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The Numerical Simulation of Enhanced Heat Transfer Tubes

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Abstract

The enhancing heat transfer mechanism of the transversally corrugated tube,converged-diverging tube and corrugated tube compared with that of the smooth tube was studied in this paper. Here heat transfer models were established with water as the medium of the enhanced heat transfer tubes .We used simplec methods and the standard k- ε turbulence model in Fluent and analyzed the impact of different tube structure on heat transfer tubes, finally, achieved visualization of flow field in enhanced heat transfer tubes. it can been concluded from the figures that: within the scope of this study, the order of three tubes according to the merits is transversally corrugated tube, converged-diverging tube and corrugated tube.

*Keywords:*heat transfer enhancement; enhanced heat transfer tube; numerical simulation; turbulence model

1. Introduction

During these twenty years, chemical, petroleum and light industry have achieved rapid development. Owing to increasing equipment capacity can reduce equipment investment and running cost, various industrial sectors are developing high-capacity and high-performance equipment. heat transfer enhancement measures are widespread concerned by people because it can improve thermal efficiency, the same as the problem of convection heat transfer enhancement .At present, several methods have been widely used in industrial practice[1-2], from all the methods, finned tube has been widely applied for advantages of increasing heat transfer area and reducing thermal resistance[3]. But the study on heat transfer enhancement of inner finned tube are relatively few, so the mechanism of it are still not very clear, it makes the design work related to heat exchanger have no clear intuitive basis to follow.

Large commercial CFD software fluent can be more accurate, fast in reflecting the whole flow process of fluid in the heat exchanger, such as the distribution of velocity field, pressure field and

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temperature field, from these we can directly get flow characteristics of fluid in the tube, so as to provide a good theoretical basis to actual design.

In this paper, turbulent flow and heat transfer characteristics in the smooth tube and other three enhanced heat transfer tubes were simulated in Fluent with cases of the wall temperature is constant, and the influences of different inner finned tubes on heat transfer enhancement were analyzed.

2. Heat Transfer Machanism in the Tube

The measures of heat transfer enhancement can be divided into active and passive enhancement, active enhancement measures need external work, so it is rarely used in usual, passive enhancement measures often contain extending surface, surface modification, tube inserts and so on, from which the tube inserts are usually used only for laminar flow, while turbulent flow most use fin tube and low-finned tube to strengthen[4]. The main mechanisms in enhanced heat transfer tube are increasing the second heat transfer surface and destroying the original velocity and temperature distribution field.

The study on heat transfer enhancement in the enhanced heat transfer tubes in this paper is mainly in the area that near the wall with low velocity, that is, the well-known laminar sublayer, most of the thermal resistance is concentrated in this layer of low velocity flow, all of enhancement technologies adopt changing the internal structure of the tubes to disturbance fluid and destroy boundary layer, so as to achieve the purpose of enhancing heat transfer. The ratio of boundary layer thickness and diameter: $y/d = 25 * Re^{-0.875}$ [5].

What can be available in heat transfer enhancement measures in tubes mainly are spirally fluted tube, transversally corrugated tube, converged-diverging tube, corrugated tube and so on. The transversally corrugated tube actually is a kind of special spirally fluted tube, when the helix angle increase to 90° and it is better than spirally fluted tube in strengthening effect[6]. Because of the role of centrifugal force and torque force, the flow of fluid in enhanced tube is much more complex than that in smooth tube, with the impact of secondary flow, mainstream in high axial velocity from pipe central area will continue to mix with the fluid that in lower axial velocity near the wall, all of these can improve the turbulence intensity, thereby enhancing the heat transfer.

3. Numerical Simulation

3.1 Model

There are some assumptions in the simulation process: current state is stable, that is, flow distribution is only related to the spatial location but not the time; fluid properties (density, specific heat and fluid viscosity, etc.) does not vary with temperature; ignoring the influence of gravity. We select the optimized structure in the physical model of four heat transfer tube, in order to avoid the impact of different parameters, the hydraulic diameter of the tubes are set to 40mm,and the length are 600mm. The numerical simulation use finite volume method to discrete the control equations, and the calculation use separated implicit solver for steady state calculations.

3.2 Equations

Control equations are 3D incompressible flow continuity equation and the navier-stokes equation of momentum and energy equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

$$\rho(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z})=-\frac{\partial p}{\partial x}+\eta(u\frac{\partial^2 u}{\partial x^2}+v\frac{\partial^2 v}{\partial y^2}+w\frac{\partial^2 w}{\partial z^2})+F_x \tag{2}$$

$$\rho(\frac{\partial v}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z})=-\frac{\partial p}{\partial y}+\eta(u\frac{\partial^2 u}{\partial x^2}+v\frac{\partial^2 v}{\partial y^2}+w\frac{\partial^2 w}{\partial z^2})+F_y \tag{3}$$

$$\rho(\frac{\partial w}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial w}{\partial z})=-\frac{\partial p}{\partial z}+\eta(u\frac{\partial^2 u}{\partial x^2}+v\frac{\partial^2 v}{\partial y^2}+w\frac{\partial^2 w}{\partial z^2})+F_z \tag{4}$$

$$\rho\frac{Dk}{Dt}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right]+G_K-\varepsilon \tag{5}$$

$$\rho\frac{D\varepsilon}{Dt}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right]+C_{\varepsilon 1}\frac{\varepsilon}{k}G_k-C_{\varepsilon 2}\frac{\varepsilon^2}{k} \tag{6}$$

$C_\mu = 0.09$, $C_{\varepsilon 1}=1.44$, $C_{\varepsilon 2}=1.92$, $\sigma_k=1.0$, $\sigma_\varepsilon=1.3$.

3.3 Boundary conditions and flow parameters

Model uses hexahedral mesh and mesh wall encryption; Inlet temperature of working fluid T = 300k, stress is a standard atmospheric pressure, temperature of the wall T = 450k. Reynolds number Re = 6680, boundary conditions are inlet velocity, temperature of the wall is constant and the outlet conditions are free flow; Counted within the entire region, ignoring the differences of wall temperature. In order to find the nature of turbulence better, the model use standard k-ε model, pressure - velocity coupling with Simplec algorithm.

4. Analysis of the simulation results

Three-dimensional turbulent flow numerical simulation of smooth tube, transversally corrugated tube, converged-diverging tube and corrugated tube based on Fluent are showed in this part, in the process, we can clearly observe the distribution of temperature, velocity, turbulent kinetic energy and skin friction coefficient from several different sections, the analysis and comparison of the influence of the different enhanced tube on heat transfer and flow characteristics are as follows.(the code of smooth tube, transversally corrugated tube, converged-diverging tube and corrugated tube in following diagrams are No.1、No.2、No.3、No.4)

4.1 Working process of the enhanced heat transfer tubes

The whole process of heat transfer inside tubes can be clearly seen through the following diagrams:

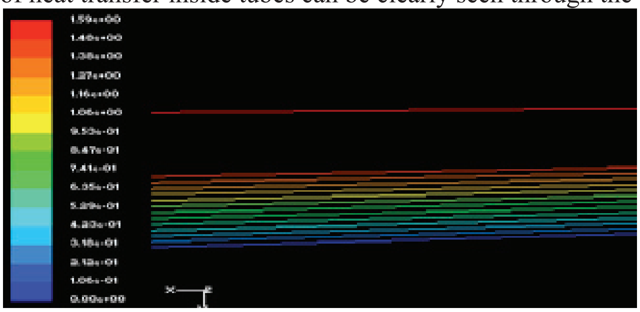

Figure 1. Speed contour distribution cross-section of No.1

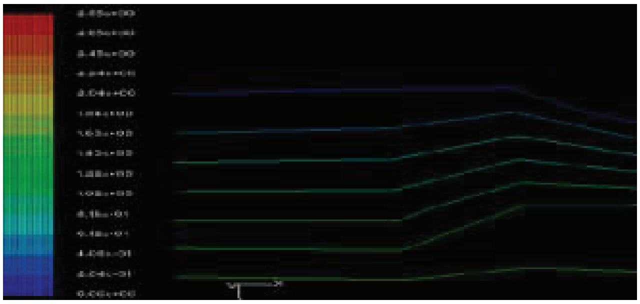

Figure 2. Speed contour distribution cross-section of No.2

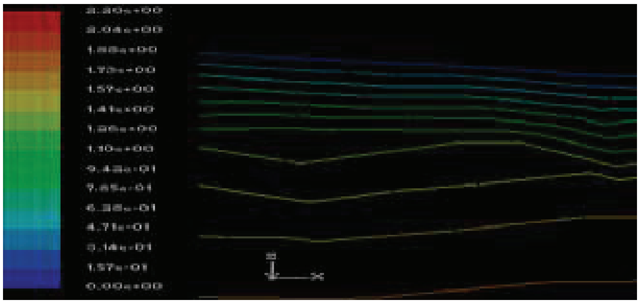

Figure 3 .Speed contour distribution cross-section of No.3

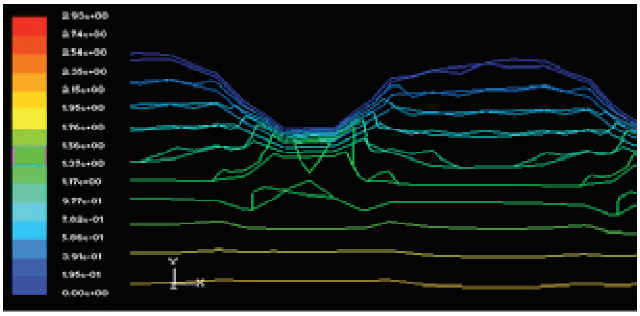

Figure 4 .Speed contour distribution cross-section of No.4

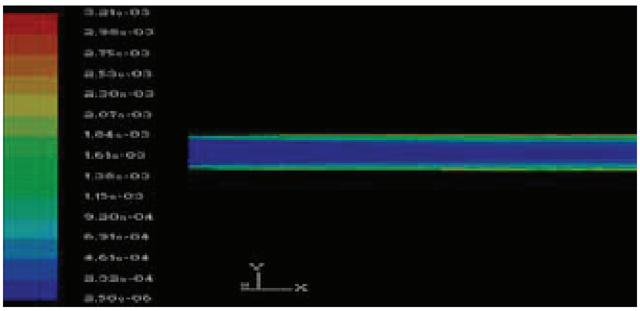

Figure 5 .Axial turbulence kinetic energy distribution of No.1

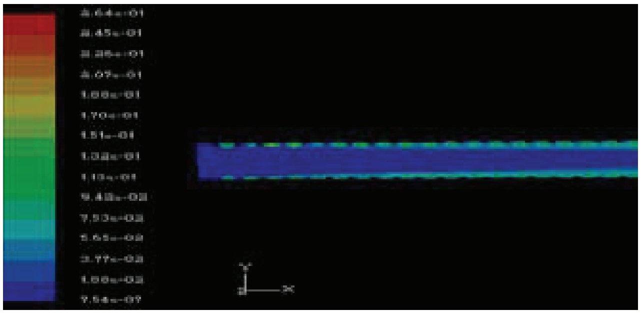

Figure 6 .Axial turbulence kinetic energy distribution of No.2

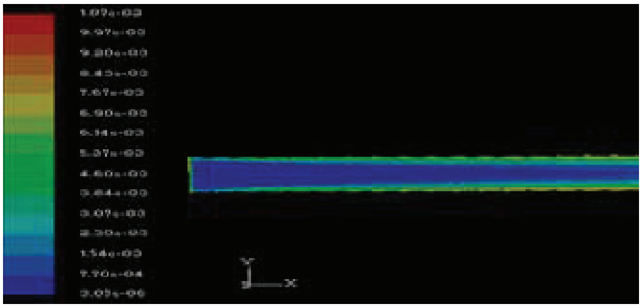

Figure 7. Axial turbulence kinetic energy distribution of No.3

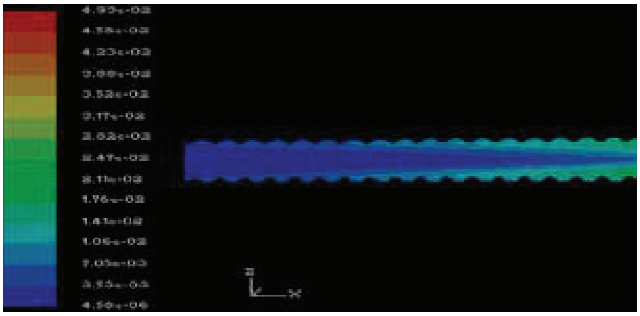

Figure 8. Axial turbulence kinetic energy distribution of No.4

The surface heat transfer coefficient is mainly determined by the changes of the radial velocity and turbulence intensity within transition zone, that is to say this three is consistent with each other.

It is clear from Figure 1 - Figure 4 that when the fluid flows through convex rib ring of the transversally corrugated tube, the speed direction near the wall surface will change, then the radial disturbance appears, and thereby prevents the formation of the boundary layer, that enhanced heat transfer to some extent. Besides, when the fluid flows through the groove ring, the velocity near the wall erodes boundary layer in axial and then axial vortex formed, that can increase the disturbance of boundary layer and promote the update of surface layer, and is conductive to the heat transfer through the boundary layer; In the converged-diverging tube, the decrease of circulation area in contraction segment accelerates the velocity of the fluid, high-speed fluid erode and disturb the boundary layer, because there are changes in the fluid particle velocity, dramatic spiral and secondary flow are formed in the transition section, it promotes mixing of fluid from the core and boundary layer area, makes the boundary layer thinning, so it could have a better heat transfer effect; In corrugated tube, as it shown in Figure 4,not only the velocity of the fluid in the trough section is increasing , washing boundary layer with high-speed, but also in upstream flow of each crest have emerged a closed recirculation region, and accompanied with circular flow in a certain speed in the recirculation zone. These will keep the cold fluid from central region and the hot fluid near the wall exchanging. Finally make the heat pass off.

Figure 5 - Figure 8 shown, in the three enhanced heat transfer tubes, fluid temperature and turbulent kinetic energy have been greatly improved compared with smooth tube, particularly in transversally corrugated tube and converged-diverging tube, their turbulent kinetic energy reached to a larger value at the part of the wall. The periodic changes in expansion and contraction section make the fluid turbulence enhanced. The scope of turbulent kinetic energy changing is much larger in corrugated tube than that in other tubes, its turbulent kinetic energy increases along the flow direction, with the changes of cross-sections, turbulent kinetic energy gradually transferred to the central region, showing the trend of increasing, and get to the maximum value in the export section.

4.2 Comparison of heat transfer effect

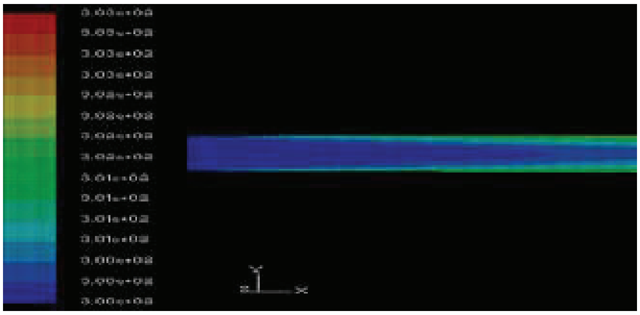

Figure 9 .Axial temperature distribution section of No.1

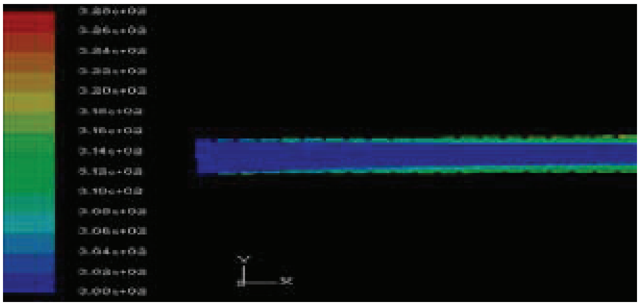

Figure 10 .Axial temperature distribution section of No.2

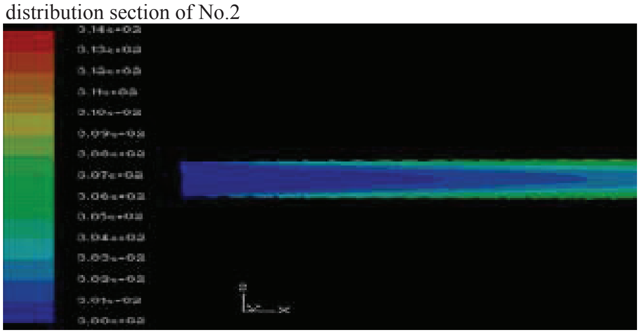

Figure 11. Axial temperature distribution section of No.3

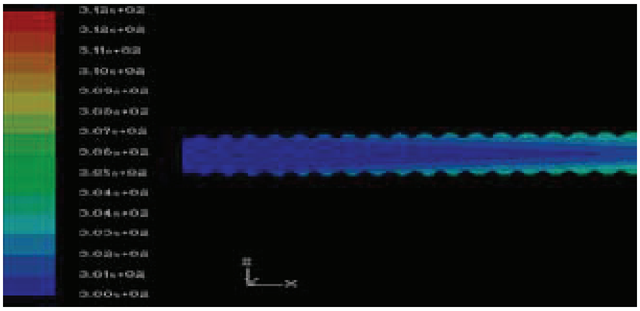

Figure12. Axial temperature distribution section of No.4

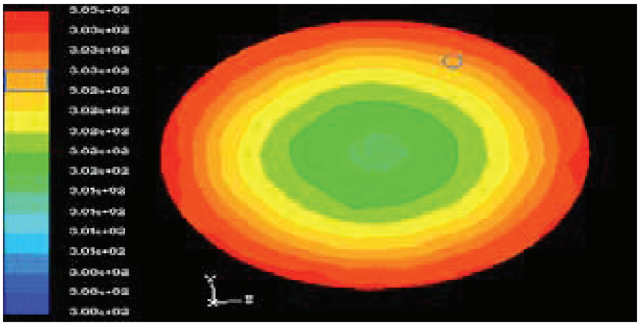

Figure 13. Outlet temperature section of No.1

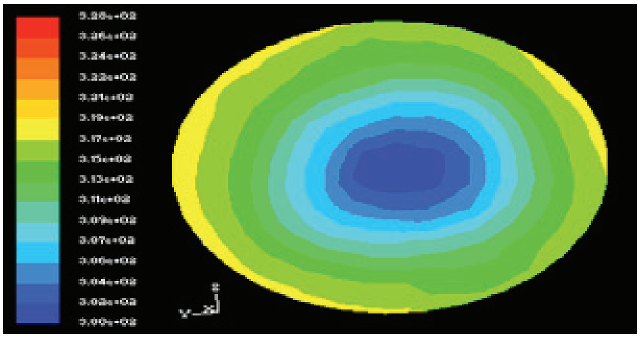

Figure 14. Outlet temperature section of No.2

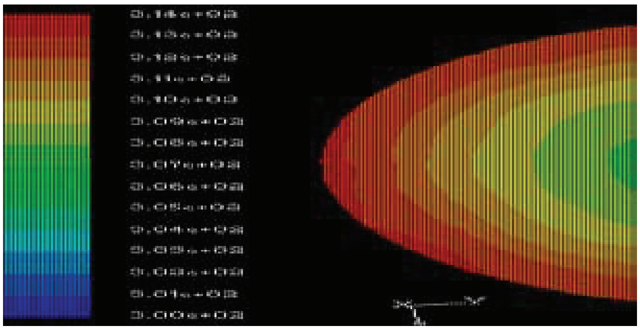

Figure 15. Outlet temperature section of No.3

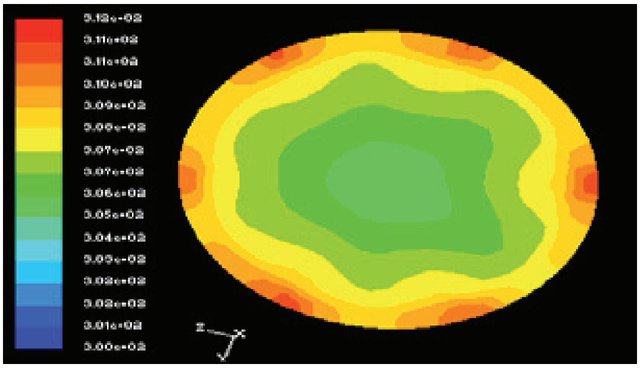

Figure 16. Outlet temperature section of No.4

As can be seen in Figure 9-Figure 16, the heat transfer effect of transversally corrugated tube is most obvious and Its maximum temperature reached 311℃-317 ℃, but the temperature in axis area is lower. It indicates that its disturbance is ineffective; the heat transfer effect of converged-diverging tube is worse than the former, its outlet temperature is mainly in 306 ℃-314 ℃, but the disturbance effects in the pipeline region and uniformity of temperature distribution are better than that of the former; The outlet temperature of corrugated tube reached 306 ℃-310 ℃, its performance of the fluid disturbance mixing effect and the uniformity of outlet temperature is best.

4.3 Analysis of integrated performance

The following is heat transfer resistance coefficient inside the tube changes with the tube length:

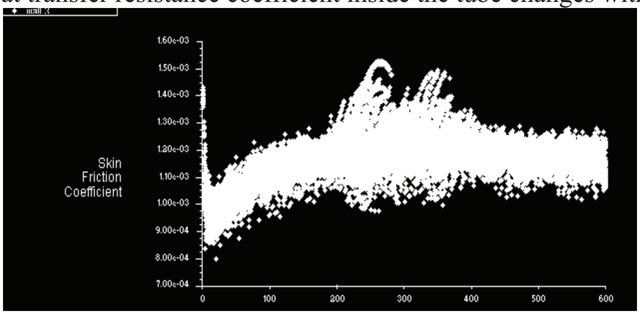

Figure 17 .Wall surface friction coefficient of No.1

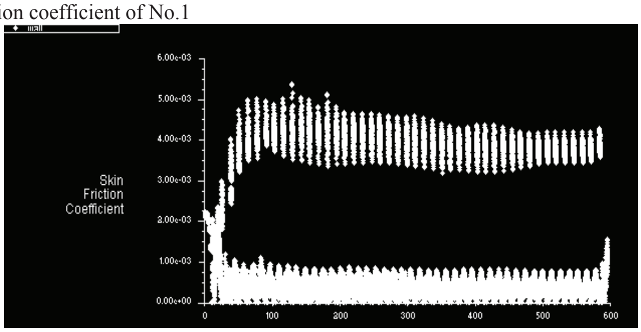

Figure 18. Wall surface coefficient of No.2

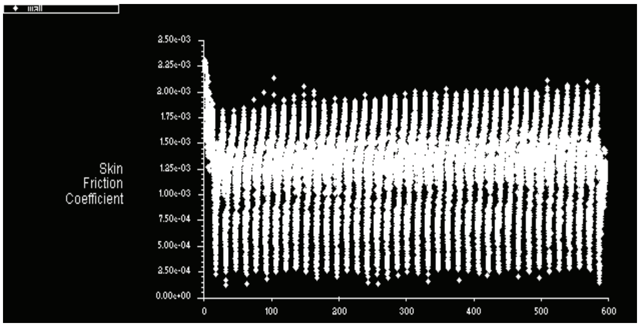

Figure 19. Wall surface friction coefficient of No.3

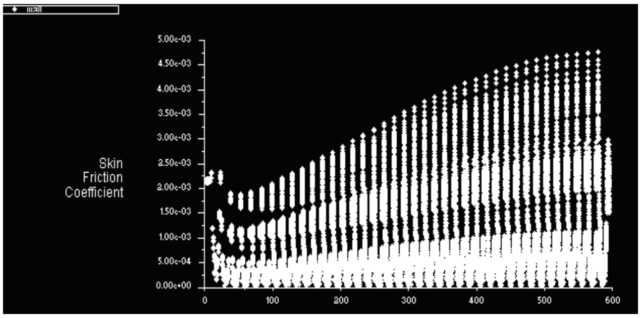

Figure 20 . Wall surface friction coefficient of No.4

In Figure17-Figure20, due to the wall structures, the surface friction coefficient of three enhanced heat transfer tubes increased in different levels compared with smooth tube. Ignoring the changes of surface friction coefficient in entrance section, in the fully developed section, the surface friction coefficient of smooth tube is about 0.0012,and for transversally corrugated tube it is about 0.004, surface friction coefficient of converged-diverging tube is mainly in 0.00025-0.00175, but that of corrugated tube is increasing with the length of the tube for the effect of disturbance, the initial value is about 0.002 and with the length its growth is 25%—40%,so the length design of corrugated tube plays a very important role in heat exchanger, in actual, the surface friction coefficient can be controlled in a certain range through the tube length. The surface friction coefficient of transversally corrugated tube is the largest, the surface friction coefficient of converged-diverging tube is relatively small, with smooth transition surface, converged-diverging tube is difficult to scale, so it is applied to heat transfer with dust particles fluid.

5. Conclusion

This paper used the computational fluid dynamics (CFD) software Fluent to analyze the flow in three sorts of enhanced heat transfer tubes and heat transfer process, with comparison of smooth tube. The flow of heat transfer enhancement and heat transfer process are described in detail, including several comparison results of heat transfer enhancement processes, heat transfer theory, the heat transfer effect and the resistance coefficient.

Analysis of heat transfer mechanism of the three enhanced heat transfer tubes are as follows: transversally

Corrugated tube constantly changes the surface shape of tubes to make fluid continuously produce radial disturbance and axial vortex, thus to strengthen the role of the erosion and the disturbance on boundary

layer, making heat transfer capacity is greatly enhanced; Converged-diverging tube adopt the periodic changes of expansion and transition section to strengthen the fluid turbulence, it also produce vortex flow and secondary flow, so as to reduce the laminar sublayer, strengthening heat transfer effect; For corrugated tube, the existence of recirculation region in each crest is the
key to the heat transfer enhancement.

Within the scope of this study, considering the turbulent kinetic and heat transfer effect, the order of the priority is: transversally corrugated tube, converged-diverging tube, corrugated pipe; But from the resistance to consider :flow resistance of transversally corrugated tube is maximum, flow resistance of Converged-diverging tube is minimum, so this tube is applicable to the heat transfer fluid containing dust particles, flow resistance of corrugated tube can be different according to the length, its good mixing effect of fluid flow is also one of advantages. According to the specific needs, the design of heat exchanger should under the consideration of their advantages and disadvantages.

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