDEX	= 1.373

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.12	0.684	17.9	579.	9.3	106.7	32.2
2	27.	10.74	0.661	17.3	576.	9.2	107.7	33.2
3	45.	10.37	0.635	16.7	585.	9.4	109.4	34.9
4	63.	10.07	0.618	16.3	578.	9.3	110.1	35.6
5	81.	9.64	0.592	15.6	573.	9.2	111.4	36.9
6	99.	9.19	0.564	14.8	571.	9.1	113.0	38.5
7	117.	8.70	0.531	14.0	583.	9.3	116.0	41.5
8	135.	8.24	0.505	13.3	563.	9.0	116.8	42.3
9	153.	7.80	0.475	12.6	576.	9.2	120.2	45.7
10	171.	7.17	0.437	11.6	567.	9.1	123.4	48.9

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.20	0.689	18.1	0.139
2	27.	10.39	0.639	16.8	0.329
3	45.	9.98	0.612	16.1	0.488
4	63.	9.57	0.587	15.4	0.606
5	81.	9.15	0.562	14.8	0.696
6	99.	8.70	0.534	14.0	0.751
7	117.	8.21	0.501	13.3	0.777
8	135.	7.53	0.461	12.2	0.717
9	153.	6.71	0.409	10.8	0.613
10	171.	5.25	0.320	8.5	0.371

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=24507.7	NGRK= 19.68	NUAVG EXPMTL = 9.30
NGRPRK= 482201.	SHRAVG= 0.549	NUAVG INTGRL = 8.67

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 18 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 75.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 84.76
THERMK	= 0.137	NINDEX	= 1.371

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.33	0.686	18.3	627.	10.0	109.3	34.3
2	27.	10.78	0.653	17.4	624.	10.0	110.9	35.9
3	45.	10.65	0.643	17.2	634.	10.1	111.9	36.9
4	63.	10.04	0.606	16.2	627.	10.0	113.7	38.7
5	81.	9.66	0.584	15.6	622.	10.0	114.8	39.8
6	99.	9.05	0.546	14.6	619.	9.9	117.3	42.3
7	117.	8.68	0.521	14.0	632.	10.1	120.0	45.0
8	135.	8.16	0.492	13.2	610.	9.8	121.3	46.3
9	153.	7.88	0.472	12.7	624.	10.0	124.1	49.1
10	171.	7.21	0.432	11.7	615.	9.8	127.8	52.8

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.37	0.688	18.3	0.145
2	27.	10.56	0.639	17.0	0.347
3	45.	10.13	0.612	16.4	0.507
4	63.	9.72	0.587	15.7	0.644
5	81.	9.30	0.562	15.0	0.737
6	99.	8.85	0.534	14.3	0.805
7	117.	8.35	0.501	13.5	0.826
8	135.	7.66	0.461	12.4	0.768
9	153.	6.82	0.409	11.0	0.647
10	171.	5.34	0.320	8.6	0.393

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=24360.7	NGRK= 21.89	NUAVG EXPMTL = 9.34
NGRPRK= 533371.	SHRAVG= 0.582	NUAVG INTGRL = 8.81

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 19 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 72.5	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 62.52
THERMK	= 0.134	NINDEX	= 1.440

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	9.99	0.680	15.8	348.	5.6	94.5	22.0
2	27.	9.68	0.659	15.3	347.	5.5	95.2	22.7
3	45.	9.36	0.635	14.8	352.	5.6	96.3	23.8
4	63.	8.86	0.602	14.0	348.	5.6	97.4	24.9
5	81.	8.46	0.575	13.4	345.	5.5	98.3	25.8
6	99.	8.10	0.550	12.8	344.	5.5	99.3	26.8
7	117.	7.66	0.518	12.1	351.	5.6	101.4	28.9
8	135.	7.07	0.480	11.2	339.	5.4	102.8	30.3
9	153.	6.66	0.450	10.5	347.	5.6	105.4	32.9
10	171.	6.25	0.423	9.9	341.	5.5	107.0	34.5

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.588

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.27	0.698	16.2	0.110
2	27.	9.44	0.643	14.9	0.250
3	45.	9.02	0.612	14.3	0.365
4	63.	8.63	0.586	13.7	0.456
5	81.	8.24	0.560	13.0	0.521
6	99.	7.83	0.532	12.4	0.558
7	117.	7.38	0.499	11.7	0.575
8	135.	6.77	0.460	10.7	0.541
9	153.	6.05	0.409	9.6	0.464
10	171.	4.75	0.322	7.5	0.282

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=31209.7	NGRK= 6.86	NUAVG EXPMTL = 8.21
NGRPRK= 214241.	SHRAVG= 0.412	NUAVG INTGRL = 7.84

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 20 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 74.0	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 61.89
THERMK	= 0.134	NINDEX	= 1.438

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.24	0.676	16.2	410.	6.6	99.3	25.3
2	27.	9.76	0.645	15.4	408.	6.5	100.4	26.4
3	45.	9.39	0.618	14.9	415.	6.6	101.9	27.9
4	63.	9.00	0.593	14.2	410.	6.6	102.8	28.8
5	81.	8.63	0.569	13.6	407.	6.5	103.8	29.8
6	99.	8.29	0.546	13.1	405.	6.5	104.9	30.9
7	117.	7.82	0.513	12.4	413.	6.6	107.4	33.4
8	135.	7.31	0.482	11.6	399.	6.4	108.5	34.5
9	153.	6.99	0.458	11.1	409.	6.5	110.9	36.9
10	171.	6.56	0.430	10.4	402.	6.4	112.7	38.7

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.588

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.57	0.698	16.7	0.120
2	27.	9.73	0.642	15.4	0.277
3	45.	9.30	0.612	14.7	0.406
4	63.	8.90	0.586	14.1	0.504
5	81.	8.50	0.560	13.4	0.575
6	99.	8.07	0.532	12.8	0.615
7	117.	7.62	0.500	12.1	0.635
8	135.	6.99	0.460	11.1	0.593
9	153.	6.24	0.409	9.9	0.505
10	171.	4.90	0.322	7.8	0.306

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=31546.0	NGRK= 8.14	NUAVG EXPMTL = 8.40
NGRPRK= 256905.	SHRAVG= 0.453	NUAVG INTGRL = 8.08

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 21 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 74.0	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 61.56
THERMK	= 0.134	NINDEX	= 1.436

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.55	0.680	16.7	470.	7.5	102.2	28.2
2	27.	10.02	0.646	15.9	468.	7.5	103.5	29.5
3	45.	9.69	0.623	15.3	475.	7.6	105.0	31.0
4	63.	9.32	0.600	14.7	470.	7.5	105.9	31.9
5	81.	8.92	0.574	14.1	466.	7.5	107.0	33.0
6	99.	8.64	0.556	13.7	464.	7.4	107.9	33.9
7	117.	8.24	0.528	13.0	473.	7.6	110.3	36.3
8	135.	7.57	0.494	12.1	457.	7.3	111.7	37.7
9	153.	7.18	0.459	11.4	468.	7.5	115.1	41.1
10	171.	6.71	0.430	10.6	461.	7.4	117.3	43.3

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	10.82	0.698	17.1	0.128
2	27.	9.96	0.642	15.8	0.297
3	45.	9.53	0.612	15.1	0.433
4	63.	9.11	0.586	14.4	0.537
5	81.	8.71	0.560	13.8	0.614
6	99.	8.27	0.532	13.1	0.653
7	117.	7.80	0.500	12.3	0.671
8	135.	7.16	0.460	11.3	0.628
9	153.	6.39	0.409	10.1	0.542
10	171.	5.02	0.322	8.0	0.330

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=32194.8	NGRK= 9.13	NUAVG EXPMTL = 8.69
NGRPRK= 293892.	SHRAVG= 0.483	NUAVG INTGRL = 8.28

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 22 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID = 42.0 % CS/SS SOL
TBULK = 73.0
DENSITY = 77.05
THERMK = 0.134

SPHEAT = 0.638
BETA = 0.00063
KLBFTHR = 61.46
NINDEX = 1.436

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.86	0.688	17.2	526.	8.4	103.6	30.6
2	27.	10.41	0.660	16.5	524.	8.4	104.8	31.8
3	45.	9.92	0.626	15.7	532.	8.5	106.9	33.9
4	63.	9.52	0.601	15.1	526.	8.4	107.9	34.9
5	81.	9.18	0.580	14.5	521.	8.3	108.9	35.9
6	99.	8.84	0.558	14.0	519.	8.3	110.1	37.1
7	117.	8.50	0.534	13.5	530.	8.5	112.4	39.4
8	135.	7.91	0.500	12.5	512.	8.2	113.9	40.9
9	153.	7.47	0.469	11.8	524.	8.4	117.3	44.3
10	171.	7.04	0.443	11.2	516.	8.3	119.2	46.2

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.588

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.02	0.698	17.4	0.135
2	27.	10.14	0.642	16.0	0.309
3	45.	9.70	0.612	15.4	0.457
4	63.	9.29	0.586	14.7	0.567
5	81.	8.87	0.560	14.0	0.645
6	99.	8.42	0.532	13.3	0.689
7	117.	7.95	0.500	12.6	0.704
8	135.	7.29	0.460	11.5	0.660
9	153.	6.51	0.409	10.3	0.567
10	171.	5.12	0.322	8.1	0.343

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=33038.0 NGRK= 9.83 NUAVG EXPMTL = 8.97
NGRPRK= 324827. SHRAVG= 0.508 NUAVG INTGRL = 8.43

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 23 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 73.0	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 61.17
THERMK	= 0.134	NINDEX	= 1.435

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.86	0.676	17.2	579.	9.3	106.7	33.7
2	27.	10.48	0.652	16.6	576.	9.2	107.7	34.7
3	45.	10.20	0.633	16.1	585.	9.4	109.2	36.2
4	63.	9.73	0.604	15.4	578.	9.3	110.5	37.5
5	81.	9.42	0.586	14.9	573.	9.2	111.4	38.4
6	99.	8.96	0.557	14.2	571.	9.1	113.2	40.2
7	117.	8.74	0.540	13.8	583.	9.3	115.1	42.1
8	135.	8.22	0.511	13.0	563.	9.0	116.2	43.2
9	153.	7.87	0.486	12.5	576.	9.2	119.2	46.2
10	171.	7.22	0.446	11.4	567.	9.1	122.6	49.6

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.588

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.21	0.698	17.7	0.143
2	27.	10.32	0.642	16.3	0.328
3	45.	9.87	0.612	15.6	0.477
4	63.	9.44	0.586	14.9	0.595
5	81.	9.02	0.560	14.3	0.675
6	99.	8.57	0.532	13.6	0.727
7	117.	8.08	0.500	12.8	0.737
8	135.	7.41	0.460	11.7	0.685
9	153.	6.62	0.409	10.5	0.584
10	171.	5.21	0.322	8.3	0.360

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=33439.8	NGRK= 10.70	NUAVG EXPMTL = 9.17
NGRPRK= 357884.	SHRAVG= 0.531	NUAVG INTGRL = 8.58

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 24 CONSTANT FLUX CASE

***** FLUID PROPERTIES *****

FLUID = 42.0 % CS/OS SOL
TBULK = 73.0
DENSITY = 77.05
THERMK = 0.134

SPHEAT = 0.638
BETA = 0.00063
KLBFTHR = 60.93
NINDEX = 1.434

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.07	0.680	17.5	627.	10.0	108.8	35.8
2	27.	10.69	0.656	16.9	624.	10.0	109.9	36.9
3	45.	10.32	0.631	16.3	634.	10.1	111.8	38.8
4	63.	9.98	0.611	15.8	627.	10.0	112.7	39.7
5	81.	9.68	0.593	15.3	622.	10.0	113.6	40.6
6	99.	9.32	0.571	14.8	619.	9.9	114.9	41.9
7	117.	9.05	0.551	14.3	632.	10.1	117.1	44.1
8	135.	8.46	0.518	13.4	610.	9.8	118.5	45.5
9	153.	8.11	0.493	12.8	624.	10.0	121.6	48.6
10	171.	7.54	0.459	11.9	615.	9.8	124.5	51.5

***** INTEGRAL SOLUTIONS FOR CONSTANT FLUX *****

INTEGRAL
KN = 0.589

NO	ANGLE	NUX	NUGPD	HX	SHEAR
1	9.	11.37	0.698	18.0	0.149
2	27.	10.47	0.642	16.6	0.341
3	45.	10.01	0.612	15.8	0.499
4	63.	9.58	0.586	15.2	0.617
5	81.	9.15	0.560	14.5	0.700
6	99.	8.69	0.532	13.8	0.748
7	117.	8.20	0.500	13.0	0.760
8	135.	7.52	0.460	11.9	0.710
9	153.	6.72	0.409	10.6	0.604
10	171.	5.28	0.322	8.4	0.369

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRK=33807.6 NGRK= 11.48 NUAVG EXPMTL = 9.42
NGRPRK= 388241. SHRAVG= 0.550 NUAVG INTGRL = 8.70

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 1 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 70.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 256.07
THERMK	= 0.145	NINDEX	= 1.187

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.67	0.594	18.2	510.	8.2	98.0	28.0
2	27.	10.30	0.574	17.6	490.	7.9	97.9	27.9
3	45.	10.11	0.563	17.3	481.	7.7	97.9	27.9
4	63.	9.59	0.534	16.4	458.	7.3	98.0	28.0
5	81.	9.07	0.506	15.5	431.	6.9	97.8	27.8
6	99.	8.51	0.473	14.5	405.	6.5	97.9	27.9
7	117.	8.07	0.450	13.8	382.	6.1	97.8	27.8
8	135.	7.16	0.399	12.2	339.	5.4	97.7	27.7
9	153.	6.53	0.364	11.1	309.	4.9	97.7	27.7
10	171.	5.84	0.325	10.0	279.	4.5	98.0	28.0

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.548
FACR = 0.984

INTEGRAL
CN = 0.561

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.51	0.585	17.9	0.125	10.75	0.598	18.3
2	27.	9.95	0.554	17.0	0.321	10.18	0.567	17.4
3	45.	9.57	0.533	16.3	0.481	9.78	0.545	16.7
4	63.	9.18	0.511	15.7	0.608	9.39	0.522	16.0
5	81.	8.72	0.486	14.9	0.689	8.92	0.497	15.2
6	99.	8.20	0.457	14.0	0.728	8.39	0.467	14.3
7	117.	7.56	0.421	12.9	0.711	7.74	0.431	13.2
8	135.	6.78	0.378	11.6	0.641	6.94	0.387	11.8
9	153.	5.76	0.321	9.8	0.506	5.90	0.329	10.1
10	171.	4.12	0.229	7.0	0.277	4.22	0.234	7.2

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=	7100.0	NGRC=	12.65	NUAVG EXPMTL =	8.59
NGRPRC=	89837.	SHRAVG=	0.509	NUAVG INTGRL =	8.22

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 2 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 72.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 250.39
THERMK	= 0.145	NINDEX	= 1.183

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.10	0.593	19.0	608.	9.7	104.1	32.1
2	27.	10.83	0.579	18.5	591.	9.5	104.0	32.0
3	45.	10.43	0.559	17.8	564.	9.0	103.7	31.7
4	63.	9.94	0.533	17.0	537.	8.6	103.6	31.6
5	81.	9.34	0.499	16.0	511.	8.2	104.0	32.0
6	99.	8.81	0.471	15.0	481.	7.7	104.0	32.0
7	117.	8.46	0.454	14.4	456.	7.3	103.5	31.5
8	135.	7.61	0.406	13.0	417.	6.7	104.1	32.1
9	153.	6.89	0.367	11.8	378.	6.1	104.1	32.1
10	171.	6.31	0.336	10.8	347.	5.6	104.3	32.3

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.548
FACR = 0.984

INTEGRAL
CN = 0.561

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.94	0.584	18.7	0.141	11.18	0.597	19.1
2	27.	10.36	0.554	17.7	0.363	10.60	0.566	18.1
3	45.	9.94	0.533	17.0	0.541	10.17	0.545	17.4
4	63.	9.53	0.511	16.3	0.681	9.75	0.522	16.6
5	81.	9.10	0.486	15.5	0.782	9.30	0.497	15.9
6	99.	8.55	0.457	14.6	0.824	8.74	0.467	14.9
7	117.	7.86	0.421	13.4	0.799	8.04	0.431	13.7
8	135.	7.09	0.378	12.1	0.731	7.25	0.387	12.4
9	153.	6.02	0.321	10.3	0.578	6.16	0.329	10.5
10	171.	4.30	0.229	7.3	0.314	4.39	0.234	7.5

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 6848.2	NGRC= 15.81	NUAVG EXPMTL = 8.97
NGRPRC= 108271.	SHRAVG= 0.575	NUAVG INTGRL = 8.56

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 3 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 73.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 247.37
THERMK	= 0.145	NINDEX	= 1.180

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.37	0.588	19.4	693.	11.1	108.7	35.7
2	27.	11.00	0.569	18.8	669.	10.7	108.6	35.6
3	45.	10.66	0.551	18.2	652.	10.4	108.8	35.8
4	63.	10.21	0.527	17.4	627.	10.0	109.0	36.0
5	81.	9.78	0.506	16.7	598.	9.6	108.8	35.8
6	99.	9.23	0.477	15.8	566.	9.1	108.9	35.9
7	117.	8.90	0.460	15.2	546.	8.7	108.9	35.9
8	135.	7.79	0.402	13.3	480.	7.7	109.1	36.1
9	153.	7.30	0.377	12.5	450.	7.2	109.1	36.1
10	171.	6.58	0.340	11.2	402.	6.4	108.8	35.8

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.548
FACR = 0.985

INTEGRAL
CN = 0.561

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.27	0.583	19.3	0.155	11.53	0.596	19.7
2	27.	10.69	0.553	18.3	0.399	10.93	0.566	18.7
3	45.	10.30	0.532	17.6	0.602	10.54	0.545	18.0
4	63.	9.89	0.511	16.9	0.761	10.12	0.522	17.3
5	81.	9.40	0.486	16.1	0.863	9.61	0.497	16.4
6	99.	8.84	0.457	15.1	0.912	9.04	0.467	15.4
7	117.	8.16	0.421	13.9	0.896	8.35	0.431	14.3
8	135.	7.33	0.378	12.5	0.810	7.50	0.387	12.8
9	153.	6.23	0.321	10.6	0.640	6.37	0.329	10.9
10	171.	4.43	0.229	7.6	0.344	4.53	0.234	7.7

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 6667.6	NGRC= 18.93	NUAVG EXPMTL =	9.28
NGRPRC= 126241.	SHRAVG= 0.638	NUAVG INTGRL =	8.85

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 4 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 73.5	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 245.55
THERMK	= 0.145	NINDEX	= 1.177

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.75	0.589	20.1	801.	12.8	113.4	39.9
2	27.	11.46	0.574	19.6	779.	12.5	113.3	39.8
3	45.	11.14	0.559	19.0	757.	12.1	113.3	39.8
4	63.	10.53	0.528	18.0	718.	11.5	113.4	39.9
5	81.	10.13	0.508	17.3	687.	11.0	113.2	39.7
6	99.	9.61	0.481	16.4	655.	10.5	113.4	39.9
7	117.	9.28	0.464	15.8	636.	10.2	113.6	40.1
8	135.	8.26	0.413	14.1	568.	9.1	113.7	40.2
9	153.	7.55	0.377	12.9	518.	8.3	113.7	40.2
10	171.	6.75	0.338	11.5	461.	7.4	113.4	39.9

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.548
FACR = 0.985

INTEGRAL
CN = 0.560

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.62	0.582	19.9	0.170	11.89	0.596	20.3
2	27.	11.03	0.553	18.8	0.438	11.28	0.565	19.3
3	45.	10.61	0.532	18.1	0.659	10.86	0.544	18.5
4	63.	10.19	0.511	17.4	0.833	10.42	0.522	17.8
5	81.	9.69	0.486	16.5	0.946	9.91	0.497	16.9
6	99.	9.11	0.457	15.6	1.001	9.32	0.467	15.9
7	117.	8.43	0.421	14.4	0.987	8.62	0.431	14.7
8	135.	7.56	0.378	12.9	0.891	7.74	0.387	13.2
9	153.	6.42	0.321	11.0	0.702	6.57	0.328	11.2
10	171.	4.56	0.229	7.8	0.378	4.67	0.234	8.0

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 6512.6	NGRC= 22.30	NUAVG EXPMTL = 9.64
NGRPRC= 145234.	SHRAVG= 0.700	NUAVG INTGRL = 9.13

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 5 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 74.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 244.42
THERMK	= 0.145	NINDEX	= 1.173

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	12.28	0.597	21.0	923.	14.8	118.0	44.0
2	27.	11.69	0.569	20.0	875.	14.0	117.8	43.8
3	45.	11.25	0.548	19.2	841.	13.5	117.7	43.7
4	63.	10.72	0.522	18.3	801.	12.8	117.7	43.7
5	81.	10.13	0.493	17.3	761.	12.2	118.0	44.0
6	99.	9.62	0.468	16.4	724.	11.6	118.1	44.1
7	117.	9.14	0.444	15.6	690.	11.0	118.1	44.1
8	135.	8.24	0.401	14.1	619.	9.9	118.0	44.0
9	153.	7.87	0.383	13.4	591.	9.5	117.9	43.9
10	171.	7.06	0.344	12.1	526.	8.4	117.6	43.6

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS	INTEGRAL
THETA= -0.548	CN = 0.560
FACR = 0.985	

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.95	0.582	20.4	0.185	12.22	0.595	20.9
2	27.	11.34	0.553	19.4	0.477	11.60	0.565	19.8
3	45.	10.92	0.532	18.7	0.718	11.17	0.544	19.1
4	63.	10.47	0.511	17.9	0.905	10.71	0.522	18.3
5	81.	9.98	0.486	17.1	1.036	10.21	0.497	17.5
6	99.	9.39	0.457	16.0	1.094	9.60	0.467	16.4
7	117.	8.67	0.421	14.8	1.075	8.87	0.431	15.2
8	135.	7.77	0.378	13.3	0.966	7.94	0.387	13.6
9	153.	6.59	0.321	11.3	0.761	6.74	0.328	11.5
10	171.	4.68	0.228	8.0	0.409	4.79	0.233	8.2

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 6347.1	NGRC= 25.99	NUAVG EXPMTL = 9.80
NGRPRC= 164937.	SHRAVG= 0.763	NUAVG INTGRL = 9.38

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 6 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 38.0 % CS/SS SOL	SPHEAT	= 0.657
TBULK	= 74.0	BETA	= 0.00059
DENSITY	= 77.02	KLBFTHR	= 243.98
THERMK	= 0.145	NINDEX	= 1.170

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	12.73	0.604	21.8	1045.	16.7	122.0	48.0
2	27.	12.22	0.581	20.9	997.	16.0	121.7	47.7
3	45.	11.65	0.553	19.9	953.	15.3	121.8	47.8
4	63.	11.14	0.529	19.0	912.	14.6	121.9	47.9
5	81.	10.53	0.500	18.0	864.	13.8	122.0	48.0
6	99.	9.94	0.472	17.0	815.	13.0	121.9	47.9
7	117.	9.65	0.459	16.5	788.	12.6	121.8	47.8
8	135.	8.48	0.403	14.5	695.	11.1	121.9	47.9
9	153.	8.17	0.387	14.0	673.	10.8	122.2	48.2
10	171.	7.41	0.351	12.7	610.	9.8	122.1	48.1

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.548
FACR = 0.985

INTEGRAL
CN = 0.560

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	12.24	0.581	20.9	0.199	12.52	0.594	21.4
2	27.	11.62	0.552	19.9	0.513	11.89	0.565	20.3
3	45.	11.20	0.532	19.2	0.776	11.46	0.544	19.6
4	63.	10.75	0.511	18.4	0.980	11.00	0.522	18.8
5	81.	10.24	0.486	17.5	1.119	10.47	0.497	17.9
6	99.	9.62	0.457	16.4	1.179	9.84	0.467	16.8
7	117.	8.87	0.421	15.2	1.153	9.07	0.431	15.5
8	135.	7.96	0.378	13.6	1.041	8.14	0.387	13.9
9	153.	6.77	0.321	11.6	0.825	6.92	0.328	11.8
10	171.	4.81	0.228	8.2	0.445	4.92	0.233	8.4

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 6215.6	NGRC= 29.77	NUAVG EXPMTL = 10.19
NGRPRC= 185055.	SHRAVG= 0.823	NUAVG INTGRL = 9.62

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 7 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 71.5	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 208.48
THERMK	= 0.142	NINDEX	= 1.232

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.68	0.608	17.9	504.	8.1	99.7	28.2
2	27.	10.24	0.582	17.2	485.	7.8	99.8	28.3
3	45.	9.83	0.559	16.5	463.	7.4	99.6	28.1
4	63.	9.31	0.529	15.6	440.	7.1	99.8	28.3
5	81.	8.96	0.509	15.0	425.	6.8	99.8	28.3
6	99.	8.48	0.483	14.2	399.	6.4	99.6	28.1
7	117.	8.00	0.456	13.4	376.	6.0	99.5	28.0
8	135.	7.45	0.424	12.5	351.	5.6	99.6	28.1
9	153.	6.65	0.378	11.1	315.	5.0	99.8	28.3
10	171.	6.05	0.344	10.1	285.	4.6	99.6	28.1

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.550
FACR = 0.986

INTEGRAL
CN = 0.563

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.45	0.594	17.5	0.122	10.69	0.608	17.9
2	27.	9.82	0.558	16.4	0.305	10.04	0.571	16.8
3	45.	9.40	0.535	15.7	0.451	9.61	0.547	16.1
4	63.	9.00	0.512	15.1	0.566	9.21	0.523	15.4
5	81.	8.56	0.486	14.3	0.642	8.75	0.497	14.7
6	99.	8.02	0.457	13.4	0.672	8.21	0.467	13.7
7	117.	7.41	0.422	12.4	0.659	7.58	0.432	12.7
8	135.	6.66	0.379	11.2	0.597	6.82	0.388	11.4
9	153.	5.69	0.323	9.5	0.476	5.82	0.331	9.7
10	171.	4.08	0.232	6.8	0.262	4.18	0.238	7.0

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 8855.6	NGRC= 8.61	NUAVG EXPMTL = 8.57
NGRPRC= 76237.	SHRAVG= 0.475	NUAVG INTGRL = 8.09

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 8 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 73.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 206.83
THERMK	= 0.142	NINDEX	= 1.228

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.90	0.599	18.3	584.	9.3	104.9	31.9
2	27.	10.44	0.573	17.5	560.	9.0	105.0	32.0
3	45.	10.27	0.563	17.2	553.	8.9	105.2	32.2
4	63.	9.75	0.534	16.3	526.	8.4	105.2	32.2
5	81.	9.33	0.513	15.6	500.	8.0	105.0	32.0
6	99.	8.86	0.487	14.8	475.	7.6	105.0	32.0
7	117.	8.42	0.463	14.1	450.	7.2	104.9	31.9
8	135.	7.71	0.424	12.9	411.	6.6	104.8	31.8
9	153.	7.00	0.384	11.7	378.	6.1	105.2	32.2
10	171.	6.26	0.344	10.5	335.	5.4	105.0	32.0

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.550
FACR = 0.986

INTEGRAL
CN = 0.563

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.80	0.594	18.1	0.135	11.05	0.607	18.5
2	27.	10.16	0.558	17.0	0.338	10.39	0.571	17.4
3	45.	9.74	0.535	16.3	0.503	9.97	0.547	16.7
4	63.	9.33	0.512	15.6	0.630	9.54	0.523	16.0
5	81.	8.85	0.486	14.8	0.711	9.05	0.497	15.2
6	99.	8.32	0.457	13.9	0.748	8.51	0.467	14.3
7	117.	7.67	0.422	12.9	0.732	7.85	0.432	13.2
8	135.	6.89	0.379	11.6	0.661	7.05	0.388	11.8
9	153.	5.89	0.323	9.9	0.530	6.03	0.331	10.1
10	171.	4.22	0.232	7.1	0.291	4.32	0.237	7.2

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 8672.8	NGRC= 10.35	NUAVG EXPMTL = 8.89
NGRPRC= 89794.	SHRAVG= 0.528	NUAVG INTGRL = 8.38

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 9 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 74.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 205.12
THERMK	= 0.142	NINDEX	= 1.225

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.30	0.601	18.9	681.	10.9	109.9	35.9
2	27.	10.86	0.577	18.2	656.	10.5	110.0	36.0
3	45.	10.50	0.559	17.6	634.	10.1	110.0	36.0
4	63.	9.99	0.531	16.8	608.	9.7	110.3	36.3
5	81.	9.54	0.507	16.0	578.	9.3	110.2	36.2
6	99.	9.06	0.481	15.2	551.	8.8	110.2	36.2
7	117.	8.59	0.457	14.4	519.	8.3	110.0	36.0
8	135.	7.87	0.419	13.2	474.	7.6	109.9	35.9
9	153.	7.29	0.388	12.2	439.	7.0	109.9	35.9
10	171.	6.36	0.338	10.7	384.	6.2	110.0	36.0

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.550
FACR = 0.986

INTEGRAL
CN = 0.563

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.14	0.593	18.7	0.148	11.40	0.607	19.1
2	27.	10.48	0.558	17.6	0.372	10.72	0.570	18.0
3	45.	10.05	0.534	16.8	0.552	10.28	0.547	17.2
4	63.	9.64	0.512	16.2	0.695	9.86	0.523	16.5
5	81.	9.15	0.486	15.3	0.786	9.36	0.497	15.7
6	99.	8.60	0.457	14.4	0.829	8.80	0.467	14.8
7	117.	7.93	0.422	13.3	0.810	8.12	0.432	13.6
8	135.	7.12	0.379	11.9	0.730	7.29	0.388	12.2
9	153.	6.07	0.323	10.2	0.579	6.21	0.330	10.4
10	171.	4.36	0.232	7.3	0.320	4.46	0.237	7.5

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 8521.8	NGRC= 12.24	NUAVG EXPMTL = 9.14
NGRPRC= 104292.	SHRAVG= 0.582	NUAVG INTGRL = 8.65

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 10 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 74.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 203.81
THERMK	= 0.142	NINDEX	= 1.222

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.75	0.608	19.7	790.	12.7	114.1	40.1
2	27.	11.24	0.581	18.9	757.	12.1	114.1	40.1
3	45.	10.92	0.565	18.3	733.	11.7	114.1	40.1
4	63.	10.51	0.543	17.6	710.	11.4	114.3	40.3
5	81.	10.01	0.517	16.8	675.	10.8	114.2	40.2
6	99.	9.35	0.483	15.7	633.	10.1	114.3	40.3
7	117.	8.78	0.454	14.7	593.	9.5	114.2	40.2
8	135.	7.91	0.409	13.3	533.	8.5	114.2	40.2
9	153.	7.30	0.378	12.2	491.	7.9	114.1	40.1
10	171.	6.47	0.334	10.9	438.	7.0	114.3	40.3

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.550
FACR = 0.985

INTEGRAL
CN = 0.563

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.45	0.592	19.2	0.161	11.72	0.606	19.7
2	27.	10.78	0.557	18.1	0.404	11.03	0.570	18.5
3	45.	10.33	0.534	17.3	0.600	10.57	0.547	17.7
4	63.	9.90	0.512	16.6	0.754	10.13	0.523	17.0
5	81.	9.41	0.486	15.8	0.854	9.62	0.497	16.1
6	99.	8.84	0.457	14.8	0.901	9.05	0.467	15.2
7	117.	8.16	0.422	13.7	0.883	8.35	0.432	14.0
8	135.	7.33	0.379	12.3	0.797	7.50	0.388	12.6
9	153.	6.24	0.323	10.5	0.631	6.39	0.330	10.7
10	171.	4.49	0.232	7.5	0.349	4.59	0.237	7.7

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 8453.8	NGRC= 14.02	NUAVG EXPMTL = 9.42
NGRPRC= 118548.	SHRAVG= 0.633	NUAVG INTGRL = 8.89

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 11 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 71.0	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 204.53
THERMK	= 0.142	NINDEX	= 1.224

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.88	0.604	19.9	875.	14.0	114.9	43.9
2	27.	11.33	0.576	19.0	836.	13.4	115.0	44.0
3	45.	10.96	0.558	18.4	805.	12.9	114.8	43.8
4	63.	10.44	0.530	17.5	771.	12.4	115.1	44.1
5	81.	9.90	0.503	16.6	731.	11.7	115.0	44.0
6	99.	9.43	0.480	15.8	692.	11.1	114.8	43.8
7	117.	9.01	0.458	15.1	664.	10.6	114.9	43.9
8	135.	8.08	0.411	13.6	596.	9.6	115.0	44.0
9	153.	7.51	0.382	12.6	555.	8.9	115.1	44.1
10	171.	6.79	0.345	11.4	499.	8.0	114.9	43.9

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.550
FACR = 0.986

INTEGRAL
CN = 0.563

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.66	0.593	19.5	0.169	11.92	0.606	20.0
2	27.	10.97	0.557	18.4	0.425	11.22	0.570	18.8
3	45.	10.50	0.534	17.6	0.631	10.74	0.547	18.0
4	63.	10.07	0.512	16.9	0.793	10.30	0.523	17.3
5	81.	9.57	0.486	16.0	0.899	9.79	0.497	16.4
6	99.	8.97	0.457	15.0	0.942	9.18	0.467	15.4
7	117.	8.29	0.422	13.9	0.926	8.49	0.432	14.2
8	135.	7.46	0.379	12.5	0.838	7.63	0.388	12.8
9	153.	6.36	0.323	10.7	0.667	6.50	0.330	10.9
10	171.	4.56	0.232	7.6	0.366	4.66	0.237	7.8

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 8682.4	NGRC= 14.62	NUAVG EXPMTL = 9.53
NGRPRC= 126944.	SHRAVG= 0.665	NUAVG INTGRL = 9.04

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 12 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 39.0 % CS/SS SOL	SPHEAT	= 0.653
TBULK	= 72.5	BETA	= 0.00060
DENSITY	= 77.03	KLBFTHR	= 202.12
THERMK	= 0.142	NINDEX	= 1.220

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	12.13	0.600	20.3	980.	15.7	120.7	48.2
2	27.	11.65	0.577	19.6	938.	15.0	120.5	48.0
3	45.	11.31	0.560	19.0	910.	14.6	120.4	47.9
4	63.	10.60	0.524	17.8	857.	13.7	120.7	48.2
5	81.	10.08	0.499	16.9	811.	13.0	120.5	48.0
6	99.	9.49	0.470	15.9	765.	12.3	120.5	48.0
7	117.	9.25	0.457	15.5	747.	12.0	120.6	48.1
8	135.	8.26	0.409	13.9	667.	10.7	120.6	48.1
9	153.	7.77	0.384	13.0	629.	10.1	120.7	48.2
10	171.	6.91	0.342	11.6	557.	8.9	120.6	48.1

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

		ACRIVOS				INTEGRAL		
		THETA= -0.550				CN = 0.562		
		FACR = 0.985						
NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.97	0.592	20.1	0.184	12.25	0.606	20.6
2	27.	11.26	0.557	18.9	0.461	11.52	0.570	19.3
3	45.	10.79	0.534	18.1	0.685	11.04	0.547	18.5
4	63.	10.35	0.512	17.4	0.862	10.59	0.523	17.8
5	81.	9.83	0.486	16.5	0.974	10.05	0.497	16.9
6	99.	9.23	0.457	15.5	1.026	9.45	0.467	15.8
7	117.	8.53	0.422	14.3	1.008	8.73	0.431	14.6
8	135.	7.66	0.379	12.9	0.911	7.84	0.388	13.2
9	153.	6.53	0.323	11.0	0.724	6.68	0.330	11.2
10	171.	4.68	0.232	7.9	0.397	4.79	0.237	8.0

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC= 8436.9	NGRC= 17.14	NUAVG EXPMTL = 9.75
NGRPRC= 144568.	SHRAVG= 0.723	NUAVG INTGRL = 9.29

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 13 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 74.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 85.15
THERMK	= 0.137	NINDEX	= 1.380

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.68	0.631	17.2	481.	7.7	101.9	27.9
2	27.	10.17	0.599	16.4	462.	7.4	102.2	28.2
3	45.	9.83	0.580	15.9	445.	7.1	102.1	28.1
4	63.	9.21	0.543	14.8	416.	6.7	102.0	28.0
5	81.	8.64	0.511	13.9	388.	6.2	101.9	27.9
6	99.	8.16	0.481	13.2	368.	5.9	102.0	28.0
7	117.	7.74	0.457	12.5	351.	5.6	102.1	28.1
8	135.	7.16	0.423	11.5	320.	5.1	101.7	27.7
9	153.	6.54	0.386	10.6	296.	4.7	102.0	28.0
10	171.	5.88	0.347	9.5	266.	4.3	102.1	28.1

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.557
FACR = 1.018

INTEGRAL
CN = 0.569

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.58	0.625	17.1	0.127	10.82	0.639	17.4
2	27.	9.69	0.571	15.6	0.294	9.91	0.584	16.0
3	45.	9.18	0.541	14.8	0.421	9.38	0.553	15.1
4	63.	8.73	0.515	14.1	0.515	8.92	0.526	14.4
5	81.	8.26	0.488	13.3	0.575	8.44	0.499	13.6
6	99.	7.76	0.458	12.5	0.604	7.93	0.468	12.8
7	117.	7.18	0.424	11.6	0.594	7.34	0.433	11.8
8	135.	6.47	0.382	10.4	0.537	6.61	0.391	10.7
9	153.	5.58	0.329	9.0	0.438	5.70	0.336	9.2
10	171.	4.10	0.242	6.6	0.254	4.20	0.247	6.8

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=14284.5	NGRC= 3.47	NUAVG EXPMTL = 8.40
NGRPRC= 49565.	SHRAVG= 0.436	NUAVG INTGRL = 7.93

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 14 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 72.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 85.15
THERMK	= 0.137	NINDEX	= 1.380

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.80	0.621	17.4	558.	8.9	104.0	32.0
2	27.	10.37	0.596	16.7	534.	8.6	104.0	32.0
3	45.	9.87	0.567	15.9	509.	8.2	104.0	32.0
4	63.	9.36	0.537	15.1	487.	7.8	104.3	32.3
5	81.	8.96	0.514	14.5	466.	7.5	104.2	32.2
6	99.	8.51	0.489	13.7	441.	7.1	104.1	32.1
7	117.	8.02	0.461	12.9	413.	6.6	104.0	32.0
8	135.	7.38	0.424	11.9	381.	6.1	104.1	32.1
9	153.	6.83	0.392	11.0	353.	5.7	104.1	32.1
10	171.	6.21	0.356	10.0	323.	5.2	104.2	32.2

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.557
FACR = 1.018

INTEGRAL
CN = 0.569

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.87	0.625	17.5	0.137	11.11	0.639	17.9
2	27.	9.93	0.571	16.0	0.316	10.16	0.584	16.4
3	45.	9.41	0.541	15.2	0.454	9.63	0.553	15.5
4	63.	8.97	0.515	14.5	0.559	9.17	0.526	14.8
5	81.	8.50	0.488	13.7	0.626	8.69	0.499	14.0
6	99.	7.97	0.458	12.9	0.654	8.15	0.468	13.1
7	117.	7.36	0.424	11.9	0.641	7.53	0.433	12.1
8	135.	6.65	0.382	10.7	0.585	6.80	0.391	11.0
9	153.	5.72	0.329	9.2	0.473	5.85	0.336	9.4
10	171.	4.22	0.242	6.8	0.275	4.31	0.247	7.0

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=14752.1	NGRC= 3.78	NUAVG EXPMTL = 8.63
NGRPRC= 55747.	SHRAVG= 0.472	NUAVG INTGRL = 8.14

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 15 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 71.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 85.06
THERMK	= 0.137	NINDEX	= 1.379

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.14	0.624	18.0	650.	10.4	107.2	36.2
2	27.	10.64	0.597	17.2	619.	9.9	107.1	36.1
3	45.	10.14	0.569	16.4	590.	9.4	107.0	36.0
4	63.	9.59	0.538	15.5	558.	8.9	107.0	36.0
5	81.	9.17	0.515	14.8	532.	8.5	107.0	36.0
6	99.	8.61	0.482	13.9	503.	8.1	107.2	36.2
7	117.	8.18	0.458	13.2	479.	7.7	107.3	36.3
8	135.	7.48	0.420	12.1	434.	7.0	107.0	36.0
9	153.	7.04	0.395	11.4	409.	6.5	107.0	36.0
10	171.	6.43	0.361	10.4	372.	6.0	106.9	35.9

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.557
FACR = 1.018

INTEGRAL
CN = 0.569

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.15	0.625	18.0	0.148	11.40	0.639	18.4
2	27.	10.19	0.571	16.4	0.341	10.42	0.584	16.8
3	45.	9.65	0.541	15.6	0.489	9.87	0.553	15.9
4	63.	9.18	0.515	14.8	0.600	9.39	0.526	15.1
5	81.	8.69	0.488	14.0	0.671	8.89	0.499	14.3
6	99.	8.17	0.458	13.2	0.706	8.36	0.468	13.5
7	117.	7.57	0.424	12.2	0.694	7.74	0.433	12.5
8	135.	6.82	0.382	11.0	0.629	6.97	0.391	11.2
9	153.	5.86	0.329	9.5	0.509	6.00	0.336	9.7
10	171.	4.31	0.242	7.0	0.294	4.41	0.247	7.1

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=	15019.9	NGRC=	4.16	NUAVG EXPMTL =	8.84
NGRPRC=	62437.	SHRAVG=	0.508	NUAVG INTGRL =	8.34

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 16 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 73.0	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 84.79
THERMK	= 0.137	NINDEX	= 1.375

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.60	0.633	18.7	749.	12.0	113.0	40.0
2	27.	11.03	0.601	17.8	714.	11.4	113.1	40.1
3	45.	10.53	0.574	17.0	679.	10.9	113.0	40.0
4	63.	9.95	0.543	16.1	641.	10.3	112.9	39.9
5	81.	9.44	0.514	15.2	612.	9.8	113.2	40.2
6	99.	8.91	0.486	14.4	576.	9.2	113.1	40.1
7	117.	8.44	0.460	13.6	546.	8.7	113.1	40.1
8	135.	7.61	0.415	12.3	490.	7.9	112.9	39.9
9	153.	7.31	0.398	11.8	474.	7.6	113.1	40.1
10	171.	6.57	0.358	10.6	426.	6.8	113.2	40.2

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.556
FACR = 1.016

INTEGRAL
CN = 0.569

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.44	0.624	18.5	0.160	11.69	0.638	18.9
2	27.	10.48	0.571	16.9	0.371	10.71	0.584	17.3
3	45.	9.92	0.541	16.0	0.531	10.14	0.553	16.4
4	63.	9.44	0.515	15.2	0.651	9.65	0.526	15.6
5	81.	8.95	0.488	14.5	0.733	9.15	0.499	14.8
6	99.	8.40	0.458	13.6	0.765	8.59	0.468	13.9
7	117.	7.77	0.424	12.5	0.752	7.94	0.433	12.8
8	135.	7.01	0.382	11.3	0.683	7.16	0.391	11.6
9	153.	6.04	0.329	9.7	0.555	6.17	0.336	10.0
10	171.	4.44	0.242	7.2	0.320	4.54	0.247	7.3

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=14777.9	NGRC= 4.88	NUAVG EXPMTL = 9.14
NGRPRC= 72076.	SHRAVG= 0.552	NUAVG INTGRL = 8.58

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 17 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 72.5	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 84.74
THERMK	= 0.137	NINDEX	= 1.373

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.86	0.633	19.1	843.	13.5	116.6	44.1
2	27.	11.31	0.604	18.3	804.	12.9	116.5	44.0
3	45.	10.87	0.579	17.5	776.	12.4	116.7	44.2
4	63.	10.29	0.549	16.6	734.	11.7	116.7	44.2
5	81.	9.74	0.520	15.7	691.	11.1	116.5	44.0
6	99.	9.16	0.488	14.8	655.	10.5	116.7	44.2
7	117.	8.66	0.462	14.0	617.	9.9	116.7	44.2
8	135.	8.02	0.427	12.9	573.	9.2	116.7	44.2
9	153.	7.43	0.397	12.0	529.	8.5	116.6	44.1
10	171.	6.65	0.355	10.7	472.	7.6	116.5	44.0

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.556
FACR = 1.016

INTEGRAL
CN = 0.569

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.68	0.623	18.9	0.170	11.95	0.637	19.3
2	27.	10.70	0.571	17.3	0.394	10.94	0.584	17.7
3	45.	10.15	0.541	16.4	0.568	10.38	0.553	16.8
4	63.	9.65	0.515	15.6	0.696	9.87	0.526	15.9
5	81.	9.14	0.488	14.8	0.779	9.34	0.499	15.1
6	99.	8.59	0.458	13.9	0.819	8.78	0.468	14.2
7	117.	7.94	0.423	12.8	0.803	8.12	0.433	13.1
8	135.	7.17	0.382	11.6	0.732	7.33	0.391	11.8
9	153.	6.16	0.329	10.0	0.591	6.30	0.336	10.2
10	171.	4.53	0.242	7.3	0.340	4.63	0.247	7.5

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=14876.6	NGRC= 5.38	NUAVG EXPMTL = 9.40
NGRPRC= 79963.	SHRAVG= 0.589	NUAVG INTGRL = 8.76

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 18 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 41.0 % CS/SS SOL	SPHEAT	= 0.643
TBULK	= 74.5	BETA	= 0.00062
DENSITY	= 77.04	KLBFTHR	= 84.72
THERMK	= 0.137	NINDEX	= 1.368

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	12.18	0.634	19.7	943.	15.1	122.4	47.9
2	27.	11.50	0.598	18.6	893.	14.3	122.6	48.1
3	45.	10.88	0.566	17.6	841.	13.5	122.4	47.9
4	63.	10.38	0.541	16.8	801.	12.8	122.2	47.7
5	81.	9.81	0.511	15.9	757.	12.1	122.3	47.8
6	99.	9.36	0.488	15.1	724.	11.6	122.4	47.9
7	117.	8.86	0.461	14.3	686.	11.0	122.4	47.9
8	135.	7.99	0.416	12.9	619.	9.9	122.5	48.0
9	153.	7.26	0.378	11.7	561.	9.0	122.3	47.8
10	171.	6.66	0.347	10.8	516.	8.3	122.4	47.9

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.556
FACR = 1.014

INTEGRAL
CN = 0.569

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.95	0.622	19.3	0.182	12.22	0.636	19.7
2	27.	10.96	0.570	17.7	0.424	11.21	0.583	18.1
3	45.	10.38	0.541	16.8	0.608	10.62	0.553	17.2
4	63.	9.87	0.515	16.0	0.745	10.10	0.526	16.3
5	81.	9.36	0.488	15.1	0.836	9.57	0.499	15.5
6	99.	8.79	0.458	14.2	0.877	8.99	0.468	14.5
7	117.	8.13	0.423	13.1	0.861	8.31	0.433	13.4
8	135.	7.34	0.382	11.9	0.785	7.51	0.391	12.1
9	153.	6.31	0.329	10.2	0.633	6.45	0.336	10.4
10	171.	4.63	0.241	7.5	0.366	4.74	0.247	7.7

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=14543.0	NGRC= 6.22	NUAVG EXPMTL = 9.49
NGRPRC= 90525.	SHRAVG= 0.632	NUAVG INTGRL = 8.97

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 19 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 69.5	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 62.95
THERMK	= 0.134	NINDEX	= 1.443

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.28	0.623	16.2	452.	7.2	97.3	27.8
2	27.	9.99	0.606	15.8	438.	7.0	97.3	27.8
3	45.	9.46	0.574	15.0	415.	6.6	97.2	27.7
4	63.	9.00	0.545	14.2	398.	6.4	97.5	28.0
5	81.	8.52	0.516	13.5	376.	6.0	97.4	27.9
6	99.	7.88	0.477	12.5	350.	5.6	97.6	28.1
7	117.	7.69	0.466	12.2	338.	5.4	97.3	27.8
8	135.	6.85	0.415	10.8	302.	4.8	97.4	27.9
9	153.	6.44	0.390	10.2	283.	4.5	97.3	27.8
10	171.	5.74	0.348	9.1	254.	4.1	97.4	27.9

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.559
FACR = 1.044

INTEGRAL
CN = 0.571

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	10.51	0.637	16.6	0.125	10.74	0.650	17.0
2	27.	9.51	0.577	15.0	0.280	9.72	0.589	15.4
3	45.	8.97	0.544	14.2	0.396	9.17	0.556	14.5
4	63.	8.53	0.516	13.5	0.484	8.72	0.527	13.8
5	81.	8.07	0.488	12.8	0.540	8.24	0.499	13.0
6	99.	7.58	0.458	12.0	0.566	7.74	0.468	12.2
7	117.	7.00	0.424	11.1	0.553	7.16	0.434	11.3
8	135.	6.34	0.384	10.0	0.506	6.47	0.392	10.2
9	153.	5.47	0.331	8.6	0.412	5.59	0.339	8.8
10	171.	4.06	0.246	6.4	0.243	4.15	0.251	6.6

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=18278.7	NGRC= 2.05	NUAVG EXPMTL = 8.19
NGRPRC= 37445.	SHRAVG= 0.410	NUAVG INTGRL = 7.77

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 20 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 72.5	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 62.14
THERMK	= 0.134	NINDEX	= 1.439

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.56	0.619	16.7	531.	8.5	104.3	31.8
2	27.	10.20	0.598	16.1	513.	8.2	104.3	31.8
3	45.	9.73	0.571	15.4	486.	7.8	104.1	31.6
4	63.	9.16	0.536	14.5	464.	7.4	104.5	32.0
5	81.	8.77	0.514	13.9	443.	7.1	104.4	31.9
6	99.	8.13	0.476	12.9	411.	6.6	104.4	31.9
7	117.	7.70	0.451	12.2	389.	6.2	104.4	31.9
8	135.	7.08	0.414	11.2	357.	5.7	104.4	31.9
9	153.	6.51	0.381	10.3	328.	5.2	104.3	31.8
10	171.	6.05	0.355	9.6	304.	4.9	104.2	31.7

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.559
FACR = 1.042

INTEGRAL
CN = 0.571

NO	ANGLE	NUX (ACRIVOS)	NUGPD (ACRIVOS)	HX (ACRIVOS)	SHEAR	NUX (INTEGRAL)	NUGPD (INTEGRAL)	HX (INTEGRAL)
1	9.	10.85	0.636	17.2	0.138	11.09	0.650	17.5
2	27.	9.83	0.576	15.6	0.309	10.04	0.589	15.9
3	45.	9.27	0.544	14.7	0.436	9.47	0.556	15.0
4	63.	8.82	0.516	14.0	0.535	9.01	0.527	14.3
5	81.	8.34	0.488	13.2	0.596	8.52	0.499	13.5
6	99.	7.83	0.458	12.4	0.624	8.00	0.468	12.7
7	117.	7.25	0.424	11.5	0.612	7.40	0.433	11.7
8	135.	6.55	0.384	10.4	0.559	6.69	0.392	10.6
9	153.	5.65	0.331	8.9	0.455	5.78	0.338	9.1
10	171.	4.19	0.246	6.6	0.267	4.28	0.251	6.8

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=18152.8	NGRC= 2.45	NUAVG EXPMTL = 8.39
NGRPRC= 44394.	SHRAVG= 0.453	NUAVG INTGRL = 8.03

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER TO POWER-LAW FLUIDS

RUN 21 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 71.0	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 62.02
THERMK	= 0.134	NINDEX	= 1.438

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	10.83	0.619	17.1	618.	9.9	107.0	36.0
2	27.	10.37	0.592	16.4	596.	9.5	107.3	36.3
3	45.	9.92	0.566	15.7	569.	9.1	107.3	36.3
4	63.	9.47	0.541	15.0	542.	8.7	107.2	36.2
5	81.	8.93	0.510	14.1	511.	8.2	107.1	36.1
6	99.	8.32	0.476	13.2	475.	7.6	107.1	36.1
7	117.	7.87	0.450	12.5	450.	7.2	107.1	36.1
8	135.	7.30	0.417	11.6	417.	6.7	107.1	36.1
9	153.	6.82	0.389	10.8	390.	6.2	107.2	36.2
10	171.	6.09	0.348	9.6	347.	5.6	107.1	36.1

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.559
FACR = 1.042

INTEGRAL
CN = 0.571

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.12	0.636	17.6	0.148	11.36	0.650	18.0
2	27.	10.09	0.576	16.0	0.334	10.31	0.589	16.3
3	45.	9.52	0.544	15.1	0.473	9.73	0.556	15.4
4	63.	9.03	0.516	14.3	0.575	9.23	0.527	14.6
5	81.	8.55	0.488	13.5	0.641	8.73	0.499	13.8
6	99.	8.02	0.458	12.7	0.670	8.19	0.468	13.0
7	117.	7.42	0.424	11.7	0.658	7.59	0.434	12.0
8	135.	6.71	0.384	10.6	0.601	6.86	0.392	10.9
9	153.	5.80	0.331	9.2	0.490	5.92	0.338	9.4
10	171.	4.30	0.246	6.8	0.288	4.39	0.251	6.9

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=18676.6	NGRC= 2.66	NUAVG EXPMTL = 8.59
NGRPRC= 49722.	SHRAVG= 0.488	NUAVG INTGRL = 8.23

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 22 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 74.5	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 60.89
THERMK	= 0.134	NINDEX	= 1.434

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.11	0.618	17.6	698.	11.2	114.2	39.7
2	27.	10.63	0.590	16.8	673.	10.8	114.5	40.0
3	45.	10.25	0.569	16.2	648.	10.4	114.4	39.9
4	63.	9.78	0.544	15.5	618.	9.9	114.4	39.9
5	81.	9.27	0.515	14.7	583.	9.3	114.2	39.7
6	99.	8.63	0.479	13.7	545.	8.7	114.4	39.9
7	117.	8.23	0.458	13.0	519.	8.3	114.3	39.8
8	135.	7.51	0.418	11.9	474.	7.6	114.3	39.8
9	153.	7.12	0.396	11.3	450.	7.2	114.4	39.9
10	171.	6.43	0.357	10.2	408.	6.5	114.6	40.1

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.559
FACR = 1.040

INTEGRAL
CN = 0.571

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.41	0.635	18.1	0.160	11.66	0.649	18.5
2	27.	10.37	0.576	16.4	0.362	10.60	0.588	16.8
3	45.	9.79	0.544	15.5	0.513	10.00	0.555	15.8
4	63.	9.29	0.516	14.7	0.624	9.49	0.527	15.0
5	81.	8.78	0.488	13.9	0.696	8.97	0.499	14.2
6	99.	8.25	0.458	13.1	0.729	8.43	0.468	13.4
7	117.	7.63	0.424	12.1	0.715	7.80	0.433	12.3
8	135.	6.90	0.384	10.9	0.653	7.05	0.392	11.2
9	153.	5.96	0.331	9.4	0.533	6.09	0.338	9.6
10	171.	4.42	0.245	7.0	0.314	4.52	0.251	7.2

***** AVERAGE HEAT TRANSFER RESULTS *****

NFRC=18273.9	NGRC= 3.16	NUAVG EXPMTL = 8.90
NGRPRC= 57672.	SHRAVG= 0.530	NUAVG INTGRL = 8.46

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 23 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 75.5	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 60.13
THERMK	= 0.134	NINDEX	= 1.432

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	11.39	0.617	18.0	797.	12.8	119.7	44.2
2	27.	10.94	0.593	17.3	761.	12.2	119.4	43.9
3	45.	10.63	0.576	16.8	741.	11.9	119.5	44.0
4	63.	9.93	0.538	15.7	693.	11.1	119.6	44.1
5	81.	9.51	0.516	15.1	662.	10.6	119.4	43.9
6	99.	9.01	0.488	14.3	633.	10.1	119.8	44.3
7	117.	8.67	0.470	13.7	608.	9.7	119.7	44.2
8	135.	8.04	0.436	12.7	563.	9.0	119.7	44.2
9	153.	7.49	0.406	11.9	524.	8.4	119.6	44.1
10	171.	6.57	0.356	10.4	461.	7.4	119.7	44.2

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.559
FACR = 1.039

INTEGRAL
CN = 0.571

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.71	0.635	18.6	0.173	11.97	0.648	19.0
2	27.	10.61	0.576	16.8	0.387	10.84	0.588	17.2
3	45.	10.02	0.544	15.9	0.551	10.24	0.555	16.2
4	63.	9.52	0.516	15.1	0.672	9.72	0.527	15.4
5	81.	9.00	0.488	14.3	0.748	9.20	0.499	14.6
6	99.	8.46	0.458	13.4	0.787	8.65	0.468	13.7
7	117.	7.83	0.424	12.4	0.772	8.00	0.434	12.7
8	135.	7.08	0.384	11.2	0.705	7.23	0.392	11.5
9	153.	6.11	0.331	9.7	0.573	6.24	0.338	9.9
10	171.	4.53	0.245	7.2	0.337	4.63	0.251	7.3

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=18242.2	NGRC= 3.58	NUAVG EXPMTL = 9.22
NGRPRC= 65284.	SHRAVG= 0.570	NUAVG INTGRL = 8.67

LOCAL FREE CONVECTION FROM HORIZONTAL CYLINDER
TO POWER-LAW FLUIDS

RUN 24 ISOTHERMAL CASE

***** FLUID PROPERTIES *****

FLUID	= 42.0 % CS/SS SOL	SPHEAT	= 0.638
TBULK	= 75.5	BETA	= 0.00063
DENSITY	= 77.05	KLBFTHR	= 59.66
THERMK	= 0.134	NINDEX	= 1.430

***** REDUCED EXPERIMENTAL DATA *****

NO	ANGLE	NUX	NUGPD	HX	QFLUX	BTUHR	TWALL	DELT T
1	9.	12.01	0.639	19.0	908.	14.5	123.2	47.7
2	27.	11.36	0.604	18.0	861.	13.8	123.3	47.8
3	45.	10.88	0.579	17.2	820.	13.1	123.1	47.6
4	63.	10.31	0.548	16.3	782.	12.5	123.4	47.9
5	81.	9.76	0.520	15.5	735.	11.8	123.0	47.5
6	99.	9.13	0.485	14.5	692.	11.1	123.4	47.9
7	117.	8.59	0.457	13.6	650.	10.4	123.3	47.8
8	135.	7.90	0.421	12.5	596.	9.6	123.1	47.6
9	153.	7.37	0.392	11.7	555.	8.9	123.1	47.6
10	171.	6.65	0.354	10.5	505.	8.1	123.4	47.9

***** SIMILAR AND INTEGRAL SOLUTIONS FOR ISOTHERMAL *****

ACRIVOS
THETA= -0.559
FACR = 1.038

INTEGRAL
CN = 0.571

NO	ANGLE	NUX	NUGPD	HX	SHEAR	NUX	NUGPD	HX
1	9.	11.92	0.634	18.9	0.182	12.18	0.648	19.3
2	27.	10.82	0.576	17.1	0.411	11.05	0.588	17.5
3	45.	10.20	0.543	16.2	0.581	10.43	0.555	16.5
4	63.	9.70	0.516	15.4	0.712	9.92	0.527	15.7
5	81.	9.17	0.488	14.5	0.790	9.37	0.499	14.8
6	99.	8.62	0.458	13.7	0.830	8.80	0.468	14.0
7	117.	7.97	0.424	12.6	0.814	8.15	0.433	12.9
8	135.	7.20	0.384	11.4	0.742	7.36	0.392	11.7
9	153.	6.21	0.331	9.8	0.604	6.35	0.338	10.1
10	171.	4.61	0.245	7.3	0.356	4.71	0.250	7.5

***** AVERAGE HEAT TRANSFER RESULTS *****

NPRC=18316.5	NGRC= 3.90	NUAVG EXPMTL = 9.39
NGRPRC= 71362.	SHRAVG= 0.602	NUAVG INTGRL = 8.83

APPENDIX B

VISCOMETRIC DATA FOR TEST FLUIDS

VISCOMETRIC DATA FOR TEST FLUIDS

Nomenclature

NINDEX	flow behavior index
KSEC	consistency index, lbm/ft-(sec)$^{2-n}$
DINNER	inner cylinder diameter, inches
DOUTER	outer cylinder diameter, inches
LEQUIN	inner cylinder equivalent length, inches
STRESS	shear stress, lb_f/ft^2
DU/PR	shear rate, 1/sec
APKSEC	apparent viscosity, lbm/ft-sec

```
$JOB
C
C       VISCOMETER DATA REDUCTION
C
         REAL NODATA, NLOG, INDEX, M, KGLOG, KG, KSEC, KHR,
        1NCHECK, NCHKLG, LENIN, LENFT
         DIMENSION RPM(30), RDG(30), TORQUE(30), STRESS(30),
        1STRCHK(30), DUDR(30), DUDRN(30), VISACP(30),
        2 APKSEC(30)
         DOUBLE PRECISION SUMX1, SUMY1, SUMXY1, SUMXX1, Y1, X1,
        1X1SQRD, XY1, SUMX2, SUMY2, SUMXY2, SUMXX2, Y2, X2,
        2X2SQRD, XY2
       1 READ(5,3) SOU, RCE, CON, T, Y, PE, TEMPT, VISCOM, DIN,
        1DOIN, LENIN, N
       3 FORMAT(2A3, F6.3, 3A3, F5.0, F3.0, 3F6.3, I3)
         READ(5,5) (RPM(I), RDG(I), I=1,N)
       5 FORMAT(F5.1, F5.1)
         DIF = DIN/12.0
         DOF = DOIN/12.0
         LENFT = LENIN/12.0
         RIF = DIF/2.0
         RCF = DOF/2.0
         IF(VISCOM .GT. 1.0) GO TO 40
         S = DOF/DIF
         STERM = (1.0 - (1.0/S**2.0))
         SL1 = ALOG(S)
         SL2 = SL1**2.0
         SL4 = SL1**4.0
         SERIES = (1.0 + SL1 + (SL2/3.0) - (SL4/45.0))/SL1
         CR = 0.5 * SERIES * STERM
         S1 = (S**2.0 - 1.0)/(S**2.0)
         C1 = 0.5 * S1 * (1.00 + 0.6667*ALOG(S))
         C2 = (S1 *  ALOG(S))/6.0
         GO TO 42
      40 S = 0.0
         STERM = 0.0
         S1 = 0.0
         C1 = 0.0
         C2 = 0.0
         CR = 0.0
         GO TO 42
      42 SPRING = 0.0000497
C
C       FLOW BEHAVIOR INDEX DETERMINATION
C
         SUMX1 = 0.0
         SUMY1 = 0.0
         SUMXY1 = 0.0
         SUMXX1 = 0.0
         DO 50 I=1,N
         Y1 = ALOG(RDG(I))
         X1 = ALOG(RPM(I))
         X1SQRD = X1 * X1
         XY1 = X1 * Y1
         SUMY1 = SUMY1 + Y1
         SUMX1 = SUMX1 + X1
         SUMXX1 = SUMXX1 + X1SQRD
         SUMXY1 = SUMXY1 + XY1
         TORQUE(I) = (RDG(I) * SPRING)/100.0
         STRESS(I) = (TORQUE(I)/RIF)/(6.2832 * RIF*LENFT)
```

```
   50 CONTINUE
      NCDATA = N
      INDEX= (NODATA*SUMXY1-SUMX1*SUMY1)/(NODATA*SUMXX1-
     1SUMX1*SUMX1)
      M = 1.0/INDEX
C
C     CONSISTENCY INDEX DETERMINATION
C
      SUMX2 = 0.0
      SUMY2 = 0.0
      SUMXY2 = 0.0
      SUMXX2 = 0.0
      IF(VISCOM .GT. 1.0) GO TO 100
C
C     CONCENTRIC CYLINDER VISCOMETER
C
      DO 60 I=1,N
      DUDR(I) = 2.0 * 3.1416 * RPM(I) * SERIES/60.0
      DUDRN(I) = DUDR(I) **INDEX
      Y2 = ALOG(STRESS(I))
      X2 = ALOG(DUDR(I))
      X2SQRD = X2*X2
      XY2 = X2 * Y2
      SUMY2 = SUMY2 + Y2
      SUMX2 = SUMX2 + X2
      SUMXX2 = SUMXX2 + X2SQRD
      SUMXY2 = SUMXY2 + XY2
   60 CONTINUE
      GO TO 120
C
C     CYLINDER IN INFINITE FLUID BATH
C
  100 DO 70 I=1,N
      DUDR(I) = (4.0 * 3.1416 * RPM(I))/(60.0 * INDEX)
      DUDRN(I) = DUDR(I) ** INDEX
      Y2 = ALOG(STRESS(I))
      X2 = ALOG(DUDR(I))
      X2SQRD = X2*X2
      XY2 = X2 * Y2
      SUMY2 = SUMY2 + Y2
      SUMX2 = SUMX2 + X2
      SUMXX2 = SUMXX2 + X2SQRD
      SUMXY2 = SUMXY2 + XY2
   70 CONTINUE
      GO TO 120
C
  120 NCHECK = (NODATA*SUMXY2 - SUMX2*SUMY2)/(NODATA*SUMXX2
     1- SUMX2*SUMX2)
      KGLOG = (SUMY2*SUMXX2 - SUMXY2*SUMX2)/(NODATA*SUMXX2 -
     1SUMX2*SUMX2)
      KG = EXP(KGLOG)
      KSEC = 32.2 * KG
      KHR = (3600. **(2.0-INDEX)) * KSEC
      CENPS = 1488.0 * KSEC
      DC 80 I=1,N
      STRCHK(I) = KG* DUDRN(I)
      APKSEC(I) = (32.2 * STRESS(I))/DUDR(I)
   80 CONTINUE
      WRITE(6,2)
    2 FORMAT( 1H1, //////, 37X,'VISCOMETER DATA REDUCTION'/)
```

```
         WRITE(6,4) TEMPT
       4 FORMAT(21X, 'FLUID', 16X, 'TEMPT = ', F4.0, 15X,
        1'VISCOMETER'///)
         IF(VISCOM .GT. 1.0) GO TO 140
         WRITE(6,6) SOU, RCE
       6 FORMAT(21X,'SOURCE = ',2A3,26X,'TYPE:  CONCENTRIC'/)
         GC TO 160
     140 WRITE(6,8) SOU, RCE
       8 FORMAT(21X,'SOURCE = ', 2A3, 26X, 'TYPE:  SINGLE'/)
         GO TO 160
     160 WRITE(6,10) CON, T, Y, PE, DIN
      10 FORMAT(21X 'TYPE    = '  F5.1, 1X, 3A3, 17X,
        1'DINNER  = ', F5.3/)
WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR 1X 'T
         WRITE(6,12) INDEX, DCIN
      12 FORMAT(21X 'NINDEX = ', F5.3, 27X, 'DOUTER  = ',F5.3/)
WARNING**  EXPECTING COMMA BETWEEN FORMAT .TEMS NEAR 1X 'N
         WRITE(6,14) NCHECK, LENIN
      14 FORMAT(21X 'NCHECK = ', F5.3, 27X, 'LEQVIN  = ',F5.3/)
WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR 1X 'N
         WRITE(6,16) KG, S
      16 FORMAT(21X 'K/G    = ',F9.7, 23X, 'S=DO/DI = ', F5.3/)
WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR 1X 'K
         WRITE(6,18) KSEC, STERM
      18 FORMAT(21X 'KSEC   = ', F9.7, 23X, 'STERM   = ',F5.3/)
WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR 1X 'K
         WRITE(6,20) KHR, SPRING
      20 FORMAT(21X 'KHR    = ', F8.0, 24X, 'SPRING  = ',F9.7/)
WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR 1X 'K
         WRITE(6,22) CENPS, CR
      22 FORMAT(21X 'CENPS  = ', F6.0, 26X, 'CR', 6X, '= ',
        1 F5.3///)
WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR 1X 'C
         WRITE(6,24)
      24 FORMAT(22X, 'RPM', 4X, 'RDG', 6X, 'TORQUE', 6X,
        1 'STRESS', 3X, 'DU/DR', 7X, 'APKSEC'/)
         WRITE(6,26) (RPM(I), RDG(I), TORQUE(I), STRESS(I),
        1 DUDR(I), APKSEC(I), I=1,N)
      26 FORMAT(21X, F4.1, F8.2, F14.10, F10.6, F8.4, F12.5)
         WRITE(6,28)
      28 FORMAT(1H1)
      85 GO TO 1
      95 STOP
         END
WARNING**  UNREFERENCED STATEMENT     95 FOLLOWS A TRANSFER


      $ENTRY
```

VISCOMETER DATA REDUCTION

FLUID TEMPT = 70. VISCOMETER

SOURCE	= SAMP 1	TYPE:	SINGLE
TYPE	= 38.0 CS/SS SOL	DINNER	= 0.235
NINDEX	= 1.192	DOUTER	= 0.000
NCHECK	= 1.192	LEQVIN	= 1.758
K/G	= 0.0121068	S=DO/DI	= 0.000
KSEC	= 0.3898389	STERM	= 0.000
KHR	= 291.	SPRING	= 0.0000497
CENPS	= 580.	CR	= 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.00	0.0000004970	0.005632	0.5271	0.34404
6.0	2.30	0.0000011431	0.012952	1.0542	0.39564
12.0	5.20	0.0000025844	0.029284	2.1083	0.44725
30.0	15.70	0.0000078029	0.088415	5.2708	0.54014
60.0	35.50	0.0000176435	0.199918	10.5416	0.61066

VISCOMETER DATA REDUCTION

FLUID   TEMPT = 80.   VISCOMETER

SOURCE = SAMP 1		TYPE:	SINGLE
TYPE	= 38.0 CS/SS SOL	DINNER	= 0.235
NINDEX	= 1.188	DOUTER	= 0.000
NCHECK	= 1.188	LEQVIN	= 1.758
K/G	= 0.0106549	S=DO/DI	= 0.000
KSEC	= 0.3430882	STERM	= 0.000
KHR	= 266.	SPRING	= 0.0000497
CENPS	= 511.	CR	= 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.90	0.0000004473	0.005068	0.5291	0.30847
6.0	2.00	0.0000009940	0.011263	1.0581	0.34274
12.0	4.60	0.0000022862	0.025905	2.1163	0.39415
30.0	13.50	0.0000067095	0.076025	5.2907	0.46270
60.0	31.60	0.0000157052	0.177956	10.5815	0.54153

VISCOMETER DATA REDUCTION

FLUID TEMPT = 90. VISCOMETER

SOURCE = SAMP 1 TYPE: SINGLE

TYPE = 38.0 CS/SS SCL DINNER = 0.235

NINDEX = 1.182 DOUTER = 0.000

NCHECK = 1.182 LEQVIN = 1.758

K/G = 0.0094558 S=DO/DI = 0.000

KSEC = 0.3044778 STERM = 0.000

KHR = 247. SPRING = 0.000049?

CENPS = 453. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.80	0.0000003976	0.004505	0.5316	0.27289
6.0	1.80	0.0000008946	0.010137	1.0632	0.30700
12.0	4.10	0.0000020377	0.023089	2.1264	0.34954
30.0	11.90	0.0000059143	0.067015	5.3159	0.40593
60.0	27.80	0.0000138166	0.156556	10.6319	0.47415

VISCOMETER DATA REDUCTION

FLUID   TEMPT = 100.   VISCOMETER

SOURCE = SAMP 1   TYPE: SINGLE

TYPE = 38.0 CS/SS SOL   DINNER = 0.235

NINDEX = 1.166   DOUTER = 0.000

NCHECK = 1.166   LEQVIN = 1.758

K/G = 0.0082077   S=DO/DI = 0.000

KSEC = 0.2642867   STERM = 0.000

KHR = 244.   SPRING = 0.0000497

CENPS = 393.   CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.70	0.0000003479	0.003942	0.5387	0.23561
6.0	1.60	0.0000007952	0.009010	1.0775	0.26927
12.0	3.60	0.0000017892	0.020273	2.1550	0.30293
30.0	10.50	0.0000052185	0.059131	5.3874	0.35342
60.0	23.00	0.0000114310	0.129525	10.7748	0.38708

VISCOMETER DATA REDUCTION

FLUID TEMPT = 70. VISCOMETER

SOURCE = SAMP 2		TYPE:	SINGLE
TYPE	= 39.0 CS/SS SOL	DINNER	= 0.235
NINDEX	= 1.251	DOUTER	= 0.000
NCHECK	= 1.251	LEQVIN	= 1.758
K/G	= 0.0143722	S=DO/DI	= 0.000
KSEC	= 0.4627861	STERM	= 0.000
KHR	= 213.	SPRING	= 0.0000497
CENPS	= 689.	CR	= 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.10	0.0000005467	0.006195	0.5021	0.39729
6.0	2.50	0.0000012425	0.014079	1.0041	0.45147
12.0	6.20	0.0000030814	0.034915	2.0083	0.55982
30.0	18.50	0.0000091945	0.104183	5.0207	0.66817
60.0	47.10	0.0000234087	0.265244	10.0414	0.85056

VISCOMETER DATA REDUCTION

FLUID TEMPT = 80. VISCOMETER

SOURCE = SAMP 2 TYPE: SINGLE

TYPE = 39.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.241 DOUTER = 0.000

NCHECK = 1.241 LEQVIN = 1.758

K/G = 0.0127904 S=DO/DI = 0.000

KSEC = 0.4118493 STERM = 0.000

KHR = 206. SPRING = 0.000049

CENPS = 613. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.00	0.0000004970	0.005632	0.5062	0.35821
6.0	2.20	0.0000010934	0.012389	1.0124	0.39403
12.0	5.60	0.0000027832	0.031536	2.0249	0.50149
30.0	16.80	0.0000083496	0.094609	5.0622	0.60179
60.0	40.50	0.0000201285	0.228076	10.1245	0.72538

VISCOMETER DATA REDUCTION

FLUID TEMPT = 90. VISCOMETER

SOURCE = SAMP 2 TYPE: SINGLE

TYPE = 39.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.224 DOUTER = 0.000

NCHECK = 1.224 LEQVIN = 1.758

K/G = 0.0113785 S=DO/DI = 0.000

KSEC = 0.3663873 STERM = 0.000

KHR = 211. SPRING = 0.000049

CENPS = 545. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.90	0.0000004473	0.005068	0.5133	0.31795
6.0	2.00	0.0000009940	0.011263	1.0266	0.35327
12.0	5.10	0.0000025347	0.028721	2.0532	0.45042
30.0	15.00	0.0000074550	0.084473	5.1330	0.52991
60.0	34.50	0.0000171465	0.194287	10.2660	0.60940

VISCOMETER DATA REDUCTION

FLUID TEMPT = 100. VISCOMETER

SOURCE = SAMP 2 TYPE: SINGLE

TYPE = 39.0 CS/SS SOL

NINDEX = 1.218

NCHECK = 1.218

K/G = 0.0101814

KSEC = 0.3278401

KHR = 198.

CENPS = 488.

DINNER = 0.235

DOUTER = 0.000

LEQVIN = 1.758

S=DO/DI = 0.000

STERM = 0.000

SPRING = 0.000049

CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.80	0.0000003976	0.004505	0.5159	0.28118
6.0	1.80	0.0000008946	0.010137	1.0318	0.31633
12.0	4.70	0.0000023359	0.026468	2.0637	0.41298
30.0	13.50	0.0000067095	0.076025	5.1592	0.47449
60.0	30.00	0.0000149100	0.168945	10.3185	0.52721

VISCOMETER DATA REDUCTION

FLUID TEMPT = 70. VISCOMETER

SOURCE = SAMP 3 TYPE: SINGLE

TYPE = 40.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.326 DOUTER = 0.000

NCHECK = 1.326 LEQVIN = 1.758

K/G = 0.0164165 S=DO/DI = 0.000

KSEC = 0.5286116 STERM = 0.000

KHR = 131. SPRING = 0.0000497

CENPS = 787. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.10	0.0000005467	0.006195	0.4737	0.42111
6.0	2.70	0.0000013419	0.015205	0.9473	0.51682
12.0	6.70	0.0000033299	0.037731	1.8947	0.64124
30.0	22.50	0.0000111825	0.126709	4.7367	0.86136
60.0	58.90	0.0000292733	0.331696	9.4734	1.12743

VISCOMETER DATA RECUCTION

FLUID   TEMPT = 80.   VISCOMETER

SOURCE = SAMP 3   TYPE: SINGLE

TYPE = 40.0 CS/SS SOL   DINNER = 0.235

NINDEX = 1.324   DOUTER = 0.000

NCHECK = 1.324   LEQVIN = 1.758

K/G = 0.0148625   S=DO/DI = 0.000

KSEC = 0.4785716   STERM = 0.000

KHR = 121.   SPRING = 0.000049?

CENPS = 712.   CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.00	0.0000004970	0.005632	0.4746	0.38210
6.0	2.40	0.0000011928	0.013516	0.9492	0.45852
12.0	6.20	0.0000030814	0.034915	1.8983	0.59225
30.0	20.80	0.0000103376	0.117135	4.7458	0.79476
60.0	52.00	0.0000258440	0.292838	9.4915	0.99345

VISCOMETER DATA REDUCTION

FLUID TEMPT = 90. VISCOMETER

SOURCE = SAMP 3		TYPE:	SINGLE
TYPE =	40.0 CS/SS SOL	DINNER	= 0.235
NINDEX =	1.313	DOUTER	= 0.000
NCHECK =	1.313	LEQVIN	= 1.758
K/G =	0.0130877	S=DO/DI	= 0.000
KSEC =	0.4214253	STERM	= 0.000
KHR =	117.	SPRING	= 0.0000497
CENPS =	627.	CR	= 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.90	0.0000004473	0.005068	0.4786	0.34099
6.0	2.10	0.0000010437	0.011826	0.9572	0.39782
12.0	5.60	0.0000027832	0.031536	1.9144	0.53043
30.0	18.20	0.0000090454	0.102493	4.7861	0.68956
60.0	44.90	0.0000223153	0.252855	9.5721	0.85059

VISCOMETER DATA REDUCTION

FLUID TEMPT = 100. VISCOMETER

SOURCE = SAMP 3 TYPE: SINGLE

TYPE = 40.0 CS/SS SCL DINNER = 0.235

NINDEX = 1.307 DOUTER = 0.000

NCHECK = 1.307 LEQVIN = 1.758

K/G = 0.0119294 S=DO/DI = 0.000

KSEC = 0.3841262 STERM = 0.000

KHR = 112. SPRING = 0.000049[illegible]

CENPS = 572. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.80	0.0000003976	0.004505	0.4806	0.30187
6.0	2.00	0.0000009940	0.011263	0.9611	0.37734
12.0	5.10	0.0000025347	0.028721	1.9222	0.48111
30.0	17.00	0.0000084490	0.095736	4.8056	0.64148
60.0	39.50	0.0000196315	0.222444	9.6112	0.74525

VISCOMETER DATA REDUCTION

FLUID TEMPT = 70. VISCOMETER

SOURCE = SAMP 4 TYPE: SINGLE

TYPE = 41.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.397 DOUTER = 0.000

NCHECK = 1.397 LEQVIN = 1.758

K/G = 0.0198567 S=DO/DI = 0.000

KSEC = 0.6393872 STERM = 0.000

KHR = 90. SPRING = 0.0000497

CENPS = 951. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.20	0.0000005964	0.006758	0.4499	0.48365
6.0	3.00	0.0000014910	0.016895	0.8998	0.60457
12.0	7.50	0.0000037275	0.042236	1.7996	0.75571
30.0	29.90	0.0000148603	0.168382	4.4991	1.20510
60.0	76.20	0.0000378714	0.429121	8.9982	1.53560

VISCOMETER DATA REDUCTION

FLUID   TEMPT = 80.   VISCOMETER

SOURCE = SAMP 4   TYPE: SINGLE

TYPE = 41.0 CS/SS SOL   DINNER = 0.235

NINDEX = 1.390   DOUTER = 0.000

NCHECK = 1.390   LEQVIN = 1.758

K/G = 0.0179725   S=DO/DI = 0.000

KSEC = 0.5787144   STERM = 0.000

KHR = 85.   SPRING = 0.0000497

CENPS = 861.   CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.10	0.0000005467	0.006195	0.4520	0.44135
6.0	2.70	0.0000013419	0.015205	0.9039	0.54165
12.0	7.00	0.0000034790	0.039421	1.8078	0.70214
30.0	26.20	0.0000130214	0.147545	4.5195	1.05120
60.0	69.30	0.0000344421	0.390263	9.0391	1.39024

VISCOMETER DATA REDUCTION

FLUID TEMPT = 90. VISCOMETER

SOURCE = SAMP 4 TYPE: SINGLE

TYPE = 41.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.377 DOUTER = 0.000

NCHECK = 1.377 LEQVIN = 1.758

K/G = 0.0162253 S=DO/DI = 0.000

KSEC = 0.5224551 STERM = 0.000

KHR = 86. SPRING = 0.0000497

CENPS = 777. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.00	0.0000004970	0.005632	0.4562	0.39752
6.0	2.50	0.0000012425	0.014079	0.9123	0.49690
12.0	6.50	0.0000032305	0.036605	1.8247	0.64596
30.0	23.00	0.0000114310	0.129525	4.5617	0.91429
60.0	61.80	0.0000307146	0.348027	9.1234	1.22833

VISCOMETER DATA REDUCTION

FLUID TEMPT = 100. VISCOMETER

SOURCE = SAMP 4 TYPE: SINGLE

TYPE = 41.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.366 DOUTER = 0.000

NCHECK = 1.366 LEQVIN = 1.758

K/G = 0.0145945 S=DO/DI = 0.000

KSEC = 0.4699422 STERM = 0.000

KHR = 85. SPRING = 0.0000497

CENPS = 699. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	0.90	0.0000004473	0.005068	0.4601	0.35472
6.0	2.30	0.0000011431	0.012952	0.9202	0.45326
12.0	6.10	0.0000030317	0.034352	1.8403	0.60106
30.0	19.90	0.0000098903	0.112067	4.6008	0.78433
60.0	55.10	0.0000273847	0.310296	9.2016	1.08585

VISCOMETER DATA REDUCTION

FLUID TEMPT = 70. VISCOMETER

SOURCE = SAMP 5 TYPE: SINGLE

TYPE = 42.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.455 DOUTER = 0.000

NCHECK = 1.455 LEQVIN = 1.758

K/G = 0.0230107 S=DO/DI = 0.000

KSEC = 0.7409448 STERM = 0.000

KHR = 64. SPRING = 0.000049

CENPS = 1103. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.30	0.0000006461	0.007321	0.4319	0.54584
6.0	3.10	0.0000015407	0.017458	0.8637	0.65081
12.0	8.40	0.0000041748	0.047305	1.7275	0.88175
30.0	36.20	0.0000179914	0.203861	4.3187	1.51996
60.0	94.90	0.0000471653	0.534429	8.6375	1.99232

VISCOMETER DATA REDUCTION

FLUID TEMPT = 80. VISCOMETER

SOURCE = SAMP 5 TYPE: SINGLE

TYPE = 42.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.446 DOUTER = 0.000

NCHECK = 1.446 LEQVIN = 1.758

K/G = 0.0209210 S=DO/DI = 0.000

KSEC = 0.6736556 STERM = 0.000

KHR = 63. SPRING = 0.0000497

CENPS = 1002. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.20	0.0000005964	0.006758	0.4344	0.50089
6.0	2.90	0.0000014413	0.016331	0.8689	0.60524
12.0	7.50	0.0000037275	0.042236	1.7377	0.78263
30.0	32.50	0.0000161525	0.183024	4.3443	1.35657
60.0	86.50	0.0000429905	0.487125	8.6886	1.80528

VISCOMETER DATA REDUCTION

FLUID TEMPT = 90. VISCOMETER

SOURCE = SAMP 5 TYPE: SINGLE

TYPE = 42.0 CS/SS SOL DINNER = 0.235

NINDEX = 1.437 DOUTER = 0.000

NCHECK = 1.437 LEQVIN = 1.758

K/G = 0.0192562 S=DO/DI = 0.000

KSEC = 0.6200510 STERM = 0.000

KHR = 62. SPRING = 0.0000497

CENPS = 923. CR = 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.10	0.0000005467	0.006195	0.4372	0.45624
6.0	2.70	0.0000013419	0.015205	0.8744	0.55993
12.0	7.30	0.0000036281	0.041110	1.7488	0.75694
30.0	28.80	0.0000143136	0.162187	4.3720	1.19451
60.0	78.90	0.0000392132	0.444326	8.7440	1.63624

VISCOMETER DATA REDUCTION

FLUID TEMPT = 100. VISCOMETER

SOURCE = SAMP 5		TYPE:	SINGLE
TYPE	= 42.0 CS/SS SGL	DINNER	= 0.235
NINDEX	= 1.430	DOUTER	= 0.000
NCHECK	= 1.430	LEQVIN	= 1.758
K/G	= 0.0175409	S=DO/DI	= 0.000
KSEC	= 0.5648154	STERM	= 0.000
KHR	= 60.	SPRING	= 0.0000497
CENPS	= 840.	CR	= 0.000

RPM	RDG	TORQUE	STRESS	DU/DR	APKSEC
3.0	1.00	0.0000004970	0.005632	0.4394	0.41267
6.0	2.50	0.0000012425	0.014079	0.8788	0.51583
12.0	6.80	0.0000033796	0.038294	1.7577	0.70153
30.0	26.00	0.0000129220	0.146419	4.3942	1.07293
60.0	70.80	0.0000351876	0.398711	8.7884	1.46084

VITA

Chong Bo Kim was born in Seoul, Korea, on [redacted]. He received his elementary, high school, and college education in Seoul. In June, 1967, he received his Bachelor of Science from Seoul National University in Mechanical Engineering.

Upon completion of his four years of college education, he came to the United States in 1967, and he was employed with Soiltest Engineering Equipment Company in Evanston, Illinois until August, 1971.

In September, 1971, he enrolled as a graduate student in the Department of Mechanical and Aerospace Engineering, University of Missouri-Columbia. He received his M.S. degree in Mechanical Engineering in May, 1973.