CHAPTER - IV

EFFECT OF CHEMICAL REACTION ON HYDROMAGNETIC DOUBLE DIFFUSIVE HEAT TRANSFER FLOW THROUGH A STRATIFIED MEDIUM IN A VERTICAL WAVY CHANNEL WITH HEAT SOURCES
1. INTRODUCTION

Coupled heat and mass transfer phenomenon in porous media is gaining attention due to its interesting applications. The flow phenomenon is relatively complex rather than that of the pure thermal convection process. Underground spreading chemical wastes and other pollutants, grain storage, evaporation cooling and solidification are the few other application areas where the combined thermosolutal natural convection in porous media are observed. Combined heat and mass transfer by free convection under boundary layer approximations has been studied by Bejan and Khair(2), Lai and Kulacki(9) and Murthy and Singh(11). Coupled heat and mass transfer by mixed convection in Darcian fluid-saturated porous media has been analysed by Lai(8). The free convection heat and mass transfer in a porous enclosure has been studied recently by Angirasa et al(1). The combined effects of thermal and mass diffusion in channel flows has been studied in recent times by a few authors, notably Nelson and Wood(14,15), Lee at al(10) and others(23,25).

In recent years, energy and material saving considerations have prompted an expansion of the efforts at producing efficient heat exchanger equipment through augmentation of heat transfer. It has been established (5a) that channels with diverging – converging geometries augment the transportation of heat transfer and momentum. As the fluid flows through a tortuous path viz., the dilated – constricted geometry, there will be more intimate contact between them. The flow takes place both axially (primary) and transversely (secondary) with the secondary velocity being towards the axis in the fluid bulk rather than confining within a thin layer as in straight channels. Hence it is advantageous to go for converging – diverging geometries for improving the design of heat transfer equipment. Vajravelu and Nayseh (23a) have investigated the influence of the wall waviness on friction and pressure drop of the generated coquette flow. Vajravelu and Sastry (24) have analysed the free convection heat transfer in a viscous, incompressible fluid confined between long vertical wavy walls in the presence of constant heat source. Later Vajravelu and Debnath (25) have
extended this study to convective flow in a vertical wavy channel in four different geometrical configurations. This problem has been extended to the case of wavy walls by McMichael and Deutsch (109), Deshikachar et al (49), Rao et al (17a) and Sree Ramachandra Murthy (20a). Hyan Goo Kwon et al(7a) have analyzed that the Flow and heat/mass transfer in a wavy duct with various corrugation angles in two dimensional flow regimes. Mahdy et al(79) have studied the mixed convection heat and mass transfer on a vertical wavy plate embedded in a saturated porous media (PST/PSE). Comini et al (3a ) have analyzed the Convective heat and mass transfer in wavy finned-tube exchangers. Jer-Huan Jang et al(58) have analyzed that the Mixed convection heat and mass transfer along a vertical wavy surface.

In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications viz., polymer production, manufacturing of ceramics or glassware and food processing. Das et al(5) have studied the effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction. Muthukumaraswamy (13) has studied the effects of reaction on a long surface with suction. Recently Gnaneswar(6) has studied radiation and mass transfer on an unsteady two-dimensional laminar convective boundary layer flow of a viscous incompressible chemically reacting fluid along a semi-infinite vertical plate with suction by taking into account the effects of viscous dissipation.

The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. A large amount of research work has been reported in this field. In particular the the study of heat and mass transfer with chemical reaction is of considerable importance in chemical and hydrometallurgical industries. Chemical reaction can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. Frequently the transformations proceed in a moving fluid, a situation encountered in a number of technological fields. A common area of interest in the field of aerodynamics is the
analysis of thermal boundary layer problems for two dimensional steady and incompressible laminar flow passing a wedge. Simultaneous heat and mass transfer from different geometries embedded in a porous media has many engineering and geophysical application such as geothermal reservoirs, drying of porous solids thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors, and under ground energy transport. A very significant area of research in radiative heat transfer, at the present time is the numerical simulation of combined radiation and convection/conduction transport processes. The effort has arisen largely due to the need to optimize industrial system such as furnaces, ovens and boilers and the interest in our environment and in no conventional energy sources, such as the use of salt-gradient solar ponds for energy collection and storage. In particular, natural convection induced by the simultaneous action of buoyancy forces resulting from thermal and mass diffusion is of considerable interest in nature and in many industrial application such as geophysics, oceanography, drying process, solidification of binary alloy and chemical engineering. Kandaswamy et al(9a)have discussed the Effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in the presence of suction or injection.

In this chapter, we discuss the effect of chemical reaction on the convective heat and mass transfer flow of a viscous fluid in a vertical wavy channel in the presence of heat sources. The governing equations are solved by using a similar perturbation technique with the slope $\delta$ of wavy boundaries as a perturbation parameter. The effect of chemical reaction, surface boundary and heat sources on flow characteristics is analyzed a detail. The rate heat and mass transfer on the boundary $\eta=\pm 1$ are also discussed.
Configuration of the Problem
2. FORMULATION OF THE PROBLEM

We consider the coupled heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium confined in a vertical channel bounded by wavy walls in the presence of constant heat sources, transverse magnetic field effects and a first order chemical reaction. The flow is assumed to be steady, laminar and two-dimensional and the surface is maintained at constant temperature and concentration. It is also assumed that the applied magnetic field is uniform and that magnetic Reynolds number is small so that the induced magnetic field is neglected. In addition, there is no applied electric field and all of the Hall effect, viscous dissipation and Joule heating are neglected. All thermophysical properties are constant except the density in the buoyancy terms of the linear momentum equation which is approximated according to the Boussinesq approximation. We consider rectangular Cartesian coordinate system $0(x,y,z)$ with walls at $y = \pm L f(\hat{x})$ with slope $\delta$. Under these assumptions, the equations describing the physical situation are given by

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

\[
\frac{u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + \beta g(T - T_e) + \beta' g(C - C_e) + \frac{\sigma B^2 u}{\rho} - \left( \frac{v}{k} \right) u
\]  

\[
\frac{u}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - \left( \frac{v}{k} \right) v
\]  

\[
\rho_0 C_p \left( u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = \lambda \left( \frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} \right) + Q
\]  

\[
\frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D \frac{\partial C}{\partial y^2} - \gamma C + k_{11} \frac{\partial^2 T}{\partial y^2}
\]

where $y$ is the horizontal or transverse co-ordinate, $u$ is the axial velocity, $v$ is the transverse velocity, $T$ is the fluid temperature, $C$ is the concentration, $T_e$ is the ambient temperature, $C_e$ is the ambient concentration and
\( \rho, g, \beta, \beta^*, \mu, \sigma, B, Q, D \) are the density, gravitational acceleration, coefficient of thermal expansion, coefficient of concentration expansion, dynamic viscosity, fluid electrical conductivity, magnetic induction, heat generation/absorption coefficient, mass diffusion coefficient and chemical reaction parameter respectively. The physical boundary conditions for the problem are

\[
\begin{align*}
    u(-f) &= 0, v(-f) = 0, T(-f) = T_1, C(-f) = C_1, \\
    u(+f) &= 0, v(+f) = 0, T(+f) = T_2, C(+f) = C_2
\end{align*}
\]

(2.5)

where \( T_1, T_2 \) and \( C_1, C_2 \) are the surface temperature and concentrations on \( y = \pm L \) respectively.

The flow is maintained by a constant volume flux for which a characteristic velocity is defined by

\[
q = \frac{1}{L} \int_{-f}^{+f} u \, dy
\]

(2.6)

In view of the equation of continuity we define the stream function \( \psi \) as

\[
\psi = \frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}
\]

(2.7)

the equation governing the flow in terms of stream function \( \psi \) are

\[
\begin{align*}
    \frac{\partial \psi}{\partial x} \frac{\partial^2 \psi}{\partial y^2} - \frac{\partial \psi}{\partial y} \frac{\partial^2 \psi}{\partial x^2} &= \mu \psi + \left( \frac{\partial \psi}{\partial y} \right)^2 - \frac{\sigma H^2}{\rho} \frac{\partial T}{\partial y} + \beta \frac{\partial}{\partial y} (T - T_s) + \\
    \beta^* g &\frac{\partial T}{\partial y} (C - C_s)
\end{align*}
\]

(2.8)

\[
\begin{align*}
    \rho c_r (-\frac{\partial \psi}{\partial x} + \frac{\partial \psi}{\partial y}) &= \lambda (\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}) + Q \quad \text{for } y = \pm L
\end{align*}
\]

(2.9)

\[
\begin{align*}
    (-\frac{\partial \psi}{\partial x} + \frac{\partial \psi}{\partial y}) &= D \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} - \gamma C + k_{ii} (\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2})
\end{align*}
\]

(2.10)

and

\[
\begin{align*}
    \psi(+f) - \psi(-f) &= -1 \quad \frac{\partial \psi}{\partial y} = 0 \quad \frac{\partial \psi}{\partial x} = 0
\end{align*}
\]

\[
\begin{align*}
    T(+f) &= T_1, & T(-f) &= T_2, \\
    C(+f) &= C_1, & C(-f) &= C_2
\end{align*}
\]
In order to write the governing equations and boundary conditions in the dimensionless form the following non-dimensional quantities are introduced

\[
x = \frac{x}{L}, \quad y = \frac{y}{L}, \quad \psi' = \frac{\psi}{(v)}, \quad \theta = \frac{T - T_i}{T_2 - T_i}, \quad C' = \frac{C - C_i}{C_2 - C_i}
\]  
(2.11)

the equations after dropping the dashes are

\[
\left( \frac{\partial \psi}{\partial x} \frac{\partial (\nabla^2 \psi)}{\partial y} - \frac{\partial \psi}{\partial y} \frac{\partial (\nabla^2 \psi)}{\partial x} \right) = \nabla^2 \psi + D^{-1}(\nu) \nabla^2 \psi + \frac{M \cdot \frac{\partial^2 \psi}{\partial y^2}}{\frac{\partial^2 \psi}{\partial x^2}} - G(\frac{\partial \theta}{\partial y} + N \frac{\partial C}{\partial y})
\]  
(2.12)

\[
P^\prime \left( \frac{\partial \psi}{\partial y} \frac{\partial \theta}{\partial x} + \frac{\partial \psi}{\partial x} \frac{\partial \theta}{\partial y} \right) = \left( \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} \right) + \alpha
\]  
(2.13)

\[
Sc \left( \frac{\partial \psi}{\partial y} \frac{\partial T}{\partial x} + \frac{\partial \psi}{\partial x} \frac{\partial T}{\partial y} \right) = \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} \right) - K C + \frac{Sc \nu \left( \frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} \right)}{N} \right)
\]  
(2.14)

and

\[
\psi(+f) - \psi(-f) = -1 \quad \frac{\partial \psi}{\partial y} = 0 \quad \frac{\partial \psi}{\partial x} = 0
\]  

\[
\theta(+f) = 1, \quad \theta(-f) = 0
\]  

\[
C(+f) = 1, \quad C(-f) = 0
\]  
(2.15)

where

\[
G = \frac{\beta g(T_i - T) L^4}{\nu^2}
\]  
(Grashof Number)

\[
M^- = \frac{\sigma \mu_c^2 H_{\nu} L^2}{\nu^3}
\]  
(Hartman Number)

\[
D^{-1} = \frac{L^2}{k}
\]  
(Darcy parameter)

\[
P = \frac{\mu C}{\lambda}
\]  
(Prandtl Number)

\[
Sc = \frac{\nu}{D}
\]  
(Schmidt Number)

\[
K = \frac{H^2}{L^2}
\]  
(Chemical reaction parameter)
\[ N = \frac{\beta \Delta C}{\rho \Delta T} \]  
(Buoyancy ratio)

\[ \alpha = \frac{QL^2}{\lambda} \]  
(Heat source parameter)

\[ \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \]
3. ANALYSIS OF THE FLOW

The main aim of the analysis is to discuss the perturbations created over a combined free and forced convective flow due to the non-uniform slowly varying boundaries. We introduce the transformation

\[ \bar{x} = \delta x \quad \text{and} \quad \eta = \frac{y}{f(\bar{x})} \]

(3.1)

On using the transformation (3.1) the equations (2.13)-(2.15) reduce to

\[
\begin{align*}
\delta \left( \frac{\partial \psi}{\partial x} \frac{\partial (F^2 \psi)}{\partial \eta} - \frac{\partial \psi}{\partial y} \frac{\partial (F^2 \psi)}{\partial x} \right) &= F^4 \psi + (D^1 f^2) F^2 \psi + \\
(M^2 f^2) \frac{\partial^3 \psi}{\partial y^3} - (G f^4) \frac{\partial \theta}{\partial \eta} + N \frac{\partial C}{\partial \eta} \\
\delta \psi f \left( \frac{\partial \theta}{\partial \eta} + \frac{\partial \psi}{\partial x} \frac{\partial \theta}{\partial \eta} \right) &= F^2 \theta + \alpha f^2 \\
\delta \psi f \left( \frac{\partial T}{\partial \eta} + \frac{\partial \psi}{\partial x} \frac{\partial T}{\partial \eta} \right) &= F^2 C - K f^2 C + \frac{\text{Sc} S_{\text{sc}}}{N}
\end{align*}
\]

(3.2)

(3.3)

(3.4)

where

\[ F^2 = \delta^2 \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial \eta^2} \]

The governing equations of the flow, temperature and concentration are coupled non-linear differential equations. Assuming the slope of the wavy wall \( \delta \) to be small, we write

\[
\psi(x, y) = \psi_0(x, y) + \delta \psi_1(x, y) + \delta^2 \psi_2(x, y) + \cdots
\]

(3.5a)

\[
\theta(x, y) = \theta_0(x, y) + \delta \theta_1(x, y) + \delta^2 \theta_2(x, y) + \cdots
\]

(3.5b)

\[
C(x, y) = C_0(x, y) + \delta C_1(x, y) + \delta^2 C_2(x, y) + \cdots
\]

(3.5c)

Substituting the above expansions (3.5a)-(3.5c) in the equations (3.2)-(3.4) and equating the like powers of \( \delta \), we obtain equations to the zeroth order as

\[
\frac{\partial^4 \psi_0}{\partial \eta^4} - M^1 \frac{\partial^2 \psi_0}{\partial \eta^2} = G_0 (\theta_0 + NC_{\text{sc}})
\]

(3.6)
\[
\frac{\partial^2 \theta_0}{\partial \eta^2} = -a \eta^2 \quad (3.7)
\]

\[
\frac{\partial^3 C_0}{\partial \eta^3} - \beta_1^2 C_0 = -\frac{ScSo}{N} \frac{\partial^3 \theta_0}{\partial \eta^3} \quad (3.8)
\]

The first order equations are
\[
\frac{\partial^2 \psi_1}{\partial \eta^2} - M_1 \frac{\partial \psi_1}{\partial \eta} = G_1(\theta_{1,0} + NC_1) + f(\psi_{1,0},\psi_{1,0,0} - \psi_{1,0,0,0}) \quad (3.9)
\]

\[
\frac{\partial^2 \theta_1}{\partial \eta^2} = Pf(\theta_{1,0},\psi_{1,0} - \theta_{1,0},\psi_{1,0}) \quad (3.10)
\]

\[
\frac{\partial^2 C_1}{\partial \eta^2} - \beta_1^2 C_1 = -\frac{ScSo}{N} \frac{\partial^2 \theta_1}{\partial \eta^2} \quad (3.11)
\]

The second order equations are
\[
\frac{\partial^2 \psi_2}{\partial \eta^2} - M_1 \frac{\partial \psi_2}{\partial \eta} = G_1(\theta_{2,0} + NC_1^2) + f(\psi_{1,0},\psi_{1,0,0} + \psi_{1,0,0} - \psi_{1,0,0,0} - \psi_{1,0,0,0}) \quad (3.12)
\]

\[
\frac{\partial^2 \theta_2}{\partial \eta^2} = Pf(\theta_{1,0},\psi_{1,0} + \theta_{1,0},\psi_{1,0} - \theta_{1,0,0} - \theta_{1,0,0}) \quad (3.13)
\]

\[
\frac{\partial^2 C_2}{\partial \eta^2} - \beta_1^2 C_2 = -\frac{ScSo}{N} \frac{\partial^2 \theta_2}{\partial \eta^2} \quad (3.14)
\]

The corresponding boundary conditions are
\[
\psi_0(+1) - \psi_0(-1) = -1 \quad \frac{\partial \psi_0}{\partial \eta} = 0 \quad \frac{\partial \psi_0}{\partial x} = 0 \quad (3.15a, b, c)
\]
\[
\theta_0(+1) = 1 \quad \theta_0(-1) = 0
\]
\[
C_0 (+1) = 1 \quad C_0(-1) = 0
\]

and
\[
\psi_i(+1) - \psi_i(-1) = 0 \quad \frac{\partial \psi_i}{\partial \eta} = 0 \quad \frac{\partial \psi_i}{\partial x} = 0 \quad (3.16a, b, c)
\]
\[
\theta_i(+1) = 0 \quad \theta_i(-1) = 0
\]
\[
C_i(+1) = 0 \quad C_i(-1) = 0 \quad (i \geq 1)
\]
4. SOLUTION OF THE PROBLEM

Solving the equations (3.6)-(3.8) & (3.9)-(3.11) subject to the boundary conditions (3.15a, 3.16a, b, c) we obtain

\[ \psi_0^0(\eta) = a_q Ch(\beta_2 \eta) + a_{10} Sh(\beta_2 \eta) + a_{11} \eta + a_{12} + \phi_1(\eta) \]

\[ \phi_1(\eta) = a_2 Ch(\beta_1 \eta) + a_3 Sh(\beta_1 \eta) + a_4 \eta^2 - a_5 \eta^3 \]

\[ \theta_0(\eta) = 0.5 \alpha_f^2 (\eta^2 - 1) + 0.5(\eta + 1) \]

\[ C_0(\eta) = \frac{a_1}{\beta_1^2} \left( \frac{Ch(\beta_1 \eta)}{Ch(\beta_1)} - 1 \right) + 0.5 \left( \frac{Sh(\beta_1 \eta)}{Sh(\beta_1)} + 1 \right) \]

\[ \theta_1(\eta) = a_{s1}(\eta^2 - 1) + a_{s2}(\eta^4 - \eta) + a_{s3}(\eta^4 - 1) + a_{s4}(\eta^4 - \eta) + \]

\[ (a_{s0} + \eta a_{s1})(Ch(\beta_2 \eta) - Ch(\beta_2)) + a_{s1}(Sh(\beta_2 \eta) - \eta Sh(\beta_2)) + \]

\[ (a_{s2} + \eta a_{s3})(Sh(\beta_2 \eta) - Sh(\beta_2)) + a_{s4}(Sh(\beta_2 \eta) - \eta Sh(\beta_2)) + \]

\[ (a_{s5} + \eta a_{s6})(\eta Sh(\beta_2 \eta) - Sh(\beta_2)) + (a_{s7} + \eta a_{s8})(\eta Sh(\beta_2 \eta) - Sh(\beta_2)) + \]

\[ a_{s9}(\eta^2 Ch(\beta_2 \eta) - Ch(\beta_2)) + a_{s10}(\eta^2 Ch(\beta_2 \eta) - Ch(\beta_2)) \]
In the case of $P=O$ and $S_{0}=O$ the results are in good agreement with that of Sudha(22a).
5. SHEAR STRESS, NUSSELT NUMBER AND SHERWOOD NUMBER

The shear stress on the boundaries $y = \pm 1$ are given by

$$\tau^* = (\mu \frac{du}{dy})_{\pm 1}$$

which in the non-dimensional form reduces to

$$\tau = \frac{\tau^*}{(\nu^2 / L^2)} = \left(\frac{du}{dy}\right)_{\pm 1}$$

and the corresponding expressions are

$$\tau_{+1} = b_1 + \delta b_2 + \delta^2 b_3 + \ldots$$

$$\tau_{-1} = b_4 + \delta b_5 + \delta^2 b_6 + \ldots$$

The rate of heat transfer (Nusselt Number) on the boundaries $y = \pm 1$ are given by

$$Nu_{\pm 1} = \left(\frac{d\theta_1}{dy} + \delta \frac{d\theta_1}{dy} + \delta^2 \frac{d\theta_1}{dy}\right)_{\pm 1}$$

and the corresponding expressions are

$$Nu_{+1} = b_7$$

$$Nu_{-1} = b_8$$

The rate of mass transfer (Sherwood Number) on the boundaries $y = \pm 1$ are given by

$$Sh_{\pm 1} = \left(\frac{dC_1}{dy} + \delta \frac{dC_1}{dy} + \delta^2 \frac{dC_1}{dy}\right)_{\pm 1}$$

and the corresponding expressions are

$$Sh_{+1} = b_9$$

$$Sh_{-1} = b_{10}$$

where $b_1, b_2, \ldots, b_{10}$ are constants given in appendix.
6. DISCUSSION OF NUMERICAL RESULTS

In this analysis we discuss the effect of chemical reaction and radiation on convective heat and mass transfer flow of a viscous electrical conducting fluid through a porous medium confined in a vertical wavy channel bounded by wavy walls situated at \( \eta=\pm f(x)=1+\beta \exp(-x^2) \). \( \beta>0 \) corresponds to dilation ratio of channel walls and \( \beta<0 \) represents constriction case. In the present analysis we confine our attention to the case \( \beta<0 \). The equations are non-linear coupled equation governing the flow, heat and mass transfer are solved by using regular perturbation technique with \( \delta \) the slope of wavy walls as the perturbed parameter. In this analysis the Prandtl Number= 0.71 and \( \delta= 0.01 \).

Fig 1-7 represent variation of axial velocity \( u \) with different values of \( G, D^1, M, \alpha, N, S_c, S_0, N_1 \) and \( \beta \). Fig.1 represents the variation of Grashof number \( G \). It is found that \( u \) exhibits a reversal behaviour at \( G=5\times10^3 \). Also \( |u| \) depreciates with increase in \( G>0 \) and enhances with increase in \( |G| \) with maximum attained at \( \eta=0 \). Fig (2) represents variation of \( u \) with \( M \) and \( D^1 \). It is found that higher the Lorentz force larger \( u \) in the flow region. Also lesser permeability of porous medium larger \( u \) in the region and for further lowering of permeability smaller \( |u| \). Also the flow exhibits a reversal flow for \( D^1=4\times10^3 \). The variation of \( u \) with heat source parameter \( \alpha \) is shown in fig.3. It is found for higher values of \( \alpha \) \( u \) exhibits a reversal flow behavior and the region of reversal flow enlarges with increase in \( \alpha \). Also \( |u| \) experiences an enhancement with increase in the strength of heat source/sink. The variation of \( u \) with buoyancy ratio \( N \) is shown in fig.4. The axial velocity \( u \) experience an enhancement when the buoyancy forces act in same direction and for the forces in acting in opposite directions \( u \) depreciates in the flow region. The variation of \( u \) with \( S_c \) and \( S_0 \) is shown in fig.5. It is found that \( u \) exhibits a reversal flow for higher value \( S_c=2.01 \) and \( S_0=1.0 \). Also \( |u| \) depreciates with increase in \( S_c \) and enhances with \( |S_0| \). The variation of \( u \) with radiation parameter \( N_1 \) and \( \beta \) is shown in fig.6. It is found that higher the construction of the channel walls larger the axial velocity and for further higher constriction of channel walls smaller \( u \) in the flow region. An increase the radiation parameter \( N_1 \)
results in a depreciation in the axial velocity everywhere in the flow region. The
effect of chemical reaction K and axial distance \( x \) is shown in fig. 7. It is found
that an increase in chemical reaction parameter \( K \) results in an enhancement in
axial velocity \( u \). Moving along the axial distance of the channel the actual velocity
experiences a depreciates in entire flow region.

The secondary velocity \( v \) which is due to the waviness of the boundary is
shown in figs. 8-14. Fig. 8 represents variation of \( v \) with Grashof number \( G \). It is
found that \( v \) is towards the boundary for \( G=10^4 \) and \( |G| \) and for higher \( G>3\times10^3 \), \( v \)
is towards the mid region. \( |v| \) enhances with increase in \( |G| \) in the entire flow
region with maximum attained at \( \eta=0 \). The variation of \( v \) with \( M \) and \( D^{-1} \) shows
that lesser the permeability of porous medium/higher the Lorentz force larger \( |v| \) in
the entire flow region (fig. 9). An increase in the strength of the heat source \( a<4 \)
depreciates \( |v| \) and for further higher values of \( a>6 \), \( |v| \) enhances in the flow region.
Also an increase in the strength of the heat sink enhances \( |v| \) in the region (fig. 10).
The variation of \( v \) with buoyancy ratio \( N \) shows that when the molecular
buoyancy forces dominates over the thermal buoyancy force \( |v| \) depreciates in the
flow region, when buoyancy forces act in the same direction and for the forces
acting in opposite directions, \( |v| \) enhances everywhere in the region (fig. 11).
The variation of \( v \) with \( S_c \) shows that lesser the molecular diffusivity smaller \( |v| \) in the
flow region and for further lowering of the molecular diffusivity smaller \( |v| \) in
region. An increasing in the Soret parameter \( S_0>0 \) depreciates \( |v| \) in the flow
region while an increase in \( |S_0| \) enhances \( |v| \) in the entire region (fig. 13). We notice
that higher the constriction of the channel (\( |\beta|<0.5 \) ) lesser \( |v| \) and for further higher
value of constriction of the channel walls larger \( |v| \) \( |v| \) enhances with increase in
the chemical reaction parameter \( K \). Moving along the axial direction of channel
walls the secondary velocity experiences an enhancement with \( x \).

The non-dimensional temperature \( \theta \) is shown in figs. 15-21 for different
parametric values. We follow the convention that the non-dimensional temperature
is positive or negative according as the actual temperature is greater/lesser than \( T_2 \)
on the right boundary \( \eta=+1 \). Fig. (15) represents variation of \( \theta \) with Grashof
number \( G \). It is found that the actual temperature reduces with increase in \( G>0 \)
and enhances with increase in $|G|$ with maximum attained at $\eta = -0.4$. The variation of $\theta$ with $M$ and $D^{-1}$ shows that higher the Lorentz force smaller the actual temperature. Also lesser the permeability of the porous medium larger the actual temperature in the flow region(fig.16). The variation of $\theta$ with heat source parameter $\alpha$ shows that for an increase in $\alpha < 4$ and an increase in $|\alpha|$ leads to an enhancement in the actual temperature everywhere in the region. Thus the presence of heat source in the flow region enhances the actual temperature in the entire flow region. The variation of $\theta$ with buoyancy ratio $'N'$ shows that the actual temperature enhances in the entire flow region irrespective of the directions of the buoyancy forces(fig.18). Fig.(19) represents the variation of $\theta$ with $S_c$ and $S_d$. It is found that lesser the molecular diffusivity larger the actual temperature in the flow region. An increase in $S_d>0$ enhances the actual temperature while it depreciates with $|S_d|$. The influence of the surface geometry on $\theta$ is shown in fig. (20). It is found that higher the constriction of the channel walls smaller the actual temperature in the flow region. Also the actual temperature depreciates with higher values of radiation parameter $N_1$. The variation of $\theta$ with chemical reaction parameter $K$ shows that an increase in $K<1.0$ depreciates the actual temperature and for higher $K>2.5$ the actual temperature experiences an enhancement. Moving along the axial direction of the channel the actual temperature enhances with $x$(fig 21).

The non-dimensional concentration $C$ is shown in figs.22-29 for different parametric values. We follow the convention that the non-dimensional concentration is positive or negative according as the actual concentration is greater/ lesser than $C_2$. Fig.22 is represents the variation of $C$ with $G$. It is found that an increase in $G>0$ enhances the actual concentration while it depreciates with $|G|$ with maximum $C$ attained at $\eta = +1$. The variation of $C$ with $M$ and $D^{-1}$ shows that higher the Lorentz force/lesser the permeability of porous medium larger the actual concentration in the flow region(fig.23). The variation of $C$ with heat source parameter $\alpha$ shows that the actual concentration exhibits an increasing tendency with increase in the strength of heat source/sink(fig.24). The variation of $C$ with buoyancy ratio $N$ shows that the actual concentration enhances when the
buoyancy forces act in the same direction and for the forces acting in opposite
directions it depreciates in region(fig.25). The variation of C with Schmidt number
$S_c$ shows that lesser the molecular diffusivity smaller the actual concentration and
for further lowering of the diffusivity larger the actual concentration. Also an
increase in $|S_0|$ results in an enhancement in the actual concentration everywhere
in the region(fig.26). The influence of the surface geometry on C is shown in
fig.27. It is found that higher the constriction of the channel walls larger the actual
concentration in the region $0.2 \leq \eta \leq 0.8$ and in the region $0.2 \leq \eta \leq 0$ the actual
concentration depreciates. Also the actual concentration experiences an
enhancement with increase in the radiation parameter $N_l$. The variation of C with
chemical reaction parameter K is shown in fig.28. It is found that an increase in
$K \leq 1.0$ enhances the actual concentration. Moving along the axial direction of the
channel walls the actual concentration experiences with x.

The rate of heat transfer at the boundary $\eta = \pm 1$ is evaluated for different
parameters and are shown in tables.1-10. It is found that Nu depreciates with G<0
and enhances with G>0 at $\eta = \pm 1$. The variation of Nu with $D^+$ shows that lesser
permeability of porous medium smaller Nu at the both the walls. With respect to
heat sources parameter $a$ the rate heat transfer enhances with increase in $a > 0$ and
depreciates with $|a|$ (tables.1&6). The variation of Nu with Hartman number M
shows that higher the Lorentz force smaller $|Nu|$ $\eta = \pm 1$ and larger $|Nu|$ $\eta = 1$. The
variation of Nu with buoyancy ratio N shows that the rate of heat transfer
depreciates when the buoyancy force act in the same direction and for the forces
acting in opposite directions $|Nu|$ enhance at $\eta = \pm 1$ (tables.2&7). The rate of heat
transfer enhances with increase in $Sc$ at $\eta = \pm 1$. The rate of heat transfer increases
with $S_0 > 0$ and depreciates with $|S_0|$ at both the walls(tables.3&8). Higher the
constriction of the walls smaller $|Nu|$ at $\eta = \pm 1$. The rate of heat transfer enhances at
$\eta = 1$ and depreciates at $\eta = -1$ with increase in the radiation parameter $N_l$
(tables.4&9). From tables.5&10 we find that the rate of heat transfer depreciates
with increase in chemical reaction parameter K. Moving along the axial direction
the rate of heat transfer enhances with $x < \pi / 2$ and depreciates for higher $x > \pi$. 

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The Sherwood number (Sh) which measures the rate of mass transfer at $\eta=\pm 1$ is shown in tables.11-20 for different parametric values. It is found that the rate of mass transfer enhances with $G>0$ and depreciates $G<0$ and lesser permeability of porous medium smaller $|\text{Sh}|$ at $\eta=\pm 1$. An increase in heat source/sink parameter results in a depreciation in $|\text{Sh}|$ at both the walls (tables.11&16). The variation of Sh with Hartman number M shows that higher the Lorentz force smaller $|\text{Sh}|$ at $\eta=\pm 1$. When the molecular buoyancy force dominates over the thermal buoyancy force the rate of mass transfer enhances when the buoyancy force act in the same direction and for forces acting in opposite directions it depreciates at $\eta=\pm 1$(tables.12&17). From tables.13&18 we notice that the rate of mass transfer enhances with increase in $S_c<0.6$ and enhances $|S_o|$ at both walls. The variation of Sh with $\beta$ shows that the higher the constriction of the channel walls lesser the rate of mass transfer. Also an increase in the radiation parameter $N_1$ leads to a depreciation in $|\text{Sh}|$ at both the walls(Tables.14&18). The variation of Sh with chemical reaction parameter $K$ shows that an increase $K<0.5$ enhance $|\text{Sh}|$ depreciates with $K<0.7$ and again enhances at higher $K>1.3$ at both walls. The variation of Sh with axial distance $x$ shows that the rate of mass transfer fluctuates at $\eta=\pm 1$(Tables.15&20).
6. REFERENCES


6. APPENDIX

\[ a_1 = \frac{1}{2} \]

\[ a_2 = \frac{1}{2} - 2f^2 \]

\[ a_3 = \frac{a_1}{\beta_1 \cosh \beta_1} \]

\[ a_4 = \frac{\beta_1^2}{2 \sinh \beta_1} \]

\[ a_5 = \frac{G}{4\beta_1^2} \]

\[ a_6 = \frac{(-Gf^2)^3}{6\beta_1^2} \]

\[ a_7 = \frac{1}{\beta_1^2\left(\beta_1^2 - \beta_2^2\right)} \]

\[ a_8 = \frac{1}{\beta_1^2\left(\beta_1^2 - \beta_2^2\right)} \]

\[ a_9 = \frac{-a_{14}}{\beta_1 \sin \beta_1} \]

\[ a_{10} = \frac{-(a_{14} + a_{13})}{\beta_1 \cosh \beta_1 + \sin \beta_1} \]

\[ a_{11} = -a_{13} - \beta_2 a_{10} \cosh \beta_2 \]

\[ a_{12} = \frac{1}{2} \left[ -a_5 \cosh \beta_1 + a_4 \beta_1 + \frac{a_5}{f} \cosh \beta_2 + a_3 \beta_1 + \frac{a_5}{f} \sinh \beta_1 + \frac{a_3}{f} - 2a_5 f' \right] \]

\[ a_{13} = \alpha f^2 \times 0.5 - a_5' \sinh \beta_1 + \frac{a_5}{f} \cosh \beta_1 + \frac{a_5}{f} - a_5' \sinh \beta_1 + \frac{a_5}{f} \cosh \beta_1 + \frac{3a_5' f'}{f} \]

\[ a_{14} = \alpha f^2 \times \left( -a_5' - \frac{3a_5' f'}{f} \right) \]

\[ a_{15} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{16} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{17} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{18} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{19} = \frac{\alpha f^2 + a_5 f'}{f} \]

\[ a_{20} = \frac{\alpha f^2 + a_5 f'}{f} \]

\[ a_{21} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{22} = \frac{0.5 \left( -a_5 f' + \alpha f^2 \right)}{f} \]

\[ a_{23} = \frac{0.5 \left( -a_5 f' + \alpha f^2 \right)}{f} \]

\[ a_{24} = \frac{0.5 \left( -a_5 f' + \alpha f^2 \right)}{f} \]

\[ a_{25} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{26} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{27} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{28} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{29} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]

\[ a_{30} = 0.5 \left( -a_5 f' + \alpha f^2 \right) \]
\( a_{26} = 0.5 \times a_{16} \)

\( a_{27} = \alpha f^3 a_s + \frac{a_s \beta \kappa f'}{f} \)

\( a_{28} = 0.5 \times \frac{a_s \beta \kappa f'}{f} \)

\( a_{29} = \alpha f^3 - \frac{a_s \beta \kappa f'}{f} \)

\( a_{31} = \alpha f^3 ( - \beta a_{16} \cos \beta + 3a_s + \beta a_6 \cos \beta ) \)

\( a_{32} = -\frac{f'}{f} ( - \beta a_{16} \cos \beta + 3a_s + \beta a_6 \cos \beta ) + \alpha f^3 ( -2a_s ) \]

\( a_{33} = a_{32} - 3a_s \alpha f' \)

\( a_{34} = -\frac{f'}{f} a_{32} + 42 \alpha f' \)

\( a_{35} = -6a_s \alpha f' \)

\( a_{36} = \alpha f' ( -\beta a_{16} \cos \beta + 3a_s + \beta a_6 \cos \beta ) \)

\( a_{37} = \alpha f' ( -\beta a_{16} \cos \beta ) \)

\( a_{38} = \alpha f' ( -\beta a_6 \cos \beta ) \)

\( a_{39} = \alpha f' ( -\beta a_6 \cos \beta ) \)

\( a_{40} = -\frac{f'}{f} \beta a_{16} \)

\( a_{41} = -\frac{f'}{f} \beta a_6 \)

\( a_{42} = +\frac{f'}{f} \beta a_6 \)

\( a_{43} = 2\alpha f' \beta a_6 \)

\( a_{44} = -2\alpha f' \beta a_6 \)

\( a_{45} = -2\alpha f' \beta a_6 \)

\( a_{46} = 2\alpha f' \beta a_6 \)

\( a_{47} = 2\alpha f' \beta a_6 \)

\( a_{48} = f_p(a_{44} - a_{34}) \)

\( a_{49} = f_p(a_{46} - a_{36}) \)

\( a_{50} = f_p(a_{48} - a_{38}) \)

\( a_{51} = f_p(a_{50} - a_{30}) \)

\( a_{52} = f_p(a_{46} - a_{36}) \)

\( a_{53} = f_p(a_{52} - a_{32}) \)

\( a_{54} = f_p(a_{54} - a_{34}) \)

\( a_{55} = f_p(a_{54} - a_{34}) \)

\( a_{56} = f_p(a_{56} - a_{36}) \)

\( a_{57} = f_p(a_{56} - a_{36}) \)

\( a_{58} = f_p(a_{58} - a_{38}) \)

\( a_{59} = f_p(a_{58} - a_{38}) \)

\( a_{60} = f_p(a_{60} - a_{40}) \)

\( a_{61} = f_p(a_{62} - a_{52}) \)
\[ a_{60} = fp(a_{20} - a_{40}) \]
\[ a_{62} = fp(a_{34} - a_{67}) \]
\[ a_{64} = fp(a_{30} - a_{43}) \]
\[ a_{65} = \frac{a_{40}}{2} \]
\[ a_{66} = \frac{a_{40}}{6} \]
\[ a_{67} = \frac{a_{41}}{20} \]
\[ a_{68} = \frac{a_{41}}{\beta^2} \]
\[ a_{70} = \frac{a_{42}}{\beta^2} + \frac{2a_{52} + 6a_{63}}{\beta_2^2} \]
\[ a_{72} = \frac{a_{55}}{\beta_2} + \frac{2a_{52} + 6a_{63}}{\beta_1} \]
\[ a_{74} = \frac{a_{57}}{\beta_2} + \frac{4a_{52} + 6a_{63}}{\beta_1^2} \]
\[ a_{76} = \frac{a_{59}}{\beta_2} + \frac{4a_{52} + 6a_{63}}{\beta_1^4} \]
\[ a_{78} = \frac{a_{57}}{\beta_1} \]
\[ a_{80} = \frac{a_{51}}{\beta_2} \]
\[ a_{82} = \frac{a_{57}}{\beta_3} \]
\[ a_{100} = -3a_{52} + 3a_{52} + 3a_{63} + a_{63} \]
\[ a_{102} = -3a_{63} \]
\[ a_{103} = \beta a_{103} - \frac{Sh \beta_1}{\beta_2^2} + \frac{2a_{52}}{\beta_3} \]
\[ a_{104} = 2 a_{102} \]
\[ a_{106} = -\beta_1 a_7 \]
\[ a_{107} = 2a_{102} - \frac{2a_{102} f'}{f} \]
\[ a_{111} = \beta_1 a_{103} \]
\[ a_{114} = \beta_1 a_{103} \]
\[
\begin{align*}
a_{159} &= -a_{141} + a_{149} & a_{160} &= -a_{143} + a_{145} \\
a_{161} &= -a_{147} + a_{149} & a_{162} &= -a_{144} + a_{148} \\
a_{163} &= \left( \frac{a_{150} + a_{155}}{2} \right) & a_{164} &= \frac{a_{152} + a_{157}}{2} \\
a_{165} &= \frac{a_{153} + a_{154}}{2} & a_{166} &= -\frac{a_{152} + a_{157}}{2} \\
a_{167} &= \frac{a_{153} + a_{154}}{2} & a_{168} &= \frac{a_{153} + a_{159}}{2} \\
a_{169} &= -\frac{a_{153} + a_{154}}{2} & a_{170} &= -\frac{a_{153} + a_{159}}{2} \\
a_{171} &= a'_{10} Ch \beta_1 + \frac{a_s \beta_3 f''}{f} Sh \beta_1 - a'_1 Ch \beta_1 + \frac{a_s \beta_3 f''}{f} Sh \beta_1 - a'_1 + \frac{2a_s f''}{f} \\
a_{172} &= -a'_{10} Sh \beta_1 + \frac{a_s \beta_0 \beta_3 f''}{f} Ch \beta_1 - a'_{10} Sh \beta_1 + \frac{a_s \beta_0 \beta_3 f''}{f} Ch \beta_1 - a'_1 + \frac{3a_s f''}{f} \\
a_{173} &= -a'_1 - \frac{2a_s f''}{f} \\
a_{174} &= -a'_1 - \frac{3a_s f''}{f} \\
a_{175} &= -a'_2 \\
a_{176} &= -\frac{a_s \beta_3 f'_3}{f} \\
a_{177} &= a'_3 \\
a_{178} &= -\frac{a_s \beta_0 f''}{f} \\
a_{179} &= a'_4 \\
a_{180} &= -a_s \beta'_3 f'' \\
a_{181} &= a'_{10} \\
a_{182} &= -\frac{a_s \beta'_3 f''}{f} \\
a_{183} &= a_{172} a_{107} + a_{108} a_{171} \\
a_{184} &= a_{173} a_{107} + a_{110} a_{171} \\
a_{185} &= a_{172} a_{108} + a_{109} a_{171} \\
a_{186} &= a_{173} a_{107} + a_{111} a_{171} \\
a_{187} &= a_{173} a_{107} + a_{112} a_{109} \\
a_{188} &= a_{173} a_{108} \\
a_{189} &= a_{174} a_{108} \\
a_{190} &= a_{173} a_{109} \\
a_{191} &= a_{174} a_{109} \\
a_{192} &= a_{175} a_{111} + a_{107} a_{179} \\
a_{193} &= a_{175} a_{111} + a_{108} a_{179} \\
a_{194} &= a_{173} a_{111} \\
a_{195} &= a_{174} a_{111} \\
a_{196} &= a_{181} a_{107} + a_{171} \\
a_{197} &= a_{181} a_{107} + a_{111} a_{172} \\
a_{198} &= a_{173} a_{110} \\
a_{199} &= a_{172} a_{107} + a_{110} a_{172} \\
a_{200} &= a_{172} a_{108} + a_{111} a_{172} \\
a_{201} &= a_{173} a_{107} + a_{112} a_{172} \\
a_{202} &= a_{173} a_{108} \\
a_{203} &= a_{174} a_{108} \\
a_{204} &= a_{173} a_{109} \\
a_{205} &= a_{174} a_{109} \\
a_{206} &= a_{175} a_{111} + a_{107} a_{179} \\
a_{207} &= a_{175} a_{111} + a_{108} a_{179} \\
a_{208} &= a_{173} a_{111} \\
a_{209} &= a_{174} a_{111} \\
a_{210} &= a_{181} a_{107} + a_{171} \\
a_{211} &= a_{181} a_{107} + a_{111} a_{172} \\
a_{212} &= a_{173} a_{110} \\
a_{213} &= a_{172} a_{107} + a_{110} a_{172} \\
a_{214} &= a_{172} a_{108} + a_{111} a_{172} \\
a_{215} &= a_{173} a_{107} + a_{112} a_{172} \\
a_{216} &= a_{173} a_{108} \\
a_{217} &= a_{174} a_{108} \\
a_{218} &= a_{173} a_{109} \\
a_{219} &= a_{174} a_{109} \\
a_{220} &= a_{175} a_{111} + a_{107} a_{179} \\
a_{221} &= a_{175} a_{111} + a_{108} a_{179} \\
\end{align*}
\]
\[
\begin{align*}
a_{199} &= a_{174}a_{110} \\
a_{200} &= \frac{a_{174}a_{106}}{2} \\
a_{201} &= a_{196}a_{126} \\
a_{202} &= a_{174}a_{108} \\
a_{203} &= a_{174}a_{108} \\
a_{204} &= \frac{a_{174}a_{108} + a_{175}a_{111}}{2} \\
a_{205} &= a_{196}a_{110} + a_{175}a_{111} \\
a_{206} &= \frac{a_{176}a_{108}}{2} \\
a_{207} &= a_{196}a_{108} \\
a_{208} &= a_{176}a_{110} \\
a_{209} &= a_{176}a_{110} \\
a_{210} &= \frac{a_{176}a_{110}}{2} \\
a_{211} &= a_{196}a_{106} \\
a_{212} &= a_{176}a_{109} \\
a_{213} &= a_{196}a_{109} \\
a_{214} &= \frac{a_{176}a_{109} + a_{177}a_{110}}{2} \\
a_{215} &= a_{196}a_{109} + a_{178}a_{110} \\
a_{216} &= \frac{a_{176}a_{110}}{2} \\
a_{217} &= a_{176}a_{110} \\
a_{218} &= \frac{a_{176}a_{110}}{2} \\
a_{219} &= a_{196}a_{110} \\
a_{220} &= a_{176}a_{110} \\
a_{221} &= a_{196}a_{110} \\
a_{222} &= \frac{a_{176}a_{111}}{2} \\
a_{223} &= a_{176}a_{111} \\
a_{224} &= \frac{a_{176}a_{111}}{2} \\
a_{225} &= a_{196}a_{111} \\
a_{226} &= \frac{a_{176}a_{111}}{2} \\
a_{227} &= a_{196}a_{111} \\
a_{228} &= a_{183} + a_{200} + a_{210} + a_{220} \\
a_{229} &= a_{172} + a_{201} + a_{211} + a_{221} - a_{225} \\
a_{230} &= a_{200} + a_{224} \\
a_{231} &= a_{201} + a_{225} \\
a_{232} &= a_{210} + a_{220} \\
a_{233} &= a_{211} + a_{221} \\
a_{234} &= a_{202} + a_{208} + a_{218} + a_{220} \\
\end{align*}
\]
\[ a_{225} = a_{203} + a_{209} + a_{219} + a_{227} \]
\[ a_{227} = a_{203} + a_{209} - a_{219} - a_{227} \]
\[ a_{230} = a_{207} + a_{213} + a_{217} + a_{225} \]
\[ a_{241} = -a_{207} + a_{213} - a_{217} + a_{225} \]
\[ a_{243} = s(a_{229} - a_{123}) \]
\[ a_{245} = s(a_{174} - a_{123}) \]
\[ a_{247} = s(a_{183} - a_{130}) \]
\[ a_{249} = (a_{187} - a_{131})s \]
\[ a_{251} = (a_{235} - a_{168})s \]
\[ a_{253} = (a_{237} - a_{170})s \]
\[ a_{255} = (a_{189} - a_{139})s \]
\[ a_{257} = (a_{191})s \]
\[ a_{259} = (a_{231} - a_{160})s \]
\[ a_{261} = (a_{233})s \]
\[ a_{263} = (a_{193} - a_{132})s \]
\[ a_{265} = (a_{195} - a_{136})s \]
\[ a_{267} = (a_{197} - a_{133})s \]
\[ a_{269} = (a_{199})s \]
\[ a_{271} = (a_{205} - a_{142})s \]
\[ a_{273} = (a_{214} - a_{162})s \]
\[ a_{275} = (a_{238} - a_{163})s \]
\[ a_{277} = (a_{240} - a_{165})s \]
\[ a_{279} = -a_{96} - a_{186} + a_{21} Sh \beta_2 - a_{71} Sh \beta_1 - a_{76} Ch \beta_1 - a_{77} Sh \beta_1 - a_{79} Sh \beta_2 \]
\[ a_{280} = -2a_{95} - a_{81} Sh \beta_1 \]
\[ a_{281} = a_{76} \beta_1 + a_{73} \]
\[ a_{282} = (a_{91} + a_{80}) \beta_2 \]
\[ a_{284} = \beta_2 a_{78} + 2(a_{78} + a_{80}) \]
\[ a_{286} = a_{76} \beta_1 + a_{72} \]

\[ \beta_1 \]

\[ a_{288} = \beta_1 a_{81} \]
\[ a_{289} = a_{79} \beta_1 + a_{81} \]
\[ a_{290} = \beta_2 (a_{81} + a_{80}) \]
\[
\begin{align*}
a_{288} &= N \left( -b_{26} \beta_1 - b_{26} \beta_4 - b_{26} \beta_6 - b_{26} \beta_8 \beta_1 \right) \\
&\quad \left( \frac{b_{27} \beta_1 + 3b_{26}}{\beta_1} \right) \\
\end{align*}
\]

\[
\begin{align*}
a_{289} &= N \left( b_{27} + 2b_{26} \right) \\
a_{290} &= N \left( b_{27} + 2b_{26} \right) \\
a_{291} &= N \beta_1 b_{27} \\
a_{292} &= N \left( b_{27} \beta_1 + b_{26} \right) \\
a_{293} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{294} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{295} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{296} &= N \left( b_{27} \beta_1 + 3b_{26} \right) \\
a_{297} &= N b_{27} \beta_1 \\
a_{298} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{299} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{300} &= N \beta_4 b_{26} \\
\end{align*}
\]

\[
\begin{align*}
a_{301} &= N \left( -b_{26} \beta_1 - b_{26} \beta_4 - b_{26} \beta_6 - b_{26} \beta_8 \beta_1 \right) \\
&\quad \left( \frac{b_{27} \beta_1 + 3b_{26}}{\beta_1} \right) \\
\end{align*}
\]

\[
\begin{align*}
a_{302} &= N \left( 2b_{27} + \beta_1 b_{26} \right) \\
a_{303} &= N \left( 2b_{27} + \beta_1 b_{26} \right) \\
\end{align*}
\]

\[
\begin{align*}
a_{304} &= N \left( 3b_{27} + b_{26} \beta_1 \right) \\
a_{305} &= N \beta_1 b_{26} \\
a_{306} &= N \beta_1 b_{26} \\
a_{307} &= N \left( 2b_{27} - \beta_1 b_{26} \right) \\
a_{308} &= N \left( 3b_{27} - \beta_1 b_{26} \right) \\
a_{309} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{310} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{311} &= N \beta_1 b_{26} \\
a_{312} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
a_{313} &= N \beta_1 b_{26} \\
a_{314} &= N \left( \beta_1 b_{26} + b_{26} \right) \\
\end{align*}
\]

\[
b_1 = \left[ -a_1' \cosh \beta_2 + \frac{a_1 \beta_1 f'}{f} \sinh \beta_2 - a_1' \cosh \beta_1 + \frac{a_1' \beta_1 f'}{f} \cosh \beta_1 + \frac{2nf'}{f} \right]
\]
\[ b_2 = \frac{S \cdot S \cdot f_p}{N} \left( a'_i \sinh \beta - \frac{a_i \beta f'}{f} \cosh \beta + a'_i \cosh \beta - \frac{a_i \beta f'}{f} \cosh \beta - a'_i - \frac{3a_i f'}{f} \right) \]

\[ b_3 = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \left( a'_i \cosh \beta - \frac{a_i \beta f'}{f} \sinh \beta + a'_i \cosh \beta - \frac{a_i \beta f'}{f} \cosh \beta - a'_i - \frac{2a_i f'}{f} \right) \]

\[ b_4 = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \left( a'_i \cosh \beta - \frac{a_i \beta f'}{f} \sinh \beta + a'_i \cosh \beta - \frac{a_i \beta f'}{f} \cosh \beta - a'_i - \frac{2a_i f'}{f} \right) \]

\[ b_5 = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \left( a'_i \sinh \beta - \frac{a_i \beta f'}{f} \cosh \beta + a'_i \cosh \beta - \frac{a_i \beta f'}{f} \cosh \beta - a'_i - \frac{3a_i f'}{f} \right) \]

\[ b_6 = a'_i \left( \frac{S \cdot S \cdot f_p}{2N} \right) \]

\[ b_7 = \frac{S \cdot S \cdot f_p}{2N} \left( \frac{a_i \beta f'}{f} \right) \]

\[ b_8 = \frac{S \cdot S \cdot f_p}{2N} \left( a'_i \beta f' \right) \]

\[ b_9 = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \times a'_i \]

\[ b_{10} = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \times \frac{a'_i \beta f'}{f} \]

\[ b_{11} = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \times a'_i \]

\[ b_{12} = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \times a'_i \beta f' \]

\[ b_{13} = \frac{\alpha^2 \cdot S \cdot S \cdot f_p}{N} \times \frac{a'_i \beta f'}{f} \]

\[ b_{14} = S \cdot a_i + \left[ \frac{-a'_i \cosh \beta_i + a'_i \beta f'}{f} \cosh \beta_i - a'_i \cosh \beta_i + a_i \beta f' \cosh \beta_i}{\frac{S \cdot S \cdot f_p}{2N}} \right] \]

\[ b_{15} = S \cdot a_i + \left[ \frac{-a'_i \cosh \beta_i + a'_i \beta f'}{f} \sinh \beta_i - a'_i \cosh \beta_i + a_i \beta f' \sinh \beta_i}{\frac{S \cdot S \cdot f_p}{2N}} \right] \]

\[ b_{16} = a_i \beta f' \left[ \frac{-a'_i \cosh \beta_i + a'_i \beta f'}{f} \cosh \beta_i - a'_i \cosh \beta_i + a_i \beta f' \cosh \beta_i}{\frac{S \cdot S \cdot f_p}{2N}} \right] \]

\[ b_{17} = -a_i \beta f' \left[ \frac{-a'_i \cosh \beta_i + a'_i \beta f'}{f} \sinh \beta_i - a'_i \cosh \beta_i + a_i \beta f' \sinh \beta_i}{\frac{S \cdot S \cdot f_p}{2N}} \right] \]

\[ b_{18} = -a_i \beta f' \]
\[ b_0 = \left[ f_s a_i \times \left( a_i' + \frac{2a_i f'}{f} \right) - \frac{a_0 f'_s b_s f_p}{N} \times a_i' \right] \]

\[ b_20 = f_s a_i \left[ a_i' + \frac{2a_i f'}{f} \right] - \frac{a_0 f'_s b_s f_p}{N} \times a_i' \]

\[ b_{21} = -f_s a_i \times \left[ a_i' \sinh \beta_i - \frac{a_0 f'_s b_s f_p}{f} \cosh \beta_i + a_i' \sinh \beta_i - \frac{a_0 f'_s b_s f_p}{f} \cosh \beta_i \right] - \frac{a_0 f'_s b_s f_p}{N} \times a_i' \]

\[ b_{22} = f_s a_i \times \left[ +a_i' \sinh \beta_i - \frac{a_0 f'_s b_s f_p}{f} \cosh \beta_i + a_i' \sinh \beta_i - \frac{a_0 f'_s b_s f_p}{f} \cosh \beta_i \right] + \frac{a_0 f'_s b_s f_p}{N} \times a_i' \frac{f'}{f} \]

\[ b_{23} = \frac{a_0 f'_s a_i}{2} + \frac{a_0 f'_s a_i''}{2} \]

\[ b_{24} = \frac{a_0 f'_s a_i}{2} + \frac{a_0 f'_s a_i''}{2} \]

\[ b_{25} = \frac{a_0 f'_s a_i}{2} + \frac{a_0 f'_s a_i''}{2} \]

\[ b_{26} = \frac{a_0 f'_s a_i}{2} - \frac{a_0 f'_s a_i''}{2} \]

\[ b_{27} = \frac{a_0 f'_s a_i}{2} \]

\[ b_{28} = -\frac{a_0 f'_s a_i}{2} \times \frac{a_0 f'_s a_i''}{2} \]

\[ b_{29} = \frac{a_0 f'_s a_i}{2} - \frac{a_0 f'_s a_i''}{2} \times \frac{a_0 f'_s a_i''}{2} \]

\[ b_{30} = -\frac{a_0 f'_s a_i}{2} \times \frac{a_0 f'_s a_i''}{2} \]

\[ b_{31} = -\frac{a_0 f'_s a_i}{2} \times \frac{a_0 f'_s a_i''}{2} \]

\[ b_{32} = \frac{a_0 f'_s a_i}{2} \]

\[ b_{33} = -\frac{a_0 f'_s a_i}{2} \times \frac{a_0 f'_s a_i''}{2} \times \frac{a_0 f'_s a_i''}{2} \]

\[ 131 \]
\[
\begin{align*}
    b_{34} &= \frac{-a_4 \beta_2 f'}{f} \times \frac{a_{10} \beta_3 f'}{f} - \frac{a_t \beta_2 f'}{f} \times \frac{a_{10} \beta_3 f'}{f} \\
    b_{36} &= \frac{S_b f}{N} \\
    b_{38} &= \frac{a_t f S_b}{\beta_1 \cosh \beta_1} \\
    b_{40} &= b_{35} \times (-\beta_2 a_{10} \cosh \beta_2 + 3a_6 + \beta_1 a_8 \cosh \beta_1) \\
    b_{41} &= b_{36} \\
    b_{43} &= -2b_{37} a_5 - 3a_6 b_{36} \\
    b_{45} &= b_{37} \beta_1 a_4 \sinh \beta_1 \\
    b_{47} &= -\beta_1 b_5 b_{35} \\
    b_{49} &= b_{35} \beta_1 a_2 \sinh \beta_1 + \frac{2a_t}{\sinh \beta_2} \\
    b_{50} &= \begin{bmatrix} -b_1 \sinh \beta_1 a_4 \sinh \beta_1 - \frac{2b_{13} a_3}{2 \sinh \beta_2} + \frac{b_{10} \beta_2 a_4}{2} \\
    b_{55} &= -3a_6 b_{39} \\
    b_{57} &= -b_1 \sinh \beta_1 a_4 \sinh \beta_1 - \frac{2b_{13} a_3}{2 \sinh \beta_2} + \frac{b_{10} \beta_2 a_4}{2} \\
    b_{58} &= \frac{b_{13} \beta_2 a_{10}}{2} - \frac{\beta_1 a_4 b_{38}}{2} + b_{55} \left( \frac{2a_t - \beta_2 a_4 \sinh \beta_1}{2 \sinh \beta_2} \right) \\
    b_{59} &= \frac{b_{13} \beta_2 a_{10}}{2} - \frac{\beta_1 a_4 b_{38}}{2} + b_{55} \left( \frac{2a_t - \beta_2 a_4 \sinh \beta_1}{2 \sinh \beta_2} \right) \\
    b_{60} &= -b_5 \beta_1 a_7 \\
    b_{61} &= -b_5 \beta_1 a_7 \\
\end{align*}
\]
\[ b_{42} = \frac{b_1 - b_{40}}{\beta_1^2} - \frac{2(b_5 - b_{44})}{\beta_1^4} - \frac{2b_3}{\beta_1^6} \]

\[ b_{43} = \frac{b_2 - b_{41}}{\beta_1^2} + \frac{6}{\beta_1^4} (b_4 - b_{43}) \]

\[ b_{44} = \frac{b_1 - b_{44}}{\beta_1^2} - \frac{12b_3}{\beta_1^4} \]

\[ b_{45} = \frac{b_1 - b_{41}}{\beta_1^2} - \frac{20b_3}{\beta_1^4} \]

\[ b_{46} = \frac{b_1}{-\beta_1^2} \]

\[ b_{47} = \frac{b_2}{-\beta_1^2} \]

\[ b_{48} = \frac{b_2 - b_{44}}{\beta_1^2} - \frac{2(b_3 - b_{49})}{\beta_1^4} \]

\[ b_{49} = - \frac{2b_{11} - b_{44}}{(\beta_1^2 - \beta_1^3)^2} = \frac{12b_{12}^2}{(\beta_1^2 - \beta_1^3)^3} = \frac{6b_{13}}{(\beta_1^2 - \beta_1^3)^4} \]

\[ b_{50} = - \frac{3b_{12}}{(\beta_1^2 - \beta_1^3)^4} + \frac{b_{43}}{\beta_1^3 - \beta_1^2} \]

\[ b_{51} = \frac{b_{12}}{\beta_1^2 - \beta_1^2} \]

\[ b_{52} = \frac{b_{11}}{\beta_1^2 - \beta_1^2} - \frac{3b_{13}}{(\beta_1^2 - \beta_1^2)^2} \]

\[ h_{43} = \frac{h_{12}}{\beta_1^2 - \beta_1^2} \]

\[ h_{44} = \frac{h_{43}}{\beta_1^2 - \beta_1^2} \]

\[ h_{45} = \frac{h_{44}}{\beta_1^2 - \beta_1^2} \]

\[ h_{46} = \frac{h_{45}}{\beta_1^2 - \beta_1^2} \]

\[ h_{47} = \frac{h_{46}}{\beta_1^2 - \beta_1^2} \]

\[ h_{48} = \frac{h_{47}}{\beta_1^2 - \beta_1^2} \]

\[ h_{49} = \frac{h_{48}}{\beta_1^2 - \beta_1^2} \]

\[ h_{50} = \frac{h_{49}}{\beta_1^2 - \beta_1^2} \]

\[ h_{51} = \frac{h_{48}}{\beta_1^2 - \beta_1^2} \]

\[ h_{52} = \frac{h_{47}}{\beta_1^2 - \beta_1^2} \]

\[ h_{53} = \frac{h_{46}}{\beta_1^2 - \beta_1^2} \]

\[ h_{54} = \frac{h_{45}}{\beta_1^2 - \beta_1^2} \]

\[ b_{55} = \frac{b_{52} - b_{53}}{2\beta_1^2} - \frac{b_{22} - b_{33}}{2\beta_1^2} \]

\[ b_{56} = \frac{b_{55}}{2\beta_1^2} \]

\[ b_{57} = \frac{b_{54} - b_{53}}{4\beta_1^2} \]

\[ b_{58} = \frac{b_{57}}{2\beta_1^2} \]

\[ b_{59} = \frac{b_{56} - b_{52}}{4\beta_1^2} \]

\[ b_{60} = \frac{b_{59}}{2\beta_1^2} + \frac{b_{55} - b_{44}}{2\beta_1^2} - \frac{b_{32} - b_{33}}{2\beta_1^2} + \frac{b_{32} - b_{33}}{4\beta_1^2} \]

\[ b_{61} = \frac{b_{60} - b_{33}}{2\beta_1^2} - \frac{b_{32} - b_{33}}{2\beta_1^2} \]

\[ b_{62} = \frac{b_{61} - b_{33}}{2\beta_1^2} \]
\[ b_{31} = \frac{b_{32}}{\beta_3^2 - \beta_1^2} \]
\[ b_{35} = \frac{b_{33}}{\beta_3^2 - \beta_1^2} \]
\[ b_{01} = \frac{b_{22}}{3\beta_1^2} + \frac{2(b_{20} - b_{31})}{4\beta_1^2} \]
\[ b_{32} = \frac{b_{22} - b_{30}}{4\beta_1^2} + \frac{b_{28} - (b_{34} - b_{20})}{3\beta_1^2} - \frac{4\beta_1^2}{4 \beta_1^2 - \beta_4^2} \]
\[ b_{34} = \frac{b_{34} - b_{30}}{4\beta_1^2} \]
\[ b_{100} = G f^i (a_{278} - Nb_{66}) \]
\[ b_{102} = G f^i (3a_{66} - 3Nb_{66}) \]
\[ b_{101} = G f^i (a_{279} + 2Nb_{66}) \]
\[ b_{103} = G f^i (4a_{67} \ldots) \]

\[ 4Nb_{66} G f^i \]
\[ b_{110} = G f^i (a_{566} + Nb_{66}) \]
\[ b_{112} = G f^i (a_{256} + a_{102}) \]
\[ b_{118} = G f^i a_{118} \]
\[ b_{111} = G f^i (a_{232} + a_{106}) \]
\[ b_{112} = G f^i (a_{308}) \]
\[ b_{114} = G f^i a_{114} \]
\[ b_{116} = G f^i a_{116} \]
\[ b_{118} = G f^i a_{118} \]
\[ b_{119} = G f^i a_{119} \]
\[ b_{120} = G f^i (a_{261} + a_{288}) \]
\[ b_{120} = G f^i (a_{264} + a_{189}) \]
\[ b_{122} = G f^i (a_{76} + a_{290}) \]
\[ b_{122} = G f^i a_{76} + a_{290} \]
\[ b_{124} = G f^i a_{291} \]
\[ b_{126} = G f^i a_{294} \]
\[ b_{126} = G f^i a_{294} \]
\[ b_{128} = G f^i (a_{287} + a_{290}) \]
\[ b_{128} = G f^i a_{287} + a_{290} \]
\[ b_{130} = G f^i a_{298} \]
\[ b_{132} = G f^i a_{300} \]
\[ b_{134} = a_{246} + b_{100} \]
\[ b_{136} = a_{264} + b_{102} \]
\[ b_{138} = a_{266} + b_{106} \]
\[ b_{140} = a_{108} + b_{254} \]

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\[ b_{142} = a_{266} + b_{110} \]
\[ b_{144} = a_{256} + b_{112} \]
\[ b_{146} = a_{250} + b_{114} \]
\[ b_{148} = a_{252} + b_{116} \]
\[ b_{150} = a_{258} + b_{118} \]
\[ b_{152} = a_{262} + b_{120} \]
\[ b_{154} = a_{264} + b_{122} \]
\[ b_{156} = a_{270} + b_{124} \]
\[ b_{158} = a_{266} + b_{126} \]
\[ b_{160} = a_{268} + b_{128} \]
\[ b_{162} = a_{274} + b_{130} \]
\[ b_{164} = a_{276} + b_{132} \]
\[ b_{166} = \frac{b_{134}}{2M_1^2} \]
\[ b_{168} = \frac{b_{136}}{12M_1^2} \]
\[ b_{170} = \frac{b_{138}}{30M_1^2} \]
\[ b_{172} = \frac{b_{138}}{\beta_i^2(\beta_i^2 - M_1^2)} \]
\[ b_{174} = \frac{b_{136}}{\beta_i^2(\beta_i^2 - M_1^2)} \]
\[ b_{176} = \frac{b_{130}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{178} = \frac{b_{132}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{180} = \frac{b_{134}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{182} = \frac{b_{136}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{184} = \frac{2b_{136}}{2\beta_i^2} \]
\[ b_{143} = a_{269} + b_{111} \]
\[ b_{145} = a_{227} + b_{133} \]
\[ b_{147} = a_{251} + b_{115} \]
\[ b_{149} = a_{233} + b_{117} \]
\[ b_{151} = a_{239} + b_{119} \]
\[ b_{153} = a_{263} + b_{121} \]
\[ b_{155} = a_{265} + b_{123} \]
\[ b_{157} = a_{271} + b_{125} \]
\[ b_{159} = a_{267} + b_{127} \]
\[ b_{161} = a_{269} + b_{129} \]
\[ b_{163} = a_{275} + b_{131} \]
\[ b_{165} = a_{2} + b_{133} \]
\[ b_{167} = \frac{b_{135}}{6M_1^2} \]
\[ b_{169} = \frac{b_{117}}{20M_1^2} \]
\[ b_{171} = \frac{b_{135}}{42M_1^2} \]
\[ b_{173} = \frac{b_{138}}{\beta_i^2(\beta_i^2 - M_1^2)} \]
\[ b_{175} = \frac{b_{136}}{\beta_i^2(\beta_i^2 - M_1^2)} \]
\[ b_{177} = \frac{a_{260}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{179} = \frac{b_{138}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{181} = \frac{b_{136}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{183} = \frac{b_{132}}{4\beta_i^2(4\beta_i^2 - M_1^2)} \]
\[ b_{185} = \frac{3b_{134}}{2\beta_i^2} \]
\[ b_{180} = \frac{b_{180}}{6\beta_1^3} \]
\[ b_{188} = \frac{-5(b_{188} + b_{190}) + 2b_{194}}{4\beta_1^3} \]
\[ b_{190} = \frac{2\beta_1 b_{194} - 5b_{194}}{4\beta_1^4} \]
\[ b_{192} = \frac{(4b_{194} - 5\beta_1 b_{194})}{4\beta_1^2} \]
\[ b_{194} = \frac{b_{194}}{6\beta_1^2} - \frac{5b_{194}}{4\beta_1^3} \]
\[ b_{196} = \frac{b_{196}}{2\beta_1^3} - \frac{3b_{196} - 5b_{194}}{2\beta_1^3} \]
\[ b_{198} = \frac{b_{198}}{8\beta_1^3} - \frac{b_{196}}{2\beta_1^3} \]
\[ b_{200} = \frac{-\beta_{200}}{4\beta_1^3} \]
\[ b_{202} = \frac{-5b_{202}}{4\beta_1^3} \]
\[ b_{204} = \frac{b_{204}}{2\beta_1^3} \]
\[ b_{206} = \frac{b_{206}}{4\beta_1^3} \]
\[ b_{208} = \frac{-\beta_{208}}{4\beta_1^3} \]
\[ b_{310} = \frac{-5\beta_{310}}{32\beta_1^3} \]
\[ b_{312} = \frac{a_{312}}{8\beta_1^3} \]
\[ b_{314} = \frac{a_{314}}{16\beta_1^3} \]
\[ b_{216} = \frac{\phi_1(1) - \phi_1(-1)}{2} \]
\[ e_2 = \frac{(b_{218} - b_{218})}{M_1 Ch M_1 - S M_1} \]
\[ e_3 = \frac{b_{215} - b_{215} - M_1 e_2 Ch M_1}{M_1 Ch M_1 - S M_1} \]
Fig. 1 Variation of $u$ with $G$

$M=0.2$, $D^1=2 \times 10^2$, $\alpha=2$, $S_0=1.30$, $S_0=0.5$, $N=1$, $\beta=-0.5$, $K=0.5$, $X=0.79$, $N1=4$

$G$ $2 \times 10^2$ $3 \times 10^2$ $4 \times 10^2$ $-2 \times 10^2$ $-3 \times 10^2$ $-4 \times 10^2$

Fig. 2 Variation of $u$ with $M$ and $D^1$

$G=2 \times 10^2$, $\alpha=2$, $S_0=1.30$, $S_0=0.5$, $N=1$, $\beta=-0.5$, $K=0.5$, $X=0.79$, $N1=4$

$M$ $0.2$ $0.3$ $0.4$ $0.2$ $0.2$

$D^1$ $2 \times 10^2$ $2 \times 10^2$ $2 \times 10^2$ $3 \times 10^2$ $4 \times 10^2$
Fig. 3 Variation of $u$ with $\alpha$

$M=0.2, D=2\times10^2, G=2\times10^2, S_c=1.30, S_0=0.5, N=1$

$\beta=0.5, K=0.5, X=0.79, N=4$

$\alpha$  2  4  6  -2  -4  -6

Fig. 4 Variation of $u$ with $N$

$M=0.2, D=2\times10^2, G=2\times10^2, S_c=1.30, S_0=0.5, \alpha=2$

$\beta=0.5, K=0.5, X=0.79, N=4$

$N$  1.0  2.0  -0.5  -0.8
Fig. 7 Variation of $u$ with $K$ and $X$

$M=0.2, D^1 = 2 \times 10^{-2}, G=2 \times 10^2, \alpha=2, S_c=1.30, S_0=0.5,$

$N=1, N1=4, B=0.5$

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Fig. 8  Variation of $v$ with $G$

$M=0.2, D^1=2\times 10^2, \alpha=2, S_c=1.30, S_o=0.5, N=1$

$N_1=4, \beta=0.5, K=0.5, X=0.79$

$G$  $2\times 10^2$  $3\times 10^2$  $4\times 10^2$  $2\times 10^2$  $3\times 10^2$  $4\times 10^2$

Fig. 9  Variation of $v$ with $M$ and $D^1$

$G=2\times 10^2, \alpha=2, S_c=1.30, S_o=0.5, N=4, \beta=0.5$

$N=1, K=0.5, X=0.79$

$M$  $0.2$  $0.3$  $0.4$  $0.2$  $0.2$

$D^1$  $2\times 10^2$  $2\times 10^2$  $3\times 10^2$  $3\times 10^2$  $4\times 10^2$
Fig. 10  Variation of $v$ with $\alpha$

$M=0.2$, $D^1=2\times10^{-2}$, $G=2\times10^2$, $S_c=1.30$, $S_o=0.5$, $N=4$.

$N=1$, $\beta=-0.5$, $K=0.5$, $X=0.79$

$\alpha$ | i | ii | iii | iv | v | vi
-------|---|---|----|---|---|---
     2 |   |   |    |   |   |   
     4 |   |   |    |   |   |   
     6 |   |   |    |   |   |   
    -2 |   |   |    |   |   |   
    -4 |   |   |    |   |   |   
    -6 |   |   |    |   |   |   

Fig. 11  Variation of $v$ with $N$

$M=0.2$, $D^1=2\times10^{-2}$, $G=2\times10^2$, $S_c=1.30$, $S_o=0.5$, $N=4$.

$\alpha=2$, $\beta=-0.5$, $K=0.5$, $X=0.79$

$N$ | i | ii | iii | iv
----|---|---|----|---
    1 |   |   |    |   
    2 |   |   |    |   
    -0.5 |   |   |    |   
    -0.8 |   |   |    |   

$\alpha$ | i | ii | iii | iv
-------|---|---|----|---
     2 |   |   |    |   
     4 |   |   |    |   
     6 |   |   |    |   
    -2 |   |   |    |   
    -4 |   |   |    |   
    -6 |   |   |    |   

Fig. 12  Variation of $v$ with $S_C$ and $S_0$

$M=0.2$, $D=2 \times 10^2$, $G=2 \times 10^2$, $\alpha=2$, $N_1=4$, $\beta=-0.5$, $N=1$, $K=0.5, X=0.79$

<p>| | | | | | |</p>
<table>
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<tbody>
<tr>
<td>$S_C$</td>
<td>2.01</td>
<td>0.6</td>
<td>0.4</td>
<td>1.30</td>
<td>1.30</td>
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<tr>
<td>$S_0$</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
<td>-0.5</td>
</tr>
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</table>

Fig. 13  Variation of $v$ with $N_1$ and $\beta$

$M=0.2$, $D=2 \times 10^2$, $G=2 \times 10^2$, $\alpha=2$, $S_C=1.30, S_0=0.5$, $N=1$, $K=0.5, X=0.79$

<p>| | | | | | | | | | | |</p>
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<td>5</td>
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</tr>
<tr>
<td>$\beta$</td>
<td>-0.3</td>
<td>-0.5</td>
<td>-0.7</td>
<td>-0.9</td>
<td>-0.5</td>
<td>-0.5</td>
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<td></td>
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</tbody>
</table>
Fig. 14 Variation of \( v \) with \( K \) and \( X \)

\( M=0.2, \, D^1=2\times10^2, \, G=2\times10^2, \, \alpha=2, \, S_C=1.30, S_\nu=0.5, \, N=1, \, N_1=4, \, \beta=0.5 \)

\begin{array}{cccccc}
K & 0.5 & 1.0 & 2.0 & 0.5 & 0.5 \\
X & \pi/4 & \pi/4 & \pi/4 & \pi/2 & \pi & 2\pi
\end{array}
Fig. 15  Variation of $\theta$ with $G$

$M=0.2$, $D^{-1}=2 \times 10^2$, $\alpha=2$, $S_C=1.3$, $S_D=0.5$, $N=4$, $N=1$, $\beta=-0.5$, $K=0.5$, $X=0.79$

$G$  
$2 \times 10^2$  
$3 \times 10^2$  
$4 \times 10^2$  
$-2 \times 10^2$  
$-3 \times 10^2$  
$-4 \times 10^2$

Fig. 16  Variation of $\theta$ with $M$ and $D^{-1}$

$G=2 \times 10^2$, $\alpha=2$, $S_C=1.3$, $S_D=0.5$, $N=4$, $\beta=-0.5$, $N=1$, $K=0.5$, $X=0.79$

$M$  
$0.2$  
$0.3$  
$0.4$  
$0.2$  
$0.2$

$D^{-1}$  
$2 \times 10^2$  
$2 \times 10^2$  
$2 \times 10^2$  
$3 \times 10^2$  
$4 \times 10^2$
Fig. 17  Variation of $\theta$ with $\alpha$

$M=0.2, D^2 = 2 \times 10^{-2}, G = 2 \times 10^{-2}, S_c = 1.30, S_0 = 0.5, N_f = 4$

$N=1, \beta = 0.5, K = 0.5, X = 0.79$

$\alpha$  2  4  6  -2  -4  -6

Fig. 18  Variation of $\theta$ with $N$

$M=0.2, D^2 = 2 \times 10^{-2}, G = 2 \times 10^{-2}, S_c = 1.30, S_0 = 0.5, N_f = 4$

$\alpha = 2, \beta = 0.5, K = 0.5, X = 0.79$

$N$  1  2  -0.5  -0.8
Fig. 19 Variation of $\theta$ with $S_c$ and $S_0$

$M=0.2$, $D^1=2\times10^2$, $G=2\times10^2$, $a=2$, $N_1=4$, $\beta=-0.5$

$N=1$, $K=0.5$, $X=0.79$

<table>
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<tr>
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<th>vi</th>
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<tbody>
<tr>
<td>2.01</td>
<td>0.6</td>
<td>0.4</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
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</table>

Fig. 20 Variation of $\theta$ with $N_1$ and $\beta$

$M=0.2$, $D^1=2\times10^2$, $G=2\times10^2$, $a=2$, $S_c=1.3$, $S_0=0.5$

$N=1$, $K=0.5$, $X=0.79$

<table>
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<th>iii</th>
<th>iv</th>
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<td>4</td>
<td>4</td>
<td>5</td>
<td>10</td>
</tr>
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</table>

$\beta=-0.3$, -0.5, -0.7, -0.9, -0.5, -0.5$
Fig. 21 Variation of $\theta$ with $K$ and $X$

$M=0.2$, $D^{-1}=2 \times 10^2$, $G=2 \times 10^3$, $\alpha=2$, $S_c=1.30$, $S_o=0.5$

$N_1=1$, $N_1=4$, $\beta=0.5$

<table>
<thead>
<tr>
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<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
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<tbody>
<tr>
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<td>2.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$X$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/2$</td>
<td>$\pi$</td>
<td>$2\pi$</td>
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</table>
Fig. 22 Variation of c with G
M = 0.2, D = 2 × 10^2, α = 2, S_0 = 1.30, S_0 = 0.5, N_1 = 4
N = 1, β = 0.5, K = 0.5, Χ = 0.79, N = 1.0

G = 2 × 10^2, 3 × 10^2, 4 × 10^2, 5 × 10^2, 6 × 10^2

Fig. 23 Variation of c with M and D
G = 2 × 10^5, α = 2, S_0 = 1.30, S_0 = 0.5, N_1 = 4, β = 0.5
N = 1, K = 0.5, Χ = 0.79, N = 1.0

M = 0.2, 0.3, 0.4, 0.2, 0.2
D = 2 × 10^2, 2 × 10^2, 3 × 10^2, 4 × 10^2
Fig. 24 Variation of c with α
M=0.2, D:\(=2 \times 10^2\), G=2 \times 10^3, S_C=1.30, S_\theta=0.5, N1=4, 
β=0.5, K=0.5, X=0.79, N=1.0

Fig. 25 Variation of c with N
M=0.2, D:\(=2 \times 10^2\), α=2, S_C=1.30, S_\theta=0.5, N1=4, 
β=0.5, K=0.5, X=0.79

\(a\) 2 4 6 -2 -4 -6

\(N\) 1.0 2.0 -0.5 -0.8
Fig. 26 Variation of $c$ with $S_C$ and $S_0$

$M=0.2$, $D^1=2\times10^2$, $G=2\times10^2$, $a=2$, $N_1=4$,
$\beta=-0.5$, $K=0.5$, $X=0.79$, $N=1.0$

<table>
<thead>
<tr>
<th>$S_C$</th>
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<td>2.01</td>
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<tr>
<td>0.6</td>
<td>0.5</td>
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<td>0.4</td>
<td>1.0</td>
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</table>

Fig. 27 Variation of $c$ with $N_1$ and $\beta$

$M=0.2$, $D^1=2\times10^2$, $G=2\times10^2$, $a=2$, $S_C=1.30$, $S_0=0.5$,
$K=0.5$, $X=0.79$, $N=1.0$

<table>
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<th>-0.5</th>
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</table>
Fig. 28 Variation of $c$ with $K$ and $X$

$M=0.2$, $D^2=2\times10^2$, $G=2\times10^2$, $\alpha=2$, $S_C=1.30$, $S_0=0.5$
$N_1=4$, $\beta=-0.5$, $N=1.0$

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<td>$K$</td>
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<td>2.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$X$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/2$</td>
<td>$\pi$</td>
<td>$2\pi$</td>
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</tbody>
</table>
### Table-1
Nusslet Number (Nu) at $\eta = 1$.
$N=1$, $S_c=0.5$, $Sc=1.3$, $M=2$, $N_1=0.5$, $\beta=0.5$, $K=0.3$, $X=\pi/4$

<table>
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<tr>
<th>$G$</th>
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<th>$vii$</th>
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<tr>
<td>$1 \times 10^2$</td>
<td>-2.82539</td>
<td>-2.12216</td>
<td>-1.40187</td>
<td>-3.31245</td>
<td>-3.24946</td>
<td>-3.03266</td>
<td>-3.08194</td>
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<tr>
<td>$D^1$</td>
<td>$1 \times 10^2$</td>
<td>$2 \times 10^2$</td>
<td>$3 \times 10^2$</td>
<td>$1 \times 10^2$</td>
<td>$1 \times 10^2$</td>
<td>$1 \times 10^2$</td>
<td>$1 \times 10^2$</td>
</tr>
<tr>
<td>$a$</td>
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<td>2</td>
<td>-2</td>
<td>-4</td>
<td>4</td>
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</tbody>
</table>

### Table-2
Nusslet Number (Nu) at $\eta = 1$.
$D^1=1 \times 10^2$, $x=2$, $S_c=0.5$, $Sc=1.3$, $N_1=0.5$, $\beta=0.5$, $X=\pi/4$, $K=0.30$

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<td>-2.65297</td>
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<tr>
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<td>1</td>
<td>-0.80</td>
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### Table-3
Nusslet Number (Nu) at $\eta = 1$.
$D^1=1 \times 10^2$, $x=2$, $M=2$, $N=1$, $N_1=0.5$, $\beta=0.5$, $X=\pi/4$, $K=0.30$

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<td>2.01</td>
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<td>1.30</td>
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<tr>
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<td>0.50</td>
<td>-1.0</td>
<td>-0.50</td>
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### Table 4
**Nusslet Number (Nu) at η = 1.**

\(D^1 = 1 \times 10^2, \alpha = 2, S_b = 0.5, S_c = 1.3, N = 1, X = \pi/4, K = 0.30, M = 2\)

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<td>-2,88678</td>
<td>-3,26486</td>
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<td>-1,29722</td>
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<tr>
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<td>-2,41516</td>
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\(N_1\)  0.30  0.50  0.70  0.50  0.50  0.50

\(\beta\)  0.50  0.50  0.50  0.30  0.70  1.50

### Table 5
**Nusslet Number (Nu) at η = 1.**

\(D^1 = 1 \times 10^2, \alpha = 2, S_b = 0.5, S_c = 1.3, N_1 = 0.50, \beta = 0.50, X = \pi/4, K = 0.30\)

<table>
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<tr>
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<th>(v)</th>
<th>(vi)</th>
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<td>-0,91709</td>
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<tr>
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<td>0,01740</td>
<td>0,80202</td>
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<td>2,78241</td>
<td>-0,15099</td>
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<tr>
<td>(1 \times 10^2)</td>
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<td>-2,82539</td>
<td>-0,99196</td>
<td>-0,01472</td>
<td>0,83999</td>
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<td>-0,15099</td>
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\(K\)  0.10  0.30  0.30  0.70  1.30  0.30  0.30  0.30

\(X\)  \(\pi/4\)  \(\pi/4\)  \(\pi/4\)  \(\pi/4\)  \(\pi/2\)  \(\pi\)  2 \(\pi\)

### Table 6
**Nusslet Number (Nu) at η = -1.**

\(N = 1, S_b = 0.5, S_c = 1.3, M = 2, N_1 = 0.50, \beta = 0.50, K = 0.30, X = \pi/4\)

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<tr>
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<th>(iv)</th>
<th>(v)</th>
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<td>3,64312</td>
<td>2,97996</td>
<td>2,90872</td>
<td>3,21758</td>
<td>3,16412</td>
</tr>
</tbody>
</table>

\(D^1\)  1 \(\times 10^2\)  2 \(\times 10^2\)  3 \(\times 10^2\)  1 \(\times 10^2\)  1 \(\times 10^2\)  1 \(\times 10^2\)  1 \(\times 10^2\)

\(\alpha\)  2  2  2  2  -4  4  6

\(X\)  \(\pi/4\)  \(\pi/4\)  \(\pi/4\)  \(\pi/4\)  \(\pi/2\)  \(\pi\)  2 \(\pi\)
### Table 7

Nusslet Number (Nu) at $\eta = 1$  
$D^2=1\times10^2, \alpha = 2, S_0=0.5, Sc=1.3, N=0.5, \beta=0.5, X=\pi/4, K=0.30$

<table>
<thead>
<tr>
<th>G</th>
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<th>iii</th>
<th>iv</th>
<th>v</th>
<th>vi</th>
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<tbody>
<tr>
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<td>3.42683</td>
<td>3.54105</td>
<td>3.65174</td>
<td>3.42683</td>
<td>3.42683</td>
<td>3.42683</td>
</tr>
<tr>
<td>$-3\times10^2$</td>
<td>3.43401</td>
<td>3.68647</td>
<td>3.66315</td>
<td>3.43401</td>
<td>3.43401</td>
<td>3.43401</td>
</tr>
<tr>
<td>$1\times10^2$</td>
<td>3.44860</td>
<td>3.55001</td>
<td>3.68647</td>
<td>3.44860</td>
<td>3.44860</td>
<td>3.44860</td>
</tr>
<tr>
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<td>3.44126</td>
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<tr>
<td>M</td>
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<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>N</td>
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<td>1</td>
<td>1</td>
<td>-0.80</td>
<td>-0.50</td>
<td>2</td>
</tr>
</tbody>
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### Table 8

Nusslet Number (Nu) at $\eta = 1$.  
$D^2=1\times10^2, \alpha = 2, M=2, N=1, N=0.5, \beta=0.5, X=\pi/4, K=0.30$

<table>
<thead>
<tr>
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<th>iii</th>
<th>iv</th>
<th>v</th>
<th>vi</th>
<th>vii</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-1\times10^2$</td>
<td>3.03259</td>
<td>3.23831</td>
<td>3.42683</td>
<td>3.51873</td>
<td>4.14997</td>
<td>4.96193</td>
<td>3.56506</td>
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<td>3.52440</td>
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<td>4.91021</td>
<td>3.56987</td>
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<tr>
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<td>3.26712</td>
<td>3.44860</td>
<td>3.53588</td>
<td>4.11522</td>
<td>4.81225</td>
<td>3.57959</td>
</tr>
<tr>
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<td>3.44126</td>
<td>3.53012</td>
<td>4.12667</td>
<td>4.88035</td>
<td>3.57471</td>
</tr>
<tr>
<td>Sc</td>
<td>0.24</td>
<td>0.60</td>
<td>1.30</td>
<td>2.01</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>$S_0$</td>
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<td>0.5</td>
<td>0.50</td>
<td>0.50</td>
<td>-1.0</td>
<td>-0.50</td>
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</table>

### Table 9

Nusslet Number (Nu) at $\eta = 1$.  
$D^2=1\times10^2, \alpha = 2, S_0=0.5, Sc=1.3, N=1, X=\pi/4, K=0.30, M=2$

<table>
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<th>iv</th>
<th>v</th>
<th>vi</th>
</tr>
</thead>
<tbody>
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<td>3.42683</td>
<td>3.32036</td>
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<td>2.74618</td>
<td>1.80256</td>
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<td>3.83747</td>
<td>3.43401</td>
<td>3.32711</td>
<td>4.22546</td>
<td>2.75087</td>
<td>1.80236</td>
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<td>3.843401</td>
<td>3.44860</td>
<td>3.34082</td>
<td>4.24058</td>
<td>2.76045</td>
<td>1.80194</td>
</tr>
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<td>$3\times10^2$</td>
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<td>3.44126</td>
<td>3.33393</td>
<td>4.23299</td>
<td>2.75563</td>
<td>1.80215</td>
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<tr>
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<td>0.70</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>B</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.30</td>
<td>0.70</td>
<td>1.50</td>
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</tbody>
</table>
Table-10
Sherwood Number (Sh) at \( \eta = -1 \).
\[ D' = 1 \times 10^2, \alpha = 2, S_e = 0.5, S_c = 1.3, N = 0.5, \beta = 0.5, X = \pi/4, K = 0.30 \]

<table>
<thead>
<tr>
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<th>( l )</th>
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<th>( iii )</th>
<th>( iv )</th>
<th>( v )</th>
<th>( vi )</th>
<th>( vii )</th>
<th>( viii )</th>
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</thead>
<tbody>
<tr>
<td>-1 \times 10^2</td>
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<td>3.42683</td>
<td>1.92804</td>
<td>1.88888</td>
<td>2.36411</td>
<td>4.97616</td>
<td>-2.30396</td>
<td>-5.68719</td>
</tr>
<tr>
<td>-3 \times 10^2</td>
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<td>1.92450</td>
<td>1.88154</td>
<td>2.37852</td>
<td>4.98325</td>
<td>0.57066</td>
<td>-5.68719</td>
</tr>
<tr>
<td>1 \times 10^2</td>
<td>12.47568</td>
<td>3.44860</td>
<td>1.91706</td>
<td>1.86549</td>
<td>2.41367</td>
<td>4.99749</td>
<td>-14.62598</td>
<td>-5.68719</td>
</tr>
<tr>
<td>3 \times 10^2</td>
<td>12.47300</td>
<td>3.44126</td>
<td>1.92084</td>
<td>1.87376</td>
<td>2.39489</td>
<td>4.99036</td>
<td>-35.98143</td>
<td>-5.68719</td>
</tr>
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<td>K</td>
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<td>0.70</td>
<td>1.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>X</td>
<td>( \pi/4 )</td>
<td>( \pi/4 )</td>
<td>( \pi/4 )</td>
<td>( \pi/4 )</td>
<td>( \pi/4 )</td>
<td>( \pi/2 )</td>
<td>( \pi )</td>
<td>2 ( \pi )</td>
</tr>
</tbody>
</table>

Table-11
Sherwood Number (Sh) at \( \eta = 1 \).
\[ N = 1, S_e = 0.5, S_c = 1.3, M = 2, N = 0.5, \beta = 0.5, K = 0.30, X = \pi/4 \]

<table>
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<tr>
<th>G</th>
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<th>( iv )</th>
<th>( v )</th>
<th>( vi )</th>
<th>( vii )</th>
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<tbody>
<tr>
<td>-1 \times 10^2</td>
<td>0.28341</td>
<td>0.26259</td>
<td>0.25375</td>
<td>-0.30203</td>
<td>-0.15022</td>
<td>0.11571</td>
<td>0.06868</td>
</tr>
<tr>
<td>-3 \times 10^2</td>
<td>0.26113</td>
<td>0.24770</td>
<td>0.24192</td>
<td>-0.27550</td>
<td>-0.14653</td>
<td>0.11344</td>
<td>0.06799</td>
</tr>
<tr>
<td>1 \times 10^2</td>
<td>0.22389</td>
<td>0.22122</td>
<td>0.22028</td>
<td>-0.23574</td>
<td>-0.13978</td>
<td>0.10900</td>
<td>0.06663</td>
</tr>
<tr>
<td>3 \times 10^2</td>
<td>0.24143</td>
<td>0.23395</td>
<td>0.23039</td>
<td>-0.25381</td>
<td>-0.14305</td>
<td>0.11120</td>
<td>0.06731</td>
</tr>
<tr>
<td>( D' )</td>
<td>1 \times 10^2</td>
<td>2 \times 10^2</td>
<td>3 \times 10^3</td>
<td>1 \times 10^6</td>
<td>1 \times 10^6</td>
<td>1 \times 10^6</td>
<td>1 \times 10^6</td>
</tr>
<tr>
<td>( \alpha )</td>
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<td>2</td>
<td>-2</td>
<td>-4</td>
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Table-12
Sherwood Number (Sh) at \( \eta = 1 \).
\[ D' = 1 \times 10^2, \alpha = 2, S_e = 0.5, S_c = 1.3, N = 0.5, \beta = 0.5, X = \pi/4, K = 0.30 \]

<table>
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<tr>
<th>G</th>
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<th>( ii )</th>
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<th>( iv )</th>
<th>( v )</th>
<th>( vi )</th>
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</thead>
<tbody>
<tr>
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<td>0.27941</td>
<td>0.27405</td>
<td>0.20098</td>
<td>0.21241</td>
<td>0.34919</td>
</tr>
<tr>
<td>-3 \times 10^2</td>
<td>0.26113</td>
<td>0.25856</td>
<td>0.25512</td>
<td>0.21381</td>
<td>0.22122</td>
<td>0.29066</td>
</tr>
<tr>
<td>1 \times 10^2</td>
<td>0.22389</td>
<td>0.22333</td>
<td>0.22262</td>
<td>0.24720</td>
<td>0.24253</td>
<td>0.21461</td>
</tr>
<tr>
<td>3 \times 10^2</td>
<td>0.24143</td>
<td>0.23999</td>
<td>0.23806</td>
<td>0.22898</td>
<td>0.23118</td>
<td>0.24761</td>
</tr>
<tr>
<td>M</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-0.80</td>
<td>-0.50</td>
<td>2</td>
</tr>
</tbody>
</table>
### Table 13
Sherwood Number (Sh) at $\eta = 1$.
$D^4 = 1 \times 10^2, \alpha = 2, M = 2, N_1 = 0.5, \beta = 0.50, X = \pi/4, K = 0.30$

<table>
<thead>
<tr>
<th>G (Sh)</th>
<th>i</th>
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<th>iii</th>
<th>iv</th>
<th>v</th>
<th>vi</th>
<th>vii</th>
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</thead>
<tbody>
<tr>
<td>$-1 \times 10^7$</td>
<td>-6.64844</td>
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<td>0.28341</td>
<td>0.14331</td>
<td>0.21167</td>
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<td>0.25646</td>
</tr>
<tr>
<td>$-3 \times 10^7$</td>
<td>-4.12340</td>
<td>0.84641</td>
<td>0.26113</td>
<td>0.13891</td>
<td>0.22097</td>
<td>0.20864</td>
<td>0.24717</td>
</tr>
<tr>
<td>$1 \times 10^7$</td>
<td>0.40085</td>
<td>0.41419</td>
<td>0.22389</td>
<td>0.13041</td>
<td>0.24374</td>
<td>0.25220</td>
<td>0.22960</td>
</tr>
<tr>
<td>$3 \times 10^7$</td>
<td>0.59719</td>
<td>0.55963</td>
<td>0.24143</td>
<td>0.13461</td>
<td>0.23157</td>
<td>0.22793</td>
<td>0.23822</td>
</tr>
<tr>
<td>Sc</td>
<td>0.24</td>
<td>0.60</td>
<td>1.30</td>
<td>2.01</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>$S_0$</td>
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<td>0.50</td>
<td>-1.0</td>
<td>-0.50</td>
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</table>

### Table 14
Sherwood Number (Sh) at $\eta = 1$.
$D^4 = 1 \times 10^2, \alpha = 2, S_0 = 0.5, Sc = 1.3, N_1 = 1, X = \pi/4, K = 0.30, M = 2$

<table>
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<tr>
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<th>iv</th>
<th>v</th>
<th>vi</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-1 \times 10^7$</td>
<td>0.32898</td>
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<td>0.00843</td>
</tr>
<tr>
<td>$-3 \times 10^7$</td>
<td>0.26050</td>
<td>0.26113</td>
<td>0.26436</td>
<td>0.28669</td>
<td>0.23153</td>
<td>0.00851</td>
</tr>
<tr>
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<td>0.19323</td>
<td>0.22389</td>
<td>0.23997</td>
<td>0.21619</td>
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<td>0.00867</td>
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<tr>
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<td>0.24143</td>
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<tr>
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<td>0.50</td>
</tr>
<tr>
<td>B</td>
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<td>0.50</td>
<td>0.30</td>
<td>0.70</td>
<td>1.50</td>
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</table>

### Table 15
Sherwood Number (Sh) at $\eta = 1$.
$D^4 = 1 \times 10^2, \alpha = 2, S_0 = 0.5, Sc = 1.3, N_1 = 0.50, \beta = 0.50, X = \pi/4, K = 0.30$

<table>
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<th>v</th>
<th>vi</th>
<th>vii</th>
<th>viii</th>
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</thead>
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<tr>
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<td>0.49391</td>
<td>-0.01357</td>
<td>-0.01316</td>
</tr>
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<td>0.17957</td>
<td>-0.01279</td>
<td>-0.01316</td>
</tr>
<tr>
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<td>0.23598</td>
<td>0.24143</td>
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<td>0.23370</td>
<td>-0.01200</td>
<td>-0.01316</td>
</tr>
<tr>
<td>K</td>
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<td>0.30</td>
<td>0.50</td>
<td>0.70</td>
<td>1.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>X</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/2$</td>
<td>$\pi$</td>
<td>$2 \pi$</td>
<td></td>
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</table>
### Table 16
**Sherwood Number \((Sh)\) at \(\eta = -1\)**

\(N=1, \, S_p=0.5, \, Sc=1.3, \, M=2, \, N_1=0.50, \, \beta=0.50, \, K=0.30, \, X=\pi/4\)

<table>
<thead>
<tr>
<th>(G)</th>
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<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
<th>(vii)</th>
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<tbody>
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<td>(-0.21125)</td>
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<td>(-0.07522)</td>
<td>(-0.07522)</td>
<td>(-0.03303)</td>
</tr>
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<td>(-0.20308)</td>
<td>(-0.20148)</td>
<td>(0.28011)</td>
<td>(-0.07374)</td>
<td>(-0.07374)</td>
<td>(-0.03266)</td>
</tr>
<tr>
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<td>(-0.18155)</td>
<td>(-0.18361)</td>
<td>(0.23996)</td>
<td>(-0.07086)</td>
<td>(-0.07086)</td>
<td>(-0.03193)</td>
</tr>
<tr>
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<td>(-0.19190)</td>
<td>(-0.19229)</td>
<td>(0.25821)</td>
<td>(-0.07228)</td>
<td>(-0.07228)</td>
<td>(-0.03229)</td>
</tr>
<tr>
<td>(D^1)</td>
<td>(1\times10^3)</td>
<td>(2\times10^3)</td>
<td>(3\times10^3)</td>
<td>(1\times10^3)</td>
<td>(1\times10^3)</td>
<td>(1\times10^3)</td>
<td>(1\times10^3)</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>-2</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

### Table 17
**Sherwood Number \((Sh)\) at \(\eta = -1\)**

\(D^1=1\times10^3, \, \alpha = 2, \, S_p=0.5, \, Sc=1.3, \, N_1=0.50, \, \beta=0.50, \, X=\pi/4, \, K=0.30\)

<table>
<thead>
<tr>
<th>(G)</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-1\times10^3)</td>
<td>(-0.22436)</td>
<td>(-0.22260)</td>
<td>(-0.22025)</td>
<td>(-0.20762)</td>
<td>(-0.20994)</td>
<td>(-0.23771)</td>
</tr>
<tr>
<td>(-3\times10^3)</td>
<td>(-0.20683)</td>
<td>(-0.20611)</td>
<td>(-0.20515)</td>
<td>(-0.22114)</td>
<td>(-0.21889)</td>
<td>(-0.19791)</td>
</tr>
<tr>
<td>(1\times10^3)</td>
<td>(-0.17756)</td>
<td>(-0.17824)</td>
<td>(-0.17922)</td>
<td>(-0.25634)</td>
<td>(-0.24054)</td>
<td>(-0.14620)</td>
</tr>
<tr>
<td>(3\times10^3)</td>
<td>(-0.19135)</td>
<td>(-0.19142)</td>
<td>(-0.19154)</td>
<td>(-0.23713)</td>
<td>(-0.22901)</td>
<td>(-0.16863)</td>
</tr>
<tr>
<td>(M)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>(N)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-0.80</td>
<td>-0.50</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 18
**Sherwood Number \((Sh)\) at \(\eta = -1\)**

\(D^1=1\times10^3, \, \alpha = 2, \, M=2, \, N=1, \, N_1=0.50, \, \beta=0.50, \, X=\pi/4, \, K=0.30\)

<table>
<thead>
<tr>
<th>(G)</th>
<th>(i)</th>
<th>(ii)</th>
<th>(iii)</th>
<th>(iv)</th>
<th>(v)</th>
<th>(vi)</th>
<th>(vii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-1\times10^2)</td>
<td>(0.33300)</td>
<td>(-1.11371)</td>
<td>(-0.22436)</td>
<td>(-0.13077)</td>
<td>(-0.20928)</td>
<td>(-0.20531)</td>
<td>(-0.21866)</td>
</tr>
<tr>
<td>(-3\times10^2)</td>
<td>(2.12207)</td>
<td>(-0.56347)</td>
<td>(-0.20683)</td>
<td>(-0.12675)</td>
<td>(-0.21873)</td>
<td>(-0.22232)</td>
<td>(-0.21090)</td>
</tr>
<tr>
<td>(1\times10^2)</td>
<td>(-0.20722)</td>
<td>(-0.27659)</td>
<td>(-0.17756)</td>
<td>(-0.11898)</td>
<td>(-0.24188)</td>
<td>(-0.26950)</td>
<td>(-0.19621)</td>
</tr>
<tr>
<td>(3\times10^2)</td>
<td>(-0.46790)</td>
<td>(-0.37312)</td>
<td>(-0.19135)</td>
<td>(-0.12282)</td>
<td>(-0.22750)</td>
<td>(-0.24321)</td>
<td>(-0.20342)</td>
</tr>
<tr>
<td>(Sc)</td>
<td>0.24</td>
<td>0.60</td>
<td>1.30</td>
<td>2.01</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>(S_p)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.50</td>
<td>0.50</td>
<td>1.0</td>
<td>0.50</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table 19
Sherwood Number (Sh) at $\eta = -1$.

$D' = 1 \times 10^2$, $\alpha = 2$, $S_o = 0.5$, $Sc = 1.3$, $N = 1$, $X = \pi/4$, $K = 0.30$, $M = 2$

<table>
<thead>
<tr>
<th>G</th>
<th>i</th>
<th>ii</th>
<th>iii</th>
<th>iv</th>
<th>v</th>
<th>vi</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-1 \times 10^2$</td>
<td>-0.27251</td>
<td>-0.22436</td>
<td>-0.20643</td>
<td>-0.24160</td>
<td>-0.22436</td>
<td>-0.13936</td>
</tr>
<tr>
<td>$-3 \times 10^2$</td>
<td>-0.22303</td>
<td>-0.20683</td>
<td>-0.19657</td>
<td>-0.20569</td>
<td>-0.20683</td>
<td>-0.13735</td>
</tr>
<tr>
<td>$1 \times 10^2$</td>
<td>-0.15997</td>
<td>-0.17756</td>
<td>-0.17876</td>
<td>-0.15582</td>
<td>-0.17756</td>
<td>-0.13345</td>
</tr>
<tr>
<td>$3 \times 10^2$</td>
<td>-0.18716</td>
<td>-0.19135</td>
<td>-0.18737</td>
<td>-0.17793</td>
<td>-0.19135</td>
<td>-0.13539</td>
</tr>
<tr>
<td>N1</td>
<td>0.30</td>
<td>0.50</td>
<td>0.70</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>B</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.30</td>
<td>0.70</td>
<td>1.50</td>
</tr>
</tbody>
</table>

### Table 20
Sherwood Number (Sh) at $\eta = -1$.

$D' = 1 \times 10^2$, $\alpha = 2$, $S_o = 0.5$, $Sc = 1.3$, $N = 1$, $X = \pi/4$, $K = 0.30$

<table>
<thead>
<tr>
<th>G</th>
<th>i</th>
<th>ii</th>
<th>iii</th>
<th>iv</th>
<th>v</th>
<th>vi</th>
<th>vii</th>
<th>viii</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-1 \times 10^2$</td>
<td>-0.10441</td>
<td>-0.22436</td>
<td>-0.35473</td>
<td>-0.01940</td>
<td>-0.12824</td>
<td>-0.31651</td>
<td>0.00422</td>
<td>0.00397</td>
</tr>
<tr>
<td>$-3 \times 10^2$</td>
<td>-0.10444</td>
<td>-0.20683</td>
<td>-0.18187</td>
<td>0.02365</td>
<td>0.49558</td>
<td>-0.20806</td>
<td>0.00470</td>
<td>0.00397</td>
</tr>
<tr>
<td>$1 \times 10^2$</td>
<td>-0.10449</td>
<td>-0.17756</td>
<td>-0.08817</td>
<td>0.00324</td>
<td>0.07797</td>
<td>-0.11782</td>
<td>0.00374</td>
<td>0.00397</td>
</tr>
<tr>
<td>$3 \times 10^2$</td>
<td>-0.10446</td>
<td>-0.19135</td>
<td>-0.11998</td>
<td>0.00628</td>
<td>0.20999</td>
<td>-0.15204</td>
<td>0.00326</td>
<td>0.00397</td>
</tr>
<tr>
<td>K</td>
<td>0.10</td>
<td>0.30</td>
<td>0.50</td>
<td>0.70</td>
<td>1.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>X</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/4$</td>
<td>$\pi/2$</td>
<td>$\pi$</td>
<td>2$\pi$</td>
<td></td>
</tr>
</tbody>
</table>