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ISSN: 0976-3376

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 08, Issue, 08, pp.5361-5364, August, 2017

RESEARCH ARTICLE

COMPARATIVE VIBRATION ANALYSIS OF SEGMENTAL BAFFLES WITH NO TUBES IN WINDOW BAFFLES IN STHE USING CHEMCAD

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ARTICLE INFO

Article History:
Received 09th May, 2017
Received in revised form
22ed June, 2017
Accepted 18th July 2017
Published online 31st August, 2017

Key words:

Vibration analysis,
Shell and tube heat exchanger,
CHEMCAD, Segmental baffles,
No tube in window baffles.

ABSTRACT

The shell and tube heat exchanger have extensive use in different process industries. Vibration becomes a problem in heat exchangers when the intensity increases to the point that it causes some part of the exchanger to fail mechanically, upsets the process conditions, or creates a condition that endangers those who work in that area. In this paper, the vibration analysis for the shell and tube heat exchanger (STHE) is carried out using CHEMCAD for two major types of baffles used in the exchanger. Such kind of analysis for a shell and tube heat exchanger has not been done before. The changes in the cross-flow velocity, critical velocity, natural frequency, vortex shedding frequency and turbulent buffeting frequency throughout the length of tube of the heat exchanger with segmental baffles and no tubes in window baffles are studied. Value of all these parameters is found to be more in case of no tubes in window baffles than the single segmental baffles.

INTRODUCTION

Vibration motions of any mechanical device in operation are typically unwanted due to wastage of energy and creating unwanted sound due to it. Vibration becomes a problem in heat exchangers when the intensity increases to the point that it causes some part of the exchanger to fail mechanically, upsets the process conditions, or creates a condition that endangers those who work in that area. Tubes being the most flexible part of a heat exchanger are vulnerable to flow-induced vibration caused by the flow of fluid past them. Danger of failure arises when the frequency of the tube vibration becomes appreciably high. So, careful designs are made to minimize unwanted vibrations. Vibration Analysis (VA) in any industry aims to detect equipment faults. In the shell and tube heat exchanger, the unsupported tube span has major impact on the various vibration mechanisms (Thombare *et al.*, 2012). The flow-induced vibration analysis of a shell and tube heat exchanger is an integral element of its thermal design. Most sophisticated thermal design software packages carry out vibration analysis as a routine ingredient of thermal design. A vibration analysis of shell and tube heat exchanger by using HTRI software is presented by (Patel, 2013). A simplified approach to optimize the design of shell tube heat exchanger by flow-induced vibration analysis is presented by using HTRI software with Horizontal Multi-pass Flow Shell with Segmental Baffle by (Gawande *et al.*, 2011). CHEMCAD is a software which is capable of modeling continuous, batch and semi-batch processes. The following flow-induced vibration mechanisms are considered by CHEMCAD to investigate the mechanical stability of a heat exchanger.

Natural frequency

Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving force. It is the frequency at which the tubes vibrate. One of the variables that affect the natural frequencies is the length of the unsupported spans. Most of the heat exchangers have multiple baffle supports and varied individual unsupported spans. The natural frequency of the heat exchanger is an essential step in estimating its potential for its flow induced vibration failure. One should find the natural frequency of vibration of the tubes to study the tube vibrations. Calculation of the natural frequency of the heat exchanger is an essential step in estimating its potential for its flow induced vibration failure (Patil *et al.*, 2014).

Vortex Shedding Frequency

When a fluid flows across a single tube, it produces a series of vortices in the downstream wake due to the separation of flow alternately from opposite sides of the tube. This alternate shedding of vortices produces alternating forces, the frequency

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of which varies directly with the velocity of flow. Vortex shedding is fluid mechanical in nature and does not depend on any movement of the tubes. For a given arrangement and tube size, the frequency of the vortex shedding for non-vibrating tubes increases as the velocity increases. The vortex shedding can excite tube vibration when it matches the natural frequency of the tubes. The movement of the tube organizes the separation of the vortices leaving the vibrating tube (Schlunder, 1983). Heat exchangers are recommended to be designed so that the natural frequency of the tubes is always greater than the frequency of the vortex shedding.

Turbulent Buffeting Frequency

Turbulence is generated when shell side fluid flow through tube bundle. When basic frequency of turbulence pulsating is proximal or equal to natural frequency of tube, fierce vibration will take place. Turbulent buffeting is defined as the fluctuating forces acting on tubes due to extremely turbulent flow on shell side of the gas. This turbulence buffets the tubes which selectively extracts energy from the turbulence at their natural frequency. So, there is greater impact of the velocity of the flowing fluid on turbulent buffeting frequency. Considering the cross-flow velocity and the critical velocity during the study of vibration becomes important due to the constant changes in magnitude and direction of the shell side fluid velocity

Cross-flow velocity

The definition for cross-flow velocity usually considered when it comes to flow-induced vibration is based on the minimum flow area through a tube row perpendicular to the primary direction of flow. For an ideal tube bank the selected velocity is well defined. For a shell and tube exchanger the interpretation of cross flow velocity is uncertain, as the number of tubes in each row varies from baffle tip to baffle tip. In order to be consistent, the cross flow velocity for shell and tube heat exchanger vibration prediction will be based on an integrated average area between the maximum and minimum number of tubes in the rows between baffle tips, on the gaps between adjacent tubes in a tube row, and on the cross flow fraction of the total flow.

Critical Velocity

The flow velocity which equalizes hydrodynamic exciting and damping forces and gives rise to hydro elastic vibrations is known as the critical velocity. In simple words, the critical flow velocity for a tube span is the minimum cross flow velocity at which that span may vibrate with unacceptably large amplitudes.

The cross flow velocity should always be less than critical flow velocity. There are many design aspects of the exchanger on which the critical velocity of the shell side depends. In this proposed work, vibration analysis of shell and tube heat exchanger with segmental baffles and no tubes in window baffles as shown in Figure 1 is carried out using CHEMCAD. Along with the vibration mechanisms considered, a study of cross-flow velocity and critical velocity is also done. This work is carry out in CHEMCAD which uses CC-THERM for the study of heat exchangers.

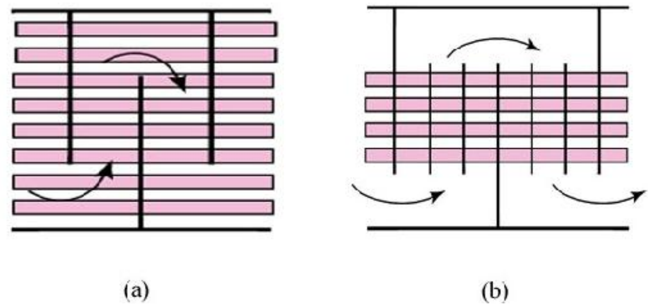

Figure 1. Types of baffles used: (a) Single segmental baffles and (b) Single segmental baffles with no tubes in windows

Procedure

A simple model of a shell and tube heat exchanger is simulated using CHEMCAD. All the dimensions of the STHE are kept constant when changing the type of baffles. The types of baffles considered for the study are segmental baffles and no tubes in window baffles as shown in Figure 1. Changes in the values of vibration mechanisms of natural frequency, vortex shedding frequency and turbulent buffeting frequency at inlet, center and outlet parts of tube are noted from the results given by CC-THERM. Also, values of cross flow velocity and critical velocity are noted from the same results. Graphs are drawn depicting the vibration in the shell side throughout the length of the heat exchanger.

RESULTS AND DISCUSSION

The results of the comparison of the vibration analysis of single segmental baffles and no tubes in window baffles indicated the results in Table 1.

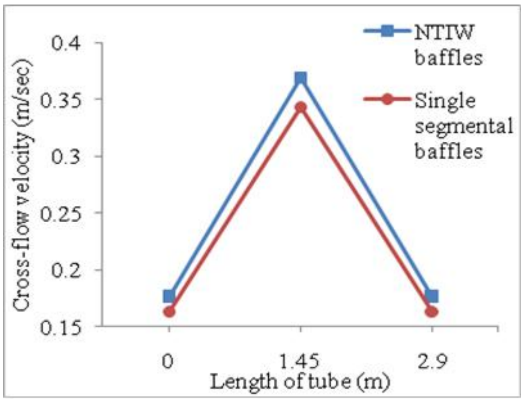

Figure 2. Cross-flow velocity vs length of tube

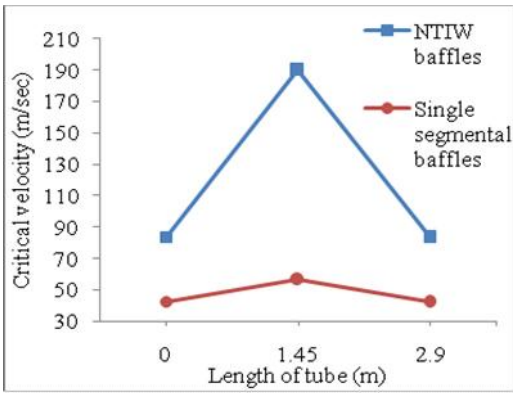

Figure 3. Critical velocity vs length of tube

Table 1. Vibration analysis of shell and tube heat exchanger by changing baffle type

Types of Baffles	Parameters	Inlet	Center	Outlet
Single Segmental	Cross-Flow Velocity (m/sec)	0.1632	0.3436	0.1632
	Critical Velocity (m/sec)	42.25	56.37	42.02
	Natural frequency (cycles/sec)	1396.93	1980.47	1393.02
	Vortex Shedding Frequency (cycles/sec)	4.63	9.75	4.63
	Turbulent Buffeting Frequency (cycles/sec)	2.73	5.75	2.73
No Tubes In Windows	Cross-Flow Velocity (m/sec)	0.1755	0.3695	0.1755
	Critical Velocity (m/sec)	83.44	189.75	83.10
	Natural frequency (cycles/sec)	3170.99	7923.78	3164.00
	Vortex Shedding Frequency (cycles/sec)	4.98	10.49	4.98
	Turbulent Buffeting Frequency (cycles/sec)	2.9389	6.1885	2.9389

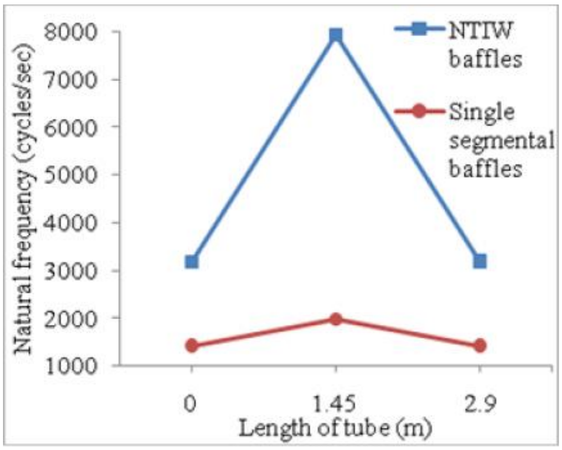

Figure 4. Natural frequency vs length of tube

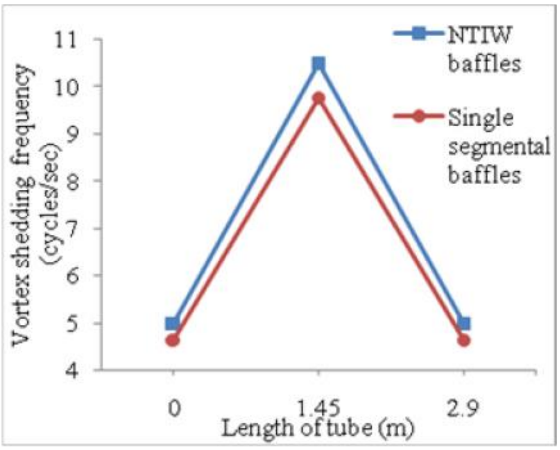

Figure 5. Vortex shedding frequency vs length of tube

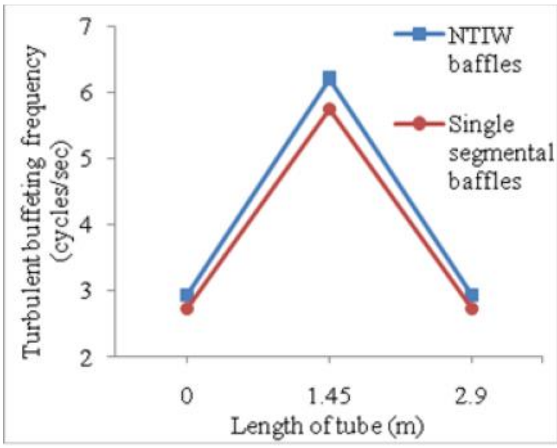

Figure 6. Turbulent buffeting frequency vs length of tube

Figure 2 depicts the cross-flow velocity against the length of tube for single segmental baffles and no tubes in window baffles. It is observed that the cross flow velocity in single segmental baffles is more than that in the no tubes in window baffles. The no tubes in window baffles incorporate supports between two baffles. This support is just a baffle with cuts on both sides of the tube field. These supports are in the way of cross-flow of the shell side which decreases the cross-flow area for a fluid flowing through the shell. This little decrease in the cross-flow area increases the velocity of the fluid slightly in case of no tubes in window than the single segmental baffles throughout the length of the heat exchanger.

Figure 3 depicts the critical velocity against the length of tube for single segmental baffles and no tubes in window baffles. It is observed that the critical velocity in single segmental baffles is less than that in the no tubes in window baffles. In the case of no tubes in window baffles, there are no tubes in the region beyond the baffle cut in the shell. Also, the no tubes in window baffles incorporate supports between two baffles. The vibration damping in shell with no tubes in window baffles are higher than the shell with single segmental baffles because of less tube unsupported span present in the no tube in window baffles. The critical velocity of a shell is directly proportional to the damping forces. Thus, the critical velocity in shell with no tubes in window is higher than the critical velocity in shell with single segmental shell. Figure 4 depicts the natural frequency against the length of tube for single segmental baffles and no tubes in window baffles. It is observed that the natural frequency in single segmental baffles is less than that in the no tubes in window baffles. The tubes beyond the baffle cut are not supported by that baffle. Thus their unsupported length increases. The natural frequency of the tube is inversely proportional to the unsupported tube length. The unsupported tube length in shell with segmental baffles is more, and so the natural frequency is less. In the case of no tubes in window baffles, there are no tubes in the region beyond the baffle cut in the shell. Also, there are supports present between two baffles. Thus, the natural frequency of the tube increases. Figure 5 depicts the vortex shedding frequency against the length of tube for single segmental baffles and no tubes in window baffles. It is observed that the vortex shedding frequency in single segmental baffles is less than that in the no tubes in window baffles. The vortex shedding frequency is directly proportional to the cross-flow velocity of the fluid in the shell. As we have already seen that the cross-flow velocity in the no tubes in window baffles in more than the single segmental baffles, the vortex shedding frequency is also high in no tubes in window baffles than the single segmental baffles. Figure 6 depicts the turbulent buffeting frequency against the length of tube for single segmental baffles and no tubes in window baffles. It is observed that the turbulent buffeting frequency in single segmental baffles is less than that in the no tubes in window baffles. The turbulent buffeting frequency is directly proportional to the cross-flow velocity of the fluid in the shell. As we have already seen that the cross-flow velocity in the no tubes in window baffles in more than the single segmental baffles, the turbulent buffeting frequency is also high in no tubes in window baffles than the single segmental baffles.

Conclusion

The vibration analysis of the shell and tube heat exchanger indicate that the cross-flow velocity, critical velocity, natural frequency, vortex shedding frequency and turbulent frequency is more in case of no tubes in window baffles than the single segmental baffles. It is also evident from the graph that these parameters increase from inlet to center and that they decrease as they approach to the outlet.

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