Int. J. Heat Mass Transfer. Vol. 32, No. 5, pp. 951–960, 1989
Printed in Great Britain

0017–9310/89 $3.00+0.00

Laminar mixed convection in power law fluids in continuous flow electrophoresis systems

R. A. BREWSTER† and T. F. IRVINE, JR.
Mechanical Engineering Department, State University of New York at Stony Brook, Stony Brook, NY 11794, U.S.A.

(*Received* 30 *October* 1987 *and in final form* 3 *November* 1988)

Abstract—Laminar mixed convection in a power law fluid flowing between vertical parallel plates is considered. Heat is generated in the fluid by a non-uniform volumetric heat source, and the plates are assumed to be adiabatic. The boundary-layer equations are solved using a finite-difference numerical technique. A knowledge of the resulting flow field is of interest in the study of continuous flow electrophoresis systems. Results are presented which show that flow redevelopments due to buoyancy effects occur as well as mixing due to a non-uniform velocity profile. It is shown that the use of pseudoplastic non-Newtonian fluids, and the proper geometry and flow rates, can effectively prevent flow redevelopments and velocity profile dispersion under conditions for which they would otherwise occur.

1. INTRODUCTION

BUOYANCY effects due to internal heat sources may sometimes cause a rearrangement of a fully-developed velocity profile. One important application in which this may occur is in the continuous flow electrophoresis device. This device now will be described in general terms. The interested reader may consult refs. [1, 2] for a discussion of the details of continuous flow electrophoresis.

In its simplest form, the continuous flow electrophoresis device consists of two parallel plates at different electric potentials (Fig. 1). A fluid (called the carrier) flows continuously between the plates. Another fluid (called the migrant mixture), which is to be separated into its component parts (migrant fractions), is injected into the flow, near the inlet. As the migrant mixture is carried between the plates, its components are displaced according to their electrophoretic mobilities. The migrant fractions may then be collected at the outlet. Generally, the carrier fluid is water. Fluids which may be separated include blood, proteins and chemical mixtures.

The fluid flow entering the duct is hydrodynamically fully-developed, so that a development of the flow will not disturb the separation process. However, if the carrier fluid is electrically conducting, as water is, then an electric current will pass through it due to the voltage gradient between the walls. As a result, non-uniform Joule heating will occur due to the different resistivities of the various migrant fractions. Because of this heating, a redevelopment of the originally fully-developed flow field may occur due to buoyancy effects. Any redevelopment means that transverse velocity components will appear. These transverse velocity components can cause the migrant fractions to mix together even as they separate, thereby decreasing the effectiveness of the electrophoresis device.

To date, only a handful of studies have been published concerning mixed convection in the flow of pseudoplastic non-Newtonian fluids. Fully-developed flow [3, 4], as well as developing flow [5–7], in ducts has been examined. A summary of the previous work in vertical channel mixed convection has also been presented by Shenoy and Mashelkar [8] and Shenoy [9]. However, there does not appear to be any published work dealing with flow of this type which have internal heat sources.

The purpose of the present study is to find ways of preventing flow redevelopments due to buoyancy effects. The addition of a polymer, carboxy methyl cellulose (CMC), to the carrier fluid (water) is proposed to accomplish this task. Laminar mixed convection between vertical parallel plates of finite height is considered. The flowing fluid is assumed to obey the power shear law, and non-uniform heat generation in the transverse direction is included. Each plate is assumed to be adiabatic, and all fluid properties are assumed to be constant with the exception of the density in the buoyancy term in the momentum equation. The conservation equations are written in dimensionless form, making the classical boundary-layer assumptions. They are solved using a finite-difference numerical scheme.

It is shown that steps can be taken which will inhibit or prevent flow redevelopments due to buoyancy effects and velocity profile dispersion. In addition to the reduction of buoyancy effects, the polymer also flattens the velocity profile which further reduces another mixing effect called velocity profile dispersion.

† Present address: Mechanical Engineering Department, University of Cincinnati, Cincinatti, OH 45221, U.S.A.

NOMENCLATURE

b	plate spacing [m]
C_p	specific heat at constant pressure [J kg^{-1} K^{-1}]
g	acceleration of gravity [m s^{-2}]
H	plate height [m]
K	fluid consistency [N s^n m^{-2}]
k	thermal conductivity [W m^{-1} K^{-1}]
n	fluid flow index [—]
p	fluid pressure [Pa]
Pe	Peclet number [—]
q'''	heat generation rate [W m^{-3}]
Ri	Richardson number [—]
Re_g	generalized Reynolds number [—]
S	slope of heat generation curve [W m^{-4}]
T	temperature [K]
$\bar{u}$	average velocity in x-direction [m s^{-1}]
u	x-direction velocity [m s^{-1}]
v	y-direction velocity [m s^{-1}]
x	coordinate [m]
y	coordinate [m].

Greek symbols

α	thermal diffusivity [m^2 s^{-1}]
β	thermal expansion coefficient [K^{-1}]
$\dot{\gamma}$	shear rate [s^{-1}]
ρ	density [kg m^{-3}]
τ	shear stress [Pa].

Subscripts

B	bulk
0	inlet conditions.

Superscripts

+	dimensionless quantities
–	average quantity.

2. GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Consider the situation depicted in Fig. 2. A fluid flows upward (against the acceleration due to gravity g) between two vertical parallel plates of height H, spaced a distance b apart. The fluid flows with an average velocity $\bar{u}$ and has a uniform inlet temperature T_0. The density of the fluid at the inlet is $\rho_0 = \rho(T_0)$. Both plates are thermally insulated, and heat is generated inside the fluid (q''').

The flow is assumed to be steady and laminar. The plates are infinitely wide, so that the flow is two-dimensional. The following four assumptions are made in the analysis.

(1) The fluid under consideration behaves as a power law fluid

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

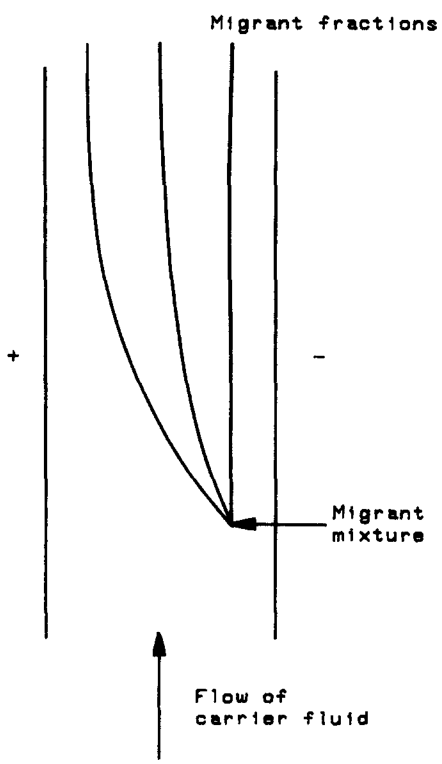

FIG. 1. Sketch of a simple continuous flow electrophoresis device.

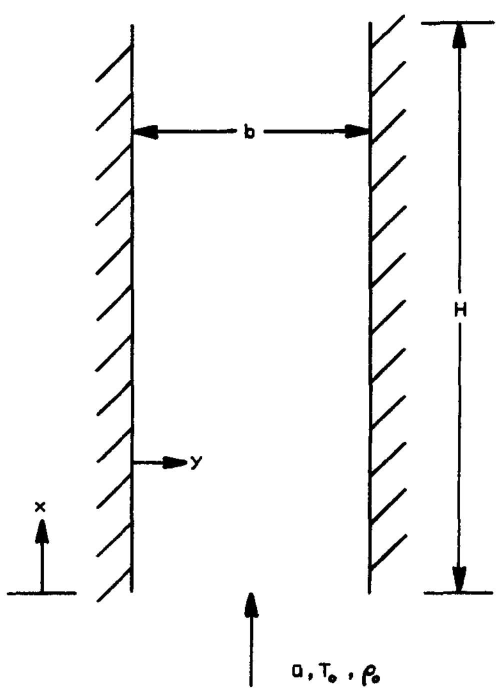

FIG. 2. Schematic of the vertical channel.

where τ is the shear stress, $\dot{\gamma}$ the shear rate, K the fluid consistency, and n the flow index of the fluid. For the particular fluids considered in this study (CMC solutions in water), this restriction is valid above a certain limiting shear rate.

(2) The Boussinesq approximations for buoyant flows are appropriate. This is true for liquids when the temperature differences are sufficiently small.

(3) The heat generation rate varies linearly in the transverse (y) direction, with no heat generated at the left-hand wall

$$q'''(y) = Sy$$

where S is the slope of the heat generation curve, and is constant. This assumption is made due to the lack of available information on the heat generation function in actual electrophoresis devices.

(4) The boundary-layer approximations are applicable. An order-of-magnitude analysis shows that the boundary-layer approximations are appropriate for the conditions considered in this study.

If u and v are the velocity components in the x- and y-directions, respectively, and p the fluid pressure, then the following dimensionless variables may be defined:

$$x^+ = \frac{x}{H}$$

$$y^+ = \frac{y}{b}$$

$$u^+ = \frac{u}{\bar{u}}$$

$$v^+ = \frac{v}{\bar{u}}\frac{H}{b}$$

$$P^+ = \frac{(p-p_0)+\rho_0 g x}{\rho_0 \bar{u}^2}.$$

The dimensionless temperature is defined in terms of an average heat generation rate

$$T^+ = \frac{T-T_0}{\overline{q'''}b^2/k}$$

where

$$\overline{q'''} = \frac{1}{b}\int_0^b Sy\,\mathrm{d}y = \tfrac{1}{2}Sb.$$

Thus

$$T^+ = \frac{T-T_0}{Sb^3/2k}$$

where k is the fluid thermal conductivity.

Using the above definitions the governing dimensionless differential equations under the preceding assumptions are

$$\frac{\partial u^+}{\partial x^+} + \frac{\partial v^+}{\partial y^+} = 0 \tag{1}$$

$$u^+\frac{\partial u^+}{\partial x^+} + v^+\frac{\partial u^+}{\partial y^+} = -\frac{\partial P^+}{\partial x^+} + \frac{1}{Re_g}\frac{\partial}{\partial y} + \left[\left|\frac{\partial u^+}{\partial y^+}\right|^{n-1}\frac{\partial u^+}{\partial y^+}\right] + Ri\,T^+ \tag{2}$$

$$u^+\frac{\partial T^+}{\partial x^+} + v^+\frac{\partial T^+}{\partial y^+} = \frac{1}{Pe}\frac{\partial^2 T^+}{\partial y^{+2}} + \frac{2}{Pe}y^+. \tag{3}$$

A fourth equation is obtained from the definition of the average velocity

$$\int_0^1 u^+\,\mathrm{d}y^+ = 1. \tag{4}$$

The resulting dimensionless parameters are the generalized Reynolds number

$$Re_g = \frac{\rho\bar{u}^{2-n}b^{n+1}}{KH}$$

the Richardson number

$$Ri = \frac{g\beta Sb^3 H}{2k\bar{u}^2}$$

and the Peclet number

$$Pe = \frac{\bar{u}b^2}{\alpha H}$$

where β is the coefficient of thermal expansion, and α the thermal diffusivity of the fluid. The flow index n is also an independent dimensionless parameter.

The velocity boundary conditions at the duct walls are

$$u^+(x^+, y^+ = 0) = u^+(x^+, y^+ = 1) = 0 \tag{5}$$

$$v^+(x^+, y^+ = 0) = v^+(x^+, y^+ = 1) = 0. \tag{6}$$

The velocity profile at the entrance of the duct is assumed to be that of a hydrodynamically fully-developed forced flow, therefore

$$u^+(x^+ = 0, y^+) = \frac{2n+1}{n+1}[1-|2y^+-1|^{(n+1)/n}] \tag{7}$$

$$v^+(x^+ = 0, y^+) = 0. \tag{8}$$

For the adiabatic walls, the thermal boundary conditions are

$$\frac{\partial T^+}{\partial y^+}(x^+, y^+ = 0) = \frac{\partial T^+}{\partial y^+}(x^+, y^+ = 1) = 0. \tag{9}$$

The temperature profile at the inlet is assumed to be uniform

$$T^+(x^+ = 0, y^+) = 0. \tag{10}$$

The duct is open at the outlet, so that the fluid pressure is equal to the ambient pressure

$$P^+(x^+ = 1) = 0. \tag{11}$$

At the duct inlet, the pressure is composed of two parts: the ambient pressure p_0 plus an additional p_{pump}

needed to pump the fluid up the channel at an average velocity $\bar{u}$

$$p(x=0) = p_0 + p_{\text{pump}}$$

or, in dimensionless form

$$P^+(x^+=0) = P^+_{\text{pump}}.$$

The quantity P^+_{pump} is not known *a priori*, but is a function of the other parameters of the problem.

3. NUMERICAL SOLUTION AND COMPARISON WITH PUBLISHED ASYMPTOTIC STUDIES

The numerical method used in this study is very similar to the one used by Marner and McMillan [5] and Gori [6, 7] to study developing mixed convection in power law fluids. Governing equations (1)–(4) and boundary conditions (5)–(11) are first written in finite-difference form. After values of the dimensionless parameters and grid spacings are chosen, the finite-difference equations are solved using a marching procedure in the x-direction. The complete finite-difference equations, as well as a detailed discussion of the solution procedure and a copy of the computer program are given in ref. [10].

Results from the computer program were compared with the results from several published heat transfer studies which are asymptotic to the present solution to verify that the solution procedure and computer coding were correct. Since most of the studies which appear in the literature consider the thermal boundary conditions of uniform wall temperature (UWT) or uniform wall heat flux (UHF), the computer code was modified to include these other thermal boundary conditions.

Both forced and free convection are asymptotes to the mixed convection problem. Also, a Newtonian fluid is simply a special case of the more general power law fluid. This allowed a comparison with published results for developing forced convection in Newtonian fluids (UWT), fully-developed forced convection in Newtonian fluids with uniform heat generation (UHF), fully-developed forced convection in power law fluids (UHF), and developing free convection in power law fluids (UHF). Excellent agreement was found in all cases. The actual comparisons are given in ref. [10].

In addition, a comparison may be made to a result obtainable analytically for the problem considered in this paper. This is accomplished by performing an energy balance over the entire duct length. Since the only source of heat in this system is the heat generated internally (the walls are adiabatic), the change in enthalpy of the fluid must equal the total heat generated over the length of the duct. This may be expressed mathematically as

$$\rho C_p \bar{u} b (T_{\text{B},H} - T_0) = H \int_0^b S y \, \mathrm{d}y = \tfrac{1}{2} S b^2 H \qquad (12)$$

Table 1. Comparison between the exact and numerical solutions for T_B^+ $(x^+ = 1)$ for a duct with adiabatic walls and internal heat generation

Pe	T_B^+ $(x^+=1)$ (exact)	T_B^+ $(x^+=1)$ (numerical)
10	0.100	0.09994
20	0.050	0.04998
50	0.020	0.01999
100	0.010	0.01000
200	0.005	0.00500

$Re_g = 5.0$, $n = 0.7$, $Ri = 10.0$.

where $T_{\text{B},H}$ is the bulk temperature at the exit of the duct ($x = H$). The bulk temperature is defined as

$$T_\text{B} = \frac{1}{\bar{u}b} \int_0^b u T \, \mathrm{d}y.$$

Obviously, the bulk temperature at the duct inlet is T_0, since the temperature field there is uniform.

Equation (12) may be rearranged to read

$$\frac{T_{\text{B},H} - T_0}{Sb/2k} = T_{\text{B},H} = \frac{\alpha H}{\bar{u} b^2}$$

or

$$T_\text{B}^+(x^+ = 1) = \frac{1}{Pe}.$$

Therefore, the dimensionless bulk temperature at the exit of the duct is simply the inverse of the Peclet number. This is true regardless of the values of n, Re_g or Ri. Table 1 shows the results of the computer program for arbitrarily chosen values of n, Re_g and Ri, and several values of Pe. The agreement between the exact and numerical calculations is very good.

4. RESULTS AND DISCUSSION

Since the purpose of this study is to model the behavior of the continuous flow electrophoresis device, numerical values for the various quantities in the problem should be chosen which are characteristic of this device. Typically, the average fluid velocity, interplate spacing, plate heights and average heat generation rates are

$$\bar{u} = 0.1 \text{ m s}^{-1}$$

$$b = 0.01 \text{ m}$$

$$H = 0.5 \text{ m}$$

$$\overline{q'''} = \tfrac{1}{2} S b = 10^6\text{–}10^7 \text{ W m}^{-3}.$$

The fluids considered are water, and solutions composed of water and CMC. For these fluids, all thermophysical properties, except for viscous properties, may be taken as the properties for water [11]. Evaluating the properties of water at $T_0 = 20°\text{C}$ and $p_0 = 1$ bar from Haar *et al.* [12], we have

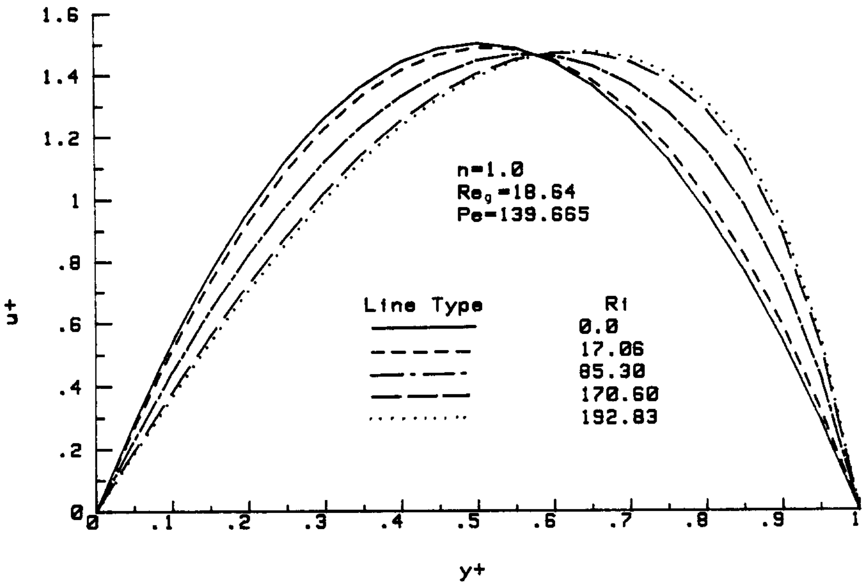

FIG. 3. Exit velocity profiles for pure water.

$$\rho_0 = 998.2\,\mathrm{kg\,m^{-3}}$$
$$k = 0.598\,\mathrm{W\,m^{-1}\,K^{-1}}$$
$$\alpha = 1.432\times10^{-7}\,\mathrm{m^2\,s^{-1}}$$
$$\beta = 2.08\times10^{-4}\,\mathrm{K^{-1}}.$$

Also from ref. [12], the viscous properties for water are

$$K = 1.071\times10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$$
$$n = 1.0.$$

For CMC solutions in water, the viscous properties of Lee [13] at 20°C may be used

$$K = 1.045\times10^{-4}\,C^{0.9492}$$
$$n = 1.193\,C^{-0.08482}$$

where $50 \leqslant C \leqslant 1000$ and C is the concentration of CMC in weight parts per million (wppm).

First, pure water flowing through the duct is considered. Figure 3 shows the velocity profiles at the exit of the duct for several values of Ri ranging from 0 (forced convection) to 192.83 (free convection). The values of $Ri = 17.06$, 85.30 and 170.60 correspond to $\overline{q'''} = 10^6$, 5×10^6 and 10^7 W m^{-3}, respectively. The curve for $Ri = 0$ also represents the velocity profile at the inlet of the duct because there is no mechanism for the temperature field to affect the flow field. Thus, the initially fully-developed velocity profile remains unchanged.

It is easily seen from Fig. 3 that as Ri is increased ($\overline{q'''}$ increased), the resulting asymmetry in the flow field is increased. The goal here is to reduce this asymmetry.

Figure 4 shows temperature profiles which correspond to the velocity profiles of Fig. 3. The temperatures on the right-hand side of the duct decrease as Ri is increased because the thermal energy in this region goes toward increasing the local velocities, and therefore shifting the velocity profile.

In Fig. 5, water with 100 wppm CMC is considered. The values of Pe and Ri have not changed because they do not contain viscous properties. Figure 5 reveals that the unwanted shift in the velocity profiles has become smaller due to the increased viscosity of the fluid. As the concentration of CMC is further increased, it is expected that the velocity profiles for the different Ri will merge.

Further proof to this effect is given in Fig. 6, where water with 300 wppm CMC is considered. We can see that there is essentially no difference in the various velocity profiles, regardless of the value of Ri. Thus, the buoyancy effects have been all but eliminated.

The designer of a system of this type might also be interested in how the addition of CMC affects the pumping pressure. Figure 7 shows that the dimensionless pumping pressure is quadrupled with the addition of 100 wppm CMC, and is increased ninefold with the addition of 300 wppm CMC.

It was mentioned previously that another deleterious effect in such electrophoresis devices occurs because of the curvature of the velocity profile. As the migrants begin to spread because of their electrophoretic mobility, they assume different y locations and different through-put velocities. Thus, they will have different residence times in the electric field and consequently different migration distances. This produces a defocusing effect which could only be completely eliminated if the velocity profile were flat or uniform.

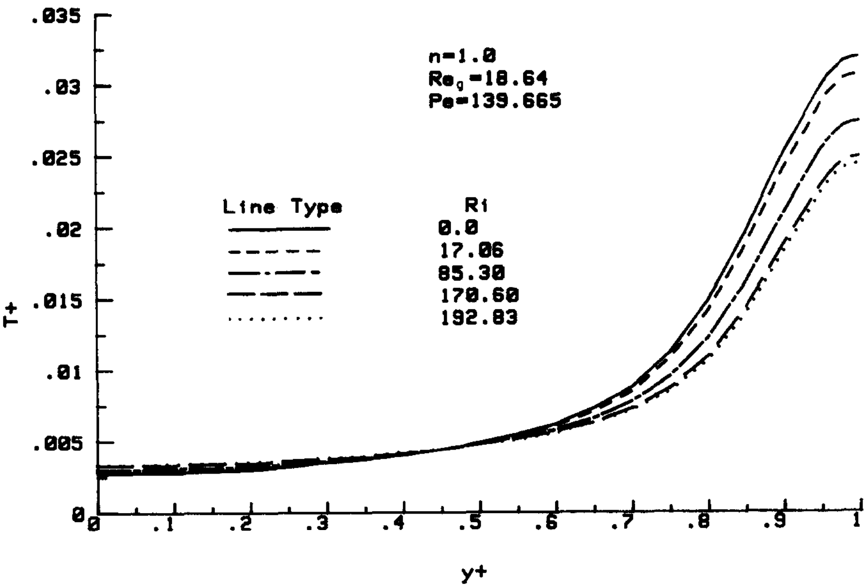

FIG. 4. Exit temperature profiles for pure water.

A significant advantage of using pseudoplastic carrier fluids, in addition to increasing the apparent viscosity, is that they tend to flatten the velocity profile. This is illustrated in Fig. 8 which shows how the dimensionless velocity field becomes more uniform as the flow index n is decreased.

Another way to negate the buoyancy effects is to decrease the Richardson number. Since the heat generation rate and non-viscous fluid properties are fixed for this problem, the Richardson number may only be changed by a change in $\bar{u}$, b or H.

A decrease in the channel width b will decrease Ri while also decreasing the generalized Reynolds number Re_g. The decrease in Re_g will make the viscous term in the momentum equation larger. Thus, a decrease in the channel width b will simultaneously increase the viscous term and suppress the buoyancy force term.

Although certain design considerations limit the amount of possible decrease of Richardson number by decreasing b, additional reductions can be obtained by increasing the apparent viscosity while holding the Reynolds number constant. This occurs because an increase in viscosity at constant Reynolds number allows an increase in channel velocity and a subsequent decrease of Richardson number. This effect

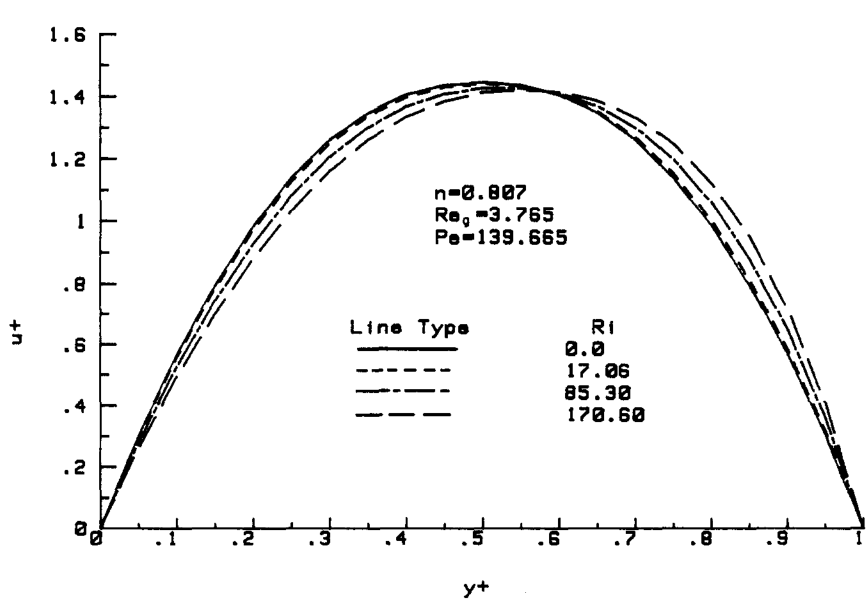

FIG. 5. Exit velocity profiles for water with 100 wppm CMC.

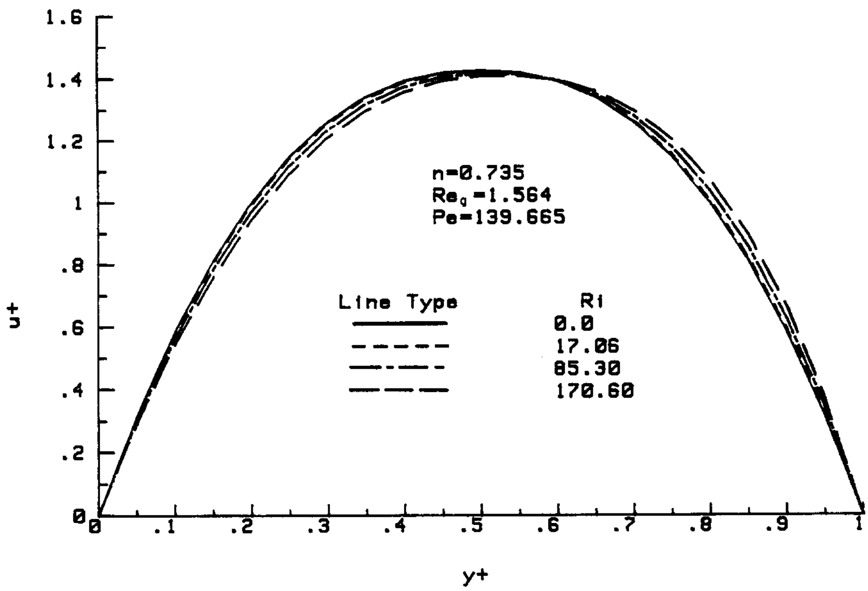

FIG. 6. Exit velocity profiles for water with 300 wppm CMC.

is illustrated in Fig. 9 which shows the decrease in Richardson number with the addition of the polymer CMC. It can be seen in the figure that the addition of 200 wppm of CMC reduces the Richardson number by approximately two orders of magnitude. The effect on the velocity profile by the addition of CMC at constant Reynolds number can be seen in Fig. 10. Here the profile is shown for $n = 1$ (0 wppm CMC), $n = 0.807$ (100 wppm CMC) and $n = 0.735$ (300 wppm CMC). As seen in the figure, for $n = 0.735$, the velocity profile is essentially symmetrical indicating a total suppression of free convection.

Therefore, to consider both effects, if the channel width b were decreased and the average velocity $\bar{u}$ increased by increasing the viscosity of the fluid through the addition of CMC, then buoyancy effects should be greatly suppressed. A numerical example will illustrate this.

Consider water with 100 wppm CMC. If the channel width b is halved, and the average velocity $\bar{u}$ is doubled, then we have

$$b = 0.005\ \text{m}$$

$$\bar{u} = 0.2\ \text{m s}^{-1}.$$

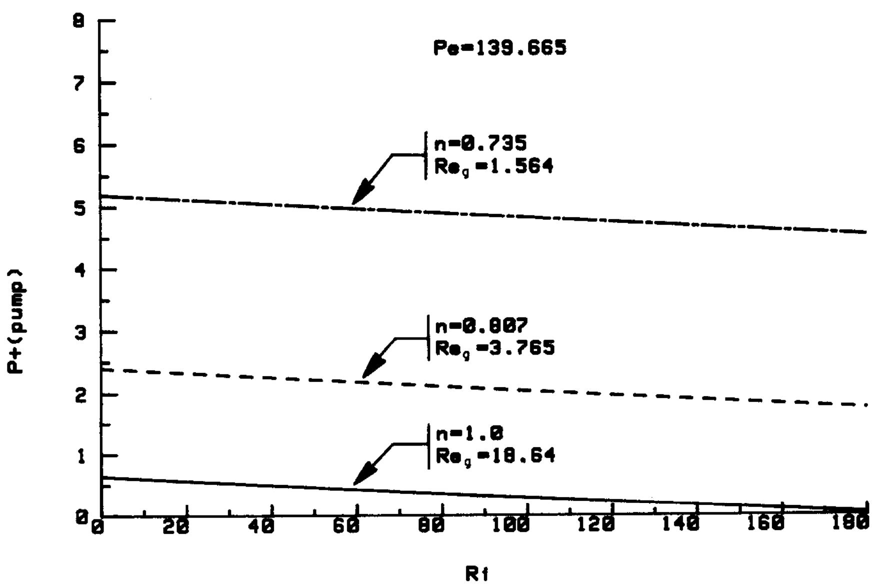

FIG. 7. Dimensionless pumping pressure vs Ri and n.

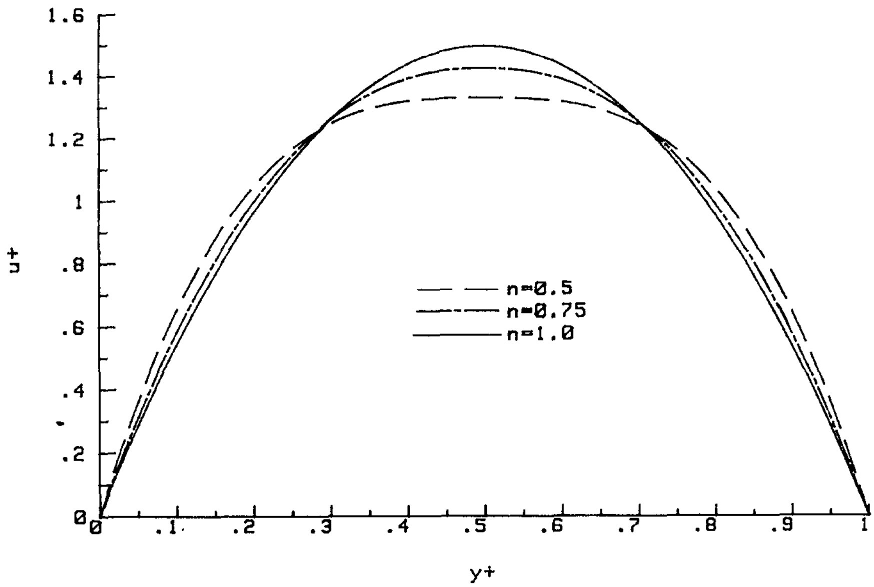

FIG. 8. Flattening of the velocity profile due to decrease in the flow index (addition of polymer).

Exit velocity profiles for the above values of $\bar{u}$ and b, and 100 wppm CMC are presented in Fig. 11 ($Ri = 10.66$ corresponds to $\overline{q'''} = 10^7$ W m^{-3}). We see that, for the range $0 \leqslant Ri \leqslant 10.66$, the buoyancy effects have been completely eliminated.

5. CONCLUSIONS

Developing laminar mixed convection between vertical parallel plates has been considered. A computer program which solves the finite-difference form of the conservation equations was used to examine ways of preventing flow redevelopments when non-uniform heat sources are present. In addition, the dispersion effects caused by a non-uniform velocity profile were considered. This problem has an application in the continuous flow electrophoresis device in which flow redevelopment and velocity dispersion will decrease its effectiveness.

It was shown that the role of buoyancy and velocity dispersion effects which produce a flow rearrangement can be suppressed by adding a polymer such as CMC

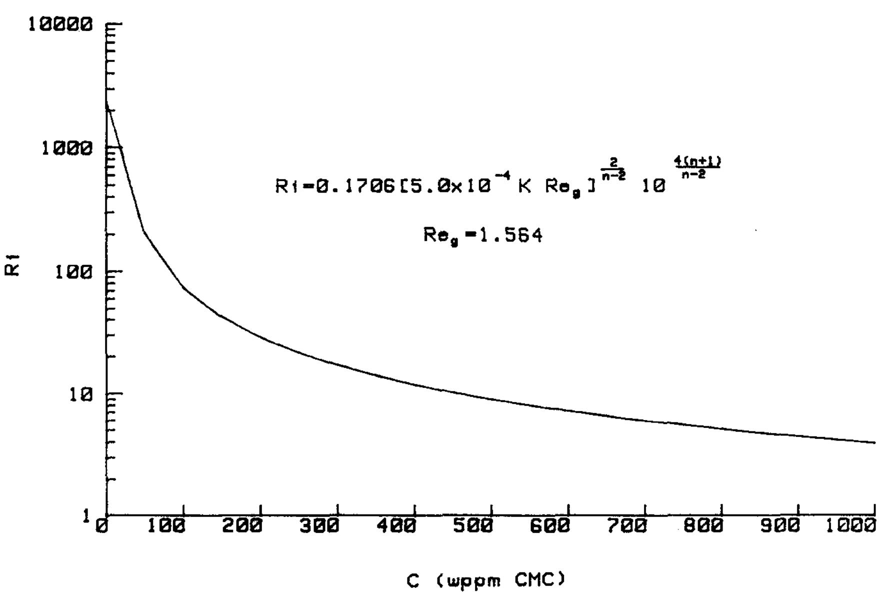

FIG. 9. Richardson number reduction with CMC addition at constant Reynolds number.

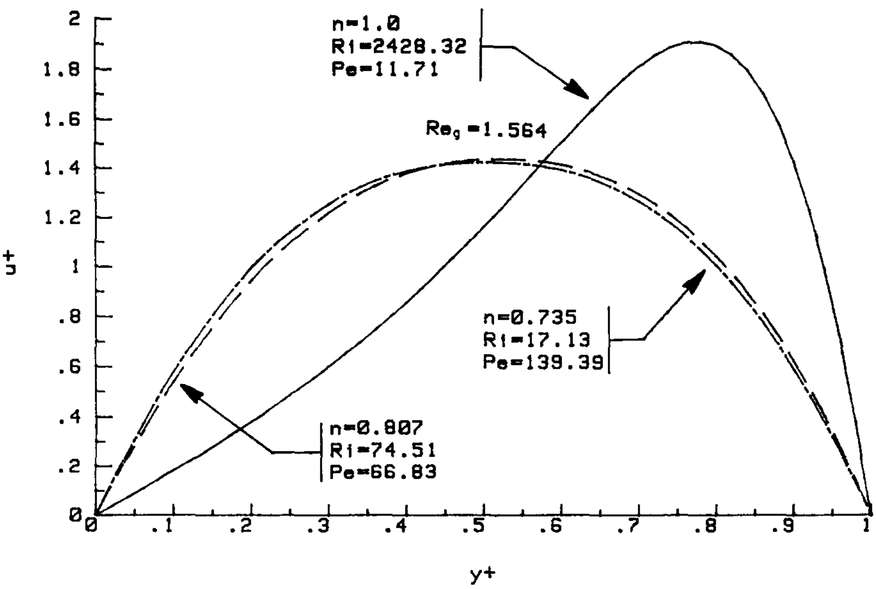

FIG. 10. Velocity profile rearrangements with CMC addition at constant Reynolds number.

to the flowing fluid. The addition of CMC has the effect of increasing the fluid's effective viscosity, and also flattens the velocity profile, which is advantageous in the electrophoresis device. The fluid pumping requirements are increased with increasing CMC concentration.

Buoyancy effects are further reduced by simultaneously adding CMC and changing other quantities to decrease the Richardson number. The Richardson number appears in the buoyancy term of the momentum equation, so that its reduction amounts to a reduction in the buoyancy force. The addition of CMC alone has no effect on the Richardson number, since it is not a function of the viscous properties. However, the addition of CMC allows an increase in the average velocity without increasing the Reynolds number and thus avoiding transition to turbulent flow. This increase in the average velocity reduces the Richardson number and thus the buoyancy effects.

Although buoyancy effects can also be reduced by using more viscous Newtonian fluids, water–polymer solutions are a convenient way to obtain high apparent viscosity fluids and have the additional advantage of reducing velocity dispersion effects by flattening the velocity profile.

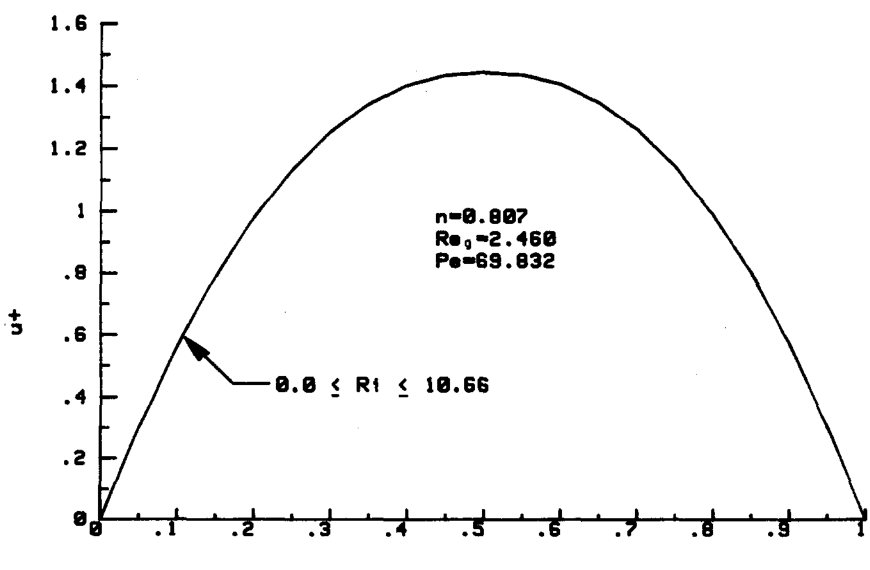

FIG. 11. Exit velocity profiles for water with 100 wppm CMC and $\bar{u} = 0.2$ m s^{-1}, $b = 0.005$ m.

REFERENCES

1. P. Matlock, G. F. Aitchison and A. R. Thompson, Velocity gradient stabilised, continuous, free flow electrophoresis: a review, *Sep. Purif. Meth.* **9**, 1–69 (1980).
2. R. Dobry and R. K. Finn, Engineering problems in large-scale electrophoresis, *Chem. Engng Prog.* **5**, 59–63 (1958).
3. S. H. DeYoung and G. F. Scheele, Natural convection distorted non-Newtonian flow in a vertical pipe, *A.I.Ch.E. Jl* **16**, 712–717 (1970).
4. M. Tanaka and N. Mitsuishi, Non-Newtonian laminar heat transfer in concentric annuli, *Heat Transfer—Jap. Res.* **4**(2), 26–36 (1975).
5. W. J. Marner and H. K. McMillan, Combined free and forced laminar non-Newtonian convection in a vertical tube with constant wall temperature, *Chem. Engng Sci.* **27**, 473–488 (1972).
6. F. Gori, Variable physical properties in laminar heating of pseudoplastic fluids with constant wall heat flux, *J. Heat Transfer* **100**, 220–223 (1978).
7. F. Gori, Effects of variable physical properties in laminar flow of pseudoplastic fluids, *Int. J. Heat Mass Transfer* **21**, 247–250 (1978).
8. A. V. Shenoy and R. A. Mashelkar, Thermal convection in non-Newtonian fluids. In *Advances in Heat Transfer*, Vol. 15, pp. 143–226. Academic Press, New York (1982).
9. A. V. Shenoy, Natural convection heat transfer to power law fluids. In *Handbook of Heat and Mass Transfer*, Vol. 1, Chap. 5, pp. 183–210. Gulf, Houston, Texas (1985).
10. R. A. Brewster, Laminar mixed convection in power law fluids with internal heat sources, M.S. Thesis, State University of New York at Stony Brook (1985).
11. T. F. Irvine, Jr., I. Kim, K. Cho and F. Gori, Experimental measurements of isobaric thermal expansion coefficients of non-Newtonian fluids, *Expl Heat Transfer* **1**, 155–163 (1987).
12. L. Haar, J. S. Gallagher and G. S. Kell, *NBS/NRC Steam Tables*. Hemisphere, Washington, DC (1984).
13. H. S. Lee, Rheological fluid properties measurements of CMC solution of water, M.S. Thesis, State University of New York at Stony Brook (1979).

CONVECTION LAMINAIRE MIXTE POUR DES FLUIDES A LOI PUISSANCE DANS DES SYSTEMES A ELECTROPHORESE

Résumé—On considère la convection laminaire mixte pour un fluide à loi puissance qui s'écoule entre deux plans parallèles verticaux. La chaleur est produite dans le fluide par une source thermique volumétrique non uniforme et les plans sont supposés adiabatiques. Les équations de couche limite sont résolues par une technique numérique de différence finie. La connaissance du champ de vitesse résultant est intéressante pour l'étude des systèmes à électrophorèse avec écoulement continu de fluide. Les résultats présentés montrent que le développement de l'écoulement à cause des effets de flottement se réalise avec un mélange dû à un profil de vitesse non uniforme. On montre que pour des fluides pseudoplastiques, une géométrie et des débits particuliers, on peut éviter effectivement le développement de l'écoulement et la dispersion des profils de vitesse.

LAMINARE MISCHKONVEKTION EINES "POWER LAW"-FLUIDS IN KONTINUIERLICH DURCHSTRÖMTEN ELEKTROPHORESESYSTEMEN

Zusammenfassung—Die laminare Mischkonvektion eines "power law"-Fluids, das zwischen zwei parallelen senkrechten Platten strömt, wird betrachtet. Im Fluid wird Wärme durch eine nicht einheitliche volumetrische Wärmequelle erzeugt, wobei die Platten als adiabat betrachtet werden. Die Grenzschichtgleichungen werden unter Verwendung eines Finite-Differenzen-Verfahrens numerisch gelöst. Die Kenntnis des resultierenden Strömungsfeldes ist für kontinuierlich durchströmte Elektrophoresesysteme von Interesse. Die vorgestellten Ergebnisse zeigen, daß sowohl Strömungsrückbildungen infolge von Auftriebseffekten als auch Durchmischung aufgrund eines uneinheitlichen Geschwindigkeitsprofils auftreten. Es wird gezeigt, daß die Verwendung pseudoplastischer nicht-Newton'scher Fluide sowie die geeignete Wahl von Geometrie und Durchsatz die Strömungsrückbildung und die Verbreiterung des Geschwindigkeitsprofils auch unter Verhältnissen verhindern kann, unter denen diese sonst auftreten würden.

ЛАМИНАРНАЯ СМЕШАННАЯ КОНВЕКЦИЯ СТЕПЕННЫХ ЖИДКОСТЕЙ ПРИ НЕПРЕРЫВНОМ ТЕЧЕНИИ В ЭЛЕКТРОФОРЕЗНЫХ СИСТЕМАХ

Аннотация—Исследуется смешанная конвекция при ламинарном течении степенной жидкости между вертикальными параллелными пластинами. Жидкость нагревается внутренним неоднородным объемным источником, а пластины рассматриваются как адиабатические. Уравнения пограничного слоя решаются численным методом конечных разностей. Данные о результирующем поле течения представляют интерес для изучения электрофорезных систем непрерывного действия. Полученные результаты указывают на перестройку структуры течения в связи с действием подъемной силы, а также на смешение из-за неоднородного профиля скорости. Показано, что использование псевдопластических жидкостей, так же как и влияние собственной геометрии и интенсивности течения могут эффективно приводить к затягиванию перестройки структуры течения и искажения профиля скорости при таких условиях, когда они происходят.