Research of Fluid Flow Characteristics for Surface Morphology of Solid

Zhiwei Yan1,2*, Jiquan Liu2,4 and Kun Zhu3

1 National Engineering Laboratory for Coal Ming Machinery, Taiyuan, Shanxi, 030006, China
2 Tai Yuan Research Institute of China Coal Technology & Engineering Group, Taiyuan, Shanxi, 030006, China
3 China Coal Technology & Engineering Group, Beijing, 100013, China
4 College of Mechatronics Engineering, NUC, Taiyuan, Shanxi, 030051, China
*Corresponding author’s e-mail: mkystewart@126.com

Abstract: A large number of asperities have been left on the solid surface after mechanical processing. Aiming at this complex shape, a laminar flow model between solid contact interfaces is established, and the irregular concavo-convex structure is used to simulate the interface structure in micro-channels, then it is studied for the flow characteristics of incompressible viscous fluids in random micro-channel. The channel of model adopts the form of 2D and 3D model. The interface structure in the microchannel is simulated with irregular micro-convex bodies, and physical quantities such as aspect ratio and length ratio are defined. It is used to analyze the influence of micro-channel on the velocity and pressure of fluid flow by Computer simulation technology. The velocity and pressure of fluid in the micro-channel increase as the area ratio of the micro-convex to the micro-channel increases, the length of the micro-protrusion is not the main factor affecting the fluid flow characteristics, the structure of the micro-convex is is one of the key factors affecting the fluid flow characteristics, they are showed by the simulation results. This research provides certain guidance and reference for solid surface design.

1. Introduction

Surface morphology has a significant impact on the friction and lubrication of contact interfaces [1]. It is not only a reflection of surface quality but also contains a large amount of manufacturing and functional information. In recent years, with the rapid development of micro-manufacturing and micro-machining processes, many scholars have begun to study microfluidic technology and microscale components, which show great potential. The advantages of microfluidic technology have received great attention in various fields [4-6]. For example, it enables the rapid development of microreactor technology and enables the devices based on microfluidic technology to be used in various processes of research and development, production, and daily life. With the progress of research methods, experimental studies of microfluidic flow have made a breakthrough, in which the influence of the characteristics of the surface morphology and the microscale flow in the channel have attracted the attention of scholars. Some believe that roughness may be an extremely important factor affecting microscale flow. Meanwhile, the surface morphology has become a focus of research.
At present, there are still many differences in the views of many scholars regarding the study of fluid flow in microchannels. Currently, many scholars mainly focus on studying regular microchannels and micro-convex bodies, which generally are rectangular, trapezoidal, triangular, or circular. Few studies on irregular microchannels and micro-convex bodies have been conducted. Peng et al. studied the resistance characteristics of regular rectangular microchannels with hydraulic diameters ranging from 133 μm to 367 μm. The study showed that the resistance characteristics obtained in microchannels were different from those in tubes with normal sizes [9]. According to the experiments conducted on the flow resistance in the microtubes of different sizes, it was found that some microtubes with the laminar flow were subjected to greater resistance than the tubes of normal size, while some tubes showed the opposite result. Gh. Mohiuddin et al. studied micro stainless steel tubes and silicone tubes [10]. The results showed that the resistance value in the micro-scale tubes obtained was greater than 64. When Re was greater than or close to 650, the resistance was no longer the same as in the conventional channels. Weili found in the experiment that the flow resistance of fluid was significantly reduced when the surface of the hydrophobic material had convex peaks and troughs, while the spacing and height of the micro-convex body had a significant effect on the resistance reduction of the fluid [11]. Bruto used a pin-on-disk tester to investigate the relationship between the wettability of solid surfaces and interfacial friction [12]. The results showed that the hydrophilic/hydrophobic properties of the wetting surface have a more direct effect on the friction coefficient. Pawlak et al. investigated the relationship between the contact angle and the friction coefficient of the contact surface using a friction and wear tester [15]. The results showed that the friction coefficient of the interface decreases with the increase of the contact angle under lubrication conditions, which was because the contact surface was a hydrophilic friction pair so that the viscous resistance of the lubricant in the interface decreased sharply.

2. Establishment and Parameter Setting of the Irregular Micro-Convex Body Model
The grid schematic of the irregular micro-convex body is shown in Figure 1. Two parallel flat plates are spaced H=40 μm. The length is L=200 μm. The pressure difference between the two ends of the plates is P=20 MPa. The fluid flows in at 3.5 m/s from the left end and out at the right end.

Figure 1 Irregular Micro-Convex Body of 2D Model

Figure 2 shows a simplified 3D irregular model. The two parallel flat plates are spaced H = 40 μm. The length is L = 220 μm. The width B = 0.1 mm. The micro-convex bodies are spaced W = 10 μm. The micro-convex bodies are uniformly distributed in the parallel flat plates, and the irregular micro-convex bodies are used to simulate the wave peaks and troughs in the plates. The area ratio D is also defined as above.
The micro-convex body consists of a series of irregular figures with has its height and length. To accurately describe its flow mechanism, three sets of random numbers are established and modeled separately for each model. The average height $h$ of the micro-convex body is 2-15 μm, respectively. There is a series of irregular micro-convex bodies between the plates. To highlight the structural variation of different micro-convex bodies between the plates, the aspect ratio $D$ is defined as:

$$D = \frac{h}{H}$$

The equation used in the current fluid flow simulation software is the Reynolds equation [10-11], which can be applied to the viscous flow of Newtonian fluid in narrow gaps. The irregular flow model uses the finite element fluid analysis software Fluent for simulation and analysis. The flow mode in the parallel flat plate is set to laminar flow, and the inlet end $L$ of the flat plate is longer, and its flow is more complicated. Because the flow in the inlet section of the microchannel is more complicated, the mesh encryption is carried out in the inlet section and the boundary layer to calculate the flow field near the wall more accurately. The pressure-inlet boundary is set to 20 MPa, and the pressure outlet boundary is set to 0. The Type is set to pressure based. Time is set to steady. The Model is set to laminar flow, ignoring the effect of gravity. The Operating Condition is set to the default setting. Inlet is set to velocity-inlet. Outlet and Wall are set to the system default. In finding the solution of the discretized equation, the accuracy of the residuals shall be controlled as 0.001, and the others are set to the default in Fluent.

3. Analysis of 2D simulation results

3.1 Analysis of the Height Variation Model of 2D Irregular Micro-Convex Body

The variation of velocity and pressure at the outlet cross-section of the central axis with the aspect ratio $D$ is shown as Figures 3. With the increase of $D$, the area occupied by the micro-convex body becomes larger, so that the effective circulation area between the flat plates is reduced, and the fluid between the parallel flat plates is squeezed. As a result, the velocity and pressure at the outlet cross-section of the central axis increase with the increase of $D$. 

Figure 2 Irregular Micro-Convex Body of 3D Model
3.2 Analysis of the Density Variation Model of 2D Irregular Micro-convex

The variation of velocity and pressure at the outlet cross-section of the central axis with the length ratio is shown as Figures 4. The plate spacing $H$ is kept constant at 40 μm, and the plate length $L$ is 200 μm. The value of $W$ is set to 6-15 μm. Three sets of random numbers are set in terms of the length in each model for simulation and analysis separately. The height $h$ of the micro-convex body is kept constant. To give a more intuitive presentation of the effect of the micro-convex body with different densities on the fluid flow, the length ratio $\sigma$ is defined as

$$\sigma = \frac{W}{L}$$  \hspace{1cm} (2)

Figure 3 Variations of Velocity and Pressure at the Outlet Cross-Section of the Central Axis with Aspect Ratio

Figure 4 Variation of Velocity and Pressure at the Outlet Cross-Section of the Central Axis with the Length Ratio by 2D model
From the figure above, it can be seen that the velocity and pressure at the outlet cross-section of the central axis remain flat. Also, the increase of the length of the micro-convex body has little impact on the velocity and pressure at the outlet cross-section of the central axis, which is because the increase of the length of the micro-convex body is equal to the decrease of the length of the flat plate, and the flow line does not have abrupt linearity. Therefore, the velocity and pressure don’t change greatly.

4. Analysis of 3D simulation results
The variation of velocity and pressure at the outlet cross-section of the central axis with the aspect ratio D in the 3D irregular model is shown in Figures 5. Each group of model was tested by three simulation tests and fitted curves were drawn. With the increase of the average height of the irregular micro-convex body and the increase of the aspect ratio, the velocity and pressure at the outlet cross-section of the central axis show an overall increasing trend within the acceptable error range.

![Figure 5 Relationship of the velocity and pressure at the outlet cross-section of the central axis with the aspect ratio by 3D model](image)

When the average height of the micro-convex body is relatively low, it has a small impact on the velocity and pressure at the outlet cross-section of the central axis, but the pressure still shows an increasing trend. This is because although the fluid is less extruded by the micro-convex body, it still increases slowly. When the average height of the micro-convex body is larger or close to the flat plate height H, the fluid is sharply extruded and the velocity and pressure increase sharply. At this time, the trend of change is sensitive, resulting in a sudden change. Therefore, the shape and distribution of the irregular micro-convex body have a huge impact on fluid flow. The variation at the protrusion of the micro-convex body is greater. At the top of the micro-convex body is the maximum value of velocity and pressure, and at the groove is the lower value of velocity and pressure.

5. Conclusion
In this paper, the irregular micro-convex body was modeled in 2D and 3D by dividing the grid with Gambit, Meshing, and Comsol respectively, and importing it into the finite element analysis software Fluent and Comsol for post-processing analysis. The parallel flat fluid flow interface was used for interface simulation. The 2D and 3D regular micro-convex bodies are used to simulate the surface morphology. Also, an interface contact model is established to study the fluid flow mechanism. The
dimensionless constants of aspect ratio and length ratio are defined. In the 2D and 3D model, the velocity and pressure in the flat plate increases as the height of the micro-convex body increases. Due to the uncertainty of the structure and distribution of the irregular micro-convex body, the error in the test can be ignored.

This paper studies the flow conditions of the irregular 2D and 3D model in the microchannel in terms of the shape and distribution of the micro-convex body, which simulates the real surface morphology to a certain extent. Although certain errors are generated due to the irregularity of the model, the flow characteristics of the microfluid are shown to a certain degree.

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