Experimental study on effect of tube arrangement mode on heat transfer characteristics of a new type of elastic tube bundle

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Abstract. 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, within the experimental parameter range, the external heat transfer coefficient of elastic tube bundles with different tube arrangement modes generally tends to reduce with fluid pulsation frequency, and increase with fluid Re number. Comparing different tube arrangement modes, it is found that overall heat transfer performance of tube bundles ranks in this order: bilateral distribution-staggered arrangement > unilateral distribution-staggered arrangement > unilateral distribution-in line arrangement.

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 [1-2]. Recently, heat transfer enhancement technology has gradually become focus of research. Gau [3] and Fu [4] 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. Chen and Tian [5-6] 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 tube bundle arrangement mode 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 tube bundle arrangement mode 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 Fig.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.

Measurement system comprises temperature, pressure, flow rate and electric power measurement. 0.2mm 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 Fig.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.

Figure 1. Schematic diagram of electric heating constant heat-flux experiment system.

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 Fig.2.

Figure 2. Distribution of temperature measuring points of the new type of elastic tube bundle.
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 3 tube bundle arrangement modes respectively. The specific arrangement modes are unilateral distribution-in line, unilateral distribution-staggered and bilateral distribution- staggered arrangement. Fig.3 a, b and c are respectively three-dimensional view of unilateral distribution-in line arrangement and bilateral distribution-staggered arrangement. Fig.3 a and b are three-dimensional overall and split view for the new type of elastic tube bundle heat exchanger adopted in experiment.

![Figure 3](image)

**Figure 3.** Three-dimensional view of unilateral distribution—in-line arrangement and bilateral distribution-staggered arrangement
4. Analysis on experimental results

4.1. Heat transfer experimental results for the new type of elastic tube bundle with different tube arrangement modes

Fig. 4 and 5 are respectively variation of external tube surface heat transfer coefficient with fluid pulsation frequency with different tube arrangements, flow rate 9.6m³/h.

Fig. 4. Variation of external tube surface heat transfer coefficient with fluid pulsation frequency with different tube arrangements, flow rate 9.6m³/h.

Fig. 5. Variation of external tube surface heat transfer coefficient with fluid pulsation frequency with different tube arrangements, flow rate 19.2m³/h.

Fig. 4 and 5 are respectively variation of external tube surface heat transfer coefficient with fluid pulsation frequency with different tube arrangements, flow rate at 9.6 and 19.2m³/h. It can be seen through the two figures that the overall heat transfer performance chart is generally identical under different experimental conditions. The external heat transfer coefficient of elastic tube bundles generally tends to reduce with fluid pulsation frequency, which shows that low frequency pulsation of shell side fluid is beneficial for heat transfer improvement. The reason might be that the velocity peak value is relatively dramatic for low frequency pulsation fluid, which is prone to vibration for elastic tube bundle, improving heat transfer property consequently. For every single chart for heat transfer characteristics, several minor peaks occur with the overall decline of heat transfer performance, the reason for which might be interaction between fluid pulsation frequency and natural frequency of the elastic tube bundle.
4.2. Analysis for tube bundle arrangement mode on heat transfer characteristics of the elastic tube bundle

Fig.6 a, b, and c are respectively contrast charts of external tube average surface heat transfer coefficient under different pulsation frequencies and tube arrangement modes. It can be seen that within the experimental parameter range, for each pulsation frequency, variation of surface heat transfer coefficient with Re number is generally identical for different tube arrangement modes. Comparing different tube arrangement modes, it is found that for most conditions overall heat transfer performance of tube bundles ranks in this order: bilateral distribution-staggered arrangement > unilateral distribution-staggered arrangement > unilateral distribution-in line arrangement. Under identical pulsation frequencies, a sharp distinction of heat transfer performance occurs for different tube arrangement modes, the gap for which is largest with fluid pulsation frequency at 15Hz, second at 45Hz, and smallest at 75Hz. Generally, the bilateral distribution-staggered tube bundle shows the best heat transfer performance, the reason for which might be that:

1) The 4 tube coils and free ends stagger with each other, and the vortex shedding generated is beneficial for intensification of tube bundle excitation force, which enhances vibration property of the tube bundle.

2) With this sort of arrangement mode, heat exchange tube bundles are more evenly distributed within inner space of the heat exchanger, which improves uniformity of inner temperature field for the heat exchanger during heat transfer process.
5. Conclusion

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, the surface heat transfer coefficient of elastic tube bundles with different tube arrangement modes generally tends to reduce with fluid pulsation frequency, and increase with fluid Re number.

3) Comparing different tube arrangement modes, it is found that overall heat transfer performance of tube bundles ranks in this order: bilateral distribution-staggered arrangement > unilateral distribution-staggered arrangement > unilateral distribution-in line arrangement.

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