Experimental study on effect of fluid impingement location on heat transfer characteristics of a new type of elastic tube bundle

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Abstract. A constant heat flux heat transfer test bed is built, and experimental study on external heat transfer characteristics of a new type of elastic tube bundle is conducted, obtaining overall and local heat transfer performance of the elastic tube bundle at different Re numbers. The results show that, the heat transfer performance for fluid entirely impacting on the free end of tube bundle is better than that of fluid completely entering from heat exchanger inlet. Besides, the greatest heat transfer performance occurs at the condition fluid entirely impinging on the small end of tube bundle. Similar heat transfer characteristics occur when fluid impinges on the big/small free end respectively, namely lower heat transfer coefficient for the fixed end and the big free end, and highest heat transfer coefficient for the small free end, the reason for which might be the differences of velocity and vibration characteristics for fluid around the tube bundle at different locations.

1. Introduction
Vibration leads to change of flow field and temperature field distribution within heat transfer range, which enhances heat transfer to a large extent [1-3]. Recently, heat transfer enhancement technology has gradually become focus of research. Gau [4] and Fu[5] conduct study on vibration and heat transfer characteristics of heat transfer tubes in air, the results of which show that vibration brings about a 40% increase for heat transfer coefficient, with Nu number increment growing less with greater Re number, and the effect of amplitude outweighs that of frequency. Bronfenbrener [6] and Lee [7] have studied the vibration and heat transfer characteristics of the heat transfer tube in water. The results show that the vibration can increase the heat transfer coefficient by 40%, the greater the number of Rev and the smaller the number of Re, the better the heat transfer. The effect of the amplitude is higher than the frequency. Cheng and Tian [8-10] put forward an elastic tube bundle heat exchanger, and the mean heat transfer coefficient of elastic tube bundle with in line arrangement reaches 3 times of that of static bundle, making significant improvement for heat transfer. However, little literature has mentioned effect of fluid impingement location on heat transfer characteristics of vibration-prone elastic element. This paper performs research on this point, and a test bed is built for
flow and heat transfer of elastic tube bundle, studying effect of fluid impingement location on heat transfer characteristics of a new type of elastic tube bundle.

2. Experimental system and method

Electric heating constant heat flux experimental system is as shown in Figure.1 for a new type of elastic tube bundle. The test bed mainly consists of test section (the new type of elastic tube bundle heat exchanger), circulating water system, electric heating system and measurement system.

![Figure. 1 Schematic diagram of electric heating constant heat-flux experiment system](image)

Measurement system comprises temperature, pressure, flow rate and electric power measurement. Φ0.2mm copper-constantan thermal couple is adopted for temperature measurement, signals of which are all transmitted to FLUKE Net-DAQ2640A data sampler. Temperature measuring points are distributed as shown in Figure.2, with tube bundle No. from outside to inside respectively #1, #2, #3 and #4. Spring pressure gauge with accuracy class 0.4 and range 0.6MPa is adopted for pressure measurement. LWGY-50A type turbine flow meter and XSJ-30 type flow totalizator are used for flow rate measurement. PZ200E type multifunctional electric power meter is employed for power measurement.

The new type elastic tube bundle consists of 4-Φ18mm red copper tube coil connected to 2 carbon joints, the coil diameter of which are respectively 540mm, 480mm, 420mm and 360mm from outside to inside. The ideal approach for tube bundle wall temperature measurement is setting infinite measuring points, which is difficult to realize in experiment; besides, introduction of too many measuring points leads to change of external conditions for test section and damage to boundary layer, which may impact validity of experiment results to a large extent. Therefore, this experiment adopts moderate amount of measuring points evenly distributed, making the influence of wall measuring points to external heat transfer coefficient as little as possible. The measuring points layout is as shown in Figure.2.
3. Tube bundle arrangement mode
The experiment carries out research on heat transfer characteristics on the new type of elastic tube bundle heat exchanger with unilateral distribution-in-line arrangement. Figure 3 a and b are three-dimensional overall view for the new type of elastic tube bundle heat exchanger adopted in experiment. The big free end refers to the location where four tubes join, and the small free end means the location where two tubes join.

![Figure 3: Three-dimensional view of unilateral distribution—in-line arrangement](image)

4. Analysis on experimental results

4.1. Heat transfer experimental results for the new type of elastic tube bundle with different fluid impingement locations
The new elastic tube bundle is a complex elastic structure. Different fluid impingement locations lead to different vibration response characteristics, which tends to cause different heat transfer characteristics. To validate this point, the paper carries out an experimental study on heat transfer characteristics for different fluid impingement locations (big/small free end). Accordingly, the former single fluid inlet for elastic tube bundle heat exchanger is transformed to dual fluid inlets, one of which is the original inlet named A channel, and the other fluid guided by hose directly to the big/small free end, named B channel.
Figure. 4 Variation of external tube surface heat transfer coefficient with ratio flow impacting on the free end

Figure. 5 Variation of external tube surface heat transfer coefficient with flow impacting on the free end

Figure 4 shows the variation of external tube surface heat transfer coefficient with ratio flow impacting on the free end. Both A and B channel are available under experiment condition, with constant total flow rate into heat exchanger. In Figure 4 the horizontal ordinate represents proportion of total flow rate impacting on the free end (B channel), and the vertical ordinate indicates external tube surface heat transfer coefficient. As is shown in the figure, the average external tube surface heat transfer coefficient presents a tendency to reduce at first and then rise with proportion of total flow rate impacting on the free end, and the valley value for heat transfer coefficient occurs at ratio flow approximately approaching 0.5 (namely equal flow rate for A and B channel), showing that increase of flow rate for either channel tends to improve vibration property for the tube bundle and enhance heat transfer performance. It is found by comparison that the heat transfer performance for fluid totally impacting on the free end is better than that of fluid entering entirely through heat exchanger inlet. The best heat transfer performance occurs with fluid impinging on the small free end, and the worst occurs with fluid impacting on the big free end with spring connection; besides, the heat transfer performance for fluid impacting on the big free end and the small free end with spring connection are approximately similar.

Figure 5 shows the variation of external tube surface heat transfer coefficient with flow impacting on the free end, with A channel cut off and B channel available, fluid entering heat exchanger entirely impacting on the free end. It can be seen from the figure that average heat transfer coefficient for the tube bundle grows with the increase of flow impacting on the free end.
Besides, the optimum overall heat transfer performance occurs with fluid impinging on the small free ends, which corresponds well with Figure. 4.

4.2. Research on local heat transfer characteristics for elastic tube bundle under different conditions

**Figure. 6** Distribution of local surface heat transfer coefficient of unilateral distributed--in-line elastic tube bundle, flow impacting on the small end=2.4m$^3$/h

**Figure. 7** Distribution of local surface heat transfer coefficient of unilateral distributed-in-line elastic tube bundle, flow impacting on the small end=4.8m$^3$/h

**Figure. 8** Distribution of local surface heat transfer coefficient of new elastic tube bundle, flow impacting on the big end=2.4m$^3$/h
Figure 9 Distribution of local surface heat transfer coefficient of new elastic tube bundle, flow impacting on the big end=4.8m³/h

Figure 6 and 7 are respectively the distribution of local surface heat transfer coefficient of the elastic tube bundle, with fluid impacting on the small free end at different flow rates. It can be seen from the figures that with fluid impinging on the small end, similar heat transfer characteristics occur for the elastic tube bundle under the two conditions. Lower heat transfer coefficient occurs at the fixed end and the big free end, while higher heat transfer coefficient occurs at the small free end, the reason for which might be that fluid velocity and vibration characteristics vary with the tube bundle locations, with fluid velocity and vibration property at the small free end better than other locations. With the growth of fluid velocity, a significant increase of heat transfer coefficient for the tube bundle can be found by comparing the two figures.

Figure 8 and 9 are respectively the distribution of local surface heat transfer coefficient of the elastic tube bundle, with fluid impacting on the big free end at different flow rates. Identical to the conditions with fluid impinging on the small end, it can be seen from the figures that with fluid impinging on the big end, similar heat transfer characteristics occur for the elastic tube bundle under the two conditions. The highest heat transfer coefficient occurs at the big end, and the valley value occurs in the region apart from the free end, while little fluctuation is observed for heat transfer performance of the small free end.

5. Conclusions
1) A constant heat flux heat transfer test bed is built, and an experimental study on external tube heat transfer characteristics of a new type of elastic tube bundle is conducted, obtaining overall and local heat transfer performance of the elastic tube bundle at different Re numbers.

2) Within the experimental parameter range, better heat transfer performance is observed for the condition with fluid entirely impacting on the free end than all fluid entering through heat exchanger inlet. Besides, the best heat transfer performance occurs under the condition fluid entirely impinging on the small free end of tube bundle.

3) With fluid impacting on big/small free end, similar heat transfer characteristics are presented for the elastic tube bundle under two conditions, namely lower heat transfer coefficient for the fixed end and the big free end, and highest heat transfer coefficient for the small free end, the reason for which might be the differences of velocity and vibration characteristics for fluid around the tube bundle at different locations.

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