EFFECT OF RADIATION AND DISSIPATION IN A CONVECTIVE HEAT TRANSFER FLOW OF A VISCOUS FLUID IN A TRIANGULAR DUCT WITH HEAT GENERATING SOURCES

Dr. Y. RajendraPrasad*

K. Satyanarayana*

Abstract:

In this paper we discuss the combined influence of radiation and dissipation on the convective heat and mass transfer flow of a viscous fluid through a porous medium in a triangular duct using Darcy model. Making use of the incompressibility the governing non-linear coupled equations for the momentum, energy are derived in terms of the non-dimensional stream function, temperature. The Galerkin finite element analysis with linear triangular elements is used to obtain the Global stiffness matrices for the values of stream function, temperature. These coupled matrices are solved using iterative procedure and expressions for the stream function, temperature are obtained as a linear combinations of the shape functions. The behavior of temperature, Nusselt number is discussed computationally for different values of the governing Parameters Ra, α, N, and Ec.

Keywords: Heat transfer, Radiation, dissipation

* S.S.B.N. Degree & P.G. College, Anantapur-515003, A.P. India

1. INTRODUCTION

The study of heat transfer and mixed convection flow in porous medium enclosures of various shapes has received much attention[4]. Interest in these natural convection flow and heat transfer in porous medium has been motivated by a broad range of applications, including Geothermal systems, Crude oil production, storage of Nuclear waste materials, ground water pollution, fibre and granular insulations. solidification of castings, etc. In a wide range of such problems, the physical system can be modeled as a two-dimensional rectangular enclosure with vertical walls held at different temperatures and the connecting horizontal walls considered adiabatic. Convective heat transfer in a Rectangular porous duct whose vertical walls are maintained at two different temperatures and horizontal walls insulated, is a problem which has received attention by many investigators [7, 9].

Han-Chieh Chiu *et. al.,* [3] have discussed mixed convection heat transfer in horizontal rectangular ducts with radiation effects. Chitti Babu *et. al.,* [2] has discussed convective flow in a porous rectangular duct with differentially heated side wall using Brinkman model.

Badruddin *et. al.,* [1] have investigated the radiation and viscous dissipation on convective heat transfer in porous cavity. Recently Padmavathi [7] have analyzed the connective heat transfer through a porous medium in a rectangular cavity with heat sources and dissipation under varied conditions. Reddaiah *et. al.,* [8] have analyzed the effect of viscous dissipation on convective heat and mass transfer flow of a viscous fluid in a duct of rectangular cross section by employing Galerkin finite element analysis. Recently Shanthi(9) has discussed the mixed convective heat and mass transfer flow of a viscous fluid through a porous medium in a rectangular duct with Soret effect.

2. FORMULATION OF THE PROBLEM

We consider the mixed convective heat and mass transfer flow of a viscous incompressible fluid in a saturated porous medium confined in the triangular duct (Fig. 1) whose base length is a and height b. The heat flux on the base and top walls is maintained constant. The

Cartesian coordinate system O (x,y) is chosen with origin on the central axis of the duct and its base parallel to x-axis.

We assume that

i) The convective fluid and the porous medium are everywhere in local thermodynamic equilibrium.

ii) There is no phase change of the fluid in the medium.

iii) The properties of the fluid and of the porous medium are homogeneous and isotrophic.

iv) The porous medium is assumed to be closely packed so that Darcy's momentum law is adequate in the porous medium.

v) The Boussinesq approximation is applicable.

Under these assumption the governing equations are given by

$$\frac{\partial u'}{\partial x'}+\frac{\partial v'}{\partial y'}=0 \qquad (2.1)$$

$$u'=-\frac{k}{\mu}\left(\frac{\partial p'}{\partial x'}\right) \qquad (2.2)$$

$$v'=-\frac{k}{\mu}\left(\frac{\partial p'}{\partial y'}+\rho' g\right)-\left(\frac{\sigma\mu_e^2 H_o^2 k}{\mu}\right)v' \qquad (2.3)$$

$$\rho_\sigma c_p\left(u'\frac{\partial T'}{\partial x'}+v'\frac{\partial T'}{\partial y'}\right)=K_1\left(\frac{\partial^2 T'}{\partial x'^2}+\frac{\partial^2 T'}{\partial y'^2}\right)+Q(T_0-T)+\left(\frac{\mu}{K}\right)(u^2+v^2)-\frac{\partial(q_r)}{\partial x} \qquad (2.4)$$

$$\rho'=\rho_0\{1-\beta(T'-T_0)\} \qquad (2.5)$$

$$T_0=\frac{T_h+T_c}{2},\ C_0=\frac{C_h+C_c}{2}$$

where u′ and v′ are Darcy velocities along θ(x, y) direction. T′, p′ and g′ are the temperature, pressure and acceleration due to gravity, T_c ,Cc and T_h ,C_h are the temperature on the cold and warm side walls respectively. ρ′, μ, ν, and β are the density, coefficients of viscosity, kinematic viscosity and thermal expansion of he fluid, k is the permeability of the porous medium, K_1 is the thermal conductivity, C_p is the specific heat at constant pressure , Q is the strength of the heat source, σ is the electrical conductivity , μ_e is the magnetic permeability of the medium ,Ho is the strength of the magnetic field and q_r is the radiative heat flux..

The boundary conditions are

$u' = v' = 0$ on the boundary of the duct

$T' = T_c$ on the side wall to the left

$T' = T_h$ on the side wall to the right (2.6)

$\frac{\partial T'}{\partial y} = 0$ on the thermally insulated base

Invoking Rosseland approximation for radiation

$$q_r = \frac{4\sigma^*}{3\beta_R}\frac{\partial T'^4}{\partial y}$$

Expanding T^4 in Taylor's series about T_e and neglecting higher order terms

$$T'^4 \cong 4T_e^3 T - 3T_e^4$$

We now introduce the following non-dimensional variables

$x' = ax$; $y' = by$; $h = b/a$

$u' = (\nu/a)u$; $v' = (\nu/a)v$; $p' = (\nu^2\rho/a^2)p$

$T' = T_0 + \theta(T_h - T_c)$ (2.7).

The governing equations in the non-dimensional form are

$$u = -\left(\frac{K}{a^2}\right)\frac{\partial p}{\partial x} \qquad (2.8)$$

$$v = -\frac{k}{a^2}\frac{\partial p}{\partial y} - \frac{kag}{v^2} + \frac{kag\beta(T_h - T_c)\theta}{v^2} \qquad (2.9)$$

$$P\left(u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y}\right) = \left(1 + \frac{4N}{3}\right)\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right) - \alpha\theta + E_C(u^2 + v^2) \qquad (2.10)$$

In view of the equation of continuity we introduce the stream function ψ as

$$u = \frac{\partial\psi}{\partial y} \; ; \quad v = -\frac{\partial\psi}{\partial x} \qquad (2.11)$$

Eliminating p from the equation (2.7) and (2.8) and making use of (2.9) the equations in terms of ψ and θ are

$$\nabla^2\psi = -Ra\left(\frac{\partial\theta}{\partial x}\right) \qquad (2.12)$$

$$P\left(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) = \left(1 + \frac{4}{3N_1}\right)\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right) - \alpha\theta + E_C\left(\left(\frac{\partial\psi}{\partial y}\right)^2 + \left(\frac{\partial\psi}{\partial x}\right)^2\right) \qquad (2.13)$$

where

$G = \frac{g\beta(T_h - T_c)a^3}{v^2}$ (Grashof number)

$D^{-1} = \frac{a^2}{k}$ (Darcy parameter)

$P = \mu c_p / K_1$ (Prandtl number)

$\alpha = Qa^2/K_1$ (Heat source parameter)

$$Ra = \frac{\beta g (T_g - T_c) a}{\nu^2}$$ (Rayleigh Number)

$$N_1 = \frac{3\beta_R K_1}{4\sigma^{\bullet} : T_e^3}$$ (Radiation parameter)

$$Ec = \left(\frac{a^4}{\mu K K_1 \Delta T} \right)$$ (Eckert number)

The boundary conditions are

$$\frac{\partial \psi}{\partial x} = 0, \frac{\partial \psi}{\partial y} = 0 \ on \quad x = 0 \ \& 1 \qquad (2.14)$$

$\theta = 1 \quad on \quad x = 0$ the sidewall to the left

$\theta = 0 \quad on \quad x = 1$ the sidewall to the right (2.15)

3.FINITE ELEMENT ANALYSIS ANDSOLUTION OF THE PROBLEM

The region is divided into a finite number of three node triangular elements, in each of which the element equation is derived using Galerkin weighted residual method. In each element f_i the approximate solution for an unknown f in the variational formulation is expressed as a linear combination of shape function. (N_k^i) $k = 1,2,3$, which are linear polynomials in x and y. This approximate solution of the unknown f coincides with actual values at each node of the element. The variational formulation results in a 3 x 3 matrix equation (stiffness matrix) for the unknown local nodal values of the given element. These stiffness matrices are assembled in terms of global nodal values using inter element continuity and boundary conditions resulting in global matrix equation.

In each case there are r distinct global nodes in the finite element domain and f_p (p = 1,2,……r) is the global nodal values of any unknown f defined over the domain then

$$f = \sum_{i=1}^{8} \sum_{p=1}^{r} f_p \ \Phi^i_p ,$$

where the first summation denotes summation over s elements and the second one represents summation over the independent global nodes and

$\Phi^i_p = N^i_N$, if p is one of the local nodes say k of the element e_i

= 0, otherwise.

f_p' s are determined from the global matrix equation. Based on these lines we now make a finite element analysis of the given problem governed by (2.12)- (2.14) subjected to the conditions (2.14) – (2.15).

Let ψ^i and θ^i be the approximate values of ψ and θ in an element θ_i.

$$\psi^i = N_1^i\ \psi_1^i + N_2^i\ \psi_2^i + N_3^i\ \psi_3^i \tag{3.1}$$

$$\theta^i = N_1^i\ \theta_1^i + N_2^i\ \theta_2^i + N_3^i\ \theta_3^i \tag{3.2}$$

Substituting the approximate value ψ^i, θ^i for ψ and θ respectively in (2.11), the error

$$E_1^i = \left(1+\frac{4}{3N_1}\right)\frac{\partial^2\theta^i}{\partial x^2} + \frac{\partial^2\theta^i}{\partial y^2} - P\left(\frac{\partial\psi^i}{\partial y}\ \frac{\partial\theta^i}{\partial x} - \frac{\partial\psi^i}{\partial x}\ \frac{\partial\theta^i}{\partial y}\right) - \alpha\theta + E_C\left[\left(\frac{\partial\psi}{\partial y}\right)^2 + \left(\frac{\partial\psi}{\partial x}\right)^2\right] \tag{3.3}$$

Under Galerkin method this error is made orthogonal over the domain of e_i to the respective shape functions (weight functions) where

$$\int_{ei} E_1^i\ N_k^i\ d\Omega = 0 \quad ,$$

$$\int_{ei=} N_k^i\left(\left(1+\frac{4}{3N_1}\right)\left(\frac{\partial^z\theta^i}{\partial x^2} + \frac{\partial^z\theta^i}{\partial y^2}\right) - P\left(\frac{\partial\psi^i}{\partial y}\ \frac{\partial\theta^i}{\partial x} - \frac{\partial\psi^i}{\partial x}\ \frac{\partial\theta^i}{\partial y}\right)\right.$$
$$\left. - \alpha\theta + \left[E_C\left(\frac{\partial\psi}{\partial y}\right)^2 + \left(\frac{\partial\psi}{\partial x}\right)^2\right]\right) d\Omega = 0 \tag{3.4}$$

Using Green's theorem we reduce the surface integral (3.3)&(3.4)without affecting ψ terms and obtain

$$\int_{ei} N_k^i \left\{ \begin{array}{l} \left(1+\frac{4}{3N_1}\right)\frac{\partial N_k^i}{\partial x}\ \frac{\partial\theta^i}{\partial x} + \frac{\partial N_k^i}{\partial y}\ \frac{\partial\theta^i}{\partial y} - p^i N_k\left(\frac{\partial\psi^i}{\partial y}\ \frac{\partial\theta^i}{\partial x} - \frac{\partial\psi^i}{\partial x}\ \frac{\partial\theta^i}{\partial y}\right) \\ \qquad - \alpha\theta + E_C\left(\frac{\partial\psi}{\partial y}\right)^2 + \left(\frac{\partial\psi}{\partial x}\right)^2 \end{array} \right\} d\Omega$$

$$= \int_{\Gamma i} N_k^i\left(\frac{\partial\theta^i}{\partial x} n_x + \frac{\partial\theta^i}{\partial y} n_y\right) d\Gamma_i \tag{3.6}$$

where Γ_I is the boundary of e_i.

Substituting L.H.S. of (3.1)- (3.2) for ψ^i and θ^i in (3.5) we get

$$\sum_1 \int_{ei}\left(1+\frac{4N}{3}\right)\frac{\partial N_k^i}{\partial x}\ \frac{\partial N_L^i}{\partial x} + \frac{\partial N_L^i}{\partial y}\ \frac{\partial N_k^i}{\partial y} - P\sum_1 \psi_m^i \int_{ei}\left(\frac{\partial N_m^i}{\partial y}\ \frac{\partial N_L^i}{\partial x} - \frac{\partial N_m^i}{\partial x}\ \frac{\partial N_L^i}{\partial y}\right) d\Omega$$

$$- \alpha\sum\theta^i \int_{ei} N N_{k\ l}\, d\Omega_i + E_C \int_{ei}\left(\left(\frac{\partial\psi}{\partial y}\right)^2 + \left(\frac{\partial\psi}{\partial x}\right)^2\right) d\Omega$$

$$= \int_{\Gamma_i} N_k^i\left(\frac{\partial\theta^i}{\partial x}\ n_x + \frac{\partial\theta^i}{\partial y} n_y\right) d\Gamma_i = Q_k^i \qquad (l, m, k = 1,2,3) \tag{3.7}$$

where

$Q_k^i = Q_{k1}^i + Q_{k2}^i + Q_{k3}^i, Q_k^i$'s being the values of Q_k^i on the sides s = (1,2,3) of the element e_i. The sign of Q_k^i 's depends on the direction of the outward normal w.r.t the element.

Choosing different N_k^i 's as weight functions and following the same procedure we obtain matrix equations for three unknowns (Q_p^i) viz.,

$$(a_p^i)(\theta_p^i) = (Q_k^i) \tag{3.8}$$

where (a_{pk}^i) is a 3 x 3 matrix, $(\theta_p^i),(Q_k^i)$ are column matrices.

Repeating the above process with each of s elements, we obtain sets of such matrix equations. Introducing the global coordinates and global values for θ_p^i and making use of inter element continuity and boundary conditions relevant to the problem the above stiffness matrices are assembled to obtain a global matrix equation. This global matrix is r x r square matrix if there are r distinct global nodes in the domain of flow considered.

Similarly substituting ψ^i and θ^i in (2.10) and defining the error

$$E_3^i = \nabla^2 \psi + \mathrm{Ra}\,(\frac{\partial \theta}{\partial \mathrm{x}}) \tag{3.9}$$

and following the Galerkin method we obtain

$$\int_\Omega E_3^i \psi_j^i \, d\Omega = 0 \tag{3.10}$$

Using Green's theorem (3.9) reduces to

$$\int_\Omega \left(\frac{\partial N_k^i}{\partial x} \frac{\partial \psi^i}{\partial x} + \frac{\partial N_k^i}{\partial y} \frac{\partial \psi^i}{\partial y} + \mathrm{Ra}\,(\theta^i \frac{\partial N_k^i}{\partial x} \right) d\Omega$$

$$= \int_\Gamma N_k^i \left(\frac{\partial \psi^i}{\partial x} n_x + \frac{\partial \psi^i}{\partial y} n_y \right) d\Gamma_i + \int_\Gamma N_k^i n_x \theta^i \, d\Gamma_i \tag{3.11}$$

In obtaining (3.11) the Green's theorem is applied w.r.t derivatives of ψ without affecting θ terms.

Using (3.1) and (3.2) in (3.11) we have

$$\sum_m \psi_m^i \left\{ \int_\Omega \left(\frac{\partial N_k^i}{\partial x} \frac{\partial N_m^i}{\partial x} + \frac{\partial N_m^i}{\partial y} \frac{\partial N_k^i}{\partial y} \right) d\Omega_i + \mathrm{Ra} \sum_L (\theta_L^i \int_{\Omega_i} \mathrm{N}_k^i \frac{\partial N_L^i}{\partial x} d\Omega + \phi_L^i N \int_{\Omega_i} \mathrm{N}_k^i \frac{\partial N_L^i}{\partial x} d\Omega \right\}$$

$$= \int_\Gamma N_k^i \left(\frac{\partial \psi^i}{\partial x} n_x + \frac{\partial \psi^i}{\partial y} n_y \right) d\Gamma_i + \int_\Gamma N_k^i \theta^i \, d\Omega_i = \Gamma_k^i \tag{3.12}$$

In the problem under consideration, for computational purpose, we choose uniform mesh of 10 triangular element (**Fig. i**). The domain has vertices whose global coordinates are (0,0), (1,0) and (1,c) in the non-dimensional form. Let e_1, e_2…..e_{10} be the ten elements and let θ_1, θ_2, …..θ_{10} be the global values of θ and ψ_1, ψ_2,……ψ_{10} be the global values of ψ at the ten global nodes of the domain (**Fig. i**).

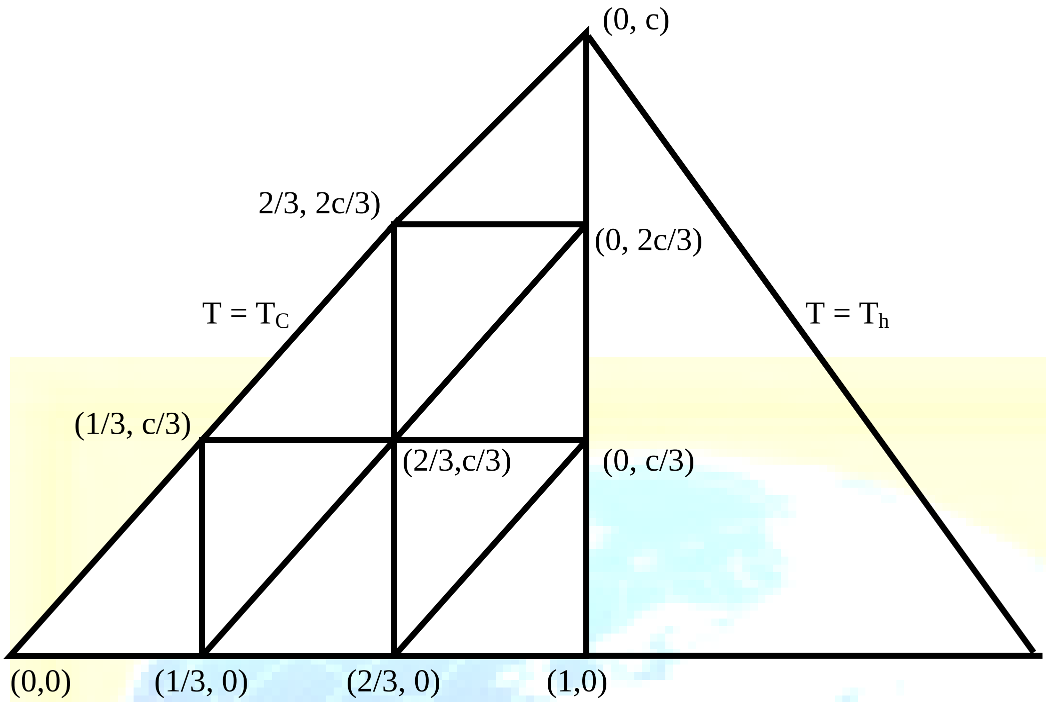


Fig.i

SCHEMATIC DIAGRAM OF THE CONFIGURATION

The domain consists three horizontal levels and the solution for Ψ & θ at each level may be expressed in terms of the nodal values as follows,

In the horizontal strip $0 \leq y \leq \frac{c}{3}$

$$\Psi = (\Psi_1 N^1_1 + \Psi_2 N^1_2 + \Psi_7 N^1_7)\, H(1-\tau_1)$$

$$= \Psi_1 (1-4x) + \Psi_2 4(x - \frac{y}{c}) + \Psi_7 (\frac{4y}{c}\ (1-\tau_1\ ) \qquad (0 \leq x \leq \frac{1}{3}\ )$$

$$\Psi = (\Psi_2 N^3_2 + \Psi_3 N^3_3 + \Psi_6 N^3_6)\, H(1-\tau_2)$$

$$+ (\Psi_2 N^2_2 + \Psi_7 N^2_7 + \Psi_6 N^2_6) H(1-\tau_3) \qquad (\frac{1}{3} \leq x \leq \frac{1}{3}\ )$$

$$= (\Psi_2 2(1-2x) + \Psi_3 (4x - \frac{4y}{c} - 1) + \Psi_6 (\frac{4y}{c}))H(1-\tau_2)$$

$$+ (\Psi_2 (1 - \frac{4y}{c}) + \Psi_7 (1 + \frac{4y}{c} - 4x) + \Psi_6 (4x-1))H(1-\tau_3)$$

$$\Psi = (\Psi_3 N^5_3 + \Psi_4 N^5_4 + \Psi_5 N^5_5)\, H(1-\tau_3)$$

$+ (\Psi_3 N^4_3 + \Psi_5 N^4_5 + \Psi_6 N^4_6) H(1-\tau_4)$ $\quad (\frac{2}{3} \le x \le 1)$

$= (\Psi_3 (3-4x) + \Psi_4 2(2x - \frac{2y}{c} - 1) + \Psi_6 (\frac{4y}{c} - 4x + 3)) H(1-\tau_3)$

$+ \Psi_3 (1 - \frac{4y}{c}) + \Psi_5 (4x-3) + \Psi_6 (\frac{4y}{c})) H(1-\tau_4)$

Along the strip $\frac{c}{3} \le y \le \frac{2c}{3}$

$\Psi = (\Psi_7 N^6_7 + \Psi_6 N^6_6 + \Psi_8 N^6_8) H(1-\tau_2)$ $\quad (\frac{1}{3} \le x \le 1)$

$+ (\Psi_6 N^7_6 + \Psi_9 N^7_9 + \Psi_8 N^7_8) H(1-\tau_3) + (\Psi_6 N^8_6 + \Psi_5 N^8_5 + \Psi_9 N^8_9) H(1-\tau_4)$

$\Psi = (\Psi_7\, 2(1-2x) + \Psi_6 (4x-3) + \Psi_8 (\frac{4y}{c} - 1)) H(1-\tau_3)$

$+ \Psi_6 (2(1 - \frac{2y}{c}) + \Psi_9 (\frac{4y}{c} - 1) + \Psi_8 (1 + \frac{4y}{c} - 4x)) H(1-\tau_4)$

$+ \Psi_6 (4(1-x) + \Psi_5 (4x - \frac{4y}{c} - 1) + \Psi_9 2(\frac{2y}{c} - 1)) H(1-\tau_5)$

Along the strip $\frac{2c}{3} \le y \le 1$

$\Psi = (\Psi_8 N^9_8 + \Psi_9 N^9_9 + \Psi_{10} N^9_{10}) H(1-\tau_6)$ $\quad (\frac{2}{3} \le x \le 1)$

$= \Psi_8 (4(1-x) + \Psi_9 4(x - \frac{y}{c}) + \Psi_{10} 2(\frac{4y}{c} - 3)) H(1-\tau_6)$

where $\tau_1 = 4x$, $\tau_2 = 2x$, $\tau_3 = \frac{4x}{3}$,

$\tau_4 = 4(x - \frac{y}{c})$, $\tau_5 = 2(x - \frac{y}{c})$, $\tau_6 = \frac{4}{3}(x - \frac{y}{c})$

and H represents the Heaviside function.
The expressions for θ are

In the horizontal strip $0 \le y \le \frac{c}{3}$

$\theta = [\theta_1 (1-4x) + \theta_2\, 4(x - \frac{y}{c}) + \theta_7 (\frac{4y}{c})) H(1-\tau_1)$ $\quad (0 \le x \le \frac{1}{3})$

$\theta = (\theta_2 (2(1-2x) + \theta_3 (4x - \frac{4y}{c} - 1) + \theta_6 (\frac{4y}{c})) H(1-\tau_2)$

$+ \theta_2 (1 - \frac{4y}{c}) + \theta_7 (1 + \frac{4y}{c} - 4x) + \theta_6 (4x-1)) H(1-\tau_3)$ $\quad (\frac{1}{3} \le x \le \frac{2}{3})$

$\theta = \theta_3 (3-4x) + 2\theta_4 (2x - \frac{2y}{c} - 1) + \theta_6 (\frac{4y}{c} - 4x + 3) H(1-\tau_3)$

$+ (\theta_3 (1 - \frac{4y}{c}) + \theta_5 (4x-3) + \theta_6 (\frac{4y}{c})) H(1-\tau_4)$ $\quad (\frac{2}{3} \le x \le 1)$

Along the strip $\frac{c}{3} \le y \le \frac{2c}{3}$

$$\theta = (\theta_7(2(1-2x)+\theta_6(4x-3)+\theta_8(\frac{4y}{c}-1))\,H(1-\tau_3) \qquad (\frac{1}{3} \le x \le \frac{2}{3})$$

$$+(\theta_6(2(1-\frac{2y}{c})+\theta_9(\frac{4y}{c}-1)+\theta_8(1+\frac{4y}{c}-4x))\,H(1-\tau_4)$$

$$+(\theta_6(4(1-x)+\theta_5(4x-\frac{4y}{c}-1)+\theta_9\,2(\frac{4y}{c}-1))\,H(1-\tau_5)$$

Along the strip $\frac{2c}{3} \le y \le 1$

$$\theta = (\theta_8 4(1-x)+\theta_9 4(x-\frac{y}{c})+\theta_{10}(\frac{4y}{c}-3)\,H(1-\tau_6) \qquad (\frac{2}{3} \le x \le 1)$$

The dimensionless Nusselt numbers(Nu) on the non-insulated boundary walls of the triangular duct are calculated using the formula

$$Nu = (\frac{\partial\theta}{\partial x})_{x=1}$$

Nusselt Number on the side wall x=1in different regions are

$Nu_1=2-4\theta_3 \qquad (0 \le y \le h/3)$

$Nu_2=2-4\theta_5 \qquad (h/3 \le y \le 2h/3)$

$Nu_3=2-4\theta_7 \qquad (2h/3 \le y \le h)$

The dimensionless Nusselt number (Nu) on the boundary wall of the triangular duct are calculated using the formula

$$Nu = (-\cos(\alpha))\frac{\partial\theta}{\partial x} + (\sin(\alpha)\frac{\partial\theta}{\partial y})_{y = x\tan(\alpha)}$$

where α is the base analysis of the triangular cross section of the duct.

$$Nu_1 = \frac{4\sqrt{2}}{3}(\theta_7 - \frac{5}{2}\theta_2)$$

$$Nu_2 = 2\sqrt{2}(\theta_6 + \frac{2}{3}\theta_8)$$

$$Nu_3 = 2\sqrt{2}(\frac{2}{3}\theta_9 - \theta_{10})$$

4. DISCUSSION OF THE NUMERICAL RESULTS

In this analysis we investigate the effect of chemical reaction on the mixed convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium in a triangular cavity.

In this analysis we discuss the effect of radiative heat flux and dissipation on all the fluid characteristics. The equations governing flow and heat transfer are solved by using Galekine finite element analysis with linear approximation functions. The effect of radiation on θ is shown in figures 1–5. It is found that the actual temperature depreciates with increase in the radiation parameter N at all horizontal and vertical levels. The effect of heat sources on θ is shown in figures 6-10. It is found that an increase in the strength of the heat sources enhances the actual temperature at the horizontal and vertical levels x = 1/3 ,2/3, while it depreciates with increase in strength of the heat sink. At the higher vertical level x = 1 the actual temperature depreciates with increase in strength of heat source / sink.(fig 10). The variation of θ with Eckert number Ec at all the levels is shown in figs 11 – 15. It is found that higher the dissipative heat larger the actual temperature at all horizontal and vertical levels. It is found that the actual temperature at horizontal levels is much greater than that at the vertical levels .

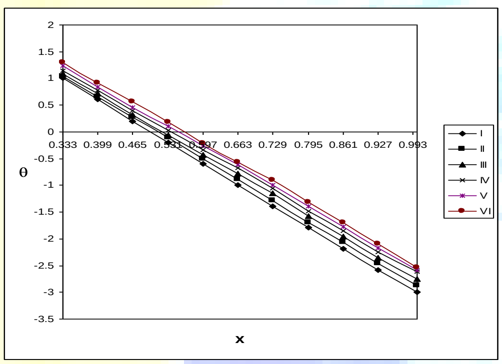


Fig. 1 : θ with α at y= $\frac{c}{3}$ level

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

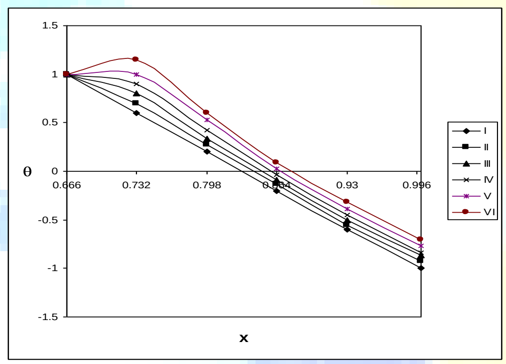


Fig. 2 : θ with α at y= $\frac{2c}{3}$ level

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

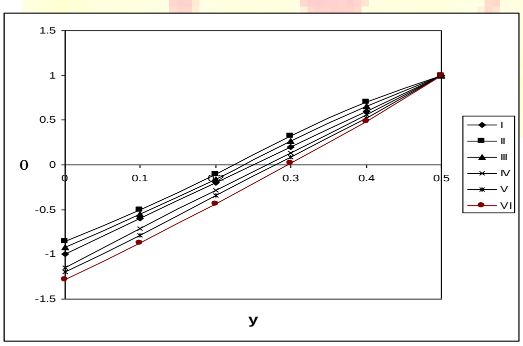


Fig. 3 : θ with α at x= $\frac{1}{3}$ level

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

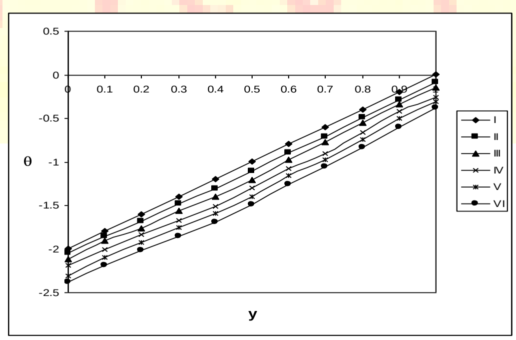
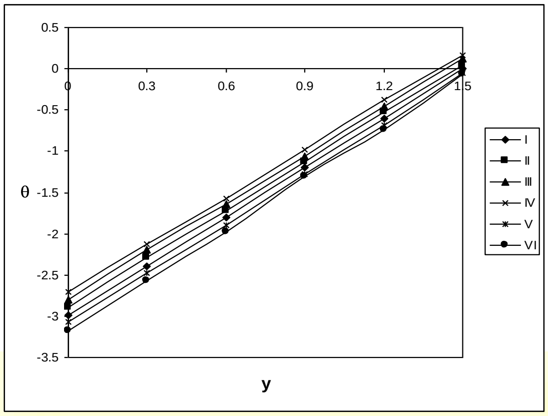


Fig. 4 : θ with α at x= $\frac{2}{3}$ level

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6



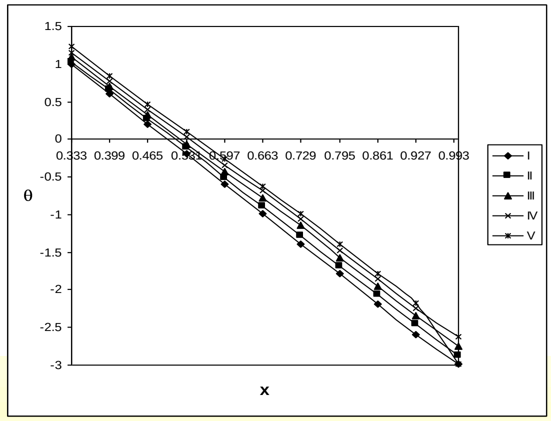
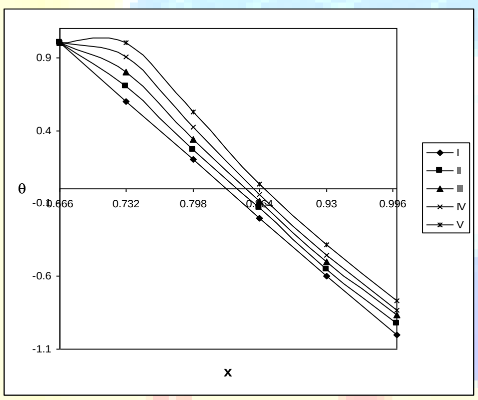


Fig. 5 : θ with α at x=1 level

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

Fig. 6 : θ with Ra at y= $\frac{c}{3}$ level

	I	II	III	IV	V
Ra	0.01	0.05	0.1	0.5	1.5



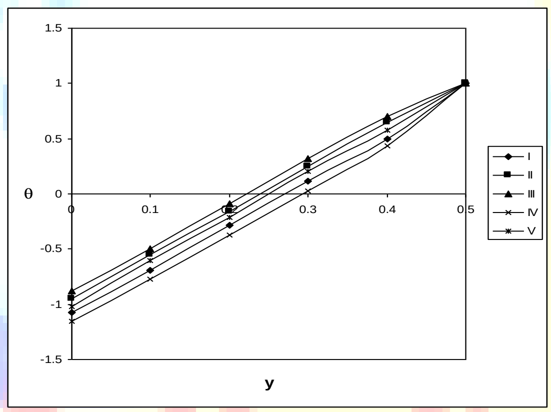
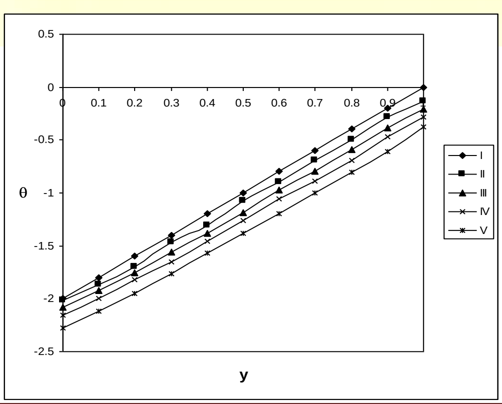


Fig. 7 : θ with Ra at y= $\frac{2c}{3}$ level

	I	II	III	IV	V
Ra	0.01	0.05	0.1	0.5	1.5

Fig. 8 : θ with Ra at x= $\frac{1}{3}$ level

	I	II	III	IV	V
Ra	0.01	0.05	0.1	0.5	1.5



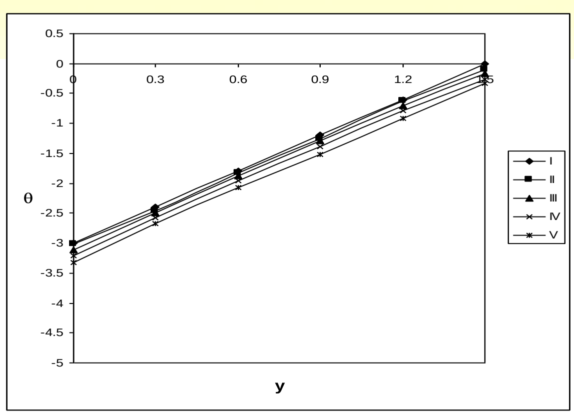


Fig. 9 : θ with Ra at x= $\frac{2}{3}$ level

	I	II	III	IV	V
Ra	0.01	0.05	0.1	0.5	1.5

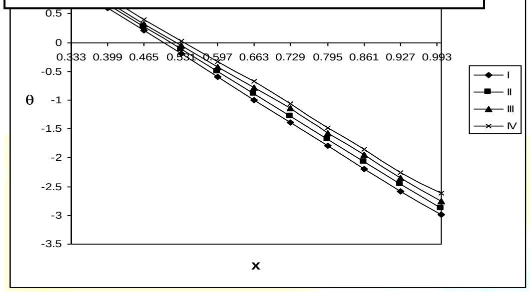


Fig. 10: θ with Ra at x= 1 level

	I	II	III	IV	V
Ra	0.01	0.05	0.1	0.5	1.5

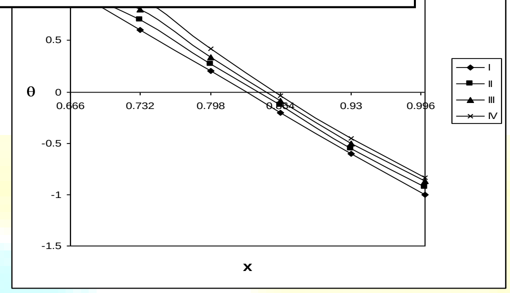
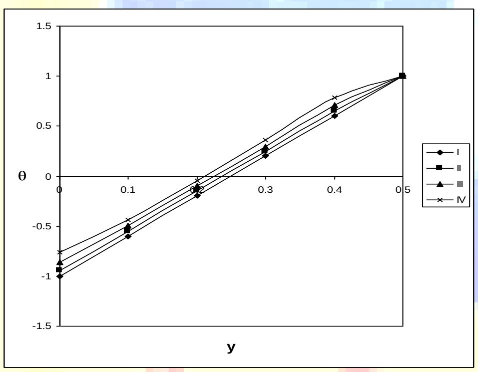


Fig. 11 : θ with ε at y= $\frac{c}{3}$ level

	I	II	III	IV
ε	0.001	0.005	0.009	0.015

Fig. 12 : θ with ε at y= $\frac{2c}{3}$ level

	I	II	III	IV
ε	0.001	0.005	0.009	0.015



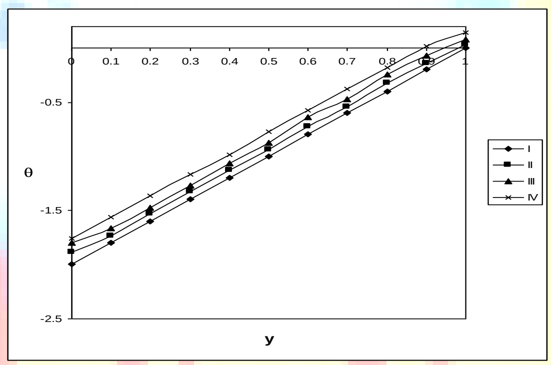


Fig. 13 : θ with ε at x= $\frac{1}{3}$ level

	I	II	III	IV
ε	0.001	0.005	0.009	0.015

Fig. 14 : θ with ε at x= $\frac{2}{3}$ level

	I	II	III	IV
ε	0.001	0.005	0.009	0.015

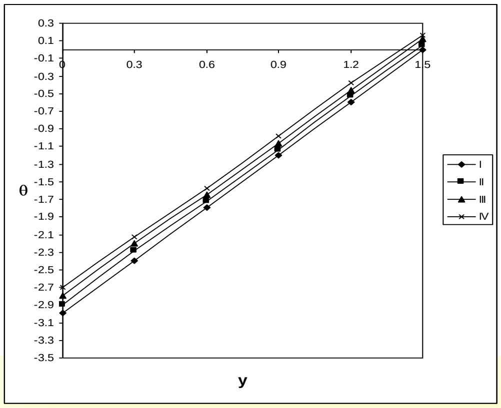


Fig. 15 : θ with ε at x= 1 level

	I	II	III	IV
ε	0.001	0.005	0.009	0.015

The rate of heat transfer on the side wall of the triangular duct shown in tables 1 – 4 for different values of Ra, N, α , and Ec. It is found that the rate of heat transfer (Nu_1) in the lower quadrant is positive and in the middle and upper quadrants it is negative for all variations. The rate of heat transfer in the lower quadrant depreciates with increase in Rayleigh number Ra>0 and enhance with $|Ra|$, while in the middle quadrant Nu_2 reduces with increase in Ra . In the upper quadrant the rate of heat transfer enhances with increase in $Ra < 2\times10^2$ and depreciates with $Ra \geq 3\times10^2$, while an increase in $|Ra|$ reduces Nu_3 (table 3). The value of Nu with radiation of parameter N shows that the rate of heat transfer enhances in the lower quadrant and depreciates in the middle and upper quadrants with increase in radiation parameter N. (table 2). The variation of Nu with heat source parameter α shows that the rate of heat transfer in the lower and upper quadrants enhance with increase α >0 while in the middle quadrant Nu depreciates with α . An increase in the strength of heat sink (α <0) enhances Nu in the lower quadrants and depreciates in the middle and upper quadrants. The effect of dissipative heat on Nu is shown in table 4.

It is found that higher the dissipative heat lesser $|Nu|$ in the lower quadrant and larger $|Nu|$ in the middle and upper quadrants.

TABLE – 1 NUSSELET NUMBER (Nu)

	I	II	III	IV	V	VI
Nu_1	5.8358	5.7560	5.6498	5.8399	5.8423	5.8478
Nu_2	-2.8196	-2.7546	-2.6675	-2.8229	-2.7870	-2.7222
Nu_1	-1.3936	-1.6697	-1.6396	-1.6954	-1.6867	-1.6736
Ra	**10**	**30**	**50**	**-10**	**-20**	**-30**

TABLE – 2 NUSSELET NUMBER (Nu)

	I	II	III	IV	V
Nu_1	5.8358	5.8400	5.8401	5.8411	5.8423
Nu_2	-2.8196	-2.8204	-2.8211	-2.8239	-2.8259
Nu_3	-1.6936	-1.6939	-1.6942	-1.6948	-1.6958
N	**0.01**	**0.05**	**0.1**	**0.5**	**1.5**

TABLE – 3 NUSSELET NUMBER

	I	II	III	IV	V	VI
Nu_1	5.8358	5.8345	5.8336	5.8396	5.8413	5.8423
Nu_2	-2.8196	-2.8194	-2.8193	-2.8216	-2.8226	-2.8237
Nu_3	-1.6936	-1.6937	-1.6940	-1.6945	-1.6946	-1.6952
α	**2**	**4**	**6**	**-2**	**-4**	**-6**

TABLE – 4 NUSSELET NUMBER

	I	II	III	IV
Nu_1	5.8358	5.8023	5.7702	5.7240
Nu_2	-2.8196	-2.7857	-2.7530	-2.7439
Nu_3	-1.6936	-1.6789	-1.6648	-1.6448
E_c	**0.001**	**0.005**	**0.009**	**0.015**

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