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Parameteric Simulation of the Heat Transfer in Vertical Channel of Viscous Fluid Flow : A Case Study of FEM Simulation

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ABSTRACT

It is found in the present attempt that the variations in parameters of G, D^{-1} & Ec the velocity on Z=0 & Z=1/2 indicates movement of the flow towards the upward direction as we move in the normal direction from y=0 to 1. In all the cases however the maximum is attained at y=0.4 while at Z=1/2 level the maximum across at y=1. The enhancement in G leads to a depreciation in θ at y=0&1/2. The fluctuations of θ with D^{-1} is shown in 17&18. It is found that the actual temperature enhances with increase in D^{-1}.

Keywords : Viscous Flow, Heat Tranfer, Permiability and Porous Medium

I. INTRODUCTION

Natural convection from protruding and flush mounted heat generating elements has received considerable attention in heat transfer literature, as they simulate heat generating electronic components such as resistors, capacitors, inductors, transformers, ICs and so on. An experimental study of natural convection from a finite thick heat source, mounted on a vertical and a horizontal plate made of Masonite is reported by Kang and Jaluria [1,2]. The heat source module is made from a highly polished stainless steel foil which is in close constant with three exposed surfaces of a stack of Bakelite strips. The study concluded that the flow and heat transfer characteristics have a strong dependence on the rate of energy input, heat source thickness and the interaction between the wakes generated by the three exposed surfaces of the heat source modul [3,4,5]. A numerical study of steady two-dimensional laminar natural convection from a single protruding heat source, mounted at mid-height of a substrate of finite thickness, was carried out by Desrayaud et al. [6]. They have conducted parameteric study by varying the thermal conductivity of the substrate, thickness of the substrate and width of the module and the study concluded that the heat transfer from the heat source is considerably affected by the thermal conductivity of the substrate. Rajkumar, Venugopal and Anil Lal [7] presented the results of Natural convection with surface radiation from a planar heat generating element mounted freely in a vertical channel. Ermolaev and Zhbanov [8] presented the results of mixed convection in vertical channel with Discrete Heat Sources at the wall.

FORMULATION OF THE PROBLEM

We analyze the free convection flow of an incompressible viscous fluid through a vertical channel filled with a porous matrix bounded by parallel impermeable walls. The flow takes place along the axis of the channel.

heat at constant pressure, this the molecular diffusivity and $k_{11}$is the cross diffusivity.

In view of the continuity equations, we take u = u (y, z)

The boundary conditions are

u = 0 on z = $\pm$ b

$$T = \pm T_1 , \qquad C = \pm C_1 \qquad (2.6)$$

$\frac{\partial u}{\partial z} = 0$, $\frac{\partial T}{\partial z} = 0$ and $\frac{\partial C}{\partial z} = 0$ on Z = 0 in view of the symmetry.

We introduce the following non-dimensional variables as follows.

$$z^* = \frac{z}{b} \quad ; \quad y^* = \frac{y}{b} \quad ; \quad \theta^* = \frac{T - T_0}{T_1 - T_0}, \qquad C^* = \frac{C - C_o}{C_1 - C_o} ,$$

$$u^* = \frac{\nu u}{\beta g b^2 (T_1 - T_0)}$$

If u^i and θ^i are the approximations of u and θ we define the errors (residual) E_1^i and E_2^i as

$$E_1^i = \frac{\partial^2 u^i}{\partial y^2} + \frac{\partial^2 u^i}{\partial z^2} - D^{-1} u^i + (\theta^i + NC^i) + S\frac{\partial u^i}{\partial y} \qquad (3.1)$$

$$E_2^i = \frac{\partial^2 \theta^i}{\partial y^2} + N_2 \frac{\partial^2 \theta^i}{\partial z^2} + GP_1 Ec[(\frac{\partial u^i}{\partial y})^2 + (\frac{\partial u^i}{\partial z})^2) + D^{-1}(u^i)^2] + P_1 S\frac{\partial \theta^i}{\partial y} \qquad (3.2)$$

$$E_3^i = (\frac{\partial^2 C^i}{\partial y^2} + \frac{\partial^2 C^i}{\partial z^2}) + \frac{S_0 Sc}{N}(\frac{\partial^2 \theta^i}{\partial y^2} + \frac{\partial^2 \theta^i}{\partial z^2}) \qquad (3.3)$$

where

$$u^i = \sum_{k=1}^{8} u_k^i N_k^i \qquad (3.4)$$

$$\theta^i = \sum_{k=1}^{8} \theta_k^i N_k^i \qquad (3.5)$$

$$C^i = \sum_{k=1}^{8} C_k^i N_k^i \qquad (3.6)$$

These errors are orthogonal to the weight function over the domain of e^i. Under Galerkin we choose the approximation functions as the weight function. Multiply both sides of the equations (3.1) - (3.3) by the weight function i.e., each of the approximation function N_j^i and integrate over the surface Ω_i we obtain

$$\int_{\Omega_i} E_1^i N_j^i d\Omega_i = 0 \qquad (j = 1,2,.........,8) \tag{3.7}$$

$$\int_{\Omega_i} E_2^i N_j^i d\Omega_i = 0 \qquad (j = 1,2,.........,8) \tag{3.8}$$

$$\int_{\Omega_{i_i}} E_3^i N_j^i d\Omega_i = 0 \qquad (j = 1.2..........,8) \tag{3.9}$$

$$\int_{\Omega_i} [\frac{\partial^2 u^i}{\partial y^2} + \frac{\partial^2 u^i}{\partial z^2} - D^{-1}u^i + (\theta^i + NC^i) + S\frac{\partial u^i}{\partial y}] N_j^i d\Omega_i = 0 \tag{3.10}$$

$$\int_{\Omega_i} [\frac{\partial^2 \theta^i}{\partial y^2} + N_2\frac{\partial^2 \theta^i}{\partial z^2} + GP_1Ec[(\frac{\partial u^i}{\partial y})^2 + (\frac{\partial u^i}{\partial z})^2) + D^{-1}(u^i)^2] + P_1S\frac{\partial \theta^i}{\partial y}] N_j^i d\Omega_i = 0 \tag{3.11}$$

$$\int_{\Omega_i} [(\frac{\partial^2 C^i}{\partial y^2} + \frac{\partial^2 C^i}{\partial z^2}) + \frac{S_o Sc}{N}(\frac{\partial^2 \theta^i}{\partial y^2} + \frac{\partial^2 \theta^i}{\partial z^2})] N_j^i d\Omega_i = 0$$

(3.12)

$$\int_{\Omega_i} [\frac{\partial N_j^i}{\partial y}\frac{\partial u^i}{\partial y} + \frac{\partial N_j^i}{\partial z}\frac{\partial u^i}{\partial z} - D^{-1}u^i N_j^i + (\theta^i + NC^i)N_j^i + SN_j^i\frac{\partial u^i}{\partial y}] d\Omega_i$$

$$= \int_{\Gamma} [N_j^i \frac{\partial u^i}{\partial y} n_y + N_j^i \frac{\partial u^i}{\partial z} n_z] d\Gamma_i \tag{3.13}$$

$$\int_{\Omega_i} [\frac{\partial N_j^i}{\partial y}\frac{\partial \theta^i}{\partial y} + N_2\frac{\partial N_j^i}{\partial z}\frac{\partial \theta^i}{\partial z} + GP_1EcN_j^i[(\frac{\partial u^i}{\partial y})^2 + (\frac{\partial u^i}{\partial z})^2 + D^{-1}(u^i)^2] + P_1SN_j^i\frac{\partial \theta^i}{\partial y}] d\Omega_i$$

$$= \oint_{\Gamma} [N_j^i \frac{\partial \theta^i}{\partial y} n_y + N_j^i \frac{\partial \theta^i}{\partial z} n_z] d\Gamma_i \tag{3.14}$$

$$\int_{\Omega_i} [N\frac{\partial N_j^i}{\partial y}(N\frac{\partial C^i}{\partial y} + S_c S_o\frac{\partial \theta^i}{\partial y}) + \frac{\partial N_j^i}{\partial z}(N\frac{\partial C^i}{\partial z})] d\Omega_i$$

$$= \oint_{\Gamma} [N_j^i (N\frac{\partial C^i}{\partial y} + S_c S_o\frac{\partial \theta^i}{\partial y}) n_y + N_j^i (N\frac{\partial C^i}{\partial z} + S_c S_o\frac{\partial \theta^i}{\partial z}) n_z] d\Gamma_i \tag{3.15}$$

where Ω_i is the serendipity element bounded by Γ_i , n_y , n_z are the direction cosines normal to Γ_i .

Substituting (3.4) , (3.5) & (3.6) in L.H.S of (3.13) , (3.14) & (3.15) we get

$$\int_{\Omega_i} \sum_{k=1}^{8} u_k^i [\frac{\partial N_j^i}{\partial y}\frac{\partial N_k^i}{\partial y} + \frac{\partial N_j^i}{\partial z}\frac{\partial N_k^i}{\partial z} - D^{-1} N_k^i N_j^i + S N_j^i \frac{\partial N_k^i}{\partial y}] d\Omega_i + \int_{\Omega_i} \sum_{k=1}^{8} (\theta_k^i + N C_k^i) N_j^i N_k^i d\Omega_i = Q_j^i \quad (3.16)$$

$$\int_{\Omega_i} \sum_{k=1}^{8} \theta_k^i [\frac{\partial N_j^i}{\partial y}\frac{\partial N_k^i}{\partial y} + N_2 \frac{\partial N_j^i}{\partial z}\frac{\partial N_k^i}{\partial z} + P_1 S N_j^i \frac{\partial N_k^i}{\partial y}] d\Omega_i + \int_{\Omega_i} \sum_{k=1}^{8} u_k^i G P_1 Ec[(\frac{\partial N_k^i}{\partial y})^2 + (\frac{\partial N_k^i}{\partial z})^2 + D^{-1}(N_k^i)^2] d\Omega_i = (Q^T)_j^i \quad (3.17)$$

$$\int_{\Omega_i} [\sum_{k=1}^{8} C_k^i \{\frac{\partial N_k^i}{\partial y}\frac{\partial N_j^i}{\partial y} + \frac{\partial N_k^i}{\partial z}\frac{\partial N_j^i}{\partial z}\} d\Omega_i - \int_{\Omega_i} N_2 Sc \sum_{k=1}^{8} u_k^i (N_j^i N_k^i) d\Omega_i$$

$$- ScS_o \int_{\Omega_i} \sum_{k=1}^{8} \theta_k^i \{\frac{\partial N_k^i}{\partial y}\frac{\partial N_j^i}{\partial y} + \frac{\partial N_k^i}{\partial z}\frac{\partial N_j^i}{\partial z}\} d\Omega_i = (Q^C)_j^i \quad (3.18)$$

where $Q_j^i = \oint_{\Gamma_i} (N_j^i)(\frac{\partial u^i}{\partial y}) n_y + N_j^i \frac{\partial u^i}{\partial z} n_z) d\Gamma_i$

$$(Q^T)_j^i = \oint_{\Gamma_i} (N_j^i)(\frac{\partial T^i}{\partial y}) n_y + N_j^i \frac{\partial T^i}{\partial z} n_z) d\Gamma_i \qquad (j = 1, 2, \ldots\ldots, 8)$$

$$(Q^C)_j^i = \oint_{\Gamma_i} [N_j^i \{N \frac{\partial C^i}{\partial y} + S_0 Sc \frac{\partial \theta^i}{\partial y}\} n_y + N_j^i \{N \frac{\partial C^i}{\partial z} + S_0 Sc \frac{\partial \theta^i}{\partial z}\} n_z] d\Gamma_i \quad j = 1,2,\ldots\ldots\ldots,8.$$

Choosing different N_k^i's corresponding to each element e_i (3.11) results in sixteen equations for two sets of unknown (u_k^i) *and* (θ_k^i) viz

$$(a_{kj}^i)(u_k^i) = Q_j^i \quad (3.19)$$

$$(b_{kj}^i)(\theta_k^i) + (c_{kj}^i) u_k^i = (Q^T)_j^i \qquad (j = 1, 2, \ldots\ldots, 8) \quad (3.20)$$

$$(m_{kj}^i)(C_k^i) + (l_{kj}^i)(u_k^i) = (n_{kj}^i)(\theta_k^i) + (Q_j^C)^i \quad (j, k = 1, 2, \ldots\ldots\ldots\ldots, 8) \quad (3.21)$$

where $(a^{i}_{k\ j})$, $(b^{i}_{k\ j})$,$c^{i}_{k\ j})$,$(m^{i}_{k\ j})$,$(n^{i}_{k\ j})$ *and* $(l^{i}_{k\ j})$ are 8 × 8 stiffness matrices and Q^{i}_{j}, $(Q^{T})^{i}_{j}$ and $(Q^{C}_{j})^{i}$ are 8 × 1 column matrices. Repeating the process with each of mn elements and making conditions as well as the boundary conditions to assemble the element matrices, we obtain global matrices for the unknowns u , θ and C at the respective global nodes which ultimately determine them on solving the matrix equation.

DISCUSSION OF NUMERICAL RESULTS

The influence of heat source on θ is exhibited in figures 1&2. We find a marginal depreciation in θ with increase in the heat source parameter α. The variation of θ with Ec reveals that higher the dissipative heat smaller the actual temperature at y=0&1 levels (figs: 5&6). The variation of θ with radiation parameter N1 shows that an increase in N1 leads to an enhancement in the actual temperature at y=0&1 levels. The variation of θ with G, D^{-1},α, Ec and N, at the vertical levels Z=0&1/2 is shown in figures 6,7, and 8.The Nusslet number which represents the rate of heat transfer has been evaluated numerically for variations in G, D^{-1},α, Ec and N. It is found that the rate of heat transfer at y=1 is positive for all variations. The rate of heat transfer at y=1 level enhances with |G| and depreciates with D^{-1}. Thus lesser the permeability of the porous medium smaller |Nu| at y=1 level. The variation of Nu with Ec and α show that, the rate of heat transfer experiences an enhancement with increase in Ec or α. This implies that the presence of the heat sources in the fluid region or higher the dissipative heat larger the rate of heat transfer at y=1 level.

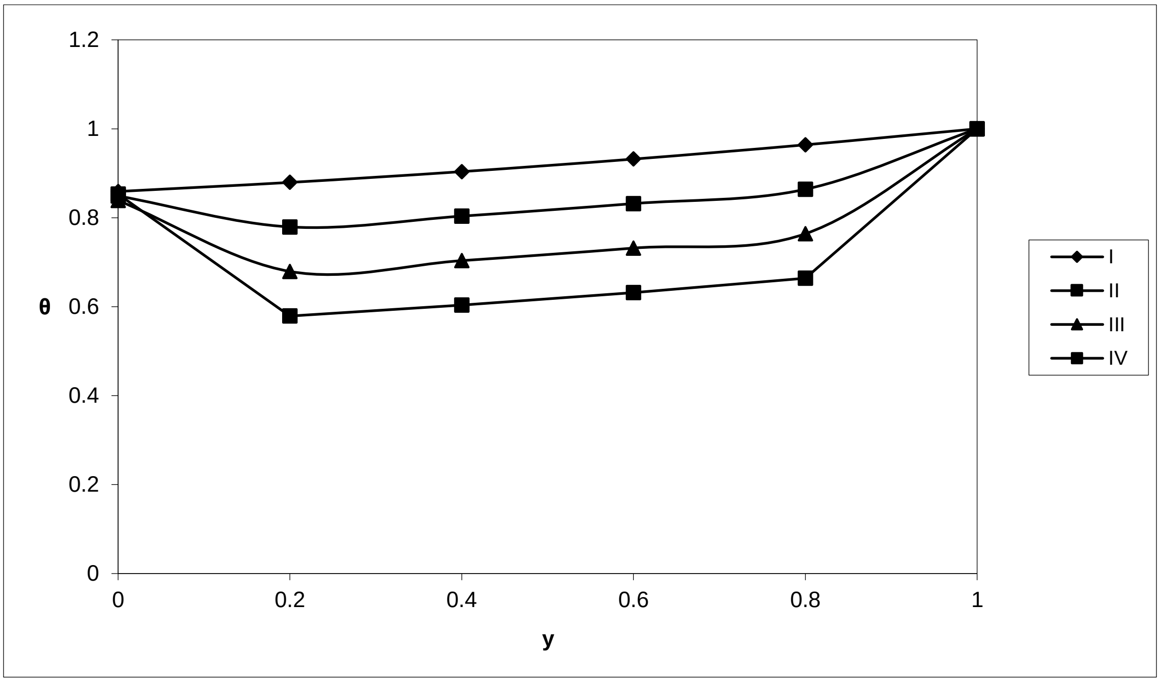

Fig. 1: Variation of θ with α at y=0 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; β =2; d=2000; z=0.5

	I	II	III	IV
α	0	2	4	10

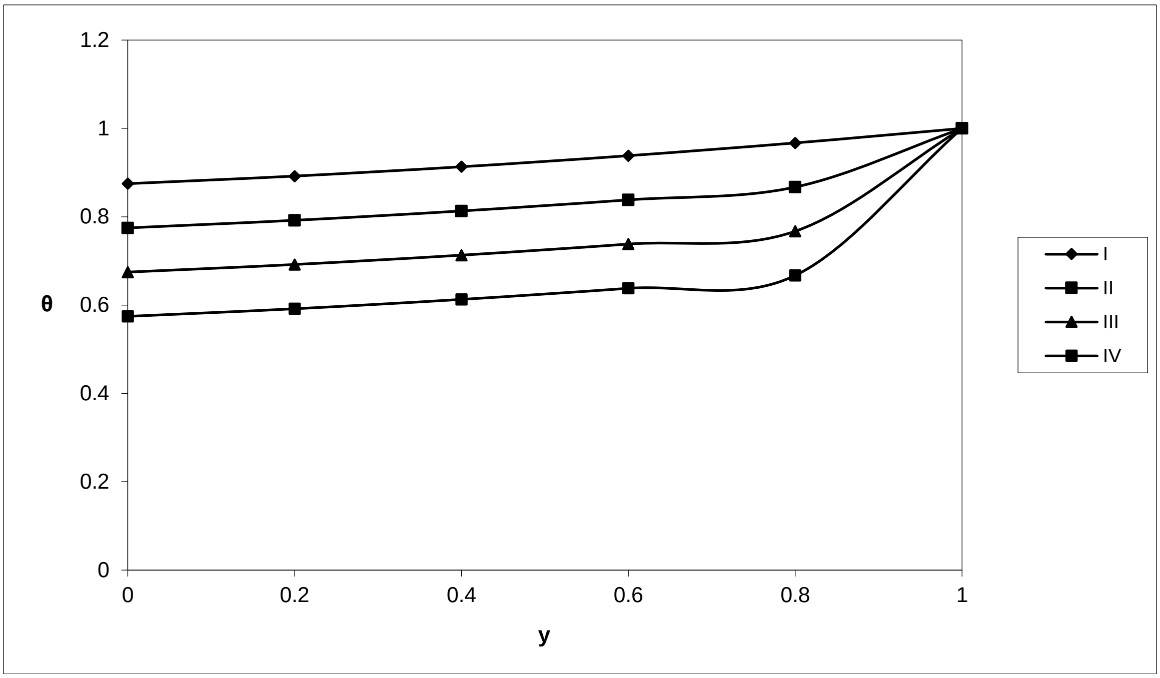

Fig. 2: Variation of θ with α at y=0.5 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; d=2000; z=0.5

	I	II	III	IV
α	0	2	4	10

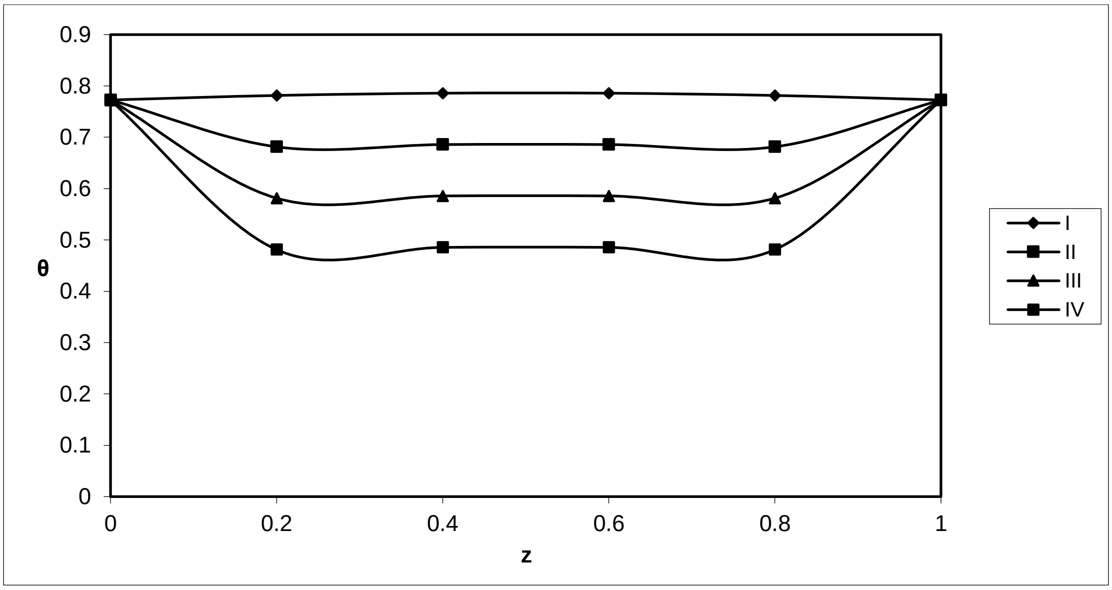

Fig. 3: Variation of θ with α at z=0 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; β =2; d=2000; z=0.5

	I	II	III	IV
α	0	2	4	10

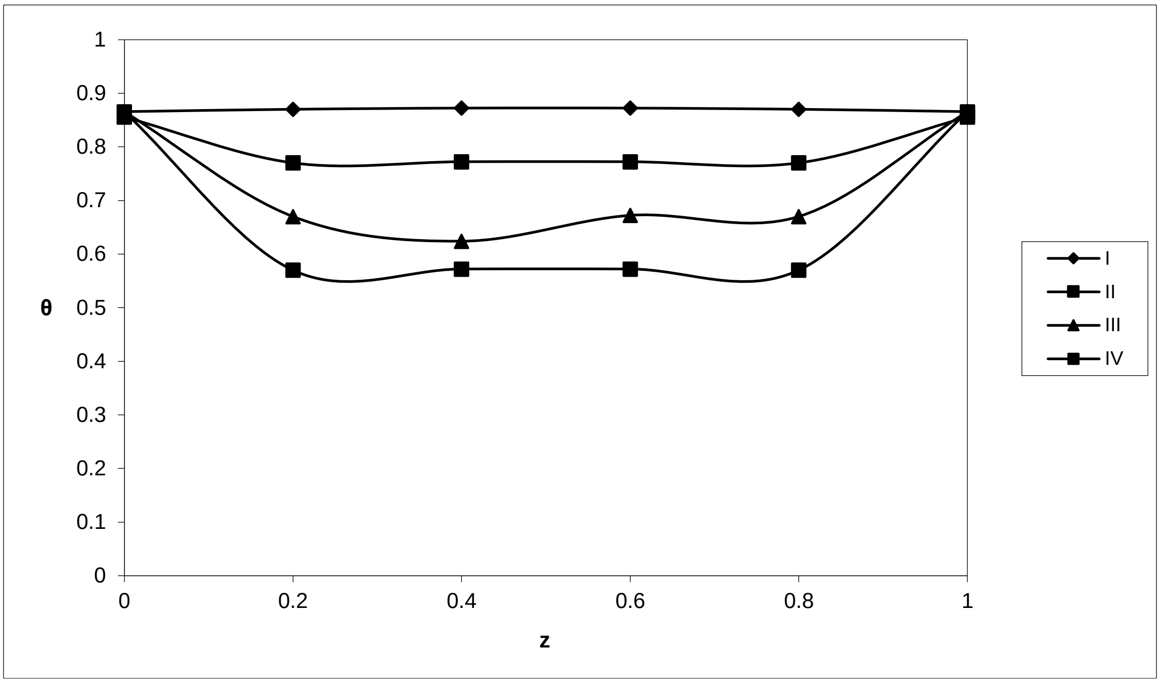

Fig. 4: Variation of θ with α at z=0.5 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; d=2000; z=0.5

	I	II	III	IV
α	0	2	4	10

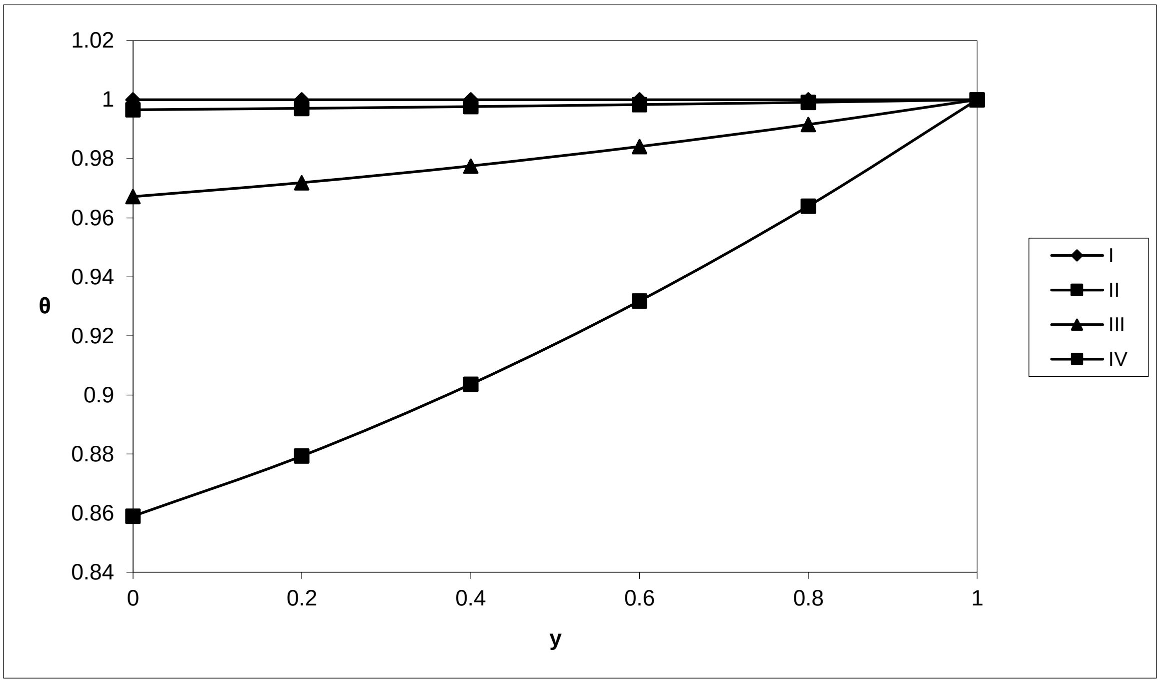

Fig. 5: Variation of θ with Ec at y=0 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; β=2; d=2000; z=0.5

	I	II	III	IV
G	10	50	100	200

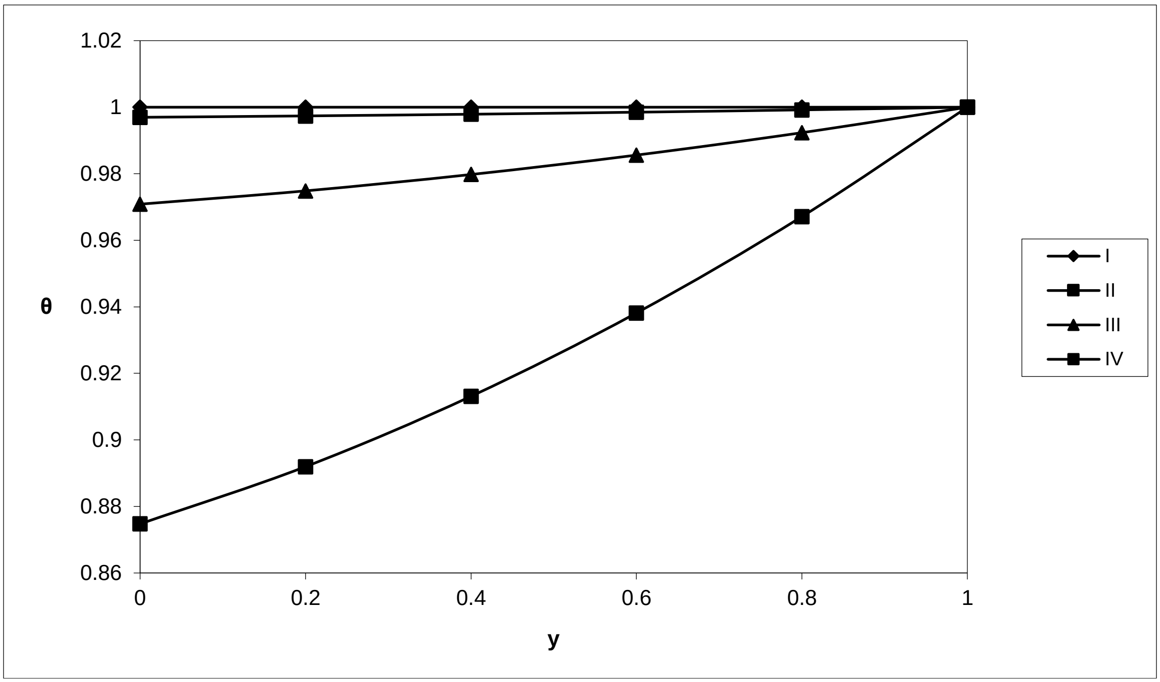

Fig. 6: Variation of θ with Ec at y=0.5 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; d=2000; z=0.5

	I	II	III	IV
G	10	50	100	200

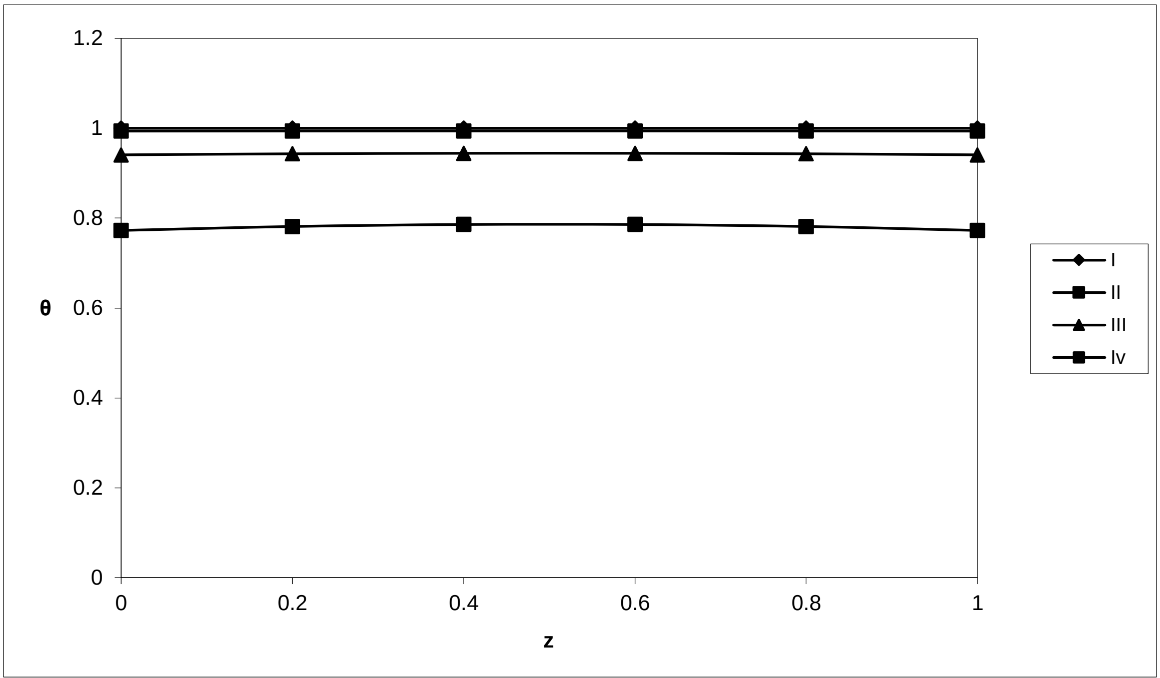

Fig. 7: Variation of θ with Ec at z=0 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; β =2; d=2000; z=0.5

	I	II	III	IV
G	10	50	100	200

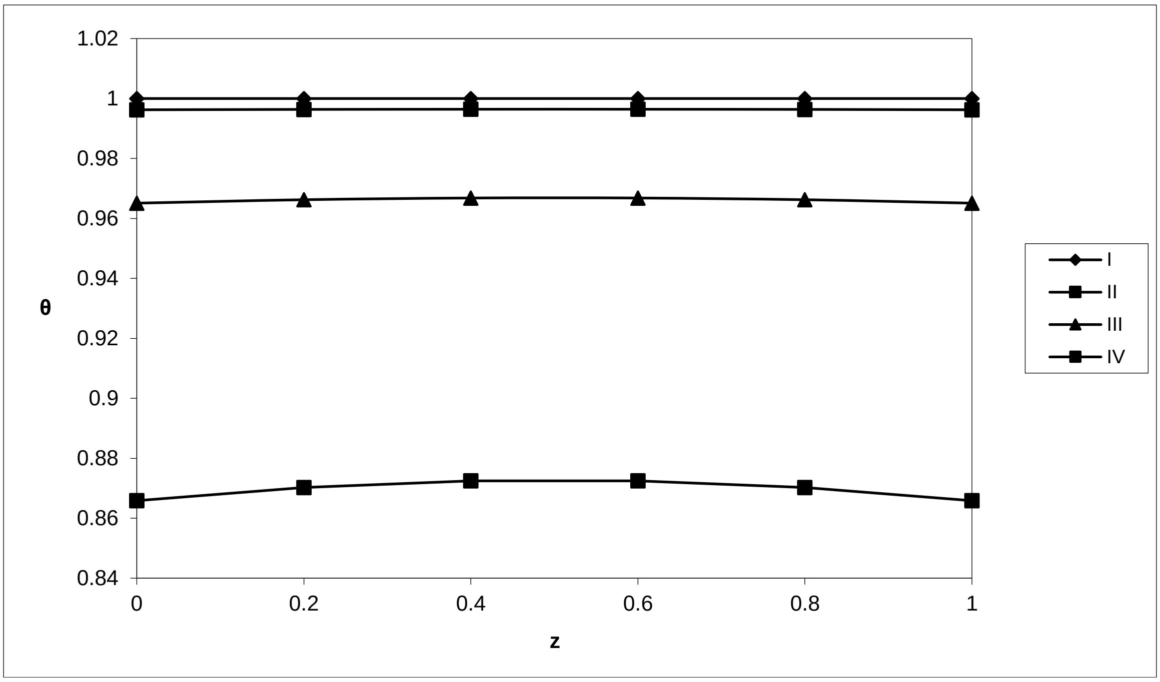

Fig. 8: Variation of θ with Ec at z=0.5 level

M=5; G=200; cn=0.5; S=0.8; k=0.5; qe=0.71; d=2000; z=0.5

	I	II	III	IV
G	10	50	100	20

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