

Effects of Manifold Structures on Velocity Distribution of V- and A-Type Microchannel Plates

Pingnan Huang*, Liqing Ye

School of Mechatronic Engineering and Automation, Foshan University, Foshan 528225, China

**Author to whom correspondence should be addressed.*

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Abstract: Flow velocity uniformity of the microchannel plate is a major factor affecting the performance of microchannel devices. In order to improve the velocity distribution uniformity of the microchannel plate, we designed two new microchannel structures: V-type and A-type. The effects of various structural parameters of the manifolds on the velocity distribution are reported. The V-type and A-type microchannel plates had a more uniform velocity distribution compared to the Z-type microchannel plate. The final result showed that it is beneficial for the V-type microchannel plate to obtain a more uniform velocity distribution when the manifold structure parameters are $X_{in} = -1$, $X_{out} = 0$, $Y_{in} = 10$, $Y_{out} = 6$, $H_{in} = 4$, $H_{out} = 1$, and $R = 0.5$.

Keywords: Microchannel; Velocity distribution; Manifolds; Structure optimization

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1. Introduction

Because microchannel devices have channel equivalent diameters of 500 and below^[1], they have attracted extensive attention due to their small size, high specific surface area, and high heat and mass transfer efficiency. At present, the application of microchannel devices is focused on microchannel reactors^[2,3] and microchannel heat sinks^[4,5]. The uniformity of flow velocity distribution between microchannels has a large impact on the performance of microchannel devices. In microchannel reactors, the uneven distribution of flow velocity between the microchannels leads to uneven residence time, resulting in uneven contact area between the reactants and the catalyst inside the microchannel, thereby reducing the reaction rate and reaction efficiency of the microchannel reactor. In the microchannel heat sink, the uneven distribution of the flow velocity causes the overall pressure drop of the microchannel plate to rise, thereby increasing the pump power. However, the heat that the fluid carries away from the microchannel plate is uneven, resulting in overheating in some areas, affecting the heat dissipation effect. How to improve the flow velocity distribution uniformity of microchannel devices is a key area of research.

At present, it is possible to alter the microchannel plate flow velocity distribution by changing the

microchannel structure, the inlet and outlet structure, the inlet flow velocity, and the number of stacking layers. The need to improve the uniformity of the microchannel plate velocity distribution has become the main restriction of the application of microchannel devices. The manifold structure of the microchannel plate is flexible and variable, and has different forms that also have a significant influence on the uniformity of the flow velocity distribution of the microchannel plate [6]. Thus, optimizing the manifold structures of the microchannel devices is one of the key ways to improve the velocity distribution uniformity.

In this article, based on the monolithic manifold structures, V-type and A-type microchannel plates are improved in order to simplify the manifold structures, decrease the flow resistance, and improve the flow uniformity. The effects of different manifold structure parameters on the velocity distribution are analyzed by simulation, and the velocity distribution of V-type, A-type, and Z-type microchannel plates is compared.

2. Computational fluid dynamics setting and analysis

The structures of V-type and A-type microchannel plates that we studied are respectively shown in **Figures 1(a)** and **1(b)**. They are formed by adding an inlet or outlet on the basis of the traditional Z-type microchannel plate. Both V-type and A-type microchannel plates are composed of a rectangular microchannel array, an inlet, an outlet, and corresponding manifold structures. The main difference between the V-type and A-type microchannel plates is that the V-type microchannel plate contains two symmetric inlets and one outlet, while the A-type microchannel plate contains two symmetric outlets and one inlet.

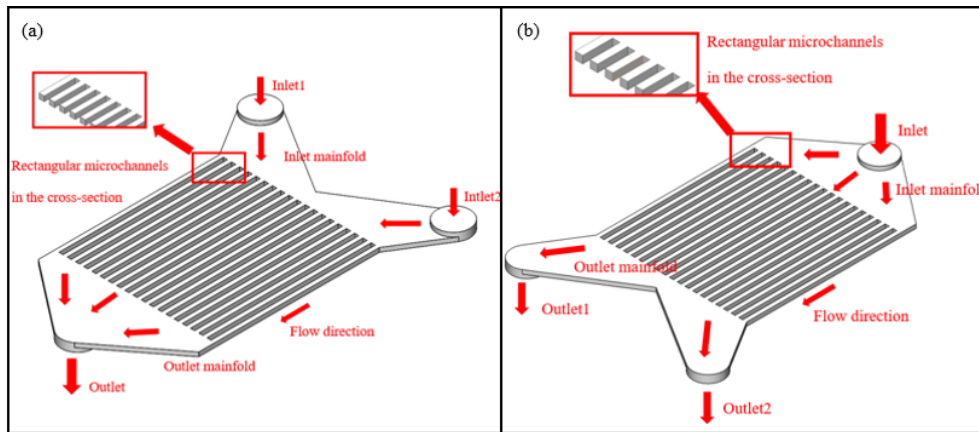


Figure 1. The structure of V and A types microchannel plates

Fluent17.0 was used to analyze the velocity distribution of the microchannel plate. The mesh division method divides the mesh by sub-areas. The microchannel array is divided by the sweep method, and the manifolds and the inlet and outlet are meshed by the automatic method. The independence test was carried out using a V-type microchannel plate reference model. The simulation results are shown in **Table 1**. The mesh unit size is controlled to be 0.05 mm in the reference model. It can be seen from the table that when the size of the control grid unit is 0.1 mm, the flow velocity distribution evaluation coefficient is only 0.064598, different from the reference model, so the overall grid is drawn by the control unit size of 0.1 mm. The result of the division is shown in **Figure 2**.

Table 1. Grid independence test

Element size (mm)	Element number	$\sigma\%$	Differ
0.25	93726	0.698523	0.429523
0.1	1383475	0.520206	0.064598
0.05	10913538	0.488641	Baseline

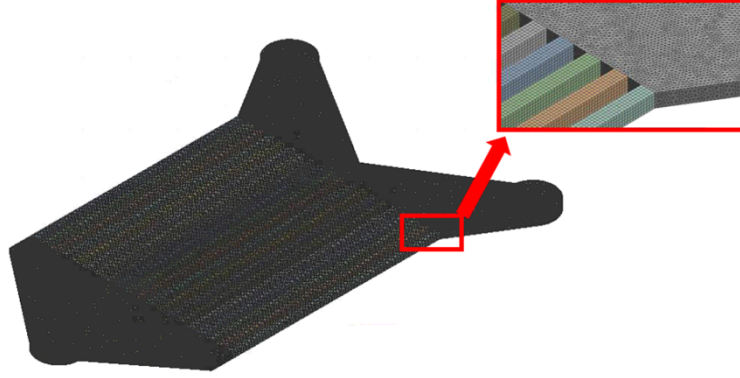


Figure 2. Mesh generation results

The inlet boundary condition is set as velocity-inlet. In order to make comparisons, the inlet quantity of flow is the same for V-type and A-type microchannel plates. Thus, the inlet velocity of the V-type microchannel plate is set as half of the A-type microchannel plate. The outlet boundary condition is set as “Pressure-Outlet.” The static pressure of the outlet is 0 Pa. The other boundary condition is set as “wall.” No slip condition is set. Flow liquid is liquid water. Density is 998.2 kg/m^3 . The temperature is 300 K and the kinematic viscosity is 1.0032×10^{-3} .

The Reynolds number is very small. Thus, the flow pattern in the microchannel plate is assumed to be laminar flow. The governing equation is:

$$\rho \frac{d\vec{v}}{dt} = -\nabla P + \mu \nabla^2 \vec{v} + \rho \vec{F} \quad (1)$$

$$\nabla \vec{v} = 0 \quad (2)$$

where ρ , P , $\vec{v}$, μ , and $\vec{F}$ are the flow density, pressure, flow velocity, dynamic viscosity, and volume force per unit, respectively. ∇ is the differential.

In order to evaluate the flow velocity uniformity between microchannels, the flow velocity distribution evaluation coefficient $\sigma\%$ is defined, as shown in Equation 3. The smaller the value of $\sigma\%$ is, the more uniform the velocity distribution:

$$\sigma\% = \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{U_c(i)}{U_m} - 1 \right)^2} \times 100\% \quad (3)$$

Where $U_c(i)$ means the flow velocity of the i th microchannel, U_m is the average value of the flow velocity of

all the microchannels. The definition is:

$$U_m = \frac{1}{N} \sum_{i=1}^N U_c(i) (i = 1, 2, 3 \dots N) \quad (4)$$

3. Results and discussion

3.1. Effects of X value

The effect of X value on the velocity distribution of V-type and A-type microchannel plates is shown in **Figure 3**. It can be seen that when the X value is -4, the flow velocity distribution curve of the V-type microchannel plate is inverted parabolic. The flow velocity of the middle microchannel is the smallest, and the flow velocity on both sides is the largest. As the value of X increases, that is, the inlet position is getting closer to the middle of the microchannel plate, the flow velocity begins to increase gradually, and the flow velocity on both sides decreases gradually. When the X value is 1, the flow velocity distribution curve is almost a parabolic shape, with minimum flow rates on both sides and large intermediate flow rates.

Figure 3(b) shows the velocity distribution on different X_{out} values of the V-type microchannel plate. When the microchannel plate is a positive V-type ($X_{out} = 0$), the velocity distribution curve is almost a horizontal line. The velocity distribution is the most uniform. As the X_{out} value increases, the outlet is far away from the middle channel, and the velocity distribution curve becomes an increasing slant, which means the velocity distribution becomes more and more uneven.

The velocity distribution of the A-type microchannel plate with the increase of the X value is shown in **Figures 3(c)** and **3(d)**. it can be seen that the bigger the X_{in} value is, the more uneven the velocity distribution is, which is similar to that of a V-type microchannel plate with different X_{out} values. It is seen that the flow velocity distribution of the V-type microchannel plate with different inlet parameters X_{in} values and the flow velocity of the A-type microchannel plate with different outlet parameters X_{out} values are similar.

3.2. Effects of Y value on the velocity distribution

The effect of Y value on the flow velocity distribution of V-type and A-type microchannel plates is shown in **Figure 4**. As for the V-type microchannel plate, when the inlet parameter $Y_{in} = 3$, the velocity distribution curve is an inverted parabolic shape, with minimum velocity in the middle channel and maximum velocity on both sides. With the increase of Y_{in} value, velocity in the middle microchannels gradually increases, and the velocity on both sides decreases gradually. When the Y_{in} value is 10, the velocity in the middle channels is almost the same, because as the Y_{in} value increases, the distance from the inlet to the intermediate channel 2 to channel 19 is almost equal, so the flow rates through channel 2 to channel 19 are also almost equal. The flow rate on both sides is slightly smaller. It may be that channel 1 and channel 20 are close to the inlet and outlet manifold turning point, and the local resistance is greater, so the flow rate is smaller.

The effect of Y_{out} value on the flow velocity distribution of the V-type microchannel plate is shown in **Figure 4(b)**. When Y_{out} value is 3, the flow velocity of the microchannel plate is distributed into a pagoda type. The flow velocity of the intermediate channel is the largest, and the flow velocity of both sides is the smallest. As the value of Y_{out} increases, the flow rate of the intermediate microchannel begins to decrease slowly, and the flow velocity at both ends begins to rise. When $Y_{out} = 6$, the velocity distribution curve is almost a horizontal line, and the velocity

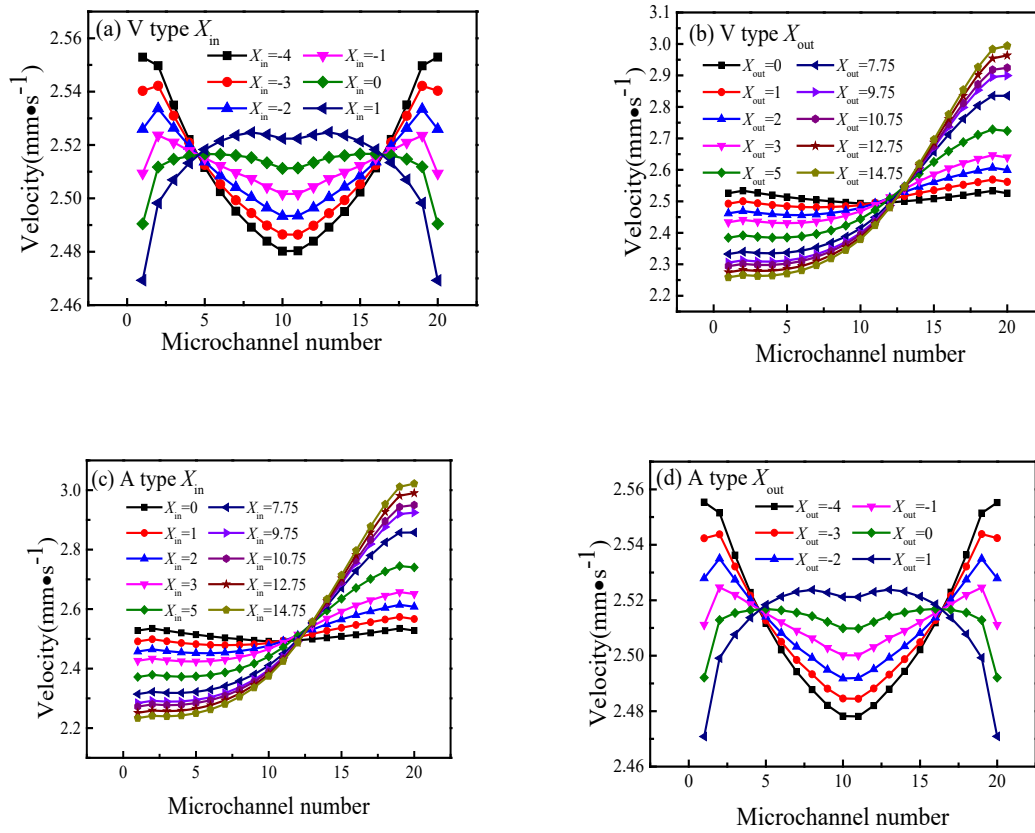


Figure 3. Velocity distribution of V-type and A-type microchannel plates at different X values. Effects of X_{in} values of (a) V-type and (c) A-type; Effects of X_{out} values of (b) V-type and (d) A-type

distribution is the most uniform. As the value of Y_{out} continues to increase, the length of the streamline flowing from the inlet to the outlet through the microchannels at both ends is longer than the length of the streamline of the intermediate microchannels at both ends is greater. Therefore, the flow rate of the intermediate microchannel continues to rise, and the flow velocity of the microchannels at both ends continues to decrease, eventually forming an inverted parabolic shape.

Comparison of **Figures 4(a)** and **4(d)**, **Figures 4(b)** and **4(c)**, it is seen that the influence of the inlet parameter Y_{in} of the V-type microchannel plate on the flow velocity distribution and the influence of the outlet parameter Y_{out} of the A-type microchannel plate on the flow velocity distribution are the same. Similarly, the influence of the V-type microchannel plate outlet parameter Y_{out} on the flow velocity distribution is the same as the influence of the A-type microchannel plate inlet parameter Y_{in} on the flow velocity distribution.

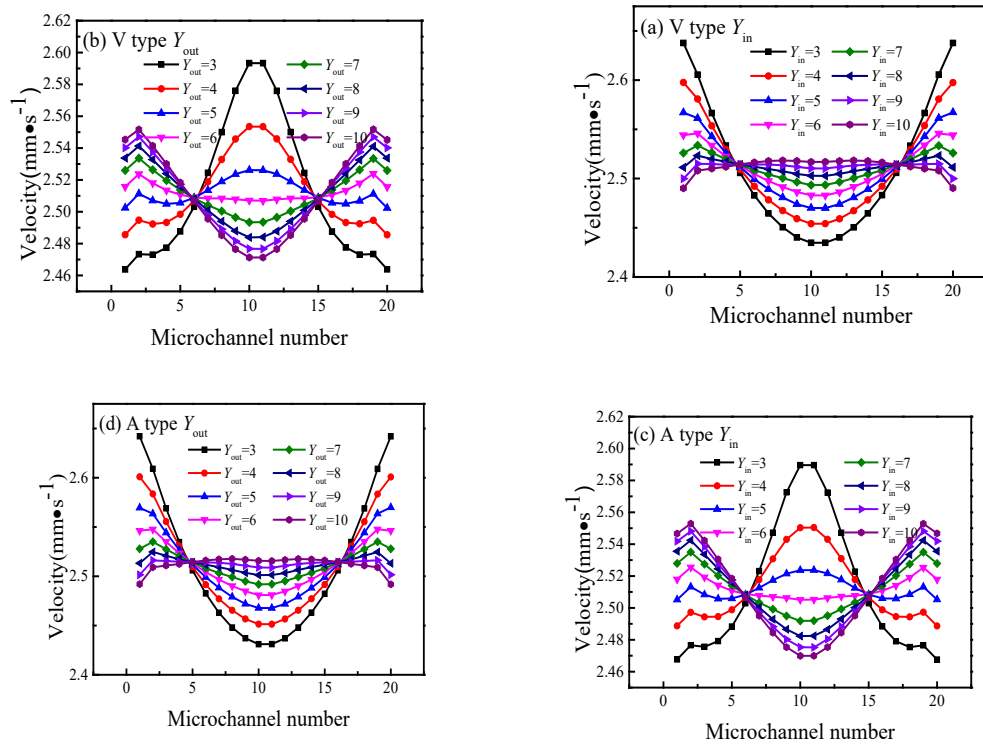


Figure 4. Velocity distribution of V-type and A-type microchannel plates at different Y values. Effects of Y_{in} values of (a) V-type and (c) A-type; Effects of Y_{out} values of (b) V-type and (d) A-type

3.3. Effects of H value

Figure 5 shows the change in velocity distribution of V-type and A-type microchannel plates with H value. It can be seen that when the inlet parameter H_{in} value is changed, the flow velocity distribution of V-type microchannel plate is similar to that of A-type microchannel plate when the outlet parameter H_{out} value is changed. When H_{in} (H_{out}) is 1, the flow velocity of V-type (A-type) microchannel plate presents a deep V-type. With an increase of H_{in} (H_{out}) value, the flow velocity of V-type (A-type) microchannel plate began to increase, and the flow velocity of both sides decreased. When the outlet parameter H_{out} of V-type microchannel plate and the inlet parameter H_{in} of A-type microchannel plate are changed, the change of velocity distribution is shown in **Figures 5(b)** and **5(c)**, respectively. When H_{out} (H_{in}) is 1, the flow velocity distribution of V-type (A-type) presents a flat M-type. As H_{in} value increases gradually, the flow velocity of the middle channels decreases, and the flow velocity of both sides increases gradually. When the value of H_{in} is 6, the velocity distribution is a deep V-type, with the smallest velocity in the middle channel and the largest velocity on both sides.

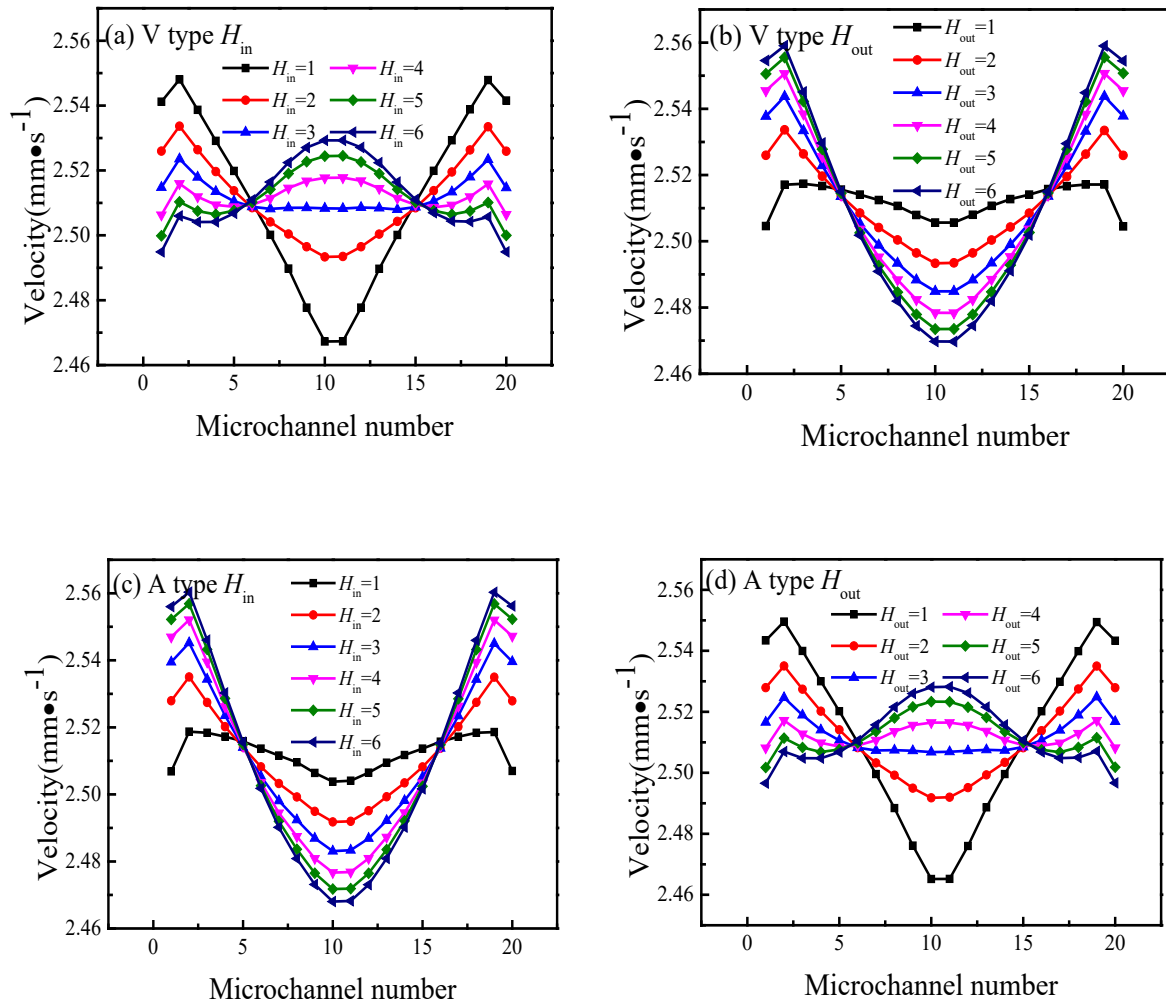


Figure 5. Velocity distribution of V-type and A-type microchannel plates at different H values. Effects of H_{in} values of (a) V-type and (c) A-type; Effects of H_{out} values of (b) V-type and (d) A-type

3.4. Effects of R value on the velocity distribution

Figure 6 shows the velocity distribution of V-type and A-type microchannel plates when the inlet and outlet radius are changed. As the radius increases, the flow velocity of the whole microchannel plate increases, because when the inlet velocity is constant, increasing the inlet radius, the inlet flow increases, so that the flow velocity of the whole microchannel plate increases. **Figure 6(c)** shows the relationship between the velocity distribution evaluation coefficient and the radius. With the increase of the radius R, the velocity distribution evaluation coefficient of V-type microchannel plates first increases and then decreases, while the velocity distribution evaluation coefficient of A-type microchannel plates monotonously increases. That is to say, as the increase of radius, the velocity distribution of V-type microchannel plate first becomes uniform and then uneven, but the velocity distribution of A-type microchannel plate becomes more and more uniform with the increase of the value of R.

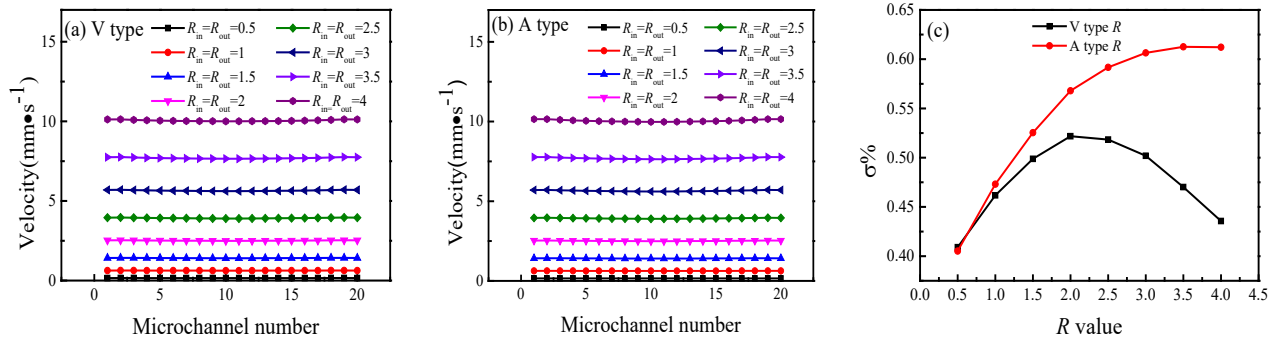


Figure 6. Velocity distribution of V-type and A-type microchannel plates at different R values. (a) V-type; (b) A-type; (c) Velocity distribution evaluation coefficient

3.5. Comparison of velocity distribution of V-type and A-type

From the above analysis, it can be found that the inlet parameters of V-type microchannel plate X_{in} , Y_{in} , and H_{in} , have the same influence on the velocity distribution as the outlet parameters of A-type microchannel plate, X_{out} , Y_{out} , and H_{out} . Similarly, changes in outlet parameters of V-type microchannel plate (X_{out} , Y_{out} , and H_{out}) have the same impact on velocity distribution as changes in inlet parameters of A-type microchannel plate (X_{in} , Y_{in} , and H_{in}). However, when the R value changes, the velocity distribution uniformity of V-type microchannel plate increases first and then decreases, while that of A-type microchannel plate increases monotonously.

3.6. Comparison of velocity distribution between Z-type and V-type and A-type

The flow velocity distribution of V-type and A-type microchannel plates is further compared to that of Z-type microchannel plates studied earlier^[6] (Figure 7). Among them, both V-type and A-type microchannel plates adopt the reference model. It can be seen that the flow velocity distribution of V-type and A-type microchannel plates is basically the same, and the flow velocity distribution presents a shallow V-type. Compared with V-type and A-type microchannel plates, the flow velocity of the Z-type microchannel plate presents a deep V-type, with a larger flow velocity on both sides and a smaller flow velocity in the middle. Combined with Figure 7(b), the evaluation coefficient of the velocity distribution of V-type and A-type microchannel plates is less than half that of Z-type microchannel plates. In other words, the velocity distribution of V-type and A-type microchannel plates is more uniform than that of Z-type microchannel plates.

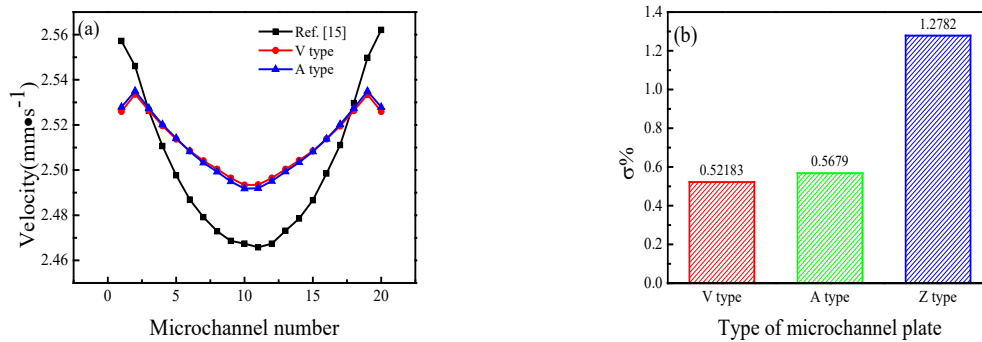


Figure 7. Velocity distribution of V-type, A-type, and Z-type microchannel plate

4. Conclusion

In this paper, two types of manifold structures, V-type and A-type, are used to study the flow velocity distribution under different manifold structure parameters. The results show that the inlet parameters of V-type microchannel plate, X_{in} , Y_{in} , and H_{in} , have the same effect on velocity distribution as the outlet parameters of A-type microchannel plate, X_{out} , Y_{out} , and H_{out} . When $X_{in} = -1$, $X_{out} = 0$, $Y_{in} = 10$, $Y_{out} = 6$, $H_{in} = 4$, $H_{out} = 1$, $R = 0.5$, the velocity distribution of V-type microchannel plate is the most uniform. Comparison of the flow velocity distribution of Z-type, V-type, and A-type microchannel plates reveals that the velocity distribution evaluation coefficient of V-type and A-type microchannel plates is less than half that of Z-type microchannel plates, and the flow velocity distribution is more uniform.

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Disclosure statement

The authors declare no conflict of interest.

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