Applications of the Strong Heat Transformation by Pulse Flow in the Shell and Tube Heat Exchanger

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Abstract: This article deals with the heat exchange coefficient varied with pulse frequency in the pulsation tube with different flow forms. The findings show that heat can be exchanged coefficient with the pulse frequency, and it has an optimal frequency. The laminar flow and turbulent flow have approximately the same optimal frequency, i.e., about 8 Hz. When the pulsation source was placed in the upstream and downstream position, the heat transformation was completed dissimilarly. These results are coincident with previous experiments.

The article also gives some information on the applications of the heat transformation by pulse flow in the shell and tube heat exchanger.

Key words: pulse flow; strong heat transformation; computation fluid dynamics; shell and tube heat exchanger

1. INTRODUCTION

From the 60's in the last century, people have been devoting themselves to improve the transformation properties of various heat equipment and applied the technology into different industrial areas. It could be seen from the heat transformation theory that there were three commonly used ways for the heat transformation, e.g. improving heat transformation coefficient, enlarging heat transformation area and increasing difference of average heat transformation. But the most widely used research was how to enhance convective heat transformation. According to the Beigles' classification method, the convective heat transformation could be divided into two: passive technique and active technique. So the research of using active technique to enhance heat exchange was a widespread concern by many scholars. Consideration about tube heat transformation in the inner gradient of temperature was mainly concentrated on the boundary layer, if boundary layer could be broken effectively and the thermo-resistance which lay in laminar boundary layer or turbulence sublayer could be diminished, we could enhance local heat exchange coefficient and intensify heat exchange process by convection. Thinking of such notion , the idea of enhancing heat exchange by pulse flow which was used in the shell and tube heat exchanger came out.

Currently, there are four conclusions which come from the research of heat exchange enhancement by pulse flow: (1)pulse flow could enhance heat exchange and improve average heat exchange coefficient noticeably[1,2,3], (2)pulsation source could improve heat exchange coefficient by convection when it was located in the upstream, but when it was located in the downstream that didn't have any patent distinction with heat exchange by invariableness flow[4], (3)the pulsation source could reduce heat exchange coefficient by convection when it was located in the downstream, which also weakened heat exchange[5-8], (4)pulse flow might enhance or weaken heat exchange that lied on flow parameter[9-11].

This article made use of FLUENT software to numerical Simulate round tube pulse flow convection problem with the same temperature which came from wall thermal boundary, using numerical ways to analyze pulse flow's infection of heat exchange.

2. PHYSICS MODEL

Round tube was 2 ms long, the inner diameter was 17 mms, flow pattern was laminar and turbulence, tube wall was adapted constant wall temperature to heating. When the pulsation source located in the upstream, tube inlet velocity could set as a cyclic varying sine function

$$u = u_0 A\sin(2\pi ft) \quad (1)$$

In the formula A ——amplitude;

f ——frequency, Hz;

When the pulsation source was located in the downstream, tube outlet pressure that could set as a cyclic varying sine function

$$p = p_0 A\sin(2\pi ft) \quad (2)$$

Assumption:

(1) The fluid was constant object property and incompressible fluid;

(2) Round tube was laid on horizon level, the effect of gravitation could be ignored;

(3) All of the interfaces and contact surfaces weren't distortion, fluid —— solid contact surface was non-slip boundary;

(4) The fluid was axisymmetrical two-dimensional flow.

To predigest more problems, considering tube inner flow and heat exchange was axisymmetrical distribution, we could take a side on the round tube axis as research object then the problem would be simplified as two-dimensional、unsteady、constant object property and incompressible fluid 、axisymmetrical flow and heat exchange[12].

When adapted FLUENT software, we considered the model was slender tube which had a large gap between length and scale, so we could use double precision solver; In the numerical simulation, the pressure interpolation selected standard format, momentum equation and energy equation chose QUICK format to disperse, pressure and velocity elected SIMPLE arithmetic to couple.

The calculation formula about average coefficient of heat transfer was

$$h = \frac{Mc_p(t'' - t')}{A\Delta t} \quad (3)$$

In the formula

h ——average heat convection property on wall, W/(㎡·K);

A ——heat transfer area, ㎡;

c_p ——fluid constant pressure specific capacity, J/(kg·K);

M ——fluid mass flux, kg/s;

t' ——fluid inlet temperature, K;

t'' ——fluid outlet temperature, K;

Δt —— logarithm average heat transfer temperature difference, K。

To indicate the effect of heat exchange reinforcing by pulse flow, we could make use of E to denote heat exchange enhancement ratio.

$$E = \left(\frac{h}{h_0} - 1\right) \times 100\% \quad (4)$$

In the formulate

h ——the heat transfer coefficient when the flow had pulse;

h_0 ——the heat transfer coefficient when the flow didn't have pulse。

3. RESULT ANALYZES

In the former experiment of pulsating flow heat exchange enhancement, we discovered that the heat exchange efficiency was completely different when pulse resource lay sat the upstream and downstream of the pipe, as a result, the text separately discussed the heat exchange when pulsation resource lays at the head and the end of the round pipe under different condition[13].

3.1 When the Pulse Source was Located in the Upstream, Turbulent Flow had Influence on the Pulse Flow

When $u_0 = 0.5$ m/s, $A = 0.3$, we have carried out the numerical calculation of the heat exchange condition under the turbulence flow pattern in the round tube. The curve chart of the pulse heat exchange enhancement ratio E changed with the frequency f as the chart 1 when it was the turbulence flow. Its total change trend was increased with the frequency at first, then reduced gradually, and then after it augment to peak it would reduce gradually. From the chart, we could know, when $0 \le f \le 4Hz$,E increased at first and then reduced with the frequency increasing;

when $f = 2Hz$, there was at a peak ,about 44%,when $4 \le f \le 16Hz$, the same with the frequency segment, E increased at first and then reduced with the frequency augmenting and reached to the peak when $f = 8Hz$, about 61%. We could know from that, there was a best value between the frequency f and the pulse heat exchange enhancement ratio E, when $f = 8Hz$, the effect of heat exchange enhancement was the best.

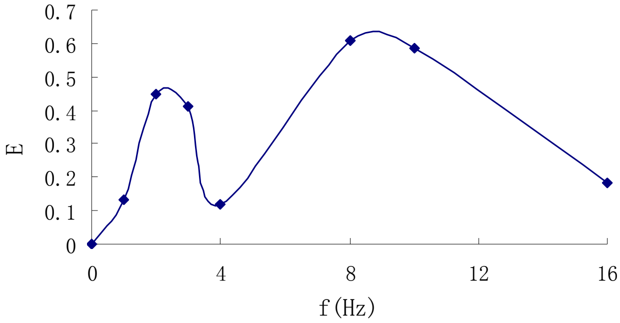

Fig. 1

3.2 When the Pulse Source was Located in the Upstream, the Laminar Flow Effected on the Pulse Flow

When $u_0 = 0.05$ m/s, $A = 0.03$, the curve chart of the pulse heat exchange enhancement ratio E changed with the frequency f as the chart 2 when it was the laminar flow. Its total change trend was increased with the frequency at first, then reduced gradually, and then after it reached to the peak it would reduce gradually. From the chart, we could know, when $0 \le f \le 2Hz$, E reduced at first and then increased with the frequency augmenting; when $f = 2Hz$, there was at peak or minimal value about -8%; when $2 \le f \le 16Hz$, E augmented at first and then reduced with the frequency augmenting and reached to the peak when $f = 8Hz$, about 23%. We could know from that, there was a best value between the frequency f and the pulse heat exchange enhancement ratio E, when $f = 8Hz$, the effect of heat exchange enhancement was the best.

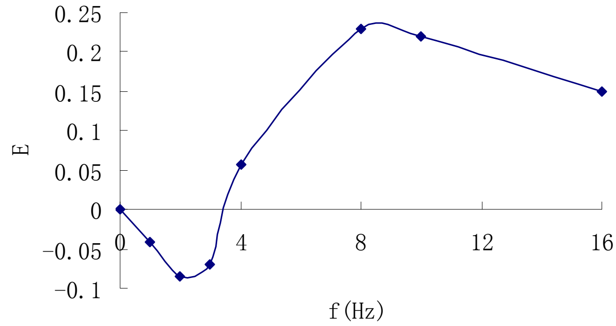

Fig. 2

3.3 When the Pulse Source was Located in the Downstream, the Turbulence Flow Effected on Pulse Flow

When $p_0 = 0.5$ atm, $A = 0.3$, the curve chart of the pulse heat exchange enhancement ratio E changed with the frequency f as the chart 3 when it was the turbulence flow. Its change trend was reduced to the minimal value with the frequency at first, then increased gradually, and then after it reduced it would gradually gentle. From the chart, we could know, when $0 \le f \le 2.5Hz$, E fast reduced at first and then increased with the frequency increasing; when $2.5 \le f \le 16Hz$, E reduced at first and then stabilized with the frequency, about -10%. With the pulsation source location changing, heat exchange effect was completely different with the condition of the pulsation source at the upstream, it was not strong but weak heat exchange.

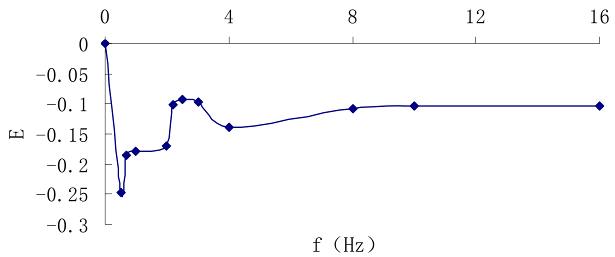

Fig. 3

4. CONCLUSION

From the above mentioned numerical analysis results we can see that from pulse flow enhance heat transformation, we get the conclusion that in different flow conditions pulsation had an alternation to laminar turbulence and heat exchange enhancement had a change in different conditions. The effectiveness of turbulence was better than that of laminar, because pulsation accelerated turbulence fluctuation of turbulence boundary layer and strengthened momentum and energy conversion which can be close to wall boundary layer. For laminar tube flow, the fluid was stratified, the perturbation of pulse was controlled by flow layer viscous force and difficult to increase convection heat transfer effectively.

The pulsation frequency also had important influence on heat exchange. Heat exchange enhancement was not only increased with pulsation frequency, it also had an optimally heat exchange enhancement frequency about 8 Hz and independency on flow form. The pulsation source had different influences on heat transfer when it was located in different places in the tube. When the pulsation source was located upstream, it would enhance heat exchange, but then it weakened heat exchange in the downstream. This paper stated that the reason could be explained as that. In the ventilation project, supply-air jet enlarged turbulence fluctuation in the flow field, suction confluence was reduced turbulence fluctuation.

The pulsation source on the upstream could accelerate turbulence fluctuation in the tube and enhance heat transfer, on the downstream like suction confluence it would reduce turbulence fluctuation and decrease heat exchange. Applying the pulsation technique to the shell and tube heat exchanger, we could enhance heat transformation efficiency without changing heat exchanger, so that it was easy to do in the real project. According to the experiment analyses, we suggested that the pulsation source of shell and tube heat exchanger should put on the upstream and control the efficiency to 8 Hz, the flow had better be turbulence flow. If we considered these data, the effect of increasing 60% heat transformation efficiency could be got.

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