Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

THE MICRO-TUBE HEAT TRANSFER AND FLUID FLOW OF AQUEOUS SOLUTIONS WITH ETHYLENE GLYCOL

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Abstract: *The main purpose of the paper is to investigate numerical modeling of the conjugate heat transfer and fluid flow through the micro-tube considering as a work fluid Ethylene Glycol. There were studied the pressure drop and heat transfer coefficient for three different aqueous solutions of Ethylene Glycol (30%, 40% and 50%) in two regimes: heating and cooling, the main conclusions being scribed in direct connection with the simulations involved by the study of this type of liquid.*

Key words: *micro-channels, viscous, heating, Ethylene-Glycol, Brinkman number*

1. INTRODUCTION

The thermal management of the electronic devices and power sources became the challenging issue in the last decade because of both, miniaturization and heat transfer rate increasing. The various cooling solutions have been proposed using both the single and two-phase heat transfer.

Micro Thermal Systems (MTS), defined as the systems in which the key size has a length scale of a micrometer, could attain the high heat transfer coefficients. For instance, they are used as the cooling devices for LSI chips. On the other hand μ - TAS (Micro Total Chemical Analyzing System), MEMS (Micro Electric – Mechanical Systems) or bio – chips are some of the examples of MTS (Lelea, 2009).

Koo et al, studied the effects of viscous dissipation on the temperature field and also on the friction factor using dimensional analysis and experimentally validated computer simulations for three different working fluids (water, methanol and iso-propanol) in micro-tubes and micro-channels. The variation of temperature with the Reynolds number was studied for rectangular channels and there was made a comparison between the experimental data and the computational results (Koo, 2004).

Celata et al, analyzed the issue of scaling effects that cause influential effects when channel geometry is reduced below a certain limit. The results were connected with the role of viscous heating in micro-channel flows, it's occurrence in the Navier Stokes equations and also there was made an experimental validation for verifying it's presence in practice. The experimental results were compared with the values existing in literature for compliance (Celata, 2006).

Hooman et al, analyzed theoretically the role of viscous dissipation on forced convection, with temperature-dependent viscosity and thermal conductivity, through microchannels and micropipes, under isoflux wall boundary condition. The analytical results can be used for macrochannels where continuum assumption, and hence, no-slip condition is still valid (Hooman, 2009; Hooman, 2010).

Tunc and Bayazitoglu investigated the convective heat transfer for steady laminar hydrodynamically developed flow in microtubes with temperature jump at the wall and viscous heating conditions. It was concluded that Nusselt number takes higher values for cooling and lower for heating (Tunc, 2001).

2. SIMULATION PART AND DISCUSSION

2.1 Establishing the relations for Nu, Po, Re criteria and Br number

The thermal properties of Ethylene Glycol are presented below:

Because Ethylene Glycol is an aqueous solution, the general form for thermal conductivity and specific heat is :

$$k = c_p = A + B \cdot T + C \cdot T^2$$

Where : T, K, temperature
A, B, C, coefficients with given values $(^{****})$

The following set of partial differential equations is used to describe the studied phenomena, considering the variable thermo-physical properties of the fluid and viscous dissipation:

Continuity equation:

$$\frac{\partial(\rho(T) \cdot u)}{\partial z} + \frac{1}{r}\frac{\partial(r \cdot \rho(T) \cdot v)}{\partial r} = 0 \qquad (1)$$

Momentum equation:

$$\frac{\partial(\rho(T)vu)}{\partial r} + \frac{\partial(\rho(T)uu)}{\partial z} = -\frac{dp}{dz} + \frac{1}{r}\frac{\partial}{\partial r}\left(\mu(T) r \frac{\partial u}{\partial r}\right) \qquad (2)$$

Energy equation:

$$\frac{\partial(\rho(T)c_p(T)vT)}{\partial r} + \frac{\partial(\rho(T) \cdot c_p(T)uT)}{\partial z} = \left[\frac{1}{r}\frac{\partial}{\partial r}\left(k(T) \cdot r \frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(k(T)\frac{\partial T}{\partial z}\right)\right] + \mu \cdot S_v \qquad (3)$$

Where the viscous dissipation term is defined as:

$$S_v = 2 \cdot \left[\left(\frac{\partial v}{\partial r}\right)^2 + \left(\frac{v}{r}\right)^2 + \left(\frac{\partial u}{\partial z}\right)^2\right] + \left[\frac{\partial v}{\partial z} + \frac{\partial u}{\partial r}\right]^2 \qquad (4)$$

The heat transfer coefficient

$$h = \frac{q}{t_w - t_b} \qquad (5)$$

The Brinkman number for constant wall heat flux is defined as:

$$\mathrm{Br} = \frac{u_m^2 \cdot \mu}{q \cdot D_i} \qquad (6)$$

Where:
c_p , J/kg K, specific heat
D , m, tube diameter
h, W/m^2 K, heat transfer coefficient
k , W/mK, thermal conductivity

Nu , Nusselt number
Po , Poiseuille constant
R, m, tube radius
Re , Reynolds number
T , K, temperature
u , v , m/s, velocity components
x, z, spatial coordinates
Greek symbols
μ , Pa s, viscosity
ρ , kg/m^3, density

The partial differential equations (1)–(4) together with boundary conditions, are solved using the finite volume method described in (Patankar, 1980). First, the parabolic flow field condition is considered and the velocity field is solved. The temperature field, as a conjugate heat transfer problem, was then solved as the elliptic problem using the obtained velocity field. As a consequence of the temperature dependent fluid properties, iterative procedure is needed to obtain the convergence of the fluid properties (viscosity, thermal conductivity, density and specific heat capacity) through the successive solution of the flow and temperature field. Further details regarding the numerical code are presented in (Lelea, 2007).

2.2 Pressure drop and heat transfer coefficient variation

There were analyzed the pressure drop and variation for the heat transfer coefficient for three different concentrations of aqueous solutions of Ethylene Glycol (30%, 40% and 50%), considering heating and cooling regimes for a value of 0.5 for the Brinkman number (+0.5 for heating regime and -0.5 for cooling regime).

The obtained results are presented in Figures 1 and 2.

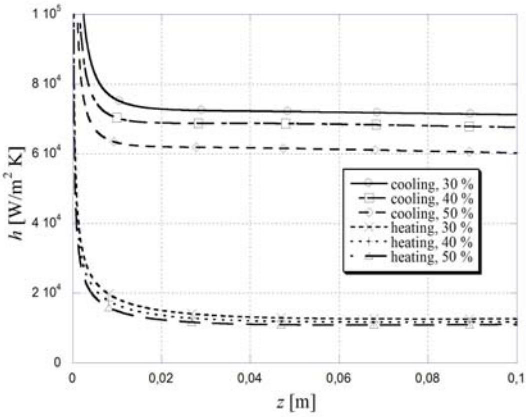

Fig. 1. Heat transfer coefficient variation with z coordinate

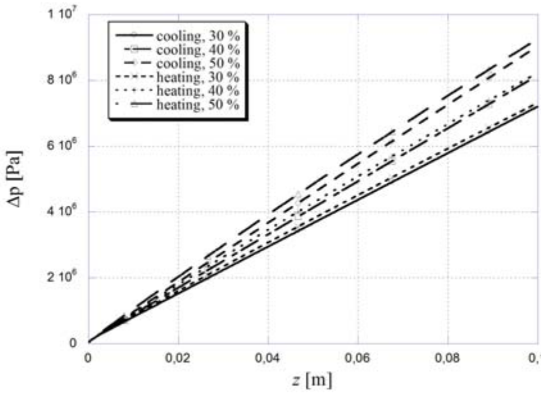

Fig. 2. Pressure drop variation with z coordinate

3. CONCLUSIONS

The numerical model for heat and fluid flow through the pipes, considering the viscous heating of the fluid. The aqueous solutions of Ethylene Glycol (30%, 40% and 50%) were considered as the working fluid. The Brinkman number is used to estimate the viscous dissipation effect with Br = 0.5 (both for heating and cooling. The following conclusions are outlined:

- Both the heat transfer coefficient and pressure drops are influenced by the viscous heating
- Different behaviours of the covered parameters are observed for heating or cooling of the tube wall.
- In the case of heat transfer coefficient the boundary layer evolution of the heat transfer coefficient is observed regardless the Ethylene Glycol Vol% in water
- The Ethylene Glycol Vol% in water slightly influences the heat transfer coefficient during the heating case
- Contrary to heating, during the cooling case the heat transfer coefficient is decreasing as the Vol% is increasing

4. ACKNOWLEDGMENT

This work was supported by CNCSIS –UEFISCSU, project number 670 PNII – IDEI 938/2008.

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