Simulation and research of chip-level micromixer with T-type based on ANSYS

Yunzheng Ran, *Luoping* Lu, *Cai* Zheng, *Fang* Fang, *Zhuo* Liu, and *Honghua* Liao*

College of Intelligent Systems Science and Engineering, Hubei Minzu University, Enshi, 445000, China

Abstract. A T-shaped chip-scale micromixer with built-in baffles is simulated and investigated based on ANSYS. This paper highlights on a comparative analysis of the effect of different numbers, rows, positions, angles and different Reynolds numbers (Re) of baffles on the mixing efficiency within a chip-scale micromixer. The simulation results demonstrate that: increase in the amount of baffles improved mixing of two fluids; the double rows of baffles significantly improve the mixing efficiency compared with the single rows of baffles; the position of the baffles relocates a certain distance to the outlet, which accelerates mixing of fluids in the chip-scale mixer; the mixing efficiency of baffle angle of 120° is also superior to that of 60°; the Re is between 0.1 and 2, which results in a high mixing efficiency; and the mixing efficiency slowly becomes lower when the Re is between 2 and higher mixing efficiencies with Re values between 0.1 and 2; Re between 2 and 40, the mixing efficiency slowly becomes lower; Re between 40 and 100, the mixing efficiency gradually rises.

Keywords: T-type chip-level micromixer, Taguchi method, Signal-to-noise ratio, Ansys, Reynold number.

1 Introduction

The chip-scale micromixer has attracted more and more attention in the fields of biochemical reaction and medical diagnosis because it can realize the mixing of different components at low Re [1]. Chip-level micromixers can be categorized into two types, active and passive, based on the presence or absence of a power supply. Passive chip-level micromixers require no additional power supply and are therefore more consistent and simpler to integrate [2].

Since the scale of the chip-scale micro-mixer is very small, the flow velocity and Re of the fluids in the micro-channels are very little, therefore the flow of fluids in chip-scale micro-mixers tends to be in a laminar state, which brings great difficulties in mixing of micro-fluids. [3]. For more efficient mixing of chip-level micromixers, numerous studies on fluid mixing in microfluidic channels have been done by many scholars. Chung et al. [4] designed the microfluidic channels into irregular shapes. When fluids flow through these irregular

* Corresponding author: 405219300@qq.com

microchannels, a series of vortices will be generated, which greatly increased fluid contact area for microfluidic mixing; Wang et al. [5] arranged a series of rectangular blocks in a microfluidic channel, and the results indicated that when the fluid flowed through the vicinity of the rectangular blocks, chaotic convection would be generated around them, thus improving the fluid mixing efficiency; Stroock et al. [6] investigated a chip-scale micro-mixer with staggered zigzag blocks in a T-shaped microfluidic channel, and showed that even if Re is very small, the phenomenon of chaotic convection will be obvious.

In this paper, based on the T-type chip-scale micromixer, a T-type chip-scale micromixer with built-in resistor of relatively simple structure and high efficiency of mixing is designed. The effects of perturbation due to different parameters and different Re on the micro-mixing efficiency of chip-scale micro-mixer are analysed, so as to derive a practical method to improve the mixing efficiency. A theoretical foundation is laid for future research design, which has certain research significance and reference value.

2 Chip-scale micro-mixer structure design

Top view schematic of a microfluidic channel of a chip-scale micro-mixer with a built-in periodic baffle structure is portrayed in figure 1. The 3D structure of the chip-scale micromixer is obtained by stretching the top view structure upward by 100 microns.

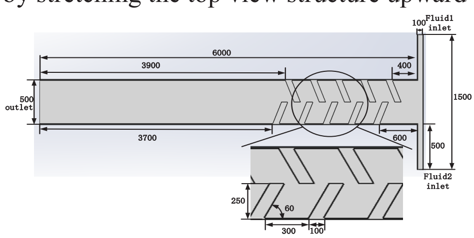


Fig. 1. Top view schematic of a microfluidic channel of a chip-scale micro-mixer with a built-in periodic baffle structure (unit: microns).

2.1 Evaluation of mixing efficiency

For the purpose of evaluating the mixing effect of the chip-level micromixer, define the mixing degree indicator as M:

$$C_i=\frac{C_m-C_1}{C_1} \tag{1}$$

$$\sigma^2=\frac{1}{N}\sum_{i=1}^{n}(C_i\text{-}C)^2 \tag{2}$$

$$M=1\text{-}\left[\frac{1}{N}\sum_{i=1}^{n}\left(\frac{C_i\text{-}C}{C}\right)^2\right]^{1/2} \tag{3}$$

where σ^2 is the temperature variance, C_i is the temperature at the outlet, C_m is the temperature at the outlet, C_1 is the lowest temperature at the inlet (25°C in this paper), C is the expected temperature fraction at the outlet at the beginning of the mixing process (0.5 in this paper), and N is the amount of sampling points on the section. The mixing effect at any position on the flow channel can be evaluated by the above evaluation index. The value of M is between 0 and 1, M=0 indicates completely unmixed, and M=1 indicates completely mixed.

3 Results and discussion

To verify the effectiveness of different number of baffles, rows, positions, angles, and different Re on mixing efficiency in a chip-scale micro-mixer proposed in this paper, this section conducts a series of parameter comparison analysis experiments in a chip-scale micro-mixer. The following sections analyse the whole experimental process in detail.

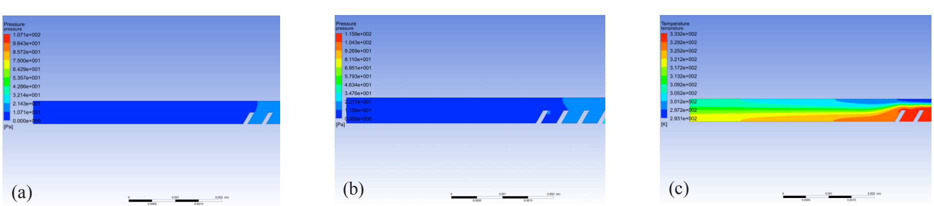
3.1 Numerical simulation condition setting

For simulation and analysis, Ansys-Workbench comes with Meshing for meshing, fluid dynamics software FLUENT for numerical simulation of the flow field inside the chip-scale micro-mixer, the two inlets are selected as 20 degrees Celsius water and 60 degrees Celsius water, the density and viscosity coefficients are not modified, and the model is selected as an incompressible model based on the pressure solver, absolute velocity equation and steady state solution.

Since the characteristic size of the chip-level micromixer is generally micron-sized, the laminar flow model is selected in this experiment. The fluid mixing zone has sufficient length to allow the fluid to mix freely, resulting in chaotic convection. Because it is a mixture of hot and cold water, it is also necessary to open the energy equation. The coupled pressure and velocity method is chosen as the Couple algorithm, and the spatial dispersion method uses a second order upwind scheme. The unit area condition is selected as liquid water, the inlet is selected as the velocity inlet, the outlet is selected as the pressure outlet, and the wall surface is selected as the non-slip wall condition. The velocity and hydraulic diameter at the inlet are selected to calculate the Re. The Re=0.5,3,9,20,50,80,100,150. In this scope of Re, the flow state includes laminar flow, spiral flow and swept flow.

3.2 The effect of the number of blocking blocks on the mixing efficiency in the chip-level micromixer

Two different structures of three-block and five-block were selected to study the effect of different numbers of blocks on the mixing efficiency of hot and cold water. When fluid1 is 20 degrees Celsius water and fluid2 is 60 degrees Celsius water, both inlet velocities are 0.1 m/s, and the baffle angle is 60°. The static pressure cloud diagram, temperature cloud diagram and streamline diagram of different number of resistance blocks as depicted in figure 2. Figure 2(a), figure 2(c), and figure 2(e) are the static pressure cloud map, temperature cloud map and streamline map of the single-row front three-block respectively. Figure 2(b), figure 2(d), and figure 2(f) are the static pressure cloud map, temperature cloud map and streamline map of the single-row front five-block respectively.



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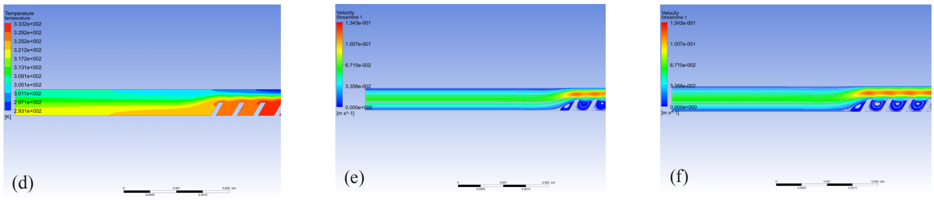

Fig. 2. Pressure-temperature clouds and flow diagrams for different numbers of blocks.

When the resistance block is increased from three to five, the comparison of figure 2(a) and figure 2(b) demonstrates that the internal pressure drop of the chip-level micromixer becomes lower, but the improvement effect is not obvious. This can be identified by comparing figure 2(c) and figure 2(d), which show that the temperature decreases significantly at each level of the resistance block. At the last level of the resistance block, the color energy level in figure 2(d) is one level smaller than that in figure 2(c), indicating that the chip-level micromixer with five resistance blocks has better internal mixing effect than the chip-level micromixer with three resistance blocks. However, from the color distribution of the temperature cloud at the outlet of the two figures, it can be seen that the distribution of hot and cold water is more obvious, the temperature span is relatively large, and the mixing effect needs to be optimized. This can be identified by comparing figure 2(e) and figure 2(f), which show that when the cavity inside the chip-level micromixer becomes narrower, the fluid velocity increases sharply, and eddy currents are generated between the two baffles. The number of eddy currents increases, which enhances chaotic convection and makes hot and cold water better mixed.

3.3 The effect of the number of baffle rows on the mixing efficiency in the chip-level micromixer

Keeping the inlet velocity, temperature and baffle angle unchanged, the effect of different baffle rows on the internal mixing efficiency of micro mixing was studied. The static pressure cloud map, temperature cloud map and streamline map of different rows of resistance blocks are demonstrated in figure 3.

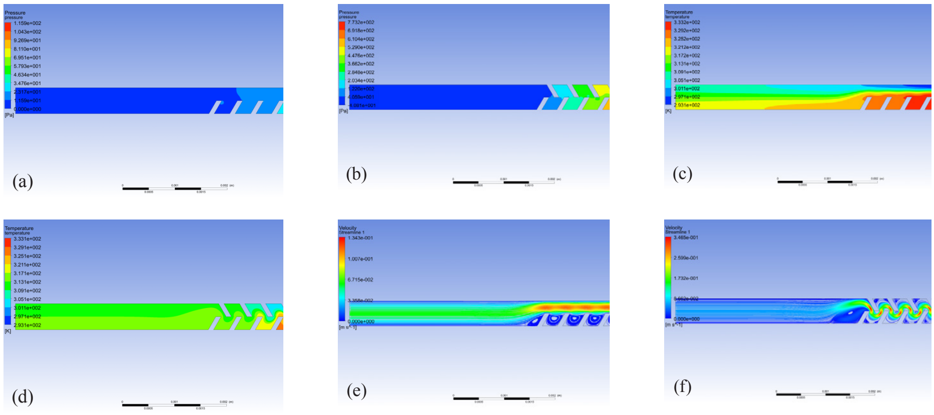

Fig. 3. The pressure temperature cloud diagram and streamline diagram of different rows of resistance blocks.

Figure 3(a), figure 3(c), and figure 3(e) are the static pressure cloud map, temperature cloud map and streamline map of single row of front five resistance blocks respectively.

Figure 3(b), figure 3(d), and figure 3(f) are the static pressure cloud map, temperature cloud map and streamline map of double row of front five resistance blocks respectively.

When the number of baffle rows increases to two rows, this can be seen by comparing figure 3(a) and figure 3(b), which show that the static pressure decreases more smoothly at each baffle, and becomes the static pressure change area between the upper and lower baffles, because the flow channel in the velocity chip-level micromixer becomes narrower, the fluid velocity increases, and the static pressure decreases accordingly. This can be identified by comparing figure 3(c) and figure 3(d), which show that in the outlet area of the chip-level micromixer, the distribution of the color energy level in figure 3(d) shows that the temperature difference at the outlet is very small, indicating that the double-row resistance block chip-level micromixer is more effective than the single-row internal mixing effect. Figure 3(f) compared with figure 3(e), the flow channel at the baffle becomes narrower, the velocity here becomes faster, and the number of eddy current regions increases, which makes the two fluids more fully mixed.

3.4 The effect of different resistance block positions on the mixing efficiency of the micromixer

The baffle position was shifted to the outlet by 1500 microns, the inlet velocity, temperature, and baffle angle were kept unchanged to study the influence of baffle position on the internal mixing efficiency of micro mixing. The pressure temperature cloud diagram and streamline diagram of different blocking positions are demonstrated in figure 4. Figure 4(a), figure 4(c), and figure 4(e) are the static pressure cloud map, temperature cloud map and streamline map of the double-row front five-block respectively; figure 4(b), figure 4(d), and figure 4(f) are the static pressure cloud map, temperature cloud map and streamline map of the double-row rear five-block respectively.

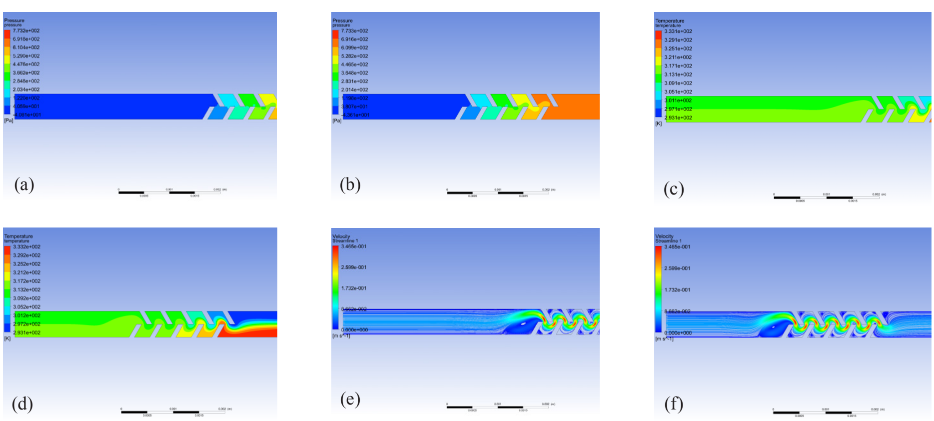

Fig. 4. The pressure temperature cloud diagram and streamline diagram of different resistance block positions.

From the above diagram, it can be observed that figure 4(a) and figure 4(b) are basically the same. The only difference is that from the inlet to the front end of the mixing zone, there are two small areas in figure 4(b) where the static pressure decreases. This is due to the sudden widening of the flow channel, where eddy currents are generated. This can be identified by comparing figure 4(c) and figure 4(d), which show that the temperature at the outlet is basically the same, but when the baffle position is shifted to the outlet by 1500 microns, the cold and hot water is mixed, and the temperature drops faster. This is due to the growth of the front end flow channel, which gives two different temperatures to obtain water for a certain time for natural heat transfer. It can be seen that the baffle position moves a certain distance to the outlet, and the fluid mixing speed is accelerated.

3.5 Effect of different block angles on the mixing efficiency of a chip-scale micromixer

The baffle offset angle was changed from 60° to 120° while keeping the inlet velocity, temperature and work mass constant. The influence of the baffle angle on the blending efficiency inside the chip-scale micro-mixer was investigated. The effect of different baffle angles on the blending efficiency of the chip-scale micro-mixer as demonstrated in figure 5. Figure 5(a), figure 5(c), and figure 5(e) show the hydrostatic pressure cloud, temperature cloud, and flow line diagrams for a baffle offset angle of 60°, respectively; and figure 5(b), figure 5(d), and figure 5(f) show the hydrostatic pressure cloud, temperature cloud, and flow line diagrams for a baffle offset angle of 120°, respectively.

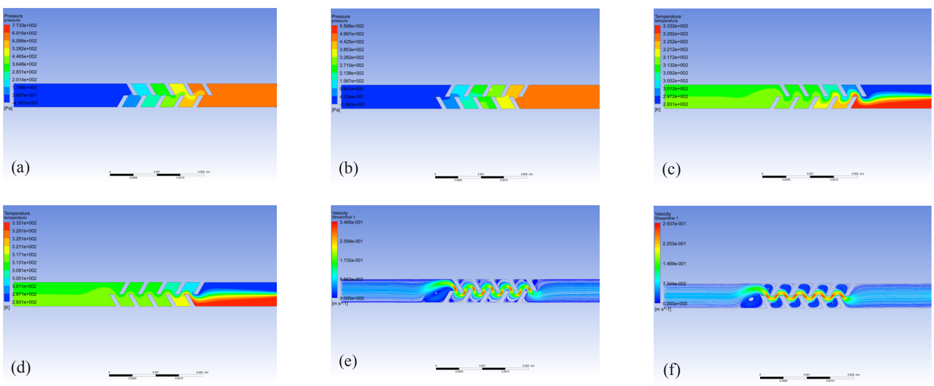

Fig. 5. Effect of different block angles on the blending efficiency of chip-scale micromixer.

As can be demonstrated from figure 5, after the baffle angle is changed from 60° to 120°, this can be identified by comparing figure 5(e) and figure 5(f), which show that the vortex between the two baffles is obviously strengthened, and the energy of the vortex is increased, which will produce a more violent perturbation effect on the fluid, enhance the contact area between the fluids, induce chaotic convection, and intensify mixing between the fluids, and the blending efficiency will be enhanced.

3.6 Influence of different block angles on the blending efficiency of a chip-scale micromixer

Five kinds of microfluidic channels with similar structures were comparatively investigated in the selected range of Re(0-100), including single row three-block with a baffle angle of 60°, single row five-block, double row ten-block with a baffle angle of 60°, double row rear ten-block with an angle of 60°, and double row rear ten-block with an angle of 120°. The relationship between mixing situation in the channel and the change of Re as depicted in figure 6.

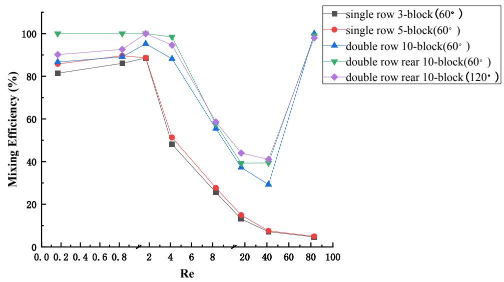

Fig. 6. Effect of different Re on mixing efficiency.

As can be demonstrated from figure 6, when the Re is low, the baffle does not yet have a material influence on the mixing, and the mixing efficiency is high. As the Re increases, the mixing effect is obviously worse. However, increased fluid contact area due to throttling effect of the gap between the baffles and a shortening of the mixing distance, which promotes the mixing to a certain extent, so the mixing effect of the chip-scale micromixer with a built-in double-row baffle is significantly better than that of the single-row T-type chip-scale micromixer. As the Re continues to increase, the flow state in the flow channel is gradually transitioned from laminar flow to vortex and swept flow state, at this time, the intensity and influence area of the vortex are obviously increased, and it becomes the dominant factor affecting the mixing, the mixing effect is significantly improved.

4 Conclusion

In this paper, a built-in block T-type chip-scale micromixer is simulated and analysed using Ansys software to investigate the effect of main parameters on the blending efficiency of the chip-scale micro-mixer. By analysing the effects of different numbers, rows, positions, angles of the block, and different Re on the blending efficiency.

Simulation results demonstrate that: the rise in the amount of baffles can effectively stretch the fluid contact surface and enhance the mixing strength and the vortex flow in the mixing area, which improves the mixing efficiency; the position of the baffles is displaced a certain distance to the exit, which accelerates the blending of the fluid; the mixing effect of the baffles with a 120° baffle is superior to that of the baffles with a 60° baffle; Re between 0.1 and 2, this time the mixing efficiency is higher; Re between 2 and 40, the fluid flow rate to accelerate the residence time in the flow channel to reduce, so the mixing efficiency is slowly becoming lower; Re between 40 and 100, the flow state in the flow channel gradually from the laminar flow to the vortex and swept flow state transition, at this time the mixing efficiency gradually pick up.

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