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THE MICRO-TUBE HEAT TRANSFER AND FLUID FLOW OF METHANOL

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Abstract: *The numerical modeling of the conjugate heat transfer and fluid flow through the micro-tube was presented in the paper, considering both situations: when is considered the existence of viscous heating and without the presence of viscous heating. One fluid with temperature dependent fluid properties is considered: methanol. Two different heat transfer conditions are considered: heating and cooling and the influence of the viscous heating on Nu and Po criteria are analyzed.*

Key words: *micro-channels, viscous heating, Nu number, Po number*

1. INTRODUCTION

The recent technological developments and advances in devices that ensure the comfort of everyday life increases the importance of micro-channel heat transfer and fluid flow. As the scale of the systems is decreasing, the effects like thermal properties variation or viscous dissipation influence the thermal and hydrodynamic behavior and could not be neglected.

The first microchannel fluid flow experiment was made by Poiseuille in 1870 on a glass tube with internal diameter ranging from 29 to 140 μm with water as the working fluid and non-heating working conditions. Based on these results, the well-known relation for the volume flow rate was established and extended lately to the macrochannels (Lelea, 2009).

Micro Thermal Systems (MTS) (Nishio, 2003), 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 (Lelea, 2009).

Arici et al. (Arici, 2009) made a numerical study related with thermally developing the laminar forced convection in a pipe including the wall conductance and viscous dissipation. The viscous dissipation is found to affect both the wall and bulk fluid temperature profiles. Significant viscous dissipation effects have been observed for large Br. Its effect becomes more pronounced downstream (Lelea, 2010).

Morini, (Morini, 2005) analyzed theoretically the limit of significance for viscous dissipation effects in microchannel flows. It was found that viscous heating decreases the fluid viscosity, so the friction factor decreases as the Reynolds number increases (Lelea, 2010).

2. EXPERIMENTAL PART AND DISCUSSION

2.1 Establishing the computational relations for Nu and Po criteria

The thermal properties of Methanol are presented below:

- Thermal conductivity:

$$k = 53.694 - 0.65369 \cdot T + 0.0029916 \cdot T^2 - 6.0761 \cdot 10^{-6} \cdot T^3 + 4.6195 \cdot 10^{-9} \cdot T^4$$

- Dynamic viscosity:

$$\mu = 0.0008153 - 1.2371 \cdot 10^{-5} \cdot \mathrm{T} + 9.5 \cdot 10^{-8} \cdot \mathrm{T}^2 - 2.9167 \cdot 10^{-10} \cdot \mathrm{T}^3$$

- Heat capacity:

$$c_p = 42579.0 - 374.19 \cdot \mathrm{T} + 1.1487 \cdot \mathrm{T}^2 - 0.0011539 \cdot \mathrm{T}^3$$

- Density:

$$\rho = 956.01 - 0.21085 \cdot \mathrm{T} - 0.0011968 \mathrm{T}^2$$

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:

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

Momentum equation:

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

Energy equation:

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

Where the viscous dissipation term is defined as:

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

Darcy friction factor is defined by the following equation:

$$f = \frac{-(dp/dz) \cdot D_i}{\rho \cdot u_m^2 / 2} \tag{5}$$

and a Re is defined as:

$$\mathrm{Re} = \frac{\rho \cdot u_m \cdot D_i}{\mu} \tag{6}$$

So, from (5) and (6) the local Po can be obtained in the following form:

$$\mathrm{Po} = f\,\mathrm{Re} = \frac{-2 \cdot (dp/dz) \cdot D_i^2}{u_m \cdot \mu} \tag{7}$$

While the local Nu number is defined with the following equation:

$$\text{Nu} = \frac{h \cdot D_i}{k(T_m)} \quad (8)$$

Where: c_p , J/kg K, specific heat
D , m, tube diameter
f , Darcy friction factor
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

2.2 Nu and Po criteria variation – first case: heating without viscous heating influence

The first case which was analyzed for the Nu and Po criteria variation taking into consideration Methanol as test fluid had as a fundamental basis the absence of viscous heating between the fluid and the walls of the micro-channel.

The graphic representation of the simulations for Nu and Po criteria, considering both the heating and cooling regimes are presented below:

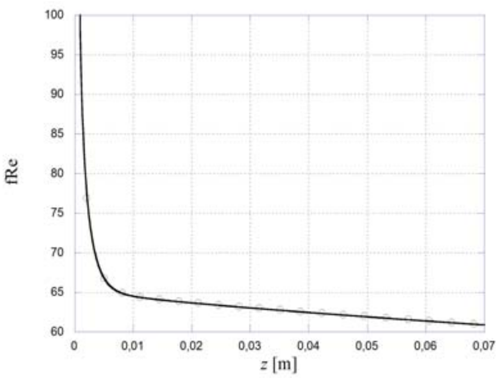

Fig. 1. Po criteria variation with axial coordinate

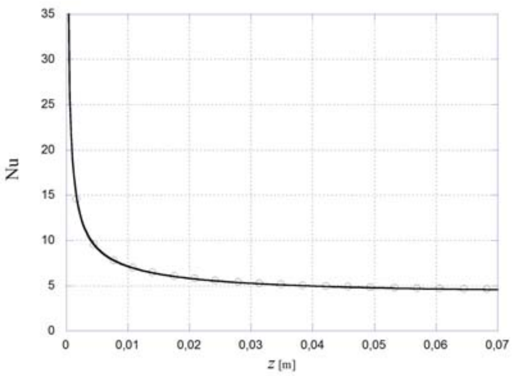

Fig. 2. Nu criteria variation with axial coordinate

2.3 Nu and Po criteria variation – second case: heating with viscous heating influence

The second case which was analyzed for the Nu and Po criteria variation taking into consideration Methanol as test fluid had as a fundamental basis the presence of viscous heating between the fluid and the walls of the micro-channel.

The graphic representation of the simulations for Nu and Po criteria, considering both the heating and cooling regimes are presented below.

4. CONCLUSIONS

The numerical model for heat and fluid flow through the pipes, considering the viscous heating of the fluid and methanol as the working fluid was analyzed. Also the temperature dependent fluid properties are considered.

In the case of the thermal results, the Nu number exhibits the classic boundary layer flow with conventional fully developed value of Nu = 4.36. On the other hand for local Poiseuille number Po=fRe it is not constant with fRe_{fd} = 64 as expected but decreasing in downward the fluid flow.

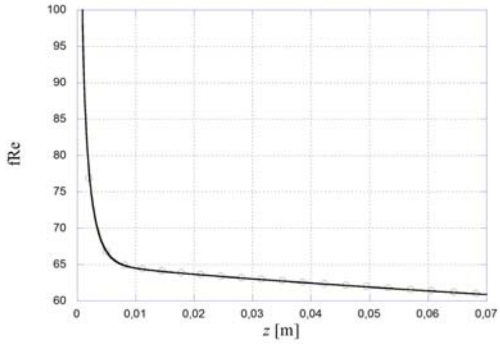

Fig. 3. Po criteria variation with axial coordinate

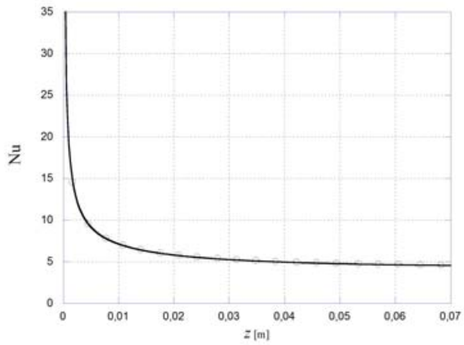

Fig. 4. Nu criteria variation with axial coordinate

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