THERMAL EQUILIBRIUM ASSUMPTION FOR FLUID FLOW IN POROUS MICRO-CHANNEL AS DESCRIBED BY A HYPERBOLIC HEAT-CONDUCTION MODEL

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Abstract - Unsteady homogeneous composite domain thermal performance described by the hyperbolic model of heat-conduction (HHC) in porous micro-channel is investigated. A solid domain (inserts) and fluid domain (matrix), each made of dissimilar material consists a composite domain,. The parameters range of which the use of the assumption of thermally equilibrium in transient natural convection flow in porous micro-channel which is expressed by a model of HHC is described. Under the existence of the HHC model, several parameters effects on the assumption of local thermal equilibrium (LTE) are investigated.

Key words - Heat conduction; composite; porous channel; hyperbolic model; thermal equilibrium assumption.

I. INTRODUCTION

The huge and fast spread of the microeletromechanical devices and its applications such as in micro-pumps, micro-turbines, and macro robotics, and in electronic equipment cooling leads to big interests in its thermo-fluid behavior.

The developing of micro-scale fluidic and thermal systems normally with characteristic length of the order of 1–100 μm and frequently operate in environmental gaseous at normal conditions, where the order of the molecular mean free path is of 100 nm. Therefore, the Knudsen number in these cases, which is the fraction of the (mean free path) of gas molecules to the characteristic dimension of channel, is in the range from 10^{-3} to 10^{-1} especially the temperature- jump and velocity- slip regime. No doubt then the need to study the effect of temperature jump and slip flow near wall must be taken it to consideration. There are many dominant factors within the micro-scale that have been recognized through a number of numerical, analytical, and experimental works.

According to the continuum flow analysis the results show failure in the approximations for the micro-scale flows as the flow gradients characteristic length (L) reaches the average distance which is moved by molecules between collisions (mean free path, λ).

The Knudsen number (Kn = λ/L) is used as an indicator for the flow rare faction degree of or the flow problem scale. Rare faction or micro-scale effects are disregarded by the Navier- stokes equations which are only precise at a very small Kn (Kn < 0.001). There are many investigations of the thermal models behavior of microchannels using different designs models, geometry and operating parameters. Many studies investigate the model of parabolic (diffusion) heat conduction. This model is capable of explain the thermally behavior of these microchannel in many realistic applications. though, there are many cases in which the heat of the HHC model is used as essential [1]. Examples of that model could be seen in the following instances: rapid transient heat conduction process, heat conduction at cryogenic temperatures high rate of heating processes and situations occupy high temperature gradient like the heat in micro- systems. Covering the temperature variation and heat flux through the domain of fluid. Cattaneo and Vernotte [2-3] recommended separately modified model of heat flux as follows.

$$\vec{q}\left(t+\bar{\tau},\vec{r}\right)=-k\vec{\nabla}T\left(t,\vec{r}\right) \qquad (1)$$

Where $\vec{q}$ is the heat flux vector, $\bar{\tau}$ is the phase lag in the heat flux vector and k is the thermal conductivity. (The effect) heat flux vector and (the cause) temperature variation across a volume of material are shown by the constitution law of Eq.(1) happen at different instant of time and the time delay between the temperature gradient and the heat flux is the relaxation time $\bar{\tau}$.

The first under taken analysis were in slip- flow regime which was the laminar heat transfer. they were under taken by [4-5] for parallel plate channel in the form of tubes and uniform heat flux or uniform wall temperature with circular tube using theory of continuum subjected to temperature jump and slip velocity boundary conditions. Many studies were conducted to investigate the slip flow problem in microrubes [6]. Still slip flow in micro-channels these require a 2– dimensional approach, its solution is moderately difficult comparing with that of the slip flow in microrubes.

Moreover, there are many studies focused on the study of the slip flow in micro-channels that are summarized in this study traced the heat transfer slip flow in micro-channels [7]. The studies results with the fact that the heat transfer decreases, increases, or stays unaffected, compared to non-dimensional variables that contain effects of rare faction and the

wall/fluid interaction. After that, there has been on huge interest in research of micro system works over the last decade [8-14].

For more than three decades, the investigations and analysis for the heat transfer media have evolved as a consequence of its significance in the engineering studies applications. Nield and Bejan [15] pointed to a new intangible improvement and applications of convection of (LTE) were it Supposedly both solid and fluid are in LTE so only single energy equation is taken into consideration. However, some studies consider the two phase model because they depend on 2-energy equations for the solid and fluid domains [16-20].

II. ANALYSIS

Consider an unsteady fluid flow naturally convicted into a parallel plate micro channel which is saturated with porous media problem. The transient in the thermal behavior channel is because of an unexpected change in the channel wall temperature. Referring to Fig. 1. And taking into account the boundary and initial conditions, the energy equations for both domains (solid and fluid) in the non-dimensional form for the HHC model are given as:

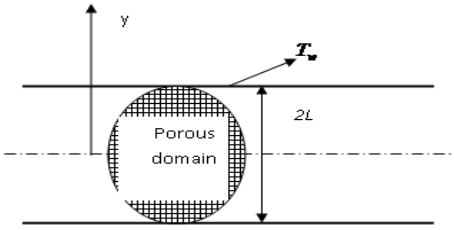


Figure 1 Schematic representation of the domain under consideration

$$\tau_f \frac{\partial^2 \theta_f}{\partial \eta^2} + \frac{\partial \theta_f}{\partial \eta} = \frac{\partial^2 \theta_f}{\partial Y^2} + Bi\left(\theta_s - \theta_f\right) + \tau_f \frac{\partial}{\partial \eta}\left(\theta_s - \theta_f\right) \quad (2)$$

$$\tau_s \frac{\partial^2 \theta_s}{\partial \eta^2} + \frac{\partial \theta_s}{\partial \eta} = \frac{K_R}{C_R}\frac{\partial^2 \theta_s}{\partial Y^2} - Bi\left(\theta_s - \theta_f\right) - Bi\tau_s \frac{\partial}{\partial \eta}\left(\theta_s - \theta_f\right) \quad (3)$$

where $C_R = \frac{(1-\varepsilon)\rho_s c_s}{\varepsilon \rho_f c_f}$, $Bi = \frac{h_v L^2}{k_f}$, $K_R = \frac{k_s}{k_f}$, $\theta = \frac{T - T_\infty}{T_\infty}$

The dimensionless parameters which are used:

$$\tau = \frac{\bar{\tau}}{t_o} \qquad \eta = \frac{t}{t_o} \qquad Y = \frac{y}{L}$$

The initial and boundary conditions are:

$$\theta_s(0,Y) = \theta_f(0,Y) = 0$$

$$\frac{\partial \theta_s(0,Y)}{\partial \eta} = \frac{\partial \theta_f(0,Y)}{\partial \eta} = 0$$

$$\theta_s(\eta,1) - 1 = Kn\frac{\psi}{\Pr} Q_s(\eta,1),$$

$$\theta_f(\eta,1) - 1 = Kn\frac{\psi}{\Pr} Q_f(\eta,1), \quad (4)$$

$$\frac{\partial \theta_s(\eta,0)}{\partial Y} = \frac{\partial \theta_f(\eta,0)}{\partial Y} = 0$$

Equations (2-4) are solved numerically based on finite difference technique.

III. RESULT AND DISCUSSIONS

The effects of several parameters on the validity of the assumption of thermally equilibrium transient natural convection flow within porous-micro-channel as described by a HHC model is investigated in Figs. 2-5.

Figure 2 illustrate the transient performance of the solid and fluid temperatures difference at different K_R. It ca be noticed that, with decreasing K_R, the divergence between the solid and fluid temperatures increases, which imply that as increasing K_R, solid domain's thermal resistance decreases or the fluid thermal resistance increases

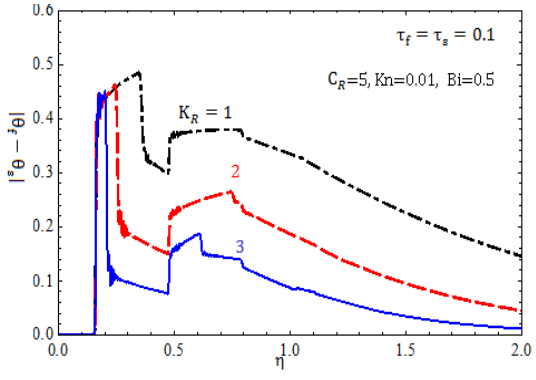


Figure 2 : Transient behavior of the difference between the fluid and solid temperatures $|\theta_f - \theta_s|$ at different K_R

Total ratio of the thermal capacity C_R effect on the transient performance of the difference between the solid and fluid temperatures is given in Fig 3. It can be noticed that the variation between the solid and fluid temperatures increases as rising the value of

C_R. Very big C_R involve that the fluid domain has small total thermal capacity $\varepsilon \rho_f c_f$, and the solid domain has high total thermal capacity $(1-\varepsilon)\rho_s c_s$. As a result, that solid domain, which caries the thermal disturbance effect, is not capable of moving large amount of its energy to the fluid domain, which is not enough to lift the temperature of fluid and this condition requests more time and may not be secured.

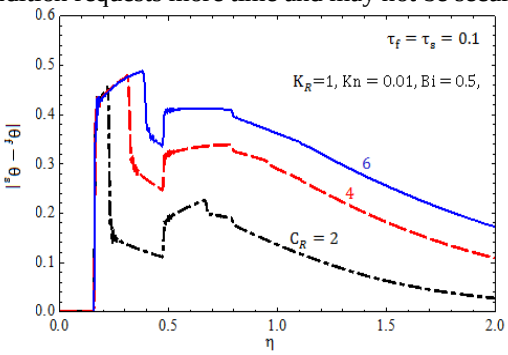


Figure 3: Transient behavior of the difference between the fluid and solid temperatures $|\theta_f - \theta_s|$at different C_R

Figure 4 illustrate the Biot number effect on the transient behavior of the variation between the solid and fluid temperatures. It is clear from this figure that as Biot number increases the difference decreases especially for $\eta > 0.5$. This means that Bi number effect on the temperature difference is unimportant at high values of Bi.

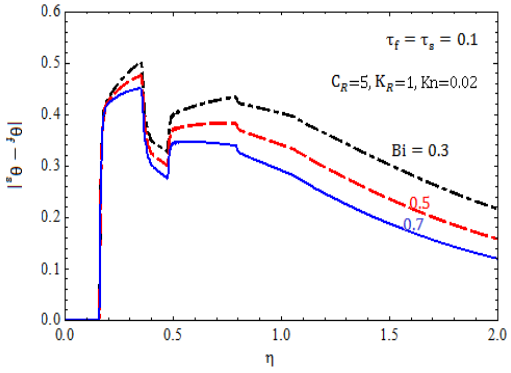


Figure4:Transient behavior of the difference between the fluid and solid temperatures $|\theta_f - \theta_s|$at different Bi

Figure 5 gives the effect of Knudsen number on the transient behavior of the difference between the solid and fluid temperatures. It is clear that the deference increases as the value of Kn decreases for $\eta < 0.5$ and in contract for $\eta > 0.5$.

The effect of different τ_f values on the transient behavior of the solid and fluid temperatures difference is shown in Fig. 6. From this Figure it can be noticed that the variation| θs-θf | increases as τ_f increases

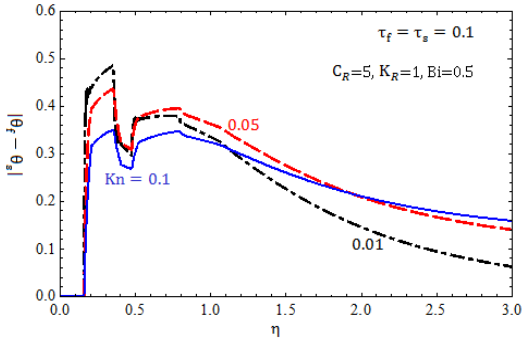


Figure5 :Transient behavior of the difference between the fluid and solid temperatures$|\theta_f - \theta_s|$ at different Kn

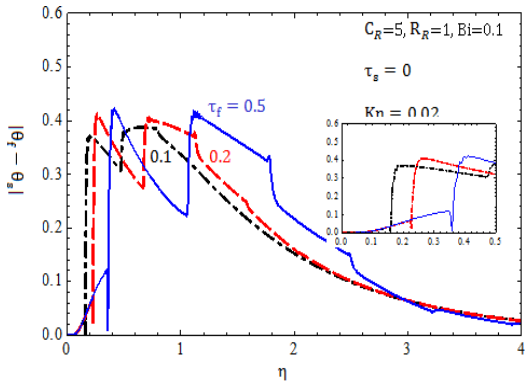


Figure 6: Transient behavior of the difference between the fluid and solid temperatures $|\theta_f - \theta_s|$at different τ_f

1.
2. **CONCLUSIONS**
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Assumption of Thermal equilibrium in porous channel within natural convection transient flow as expressed by a HHC model is investigated. It is found that the assumption of LTE is mostly significant affected by the Biot number, total thermal capacity ratio and volumetric thermal conductivity ratio. The assumption of LTE is secured for great values of Biot number, phase lag in heat flux, total thermal capacity ratio

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