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Design and application of a new distributed pulsating flow generator in elastic tube bundle heat exchanger

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ABSTRACT

In order to realize reasonable and effective excitation of the vibrations in heat exchanger, a new distributed pulsating flow generator (DPFG) is proposed. The pulsating flow frequencies and intensities of different branch pipes of the DPFG are studied. Based on the vibration test bed, the vibration characteristics of the elastic tube bundles (ETBs) are tested. In addition, the heat transfer performances (HTPs) of the ETBs are numerical studied under different flow-induced conditions. The results indicate that the pulsating flows with substantially the same frequency and intensity can be generated in all branch pipes of the DPFG based on the appropriate sizes of vertical pipe and horizontal pipe. For the ETBs suffer the pulsating fluid and shell-side fluid, the ETBs have two vibration frequencies, i.e. the constant frequency and variable frequency. The constant frequency is caused by the shell-side fluid, and the variable frequency is caused by the pulsating fluid. In addition, the DPFG not only greatly improves the vibration intensities and uniformity of the ETBs, but also greatly improves the HTPs.

1. Introduction

Heat exchangers are equipment that used to achieve heat exchange between different kinds of media [1–3]. By replacing the rigid heat transfer tubes with the elastic heat transfer tubes, the elastic tube (copper tube) bundle (ETB) heat exchanger utilizes the flow-induced vibrations to realize compound heat transfer enhancement [4,5]. This opens up a new direction for the application of the passive heat transfer technology in heat exchangers [6]. In the design of the heat exchangers, it is necessary to ensure that the internal ETBs achieve heat transfer enhancement without fatigue damage [7]. The pulsating flow generators (PFGs) (devices capable of generating pulsating flows) are effective devices for realizing reasonable and effective excitation of the flow-induced vibrations [8]. Correspondingly, the design and development of the PFGs become important parts of the development of new ETB heat exchangers in recent years [9].

The PFGs can be divided into two types, i.e. the active pulsating flow device and passive pulsating flow device, depending on whether other ancillary equipment and external energy consumption are required [9]. The active pulsating flow device mainly includes a mechanical driven pulsating valve [10], a vane-type PFG [11,12], etc. The passive pulsating flow device mainly includes a self-excited oscillating cavity [13], an impeller-driven PFG [11], etc. However, these devices are not suitable for vibration excitation and control devices as ETB heat exchanger because of their complex structure, high technical difficulty, poor controllability or extra energy consumption. It is well known that two rows of cross-arranged fluid vortices will be formed when the fluid flows around a spoiler with a certain shape. Based on this theory, an independent PFG is proposed [8]. This PFG has a simple structure and does not require additional energy during operation. Further studies show that the independent PFG cannot solve the problem of low vibration uniformity of the ETBs in heat exchanger. And also, the independent PFG cannot achieve the desired vibration for heat transfer enhancement [9]. However, the vibration-induced concept needs to draw our attention.

Up to now, researchers have conducted many studies on the flow-induced vibration of the heat transfer elements. Numerous studies show that the natural vibration mode of the ETB mainly includes out-of-plane vibration and in-plane vibration [14,15]. And also, the vibrations of ETBs are mainly presented as small frequency and low amplitude. Based on numerical simulation, the vibration characteristics of the ETB under tube-side fluid (fluid inside the tube) or/and shell-side fluid (fluid outside the tube) have been studied [16,17]. Results indicate that the vibration intensity increases with increasing flow rate of the tube-side or/and shell-side fluid, and the ETB vibrations under different working conditions are mainly presented as in-plane vibration. Similarly, vibration characteristics of six-row ETBs under the induction of the shell-side fluid have been numerically studied based on the numerical

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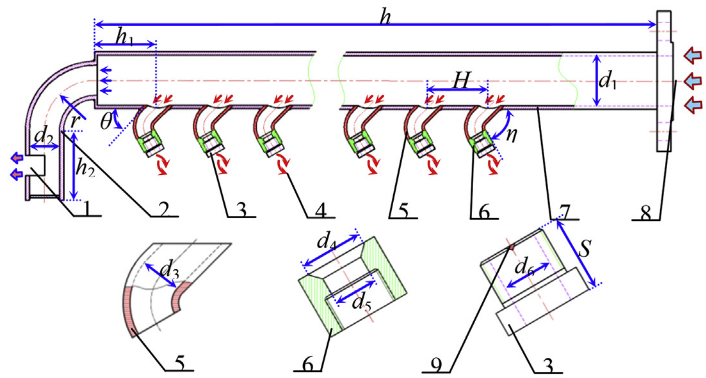

1. Shell-side fluid inlet; 2. Horizontal pipe; 3. Pulsating flow pipe; 4. Pulsating flow outlet; 5. Branch elbow; 6. Diversion pipe; 7. Vertical pipe; 8. Fluid inlet; 9. Pulsating element.

Fig. 1. Schematic diagram of a new DPFG.

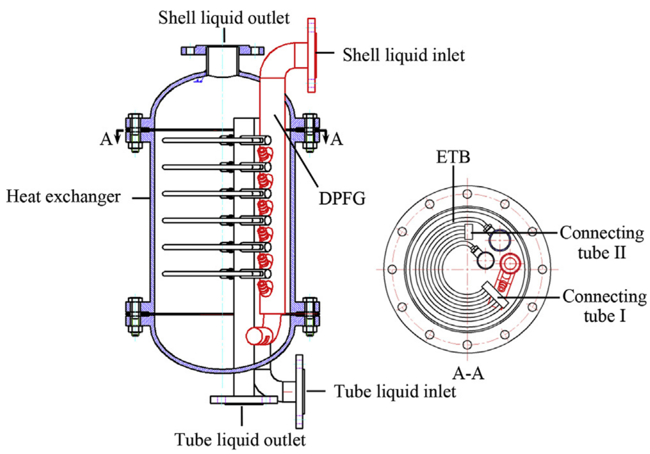

Fig. 2. Installation of the DPFG in heat exchanger.

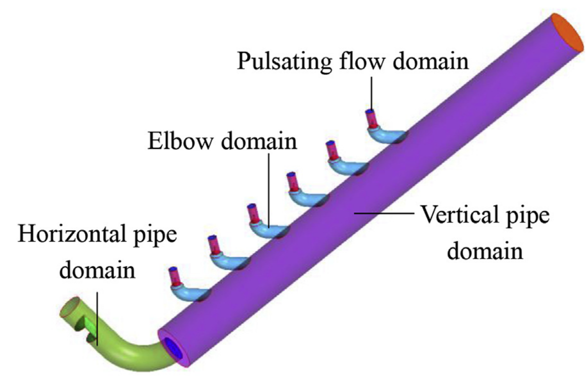

Fig. 3. Fluid domain of the six-branch DPFG.

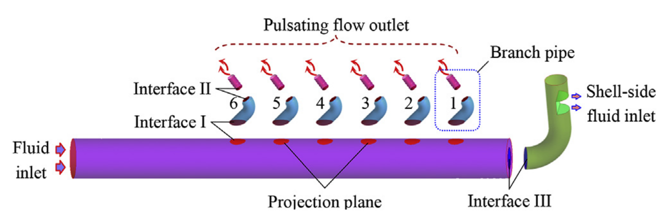

Fig. 4. Schematic diagram of the fluid domain segmentation.

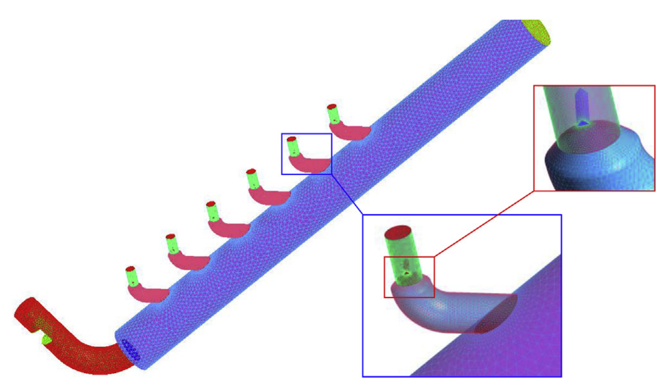

Fig. 5. Grid distribution of fluid domain of the six-branch DPFG.

Table 1
Selection of the steel pipe size.

Numbers	Vertical pipe		Horizontal pipe	
	Outer diameter (mm)	Wall thickness (mm)	Outer diameter (mm)	Wall thickness (mm)
1	45	2.5	32	3.5
2	50	2.5	38	4.0
3	60	3.0	42	3.5

Table 2
Six combinations used to calculate.

Combinations	d_1 (mm)	d_2 (mm)	Combinations	d_1 (mm)	d_2 (mm)
I	40	25	IV	45	30
II	40	30	V	54	30
III	45	25	VI	54	35

simulation [7]. Results show that mainly vibrations of the ETBs are expressed as out-of-plane vibration. The main function of flow-induced vibration is to achieve enhanced heat transfer. Researchers have conducted many studies on the vibration-enhanced heat transfer of the heat transfer elements. Under different Reynolds number conditions, the heat transfer characteristics have been numerical studied based on a cylinder with a flexible plate [18]. Results indicate that the highest increase amplitude of the Nusselt number is 90%. Based on different flow-induced conditions, the heat transfer performances (HTP) of the ETB heat exchanger have been experimental studied [4,19]. Results demonstrate that the flow-induced outside-tube heat transfer coefficient is more than two times than that of the fixed ETB. Under pulsating flow induction, the heat transfer coefficient is further increased by 100–150%. In the field of numerical simulation, the HTPs of six-row