EFFECTS OF MATERIAL PROPERTIES ON LIQUID FLOW AND HEAT TRANSFER IN RECTANGULAR MICROCHANNELS

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Summary The effects of material properties on the liquid flow and heat transfer in microchannel were investigated based on the numerical simulation method. Thermal boundary conditions are same for different cases in the numerical simulation but the flow and heat transfer characters are quite different because of variations of the liquid viscosity, specific heat and thermal conductivity. These parameters except the viscosity have effects on the Nusselt number but the variable viscosity makes the friction factor changed.

INTRODUCTION

To improve the reliability and accuracy of the microflow devices like micromixer, microsensor and so on, some basically properties of microflow must be investigated. The physical properties of liquid and solid materials which can assumed to be constant for conventional size channels should be careful investigated in microscale flow. A three-dimensional model was developed by Fedorov and Viskanta [1] to investigate flow and conjugate heat transfer in the micro-channel. The wall temperatures increase drastically in the longitudinal distance within the small inlet portion of the channel and then do not change. Experimental studies of the convection heat transfer in microchannels presented by Morini [2] show that the variations of liquid properties have obvious effects on the experimental results. The present paper is devoted to numerically simulate flow and heat transfer in microchannel and focuses on the effects of liquid and solid material physical properties.

SIMULATION MODEL AND DATA REDUCTION

Simulation model

Microflow can be simulated by two different methods. For liquid, the continuum assumption is suitable for the microflow [3]. In this paper, the simulation method based on the continuum assumption is used. The microchannel of simulation with rectangle cross-section [4] is shown in Fig.1. Where H_1=5000μm, H_2=14200μm, W_1=150μm, a=300μm, b=800μm, length of the microchannel is 50mm and the heat flux is 187500W/m^2. The physical properties of water and copper are assumed to change with the temperature. Piecewise linear relationship between the temperature and properties of copper is shown in Table 1. Morini [2] indicated that the relationship of temperature and viscosity for water can be shown as

$$\ln\left(\frac{\mu}{1.788e-3}\right) \approx -1.704 - 5.306\left(\frac{273}{T}\right) + 7.003\left(\frac{273}{T}\right)^2 \tag{1}$$

Table 1 Properties of copper at different temperature

Temperature (K)	Specific heat (J/(Kg K))	Thermal conductivity (W/(m K))
293	384	109
373	394	124
473	408	142

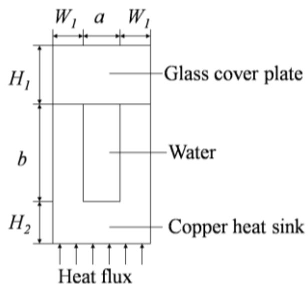

Fig.1 The cross-section of simulation model

Data reduction

The friction factor which evaluates the resistance of liquid in the microchannel is obtained from Darcy Equation.

$$f = 2\Delta p \frac{D_h}{L} \frac{1}{\rho u^2} \tag{1}$$

where Δp is the pressure drop between the inlet and outlet, ρ is the water density, and u is the average velocity of water flow through the microchannel. Nusselt number based on the heat transfer coefficient is defined as Eq.(2).

$$Nu = \frac{Mc_p\left(T_{out} - T_{in}\right)}{A\Delta T} \frac{D_h}{\lambda} \tag{2}$$

where λ is the water thermal conductivity, A is the area of heat transfer wall, ΔT is the temperature difference between the wall and water, M is the mass flow rate of water, c_p is the specific heat of water, and T_{out} and T_{in} are the temperature of water at the outlet and inlet of the microchannel.

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RESULTS AND DISCUSSION

For a microchannel with determined geometry, the Nusselt number obtained from Eq.(2) is a dimensionless number that indicates the heat transfer of fluid flow in a microchannel is varied with the Reynolds number and relates to the apparent friction factor and Reynolds number.

Effect of heat properties of copper

Liu and Pang [5] presented that the simulation profile of Nusselt number under different Reynolds number obtained in constant properties are parallel to but not the same as experimental results of the literature [4]. They attributed the difference between simulation results and experiment ones to two reasons that the physical properties of the solid material used in the simulation including density, specific heat and heat transfer coefficient are not quite identical with those in the experiment but average values of them and there are some differences cased by the measuring methods of the experiment. The effects of copper's specific heat and thermal conductivity are shown in Fig.2. The Nusselt number increases gradually with the Reynolds number for every method and the three profiles are following the similar trend. The physical properties are changing during the experiment process so the simulation result of vary properties can fit the experiment one quite well but the constant properties result can only predict the tendency. Physical properties of copper have no effect on the flow performance because the liquid properties and boundary conditions of the flow did not change (As seen in Fig.3).

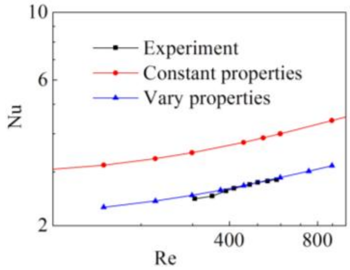

Fig.2 Effects of copper's physical properties on Nusselt number

Effect of water's viscosity

At the same driven pressure, the viscosity which depends on the temperature of water increases the velocity but decreases the temperature of the water in the microchannel. The apparent friction factor for viscosity depended on temperature is obviously smaller than that for constant viscosity and the effect is larger at low Reynolds number than high ones as shown in Fig.4. While the variable viscosity huge improves the velocity and the Reynolds number of the water flow, the heat transfer performances, such as Nusselt number, are also improved. So the profiles of Nu-Re are the same for constant and variable viscosity (As seen in Fig.5).

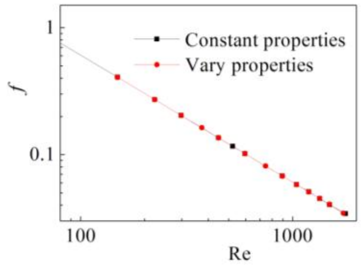

Fig.3 Effects of copper's physical properties on apparent friction factor

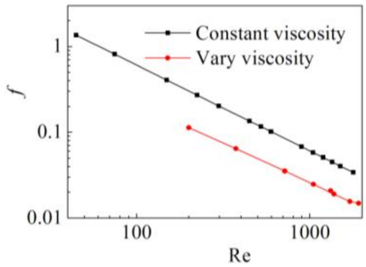

Fig.4 Effects of water viscosity on apparent friction factor

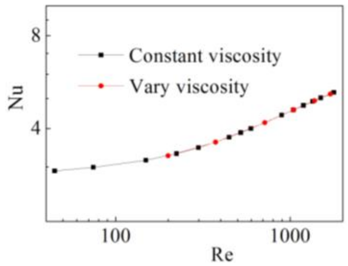

Fig.5 Effects of water viscosity on Nusselt number

CONCLUSIONS

Fluid flow in rectangular copper microchannel was numerically investigated and first compared with experiment datum. It is found that Nu-Re profile of variable copper physical properties can fit the experiment one quite well but the constant properties can only predict the tendency. The apparent friction factor for viscosity depended on temperature is obviously smaller than that for constant viscosity.

ACKNOWLEDGEMENT

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