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Design guidelines for fluid-elastic instability of tube bundles subjected to two-phase cross flow

Key words: Tube bundle; Fluid-elastic instability; Two-phase cross flow; Heat exchangers design guidelines

Research Background

1

Vibration damage and failure accidents of shell-and-tube heat exchangers are increasing.

2

Compared with single-phase flow induced vibration, two-phase flow induced vibration is more complex.

3

Fluid-instability is the most common and destructive in both single-phase and two-phase flows.

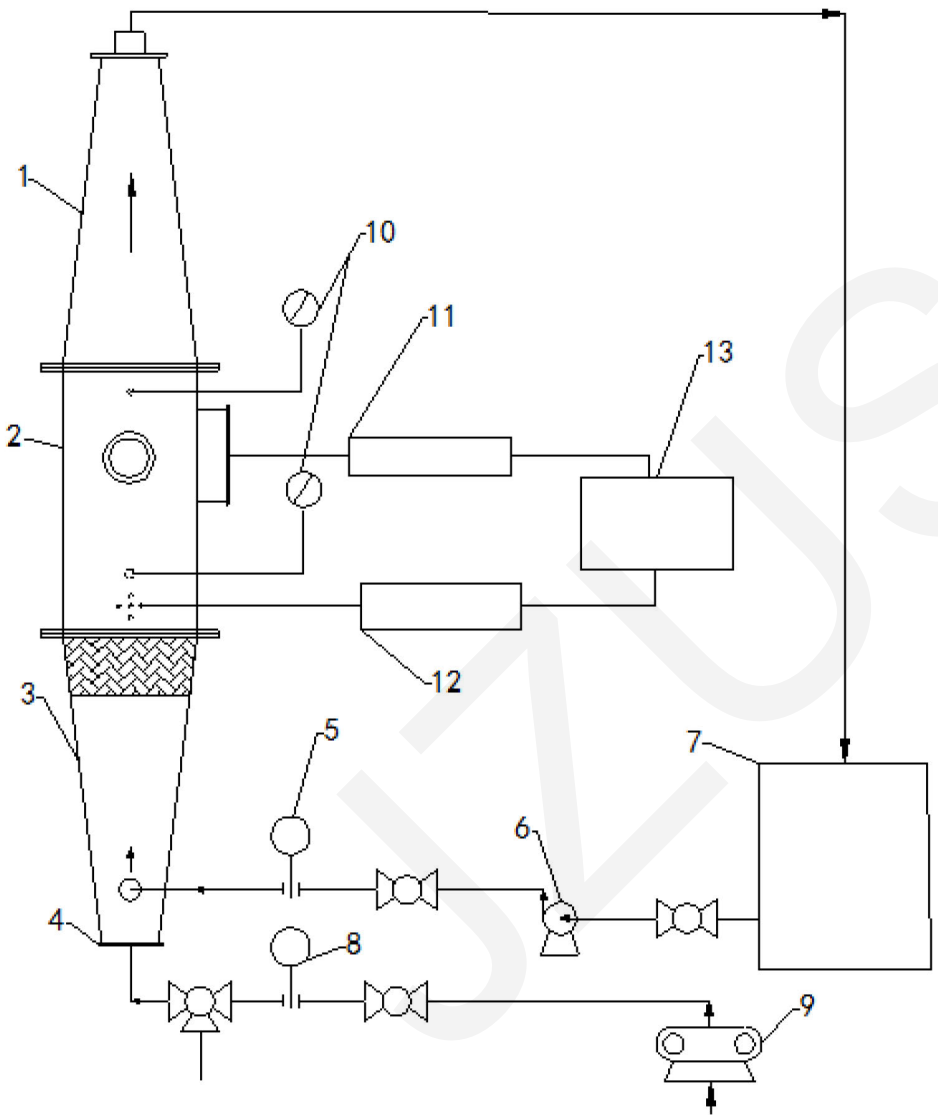
Our innovations

01 To avoid fluid-elastic instability, the suitable arrangement and pitch-to-diameter ratio of tube bundles are determined.

02 A method to determine the instability constant based on Connors criterion is established, and a new recommended value is proposed.

03 The rationality and reliability of the instability constants recommended in this paper are verified by comparing with other research results.

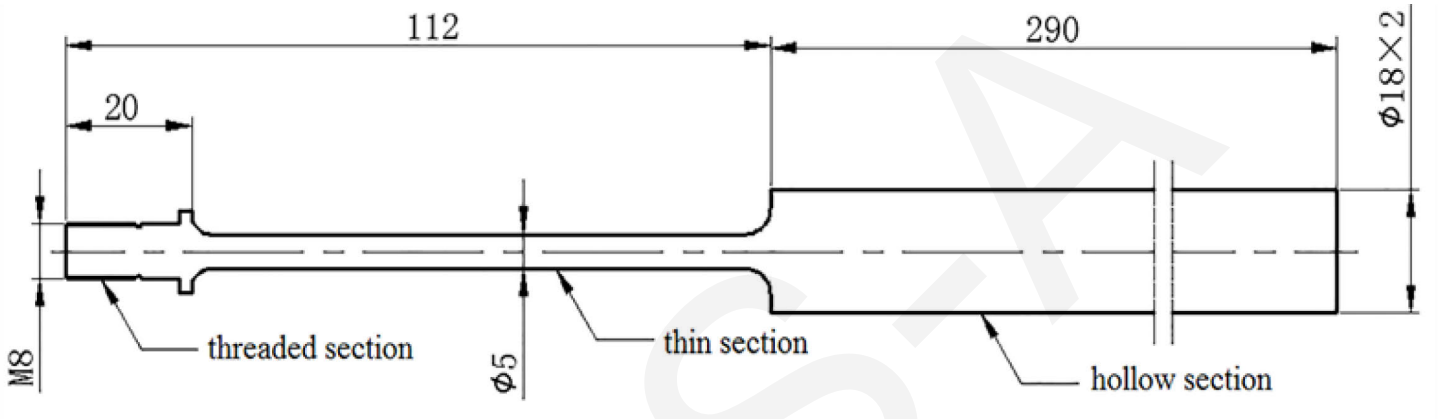
Experimental Apparatus



1. Outlet chamber; 2. Test chamber;
3. Inlet chamber; 4. Gas distributor;
5. Electromagnetic flowmeter;
6. Centrifugal pump; 7. Storage tank;
8. Rotor flowmeter; 9. Air compressor;
10. Pressure gauge; 11. Static-dynamic strain gauge; 12. Dual conductivity probe;
13. Computer.

Fig. 1 Experimental apparatus

Experimental Apparatus



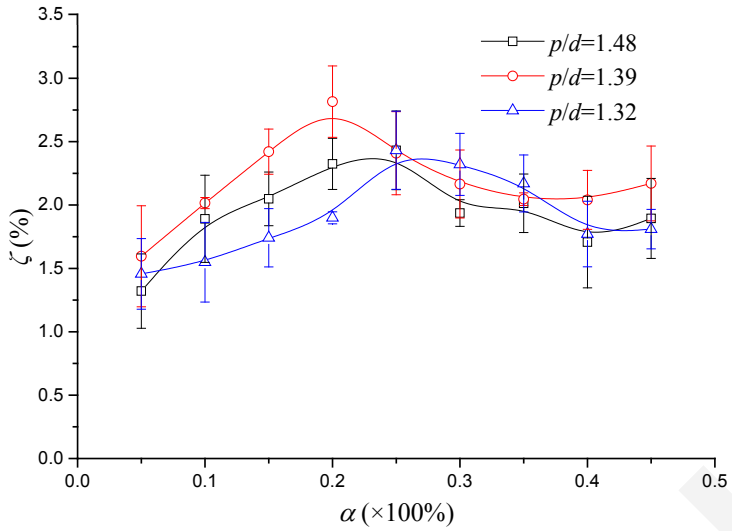
(a) Structural dimensions of a single tube



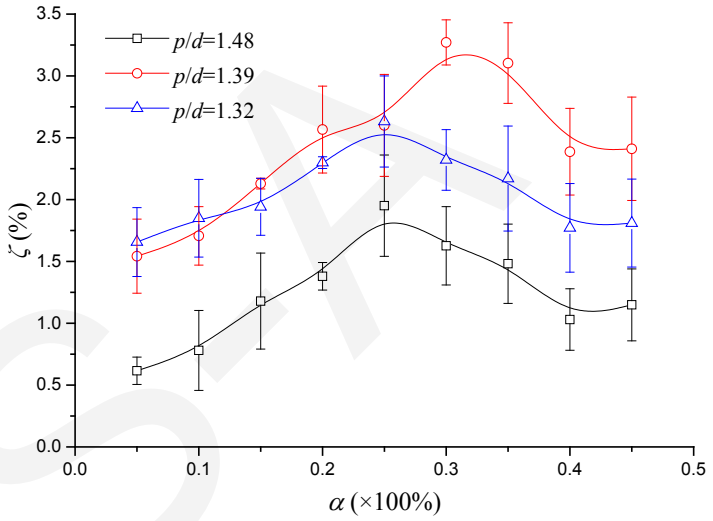
(b) A tube array

Fig. 2 Experimental tubes

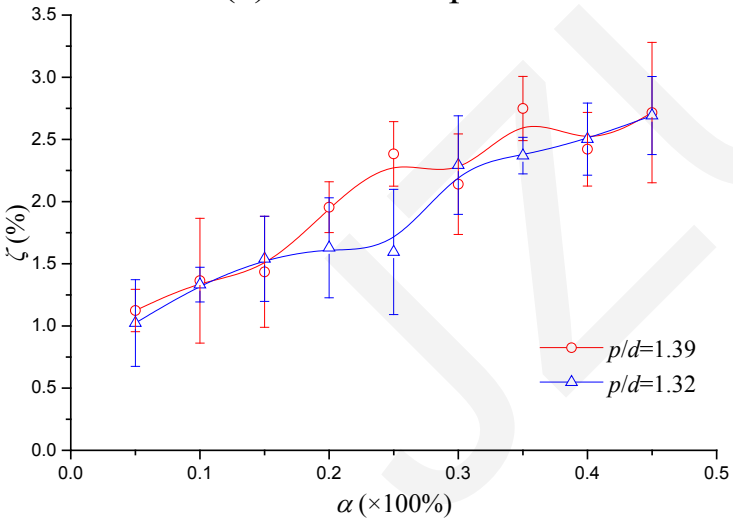
Results



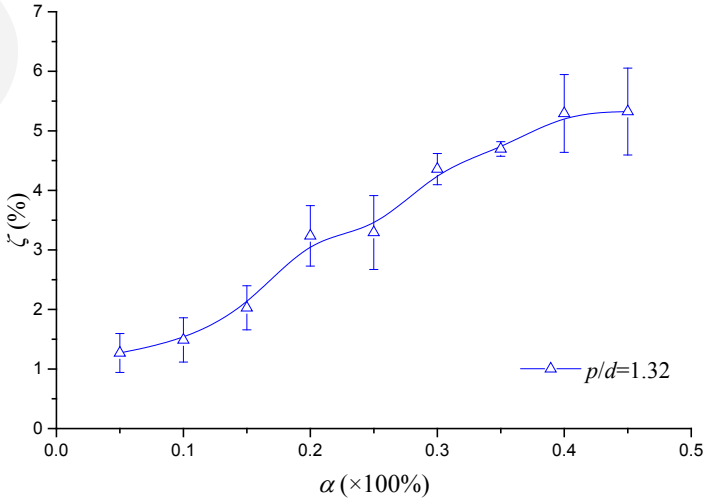
(a) Normal square



(b) Normal triangular



(c) Rotated square



(d) Rotated triangular

Fig. 3 Effect of the volumetric void fraction on the damping ratio

Results

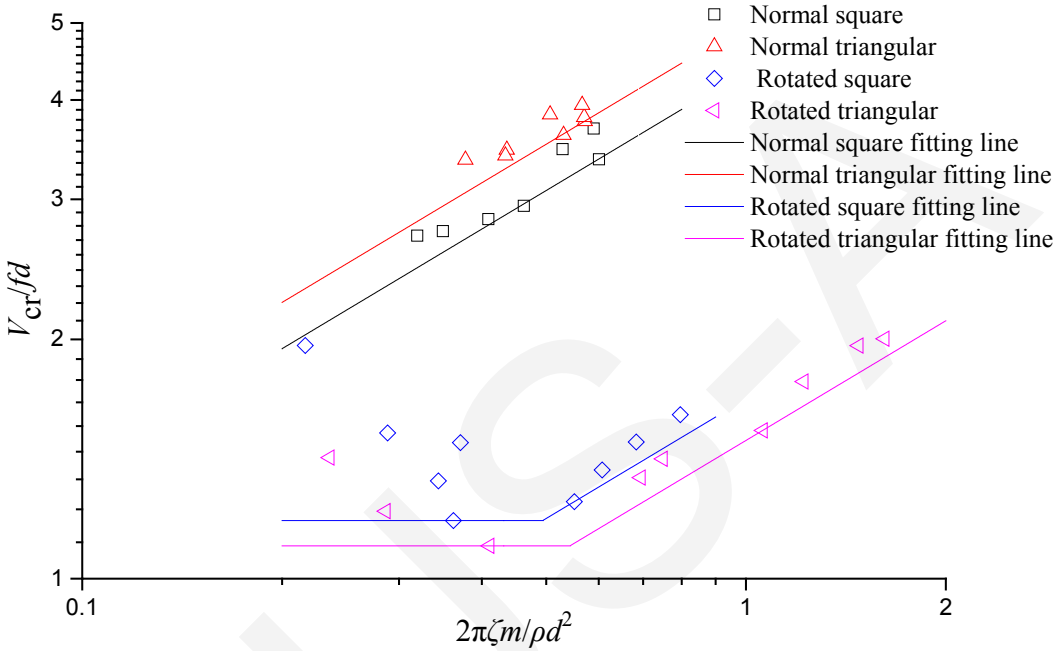


Fig. 4 Stability map of four tube bundle arrangements with p/d=1.32

Table 1 Values of K for four tube bundle arrangements with p/d=1.32

p/d	Arrangement	Instability constant K		Exponent n
1.32	Normal square	4.35		0.5
	Normal triangular	4.98		0.5
	Rotated square	$2\pi\zeta m/\rho d^2 \leq 0.50$	1.18	0
		$2\pi\zeta m/\rho d^2 > 0.50$	1.68	0.5
	Rotated triangular	$2\pi\zeta m/\rho d^2 \leq 0.54$	1.10	0
		$2\pi\zeta m/\rho d^2 > 0.54$	1.49	0.5

Results

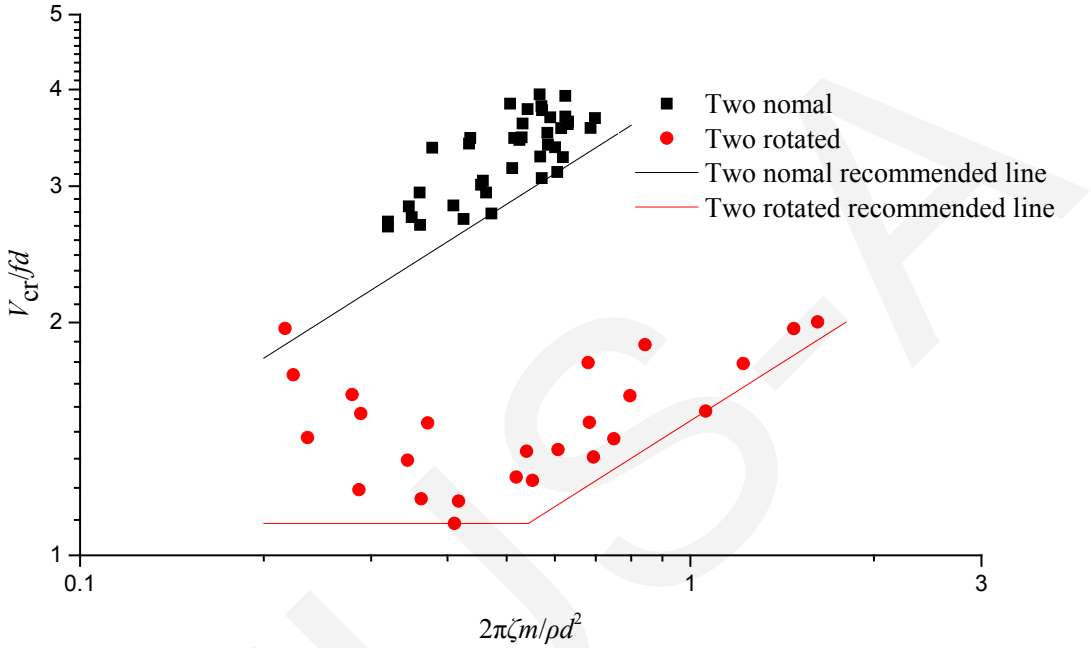


Fig. 5 Determination of instability constant *K* for four tube bundle arrangements with different pitch-to-diameter ratios

Table 2 Recommended values of the instability constant *K*

Arrangement	Recommended value	
Normal square / Normal triangular	4.0	
Rotated square / Rotated triangular	$2\pi\zeta m/\rho d^2 \leq 0.54$	1.1
	$2\pi\zeta m/\rho d^2 > 0.54$	1.5

Conclusions

1. Generally, with increasing void fraction, the damping ratio of normal square and normal triangular tube bundles first increased and then decreased, while the damping ratio of rotated square and rotated triangular tube bundles increased monotonically. The damping ratio of the rotated triangular tube bundle was the largest among the four tube bundle arrangements under the same operating and geometric conditions.

2. The tube bundle was more prone to fluid-elastic instability in the lift direction than in the drag direction. The normal square and normal triangular tube bundles with a pitch-to-diameter ratio of 1.48 were more susceptible to fluid-elastic instability than those with a pitch-to-diameter ratio of 1.32. The order of stability of the four tube bundle arrangements with the same pitch-to-diameter ratio from high to low was: normal triangular, normal square, rotated square, rotated triangular. Therefore, to avoid fluid-elastic instability, the normal triangular arrangement with a small pitch-to-diameter ratio is recommended for large shell-and-tube heat exchangers subjected to two-phase cross flow.

3. Based on the classification of tube bundle arrangements, a method to determine the instability constant was proposed. The value of the instability constant K was 4.0 for the two normal bundles, and 1.1 for the two rotated bundles when $2\pi\zeta m/\rho d^2 \leq 0.54$ and 1.5 when $2\pi\zeta m/\rho d^2 > 0.54$. A comparison with other research results indicated that the instability constants proposed in this paper are reasonable and reliable for two-phase cross flow when the void fraction is less than 50%.