Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(6):2020-2024

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

The unsteady flow characteristic research on the initial period flow of micro channel

Wang Xiaorong, Zhang Jinxin, Tian Guizhong, Xue Long and Cao Weilong

Institute of Mechanical Engineering, JiangSu University of Science and Technology, Zhenjiang, China

---

ABSTRACT

To obtain stable solution flow is very important to biological cell micro injection; this paper adopts the method of computational fluid dynamics, unsteady flow dynamic characteristics of the conical micro channel initial flow were researched. The independence of the model grid was verified; the error between exit speed and the theoretical value is within 5%. Established the micro channel gas-liquid two phase unsteady flow model, under different inlet pressure, flux and flow resistance characteristics of the solution in the conical micro channel were studied. Through the study found that flux is fluctuation in the initial period of the micro channel flow, under the minimum inlet pressure that can flow, except the time liquid film flow fluctuation broken, flow tends to be stable within the entire circulation time, and the flow is very small. With the increase of inlet pressure, micro channel flow increasing, within flow time flux volatility increases, and the greater the inlet pressure, the earlier the volatility moments. Micro channel flow resistance change over time, the smaller the inlet pressure, the greater the resistance and the instantaneous maximum flow resistance after flow stability. The results show that Choose inlet pressure slightly higher than the critical flow pressure can get good liquidity; flow is stable and easy to control. The study provides reference for the research of biological micro fluid injection.

Key words: Microchannel; microflow; biological injection; flow characteristic

---

INTRODUCTION

Micro channel device has excellent performance and is widely applied in biological cell injection, micro flow heat exchange, micro fluidic device, bionics, printer nozzle, and transmission of reactants, particle separation and the micro flow sensor [1-4]. With the development of micro/nano technology, more attention paid to the study of micro channel flow and heat transfer, the research of micro-scale flow and heat transfer not only provide wider space for the application of MEMS technology, but also has very important academic significance to enrich and perfect the theory of fluid mechanics [5-7].

At present, the study of micro channel flow characteristics are mostly steady flow and the fluid resistance characteristics after flow stability. Alma Halelfadl focused on analytical optimization of a rectangular micro channel heat sink, they analyzed the effects of the temperature, the channel aspect ratio, the channel wall ratio to the flow characteristic [8]. Na Liu had studied the pressure drop during condensation of R152a in circular and square micro channels .The results show that heat-transfer coefficients and pressure drop both increase with increasing mass flux and vapor mass quality while decrease with increasing saturation temperature. Channel geometry has much effect on heat transfer at low mass fluxes while has little effect on pressure drop [9]. Yan Han have investigated the characteristics of gas flow in micro channels under the coupled effects of random surface roughness and velocity slip by the method of computational fluid dynamics [10].

Due to the phenomenon of capillary in micro channel, it needs to overcome the surface tension in the process of initial flow to flow, so flux fluctuation and uneven phenomenon exist in flow process of the initial flow and the research is relatively small. But given the flow stability is of great significance for injection, the initial moments flux has great influence on the subsequent micro fluid flow. Due to the initial flow cannot obtain the quantitative solution by adjusting biological micro injection machine, so it is necessary to simulate the flow process of micro channel initial flow. In this paper, through the simulation of solution flow process in micro channel initial period, the flow characteristics are analyzed and the results can provide references to the research in the field of micro fluid injection.

1. MICRO CHANNEL FLOW PROCESS SIMULATION

2.1 Control equation

Due to Kn < 0.1, so the control equation is still continuous equation and Navier - Stockes equation:

$$\frac{d\rho}{dt} + \rho\frac{\partial u_j}{\partial x_j} = 0 \tag{1}$$

$$\rho\frac{du_i}{dt} = \rho f_i - \frac{\partial}{\partial x_i}\left(p + \frac{2}{3}\mu\frac{\partial u_j}{\partial x_j}\right) + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \tag{2}$$

Due to the flow of incompressible flow, thus:

$$\frac{\partial u_j}{\partial x_j} = 0 \tag{3}$$

$$u_j\frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{1}{\rho}\frac{\partial}{\partial x_j}\left(\mu\frac{\partial u_i}{\partial x_j}\right) \tag{4}$$

The above equation can be written as follows:

$$\frac{\partial}{\partial x_j}(\mu_j\varphi) = \frac{\partial}{\partial x_j}\left(\Gamma_\varphi\frac{\partial\varphi}{\partial x_j}\right) + S_\varphi \tag{5}$$

Thereinto, φ is the general dependent variable, S_φ is all the other phase that cannot be represented as convection or diffusion item.

2.2 Calculation model and boundary conditions

This article uses the taper pipe channel to simulate process of micro needle injection, shaft section of channel model is shown in figure1, circular diameter of channel section is D and d respectively, long is L, working medium is water. Boundary conditions are shown in figure 2, inlet pressure is given, outlet pressure is atmospheric pressure, and no slip wall for adiabatic wall, initial flow area Ⅰ is water, regionalⅡ is air, temperature is 293K, the effect of surface tension is considered.

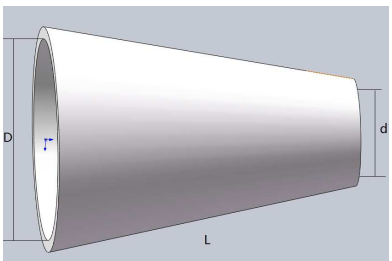


Fig 1 Channel model simplified figure

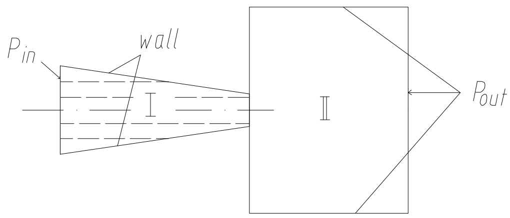


Fig 2 Boundary conditions

2. NUMERICAL CALCULATION

Grid computing area figure is shown in figure3, the grid total quantity is 9600. Before the formal calculation, it needs to verify the result of calculation is not dependent on the grid and the correctness of the inspection procedures, for pipe of the diameter D and length L laminar flow field, numerical simulation was done, and compared the velocity distribution at the exit calculated with the analytical solution of the pipe laminar flow field. Due to the pipe geometric symmetry, only calculates half of the flow field, the calculation results are shown in figure 4, compared with the theoretical value, the error of numerical calculation results is less than 5%.

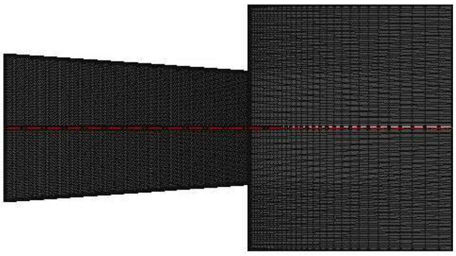


Fig 3 Grid of computing domain

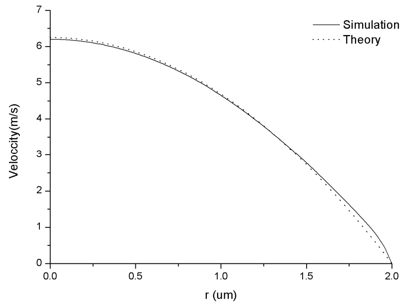
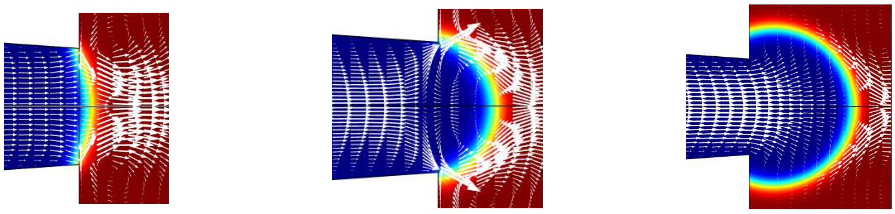


Fig 4 Entrance velocity diagram

3. CALCULATION RESULTS AND ANALYSIS

3.1 The influence of different inlet pressure on the flux

For the above channel, micro needle injection channel flow characteristics were calculated when the inlet pressure P_{in} = 0.0925, 0.095, 0.10, 0.12 MPa, including the P_{in} = 0.0925 MPa, which is the minimum inlet pressure micro needle syringe can flow, figure5 is the volume fraction velocity vector diagram of P_{in} = 0.0925 MPa, figure6 is the micro channel mass flow rate under different inlet pressure.



t=0.1us t=1us t=10us

Fig5 P_{in} = 0.0925 MPa flow state diagram at different time

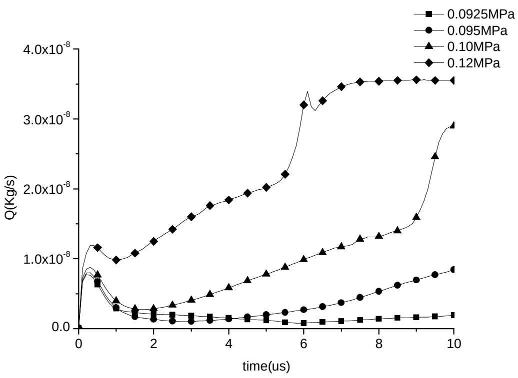


Fig 6 Mass flow rate variation over time

The figure5 shows that at the initial flow moment, for the water in the micro channel, and the outside world is the gas, liquid membrane formed at the gas and liquid junction, liquid membrane have a retarding effect on flow, this effect is called surface tension and the size of surface tension is with the relevant of the shape of the liquid film. In order to observe the flow state of water near the liquid film easily, the micro channel exit flow area was intercepted and amplified which is shown in figure5. When the P_{in}=0.0925MPa, the initial stage of the micro channel flow, due to the influence of surface tension, liquid membrane formed at the exit, and no liquid flow inside the micro needle syringe; As time increases, the liquid film increases gradually, when t=1 us, liquid film reaches critical broken state, water reflux near the liquid membrane, it indicates that there are inverse pressure gradient; When liquid membrane broken, water spewing from the micro channel; when t=10 us, the micro channel flow leveling off, spewing water near the micro channel exit formed a mushroom head flow area.

With the increase of inlet pressure, in instantaneous of liquid membrane broken, flow peak increases, and the flow is greater volatility in the short term. When the P_{in}=0.0925 MPa, flow gradually become stable after liquid film crushing, the late flow was stable in 1.92×10^{-14}kg/s, which is the smallest flux. When the P_{in} increases to 0.095MPa, with the increase of time flows slowly rising, when t=10 us, the flux is 3.58×10^{-14} kg/s. When the P_{in}=0.10MPa, flow increased gradually after liquid film crushing, when t=9 us, flow surged, from 1.4×10^{-14} kg/s to 2.5×10^{-14}

kg/s, when the P_{in}=0.12MPa, flow surge moment is t=0.58 us ahead of time, flux sharply increased from 2.1×10^{-14} kg/s to 3.3×10^{-14} kg/s. Visible, when P_{in}=0.0925MPa, under the minimum inlet pressure of the micro channel flow, except flow fluctuation when the liquid film broken, the entire circulation time flow tends to be stable, and the flux is very small. With the increase of inlet pressure, micro channel flow increase, and flux of micro channel increased, and in the circulation time flux volatility increased, the greater the inlet pressure the earlier the volatility moments.

3.2 Influence of different inlet pressure on the drag coefficient

Flow is incompressible flow, the friction coefficient *f* is function of import and export pressure difference *ΔP*, form is as follows:

$$f = \frac{2D_h \Delta P}{\rho U^2 L} \quad (6)$$

Thereinto, *U* is cross section average speed; *ρ* is fluid average density, D_h and *L* are respectively the hydraulic diameter and length of micro channel.

Figures 7 and 8 are outlet pressure and velocity changing with time curve respectively under different inlet pressure, when the inlet pressure is 0.925MPa, export pressure is about 0.9MPa, far higher than the other three curves, and the outlet pressure over time slowly decreases, and exit velocity is relatively stable; When the inlet pressure increased to 0.10MPa, at 8.5us export pressure plummeted to 0.002MPa, exit velocity reached 4.5 m/s at the same time, the syringe will spit out a lot of water at the moment, it is difficult to complete quantitative injection; When the inlet pressure is 0.12MPa, export pressure drop moment is to 6 us in advance, and exit velocity increases to 5.5 m/s. All the above, when the inlet pressure is critical flow pressure, outlet pressure is bigger, flow gently, easy to control.

In order to study the influence of inlet pressure change on the change of the friction factor, figure9 is f changes under different inlet pressure. It can be found that initial moment due to liquid film has not been destroyed, so liquid flow velocity is zero in the micro needle channel, the flow resistance is infinity, when liquid membrane damaged, the instantaneous flow resistance is almost zero. Resistance coefficient decreases with the increase of inlet pressure, drag coefficient is reduced, the peak decreased, and the peak moment in advance, that shows increase he inlet pressure can improve the flow ability of fluid, but the flow fluctuation is bigger, it is not conducive to quantitative injection, and the inlet pressure is too small, micro channel liquidity becomes bad, and even can't flow. Choose inlet pressure slightly higher than the critical flow pressure can get good liquidity; flow is stable and easy to control.

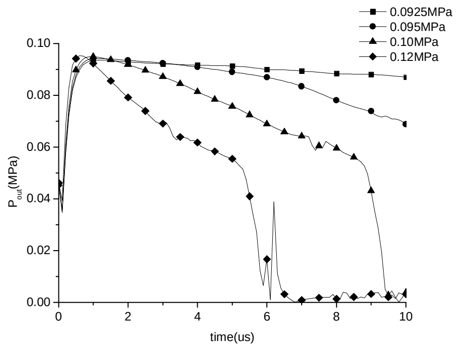


Fig 7 Outlet pressure variation with time

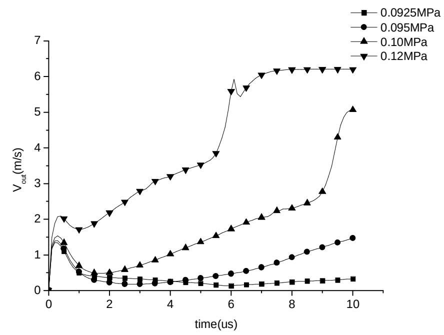


Fig 8 Exit velocity variation over time

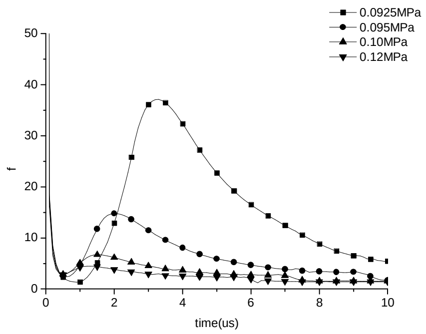


Fig9 Friction coefficient variation over time

CONCLUSION

(1) The flow is fluctuating in the early period of the micro channel flow, under the minimum inlet pressure that can flow, except the flow fluctuation at the liquid film of broken time, flow tends to be stable throughout the circulation time, and flux is very small. Micro channel flow increase with the increase of inlet pressure, and flow volatility increased at whole circulation time, and the greater the inlet pressure, the earlier the volatility moments.
(2) The micro channel flow resistance changes over time, the smaller the inlet pressure, the greater the resistance after flow stability, the greater the instantaneous maximum flow resistance too.
(3) Choose inlet pressure slightly higher than the critical flow pressure can get good liquidity; flow is stable and easy to control.

Acknowledgments
The authors wish to thank the National Natural Science Foundation of Education Department in JiangSu Province for contract 12KJB410001**,** the National Natural Science Foundation of China for contract 51005108, under which the present work was possible.

REFERENCES

[1] Huang, L.; Lee, M. S.; Saleh, K.; Aute, V.; Radermacher, R. *Applied Thermal Engineering* **2014**, *65*, pp.447-457.
[2] Afzal, A.; Kim, K. *Chemical Engineering Science* **2014**, *116*, pp.263-274.
[3] Nandi, T. K.; Chattopadhyay, H. *International Communications in Heat and Mass Transfer* **2014**, *56*, pp.37-41.
[4] Martínez-Ballester, S.; Corberán, J.; Gonzálvez-Maciá, J. *International Journal of Refrigeration* **2013**, *36*, pp.191-202.
[5] Duan, Z.; He, B. *International Communications in Heat and Mass Transfer* **2014**, *56*, pp.25-30.
[6] Ganapathy, H.; Shooshtari, A.; Choo, K.; Dessiatoun, S.; Alshehhi, M.; Ohadi, M. *International Journal of Heat and Mass Transfer* **2013**, *65*, pp.62-72.
[7] Chai, L.; Xia, G.; Zhou, M.; Li, J. *International Communications in Heat and Mass Transfer* **2011**, *38*, pp.577-584.
[8] Halelfadl, S.; Adham, A. M.; Mohd-Ghazali, N.; Maré, T.; Estellé, P.; Ahmad, R. *Applied Thermal Engineering* **2014**, *62*, pp.492-499.
[9] Liu, N.; Li, J. M.; Sun, J.; Wang, H. S. *Experimental Thermal and Fluid Science* **2013**, *47*, pp.60-67.
[10] Yan Han Zhang Wen-Ming Hu Kai-Ming Liu Yan Meng Guang.*Investigation on characteristics of flow in microchannels with random surface roughness. Acta Phys. Sin* **2013**, pp.290-295