Investigation of header configuration and its effect on flow maldistribution in plate-fin heat exchanger

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In order to enhance the uniformity of flow distribution, a baffle with small holes of different diameters is recommended to install in the header. The flow maldistribution parameter S is obtained under different header configuration. When the baffle is properly installed with an optimum length, with stagger arranged and suitably distributed holes from axial line to baffle boundary, the ratio of the maximum velocity to the minimum drops from 3.04~3.44 to 1.57~1.68 for various Reynolds numbers. The improved configuration is of great significance in the improvement of plate-fin heat exchanger.

INTRODUCTION

Plate-fin heat exchangers are widely used in process industries because of their higher efficiency, more compact structure and lower costs than two-stream heat exchanger networks [1,2]. In the design of plate-fin heat exchanger, it is usually presumed that the inlet flow and temperature distribution across the exchanger core are uniform and steady. However, the assumption is generally not realistic under actual operating conditions due to various reasons. The design of the header significantly affects the velocity distribution approaching the face of exchanger core. The flow maldistribution effects have been well recognized and presented for heat exchangers. While the literature of improved configuration to enhance the flow uniformity in plate-fin heat exchanger is little in recent years. Zhang[3] proposed a structure of two-stage-distribution and the numerical investigation shows the flow distribution in plate-fin heat exchanger is more uniform if the ratios of outlet and inlet equivalent diameters for both headers are equal. In this paper, a simple way is put forward to homogenize the flow distribution. A baffle with small-size holes is installed in the traditional header to optimize the header configuration. The investigation on the effect of the configuration of the baffle on the flow distribution is presented.

BASIC CONFIGURATION AND ITS IMPROVEMENT

A schematic view of conventional header (denoted as configuration A) presented in this study is shown in Fig.1. There are 43 micro-passages in the outlet of the header. Composite constructive grids are used in the analog computation and the finest implemented grid involved about 245,817 cells. There are selective refined grids in some local place where parametric variation is severe. In this work, CFD software FLUENT was employed to simulate the fluid flow distribution and pressure drops in the header of plate-fin heat exchanger. Continuity equation and momentum equation are discretized using finite volume method and two-equation K-ε flow turbulent model is used in the calculation [4]. Semi-implicit SIMPLER Algorithm is used in the velocity and pressure conjugated problem and second order upwind difference scheme is used in convective terms [5]. Boundary conditions and convergent condition are as follows: Inlet fluid Reynolds numbers and pressure are given. The wall condition is adiabatic and no slip occurs on the wall. Convergence criterion is specified to residuals $\leq 1.0\times 10^{-6}$.

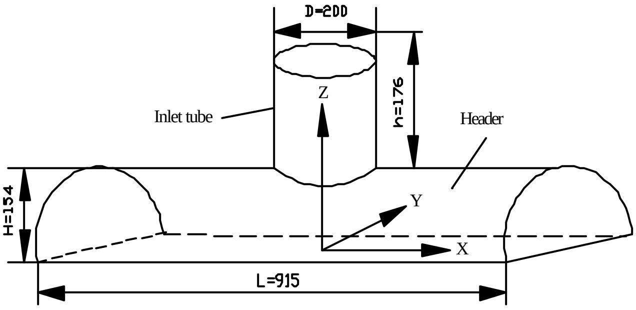

Figure 1 Model of header construction

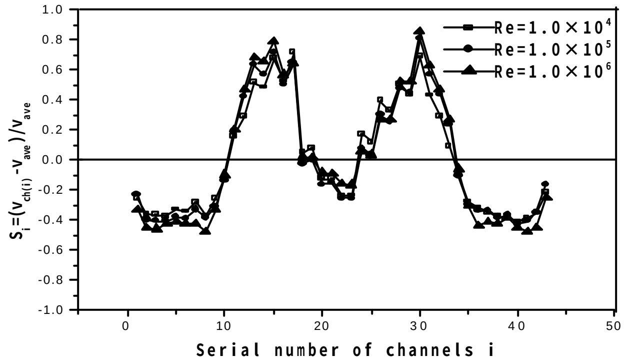

Figure 2 S_i at different Re

Two parameters are introduced in this paper to evaluate the flow maldistribution, namely, relative flow maldistribution parameter S_i and absolute flow maldistribution S, which are defined as follows:

$$S_i = \frac{v_{ch(i)} - v_{ave}}{v_{ave}} \quad (1) \qquad S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(v_{ch(i)} - v_{ave}\right)^2} \quad (2)$$

Where N stands for the passage number (here is 43), $V_{ch(i)}$ stands for the velocity of each passage and V_{ave} stands for the average velocity of all the passages.

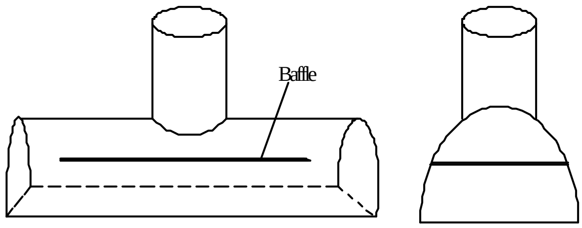

Figure 3 Definition of the baffle position in the header

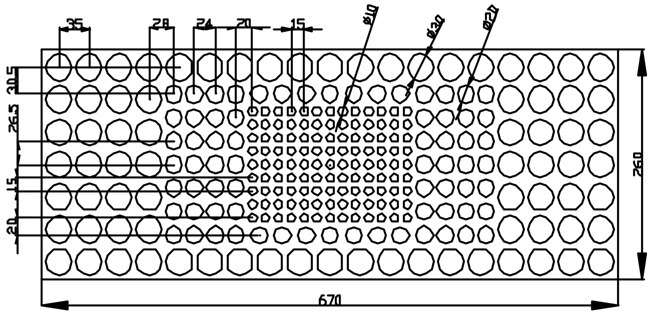

Figure 4 Baffle construction of configuration B

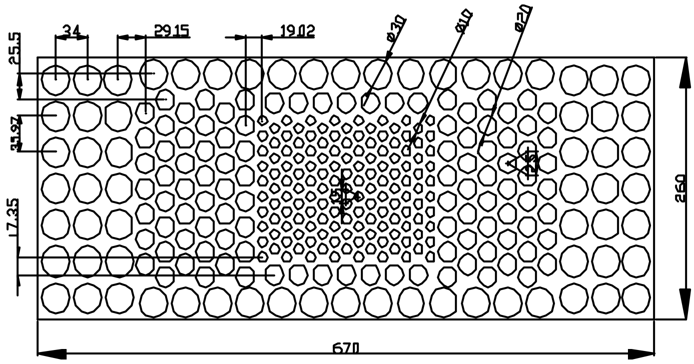

Figure 5 Baffle construction of configuration C

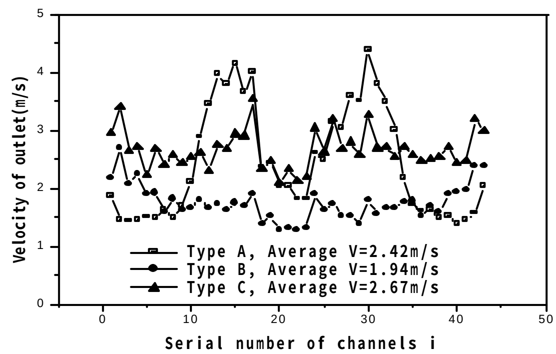

Figure 6 Outlet velocity of different headers

Fig.2 presents the numerical results of conventional configuration A. The flow maldistribution of the outlet along the x direction is very serious and the absolute flow maldistribution S is equal to 0.95, where the average value for y direction is adopted. Because the flow header has larger dimension comparing to the inlet tube diameter, the fluid tends to go preferentially into the channels in the center. And it has been found that the best position for the perforated grid is midway between the inlet tube and the core of the header [6]. So a baffle with small holes is put forward to install at the 1/2 height of the header symmetrically, which is demonstrated in Fig.3. The small holes are arranged in the baffle according to the velocity distribution, and the punched ratio is gradually increasing in symmetry from the axial line to the boundary. It is presumed that $\int v\mathrm{d}A$ is equal to a constant value under ideal condition. Thus the fluid flow is distributed uniformly before it reaches the header outlet and the expected object of uniform distribution is achieved.

The baffle configurations are demonstrated in Fig.4 and Fig.5, in which the baffle with in line arranged holes is denoted as configuration B (Fig.4) while the one with in stagger arranged holes is denoted as configuration C (Fig.5). For the improved configurations, the velocities increase in the zone of two ends of header and decrease in the zone near the axial line. Thus, the fluid flow is distributed more uniformly. Unfortunately the pressure drop may increase and result in the decrease of mean velocities to some extent, which is inevitable but not anticipated. So it is obliged to get the suitable baffle configuration for getting the optimum point of uniform flow distribution and pressure drops.

OPTIMIZATION OF BAFFLE CONFIGURATION

The velocity distribution of three header configurations is shown in Fig.6 in order to compare the effects of different hole distributions. The curves in Fig.6 illustrate the distribution characteristics of flow velocity and their differences for three configurations at similar working conditions. The inlet conditions are the same at $Re=1.0\times10^5$ and p = 27kPa. It is indicated that the average velocity is 1.94m/s and the absolute maldistribution parameter is 0.36 for configuration B, while they are 2.67m/s and 0.32 for configuration C, respectively. It shows that the average velocity of configuration C is much larger than that of configuration B. It is easily understood that when the hole distribution in the baffle is changed from in-line arrangement to staggered arrangement, the punched ratio on the baffle will increase from 47% to 53%, and the flow resistance brought about by baffle necessarily decreases. Moreover, the increase of punched ratio leads to the increase of flow area on the baffle and further results in the decrease of S. The improvement of header configuration with a stagger arranged baffle should be selected firstly.

The location where the baffle is installed has been determined to the 1/2 height of the header, and the thickness of the baffle is determined to 5mm, so the baffle is 260mm in width. The diameters of the three kinds of holes are the same as described above. Fig.7 shows the flow distribution performance along with the change of relative length of baffle to header at $Re=1.0\times10^5$. The average velocity decreases when the baffle length increases, and also the flow resistance increases and brings about the increase of pressure drops. The influence of the baffle on flow distribution is significant along with the increase of baffle length since the absolute maldistribution parameter S decreases. Combinative consideration of the relationship between the average velocity and the absolute maldistribution parameter S, leads to selection of the baffle length as 670mm, which is just 3/4 of the length of header.

For the baffle configuration as above mentioned, the average velocity of configuration C is larger than that of configuration A due to the decrease of the highest fluid velocity. For configuration C, the velocity distribution is mostly concentrated in the range of 2.5 and 4.0 m/s. The numbers of passages with the flow velocity between 2.5 to 4.0 m/s takes about 72% of the whole passages at $Re=1.0\times10^5$. While for configuration A, the velocity distribution is concentrated between 1.0~2.5 m/s, which takes about 65% of the numbers of whole passages. The flow velocity ratio of the maximum to the minimum drops from 3.04~3.44 of configuration A to 1.57~1.68 of configuration C, which reflects a more uniform flow for the improved header. From the above discussion, the effect of header configurations on flow maldistribution is prominent. The flow velocity of the passages near the boundary can be enhanced effectively by changing the header configuration from A to C. The flow velocity distribution of configuration C gives the most uniform result among the cases considered in this paper.

From above discussion, it can be concluded that the determination of baffle configuration has the relationship with the diameter of inlet tube, the length and diameter of header, the diameters and distribution of holes when the baffle installation location has been defined. Fig.8 shows the distribution of punched ratio, in which the staircase curve is drawn according to the realistic condition and the smooth curve is simulated from the former. The correlation of punched ratio along with the position in the direction of baffle length under the ideal situation should be established as follows:

$$d = 47.75 + \left(\frac{X}{100}\right)^2 \quad (3)$$

where d stands for the punched ratio (%) and X stands for the X position along with the baffle length (mm). In practical condition, if the holes on baffle can be punched according to the simulated smooth curve, we can get $\int v\mathrm{d}A$=const and the flow can be distributed more uniformly than the configuration C.

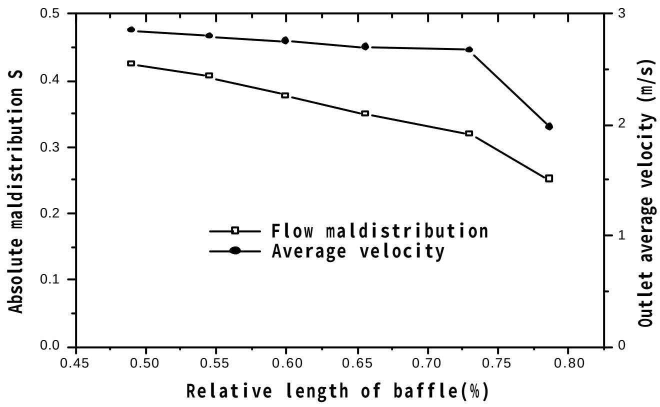

Figure 7 S and average velocity versus baffle length

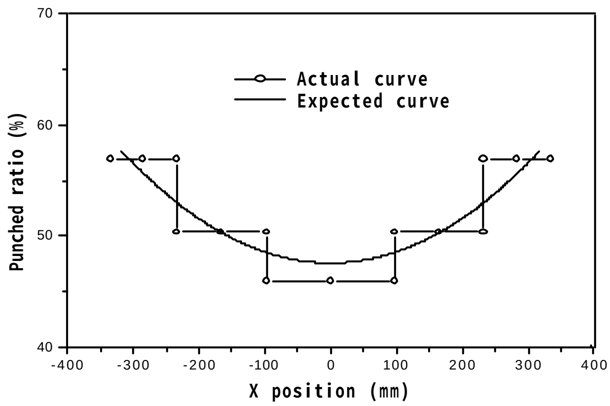

Figure 8 Punched ratio versus x position

CONCLUSION

The results of calculation indicate that the improved header configuration can effectively enhance the fluid flow uniformity. The flow absolute maldistribution parameter S in plate-fin heat exchanger has been reduced from 0.95 to 0.32 by installing the baffle. When the baffle is proper in length, the holes are distributed in staggered arrangement, and the punched ratio gradually increases from axes along with the dam board length, the ratio of the maximum flow velocity to the minimum flow velocity may drop from 3.04~3.44 to 1.57~1.68 for various Reynolds numbers. The fluid flow distribution in plate-fin heat exchanger is more uniform by the optimum design of the header configuration. The baffle is lower in cost and convenient in assembly, while the effect of the fluid flow distribution uniformly by the improved configuration is obvious. The conclusion of this paper is of great significance in the improvement of plate-fin heat exchanger.

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