

## *The research progress of micro-scale flow and convection heat transfer*

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**Abstract**—Macroscopic fluid flow and heat transfer is currently in the field of modern thermal science. This article analyzes the basic theory, characteristic and research progress of macroscopic fluid flow and heat transfer. Then illustrates the next step for the research focus.

**Keywords**—macroscopic fluid flow; macroscopic heat transfer; research progress

### I. INTRODUCTION

Macroscopic heat transfer is now the academic frontiers of the international heat transfer branches.

Macroscopic heat transfer is aiming at the following law's research: macroscopic thermal conductivity, macroscopic phase change heat transfer, macroscopic convection heat transfer, macroscopic radiation, it has important academic value and Engineering significance. This article analyzes the basic theory, characteristic and research progress of macroscopic fluid flow and heat transfer, and provide a reference for research.

### II. MACROSCOPIC FLUID CHARACTERISTIC

In micro-nano scale, when characteristics of the scale is much larger than mean free path of the fluid molecules, the continuum hypothesis still holds, but due to the characteristics of smaller scale, make the relative importance of various affecting factors changed

#### A. Scale effect

In fluid motion, the force acting on the fluid mainly are the volume and surface forces. Length scale is basic characteristics of the force, the volume force is three times the characteristic length, while the surface force depends on one or two times the characteristics of the scale. With the decrease of the flow scale, the ratio between surface force and volume force increase, up to one million times. This strengthens the interaction of surface force and other surface's effect. In micro-nano scale, surface force and other surface effect play an important role. The increase ratio between

surface and volume will impact the transmission of Mass, momentum and energy through the surface.

#### B. Surface force

The flow in micro-nano system appeared some new phenomena due to the effect of surface force. The surface force can often be neglected in the flow on a large scale. Before discussing different surface force, it is important to know that the force are derived from the intermolecular interaction force. Fundamental forces between the molecules is essentially a short-range force (less than 1nm), but the cumulative effect can lead to a long range effect more than 0.1μm, such as the liquid surface tension effect. In addition, all interaction force between the molecules is essentially the electrostatic force, once the schrodinger equation determines the spatial distribution of electronic, all intermolecular interaction force can be calculated from the classical theory of static electricity, but generally use the experience or half experience's force law.

#### C. Relative surface roughness

In the normal flow, the shape on the wall has no effect to the laminar flow, except turbulent flow and transition region. But in the micro-nano flow, although the flow in the tube is almost laminar flow, with the decrease of the scale, the relative surface roughness (The ratio of wall roughness  $\Delta$  and diameter  $d$ ) increase, thus produce an affection which can't be ignored to micro flow. In the small pipe, even if the roughness is small, the surface roughness can increase the flow resistance of fluid. In the micro-nano flow, not only the size of the roughness element have an effect on flow, the distribution of the unit also has a certain influence on flow.

#### D. Fluid polarity

Fluid presents no polarity in general, but whether the fluid contains polar ion has a significant effect on flow characteristics. For polar fluids, due to the polarity of ion adsorption, the flow resistance will outweigh the nonpolar fluid. Even for non-polar fluid, the flow resistance is also not identical. By the experimental observations of Stemme, the distilled water in the 0.2 μm pipe flow resistance is only one third of the alcohol. Although there isn't a satisfactory explanation about the influence of polar and nonpolar liquids on flow, but the influence of polarity is obvious

### III. THE PARAMETERS OF MICRO-SCALE FLOW FIELD

In the micro-nano scales rarefied gas flow, Often adopt Knudsen number to represent the degree of thin of the fluid. Reynolds number is defined as the ratio of the average molecular free path of the gas and the flow field characteristic scale.

$$Kn = \frac{\lambda}{L}$$

“ $\lambda$ ” is the average of molecular free path, “ $L$ ” is the characteristics of the flow field scale. For gas, the mean free path is molecules’ average distance between the two collision. When the hard sphere model is used, the average of molecular free path can be written as:

$$\lambda = \frac{1}{\sqrt{2}nd^2}$$

“ $n$ ” is the number density of molecules, “ $d$ ” is the molecular diameter. According to the relation between the pressure and temperature

$$p = nk_B T$$

“ $k_B$ ” is the Boltzmann constant, The average of molecular free path can be written as the following form:

$$\lambda = \frac{k_B T}{\sqrt{2}\pi d^2 p}$$

The characteristics of the flow field scale can defined from a certain characteristic length in a system, also can be defined as a macro gradient, for example:

$$L = \frac{\rho}{dp/dx}$$

According to the Knudsen number, we can put the flow is divided into four zones:

$Kn \leq 0.001$ ,	continuous zone
$0.001 < Kn \leq 0.1$ ,	slip zone
$0.1 < Kn \leq 10$ ,	transition zone
$Kn > 10$ ,	free molecule zone

In continuous zone, fluid motion can be described by continuous media control equation. When not considering viscous, Euler equation can be used. When considering viscous, Navier-Stokes (N-S) equation with no slip boundary condition is used to simulate the fluid motion. When the thin effect begins to reflect in the slip zone, fluid start deviating from the thermodynamic equilibrium, the fluid can still be described by N-S equations, but slip boundary condition is needed on the boundary. In the free molecular zone, fluid motion must be described with the idea of particle movement and simulated by the Monte Carlo (Direct Simulation Monte Carlo, DSMC) theory. Fluid in the transition zone can't be

treat as a continuous medium, and also not as a free molecular flow, the simulation in this zone is the most difficult. As shown in figure 1 is the approximate boundaries in the gas flow simulation of micro-nano scale, “ $\delta$ ” is the average molecular spacing, under the “ $L/\delta = 20$ ” line statistical fluctuation is obvious.

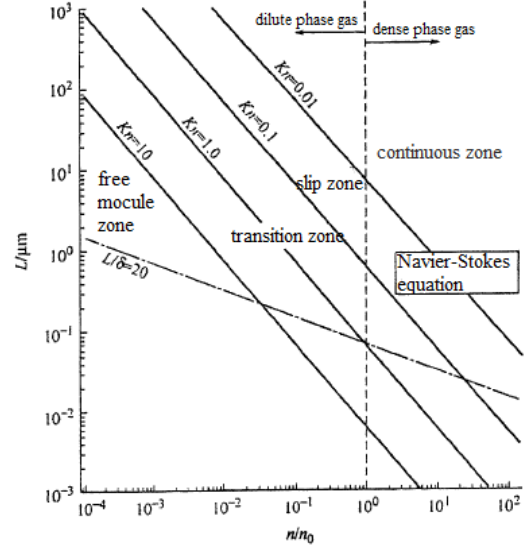


Figure 1. the approximate boundaries in the gas flow simulation of micro-nano scale

### IV. THE RESEARCH PROGRESS OF MICROSCALE CONVECTION HEAT TRANSFER

According to the traditional knowledge, the heat transfer coefficient of the fluid flow in a smooth tube follows the following empirical formulae:

Fully developed turbulence ( $Re > 10000$ ):

$$Nu = 0.023 Re^{0.8} Pr^{0.4}$$

Fully developed laminar flow ( $Re < 2200$ ):

$$Nu = 1.86 (Re Pr)^{0.33} (d/L)^{0.33} (\mu_f / \mu_w)^{0.14}$$

Transition region ( $2200 < Re < 10000$ ):

$$Nu = 0.116 [Re^{2/3} - 125] Pr^{1/3} [1 + d/L]^{2/3} (\mu_f / \mu_w)^{0.14}$$

“ $d$ ” is the pipe diameter, “ $L$ ” is the length, “ $\mu$ ” is the fluid viscosity.

Tuckerman and Pease<sup>[1]</sup> put forward the use of micro structure of rectangular groove on the underside of the chip substrate in 1981, the experimental results proved the cooling capacity of this kind of micro rectangular groove, the highest cooling capacity can reach  $790 W/cm^2$ , which is in good agreement with the theoretical value.

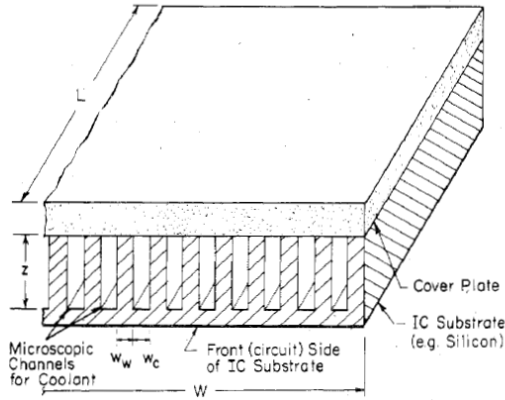


Figure 2.the micro channel structure

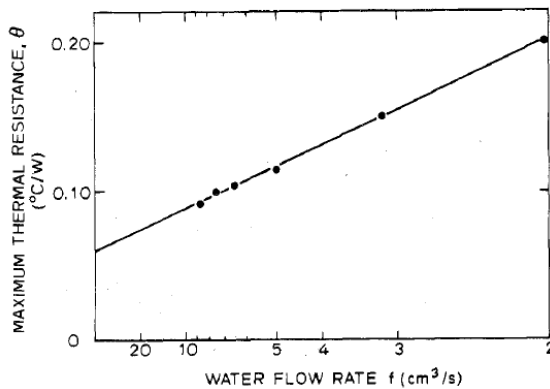


Figure 3.The thermal resistance curve along with the change of flow rate in the third case

Wu and Little<sup>[2]</sup> put forward the experimental research with nitrogen through micro groove of four different structure, the depth of micro groove is 87~97mm, length is 312~574mm. It was found that the heat transfer has three different areas: When Re is less than 100 is laminar flow, the heat transfer characteristics and the size of the micro groove way has a lot to do. When  $1000 < Re < 3000$  is a transition zone, heat transfer relations are complex, and cannot be described with a single experience expression, when  $Re > 3000$  is a turbulent area.

Peng and Wang<sup>[3]</sup> has studied the heat transfer characteristics on the liquid flow without phase change in individual micro channel and micro groove structure, mainly involves micro groove single-phase heat transfer and the conversion of flow form, as well as the liquid changes in thermal and physical properties related to the conversion process caused by the temperature increase.

The experiment in the forced convection of liquid in the tank found that the fully developed turbulence starting in Re 1000 to 1500, and the transition area starting in the range of 300 to 800; Laminar flow and the transition section are complex, there were significant differences with regular size results, heat transfer and flow is affected by geometric parameters.

$$Nu = 0.00805 Re^{0.8} Pr^{1/3}$$

And found that heat transfer can be used in the form of a traditional Dittus-Boelter relational, but constant changes from 0.023 to 0.00805. Experiment also found that the fluid flow rate, liquid super-cooling degree, the number and size of micro slot way will affect the heat transfer characteristic of micro slot.

Xin<sup>[4]</sup> operate an experiment of the forced flow resistance and heat transfer performance in six different structure size of the micro rectangular groove passage. The results show that under the experimental conditions, the water flowing in the micro groove, the transition from layer turbulent flow starts in Re 1400-1800, which is in advance than the large size channel.

$$Nu = 1.51(Re Pr D / L)^{0.5545} (h / W_c)^{-0.3615} (\mu_f / \mu_w)^{0.11}$$

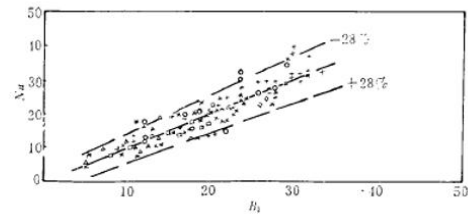


Figure 4.Comparison of experimental datas with the equation

Guo and Huang<sup>[5]</sup> operate an experiment on the unidirectional flow resistance characteristics and heat transfer characteristics of the refrigerant R12 in the micro-flow channel. Experimental results show that there is a big difference in the flow forces and heat transfer characteristics with the general scale flow channel. The resistance coefficient laminar flow is higher than the resistance coefficient in conventional-sized flow path, the critical Reynolds number is also reduced.

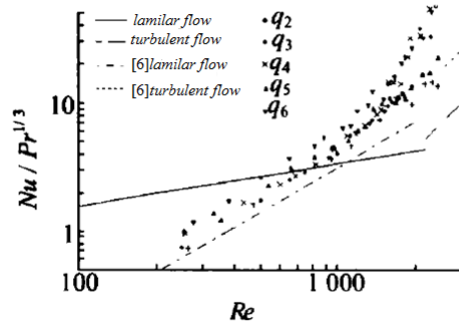


Figure 5.conventional scale compared with microscale flow heat transfer

Zhou<sup>[6]</sup> operate experimental research and theoretical calculations of single-phase flow resistance and heat transfer characteristics of the micro-channel heat exchangers, and found that the experimental data fRe in the micro-channel is higher than the predictive data of traditional theory, and increases with the Reynolds number, the heat transfer coefficient is significantly less than the traditional theoretical predictions. Because the heat boundary layer of micro-channel is not fully developed, the convective heat transfer

coefficient is increasing with the Re number ,in addition, under the same thermal conditions, improve the working fluid inlet temperature or increase the heat load can decrease the pressure drop in the test segment. Zhou obtained the resistance and heat transfer correlations in micro-channel heat exchangers.

## V. CONCLUSIONS

Microscale flow and heat transfer is one of the most challenging research field, it has important academic value and engineering significance. With this enhanced heat transfer practical applications continues to expand, the experimental and theoretical studies is increasingly going deeper.

The mechanism and the factors of microscale single-phase flow and heat transfer are complex, to get a clear understanding of its generation process and make accurate predictions is difficult, the more precise experimental methods and parameters measurement system will help further research.

Using MEMS technology processing experiment parts, visualization techniques, high-speed photography and

experimental methods of infrared temperature measurement, then simplifying the corresponding mathematical model on theoretical analysis are effective and meaningful topics will, which will be the focus of future research work.

## EPILOGUE

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