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ENHANCED HEAT TRANSFER OF HEAT-EXCHANGE EQUIPMENT BY PULSATING AIR FLOW

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РАСШИРЕНИЕ ТЕПЛОВОЙ ПЕРЕДАЧИ ТЕПЛООБМЕННОГО ОБОРУДОВАНИЯ ИМПУЛЬСОМ ВОЗДУШНОГО ПОТОКА

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Abstract. This paper designs a pulsating generator to provide pulsating air flow for experiments the relationship between the average flow velocity, pulse and pulsation amplitude and the pulsating flow enhancement heat transfer ratio was discussed respectively. The characteristics of the pulsating flow enhanced heat transfer were analyzed, and the academic research and engineering application of pulsating heat transfer was proposed. This inevitably has an optimal pulsating frequency value at which the maximum vortex generation can be obtained within one pulsation cycle to obtain maximum heat transfer effect, for example, in this experiment; the optimal frequency is 1–1.25 Hz. The effect of Reynolds number Re on the low-frequency pulsation convection heat transfer process is that the low-frequency pulsation can only enhance the convective heat transfer within a certain range of Reynolds numbers. If it exceeds this range, the convective heat transfer is weakened.

Аннотация. В статье описывается пульсирующий генератор для обеспечения пульсирующего потока воздуха для экспериментов. Обсуждалась зависимость между средней скоростью потока, амплитудой пульса и пульсации и отношением теплопередачи к увеличению пульсирующего потока. Были проанализированы характеристики импульсного теплообмена с пульсирующим потоком, предложены академические исследования и инженерное применение пульсирующего переноса тепла. Это неизбежно имеет оптимальное значение частоты пульсации, при котором максимальная генерация вихрей может быть получена в течение одного цикла пульсации для получения максимума эффект теплопередачи, например, в этом эксперименте оптимальная частота составляет 1–1,25 Гц. Влияние числа Рейнольдса Re на низкотемпературный процесс конвекции тепловой волны заключается в том, что низкочастотная пульсация может только усилить конвективный теплообмен в определенном диапазоне чисел Рейнольдса. Если он превышает этот диапазон, конвективная теплопередача ослабляется.

Keywords: pulsating generator, pulsating air flow, frequency, Reynolds number, enhance.

Ключевые слова: пульсирующий поток, пульсирующего генератора, частота, число Рейнольдса, усиление.

Research Background and Theoretical Research

In recent years, with the development of industry, the increasing demand for energy has caused the energy issue to become an increasingly tense problem. Pulsating flow is a common flow phenomenon in nature and industrial production, for example, blood flow in the body, fluid flow in the compressor, and so on. The use of pulsating flow to enhance heat transfer is currently a new direction for the study of enhanced heat transfer technology [1].

The study of pulsating flow heat transfer technology began in the early part of the last century. According to the research history of pulsed flow heat transfer, it can be divided into three phases: origin, development and prosperity.

Pulsating flow heat transfer originated in the 1930s. When Richardson [2] measured the velocity of a steady-state flow and pulsating flow in a tube using a hot wire anemometer, it was found that there was a deviation between the theoretical value of the velocity gradient in the tube cross-section and the calculated value. The speed characteristics of the pulsating flow are found: the ring effect, which is the origin of the pulsating heat transfer study. In the following years, scholars began to conduct in-depth research on pulsating heat transfer. Allan T. Tayler and Frank B. West [3] had studied the heat transfer characteristics of the pulsating water flow generated in the reciprocating pump and had obtained a better heat transfer enhancement effect. According to the pulsating flow heat transfer experiment, Robert Lemlich [4] obtained the calculation method of the heat transfer ratio using the pulsating heat transfer method and summarized the existing pulsating heat transfer research.

Since the 1970s, pulsating heat transfer research has entered a period of rapid development. Wilkinson and Edwards [5] carried out the problems in the transition of the pulsating flow in the tube from laminar flow to turbulent flow. Thomann and Merkli [6] studied the boundary layer heat transfer problem under non-steady state conditions and the prospects of the discipline have been elaborated in detail, including the problems of unsteady combustion of rocket fuels and air-enhanced heat exchange problems under non-steady state conditions. Ghaddar [7–8] simulated the convective heat transfer mechanism of the fluid in the channel with periodic changes in the cross-section and found that increasing the pulsation can expand the fluid instability, enhance the fluid mixing and lead to the enhancement of heat transfer, and conclude that the pulsating flow periodically changes the cross-section. The channel can effectively enhance heat transfer.

With the advancement of science and technology, computer technology has been gradually applied to various disciplines due to its advantages of high efficiency, rapidity, and accuracy. The numerical simulation technology of CFD software is widely used in heat transfer technology, which makes the pulsating flow heat transfer technology develop rapidly. The deeper and more extensive research on the pulsating flow heat transfer research has been conducted [9–13]. Cho and the other person [14] used the pulsation experiment to summarize the boundary layer equations in laminar flow during pulsation heat transfer. Mackley [15] used a circular tube with an annular inner rib to perform a pulsation experiment and found that the wall containing the inner fins can significantly enhance the heat transfer effect by the pulsating flow. Nishimura [16–17] researched and analyzed the flow field changes and pressure drop in fluid flow in two-dimensional wave wall tubes. In later studies, Nishimura [18–20] also used a visual experiment to study the pulsating flow problem in the corrugated channel. Attyay and Habib [21] used air as a medium to study the relationship between the pulsation frequency and the Nusselt number and Reynolds number of the media flow in laminar flow. Greiner [22] studied the pulsating heat transfer problem by experiment and found that there is an optimal pulsation frequency. The thermal effect can be enhanced significantly, when the fluid is at the optimal pulsation frequency. Numerical simulations were conducted and the relationship between the pulsation frequency and the degree of enhanced heat transfer was obtained.

The mechanism of pulsating heat transfer

The fluctuating heat transfer of fluid pulsation is mainly due to the pulsation of the fluid, which results in a large number of vortices generated at the wall surface, thinning the viscous underlayer closely to the wall surface, increasing the turbulence degree of the main fluid, increasing the fluid mixing, and destroying the boundary layer. Increase the effect of the heat transfer surface to achieve the purpose of enhancing heat transfer. The entire heat transfer enhancement process is divided into three closely linked links: generation, decomposition, and diffusion of vortices. In this process, the generating link is dominant, and the greater the vortex generation density, the better the heat transfer effect, and the generation of vortices is the result of increasing the radial velocity gradient along the wall surface, resulting in large radial velocity gradients. Can achieve enhanced heat transfer effect.

Experimental Research

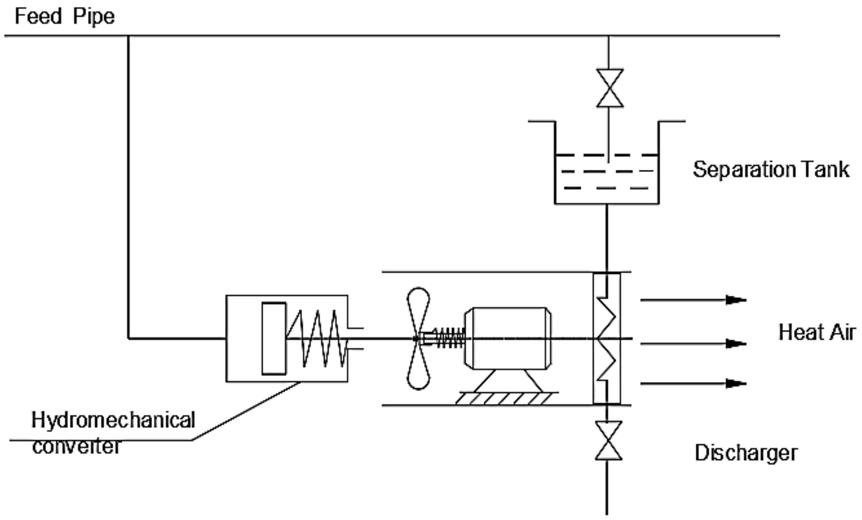

Figure 1. Experimental installation diagram.

Working principle

As the figure 1 shows, in the feed pipe, there is hot water with a constant pressure of 0.4 MPa, and more than 10 litres of hot water is added to the tank. The purpose is to provide the heat exchanger with water after the start of the experiment. At the same time, a water diversion pipe is provided from the compensating water pipe to provide a pulsed water flow to the pulse generator. When the pulse generator starts to operate, and the speed governing motor is at a different speed, a pulsed water flow with different frequencies will be applied to the front of the heat exchanger. In this process, the pulse pressure varies from 0.4 MPa to 0.6 MPa. The piston device in the hydromechanical converter drives the ejector pin to push the fan to reciprocate. When the motor that drives the fan starts to operate, the fan will apply pulsed air flow of different frequencies to the heat exchanger, and then records the heat transfer through the thermocouple temperature sensor.

Equipmental devices

Figure 2. Equipmental devices.

Experimental calculation method

A thermocouple temperature sensor was installed at the inlet and outlet of the test section to measure the temperature of the fluid at the inlet and outlet of the heat exchanger. At the same time record the ambient temperature in the laboratory. By recording the temperature entering and exiting the heat exchanger, the temperature difference between the inlet and outlet heat exchangers can be obtained.

The efficiency of the temperature of the inlet and outlet heat exchangers relative to the indoor temperature is calculated by the following formula:

$$\varepsilon=\frac{T_1\text{-}T_2}{T_1-T_0}\times 100\%$$

T_1 — inlet temperature of heat exchanger, T_2 — outlet temperature of heat exchanger, T_0 — the ambient temperature.

The amount of heat taken by the hot water in and out of the heat exchanger:

$$N=CV\Delta T$$

C — Specific heat capacity of water, 4187 J / (kg ℃); V — Water flow through the heat exchanger, L/s; ΔT — Temperature difference of heat exchanger inlet and outlet.

The effective heat dissipated from the heat exchanger to the room is:

$$N^{'}=N\varepsilon/0.0787$$

Heat transfer coefficient of heat exchanger

$$h=\frac{N}{A\cdot\Delta T}$$

A — Heat transfer area of heat exchanger, 0.98 m^2

The Reynolds number of the disturbance air flow, Re:

$$\mathrm{Re}=\frac{\rho vd}{\mu}$$

ρ — Air flow density, 1.3 kg/m^3

ν — Velocity of the air flow, m/s

d — The effective diameter of the air flow channel, 0.3 m.

μ — The kinematic viscosity of air, $14.8\times10^{-6}m^2/s$

Impact of pulsating frequency

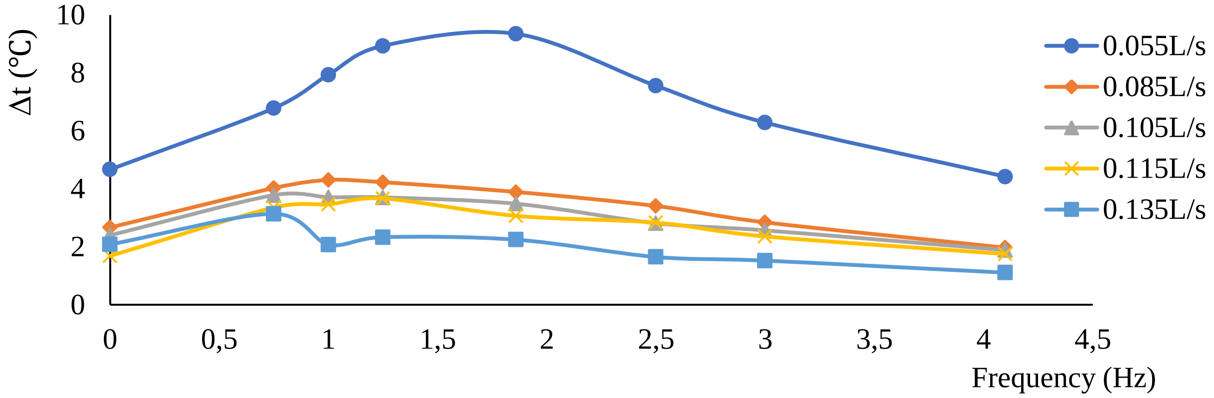

Figure 3. Effective temperature difference of heat exchanger inlet and outlet map

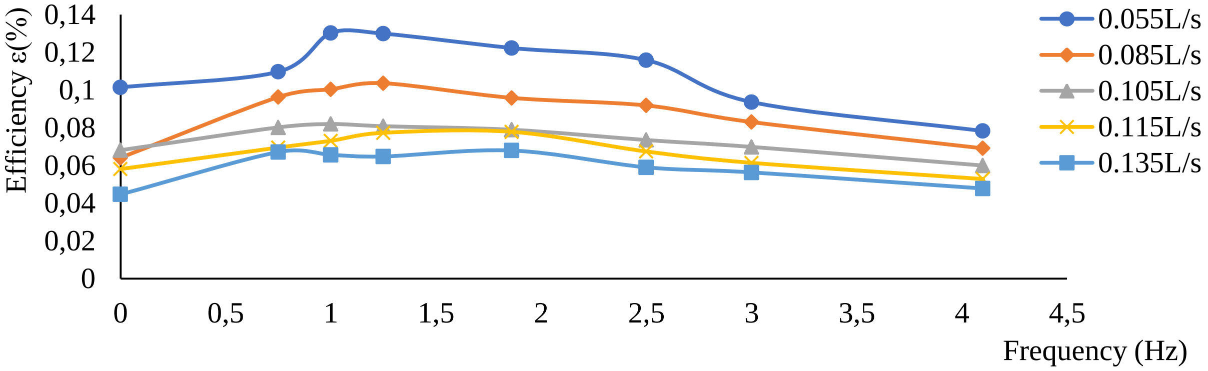

Figure 4. Temperature difference versus ambient temperature efficiency graph

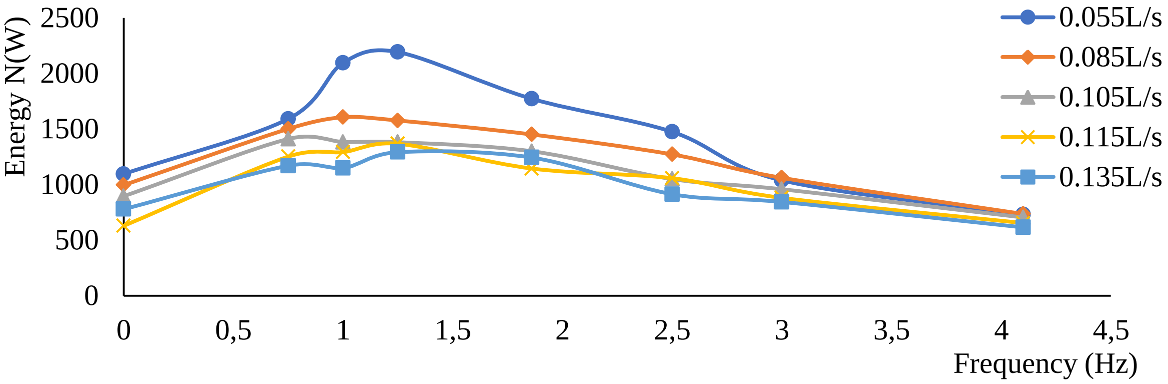

Figure 5. Effective heat amount of heat exchanger

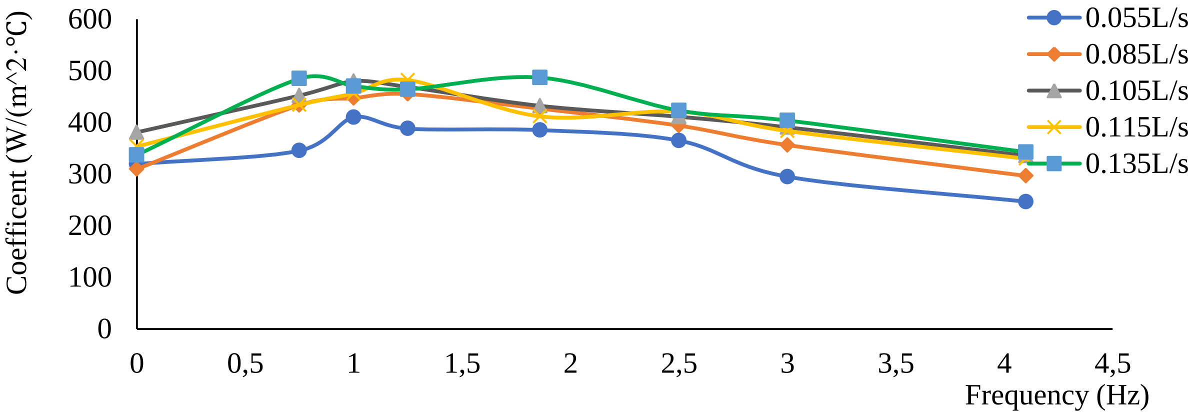

Figure 6. Heat coefficient of heat transfer

Figure 3–6 shows the trend of effective temperature difference, ambient temperature efficiency, effective heat amount, heat transfer coefficient at different flow rates in different pulsation frequencies.

The influence of the pulse frequency on the effective temperature difference, ambient temperature efficiency, effective heat amount, heat transfer coefficient increases first and then decreases (Table).

Table.

REYNOLDS NUMBER OF AIR FLOW UNDER DIFFERENT FREQUENCY

f(Hz)	*0*	*0.75*	*1*	*1.25*	*1.86*	*2.5*	*3*	*4.1*
Re	31621.6	29513.5-32013.7	31885.1-35574.3	36364.9-39263.5	40317.6-44006.8	40581.1-46641.9	42689.2-47432.4	43479.8-48239.9

From the change of Reynolds number at different pulsating frequencies of the pulsed air flow, the Reynolds number increases significantly with the increase of the pulse frequency, and from the value of the Reynolds number, the values clearly belong to the range of turbulence disturbance. Therefore, we can know that the pulsed air flow provided by the fan is a turbulent flow. The effect of Reynolds number Re on the low frequency pulsation convection heat transfer process is that the low frequency pulsation can only enhance the convective heat transfer within a certain range of Reynolds numbers. If it exceeds this range, the convective heat transfer is weakened.

Conclusion

From the experimental results, the following conclusions can be drawn:

1) The pulsation frequency is an important factor affecting the heat transfer. When the fan starts to rotate, and at the same time pulsation occurs, the air flow rate applied to the heat exchanger is constantly changing. At this time, the frequency of the fan pulsation directly affects the flow rate of the air flow applied to the heat exchanger fins. The flow rate of this air flow is also in constant change, the radial velocity of the air flow on the fin surface changes gradually.

2) At low frequencies, increasing the pulsation frequency, that is, reducing the pulsation period, it can increase the rate of change of the velocity gradient and the velocity gradient, which is beneficial for heat exchange. However, for the high pulsation frequency, the velocity gradient and rate of change of velocity will be weakened, so that the flow rate cannot be sufficiently attenuated, and it is not conducive to enhancing heat transfer. Moreover, too high pulsation frequency may cause excessive flow resistance, reduce the economic efficiency of heat transfer, and increase energy consumption. Therefore, if the frequency is too high or too low, the maximum amount of vortex generation cannot be guaranteed, and the optimal heat exchange effect cannot be achieved. This inevitably has an optimal pulsating frequency value at which the maximum vortex generation can be obtained within one pulsation cycle to obtain maximum heat transfer effect, for example, in this experiment, the optimal frequency is 1-1.25 Hz.

3) The entire heat transfer enhancement process is divided into the generation, decomposition, and diffusion of a single vortex. In this process, the vortex generation process is dominant and directly determines the effect of pulsation enhancement. The greater the density of fluid vortices, the more intense the exchange of fluid energy at the center fluid and the wall surface, and the better the heat exchange effect.

4) The effect of Reynolds number Re on the low frequency pulsation convection heat transfer process is that the low frequency pulsation can only enhance the convective heat transfer within a

certain range of Reynolds numbers. If it exceeds this range, the convective heat transfer is weakened.

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