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A Survey on Vortex Induced Vibration of Cross Flow Heat Exchanger Tubes

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***Abstract* - Heat exchanger plays a major role in many of its application like in Nuclear power plants and Thermal power plants. Analysis of heat exchanger is essential to avoid consequences which may be severe. Since last few decades many experiments have been performed to understand the phenomenon of flow induced vibration on the heat exchanger tubes. This review introduces different phenomenon of flow induced vibration which affect the performance of the tubes. Mainly the phenomenon and the parameters related to the vortex induced vibration are reviewed. Also different types of fluids and types of arrangement of tube have been reviewed.**
Keywords: Heat Exchanger, flow induced vibration, vortex induced vibration.

I. INTRODUCTION

The interaction between the fluid flow and the cylindrical structures play an important role in many applications of engineering. Due to its practical importance, flow around the cylindrical structures has been studied. Examples of such cylindrical structures are heat exchanger tubes, offshore platforms, bridges and chimneys. The fluid flow around the cylindrical structures exhibit various physical phenomena like turbulence buffeting, vortex induced vibration, fluid-elastic instability and acoustic resonance which may severely damage the cylindrical structures. In heat exchanger, the cylindrical tubes are placed in close proximity to one another and there are large numbers of tubes. The forces experienced by the cylindrical tubes and the flow field around the tubes are entirely different compared to the single tube immersed in the fluid flow. Vortex induced vibration is the major consideration since heat exchanger are designed keeping in mind the threshold for fluid-elastic instability.

A. Phenomenon Of Vortex Induced Vibration

In heat exchanger, cross flow of the fluid in the shell and the tube are observed. As the fluid from shell flows towards the leading edge of the cylindrical tubes, the pressure of the fluid rises from free stream pressure to stagnation pressure. This rise in pressure forces the flow about the cylindrical tube as boundary layers are developed on both sides of the tube. As the fluid flows, boundary layers separate from both the sides of the cylindrical tubes. The innermost portion of the shear layers are in contact with the cylinder moves slowly than the outermost portion of shear layers, thus forming a wake. The oscillation of wake gives rise to an oscillatory force on the tube as amplitude of wake oscillation increases with the increase in the flow velocity. Oscillation of wake is associated with the shedding of vortices from the wake region. When the frequency of wake oscillation and natural frequency of the tube equals each other, resonance occurs. As a result large amplitude of vibration is possible which will lead to failure of the system.

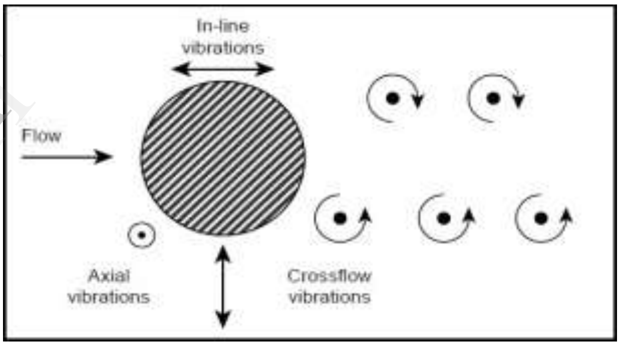

Figure 1 Vortices Shedding of the tube [3]

II. LITERATURE SURVEY

Heat exchangers are not mass produced but they are individually designed and manufactured as per the requirement in different applications. After knowing the significance of role of heat exchanger in different applications, many researchers have tried to minimize the parameters that may damage it.

Of the many components of shell and tube heat exchangers, the tubes are the most flexible and hence more prone to vibration [5]. The fluid flowing from the shell sides towards the tubes are mainly responsible for the inducement of the flow induced vibration. Because of the wake formation behind the tube, oscillatory force acts on the tube. When the frequency of oscillation coincides with the natural frequency of the tube, resonance occurs. The fluid used in the heat exchanger can be a single phase fluid (i.e. liquid or gas) or a multiphase fluid [1]. Flow induced vibration are mainly responsible for the failure of the heat exchanger. Vibrations that are produced in the axial direction are very little compared to the cross-flow direction compared to the cross-flow induced vibration [5].

A. Arrangement of the tubes

Many experiments have been carried out to understand the phenomena of flow induced vibration mainly vortex induced vibration. One of the parameters that affect the output is the arrangement of tubes. Experiments were first carried out on the single tube immersed in the fluid. Later two types of array arrangement were used for carrying out the experiments namely inline array and staggered array arrangement.

Researchers (published)	Fluid	Tube Array
Hara and Ohtani (1981)	Air-water	Single tube
Hara (1987)	Air-water	Single row
Gay et al. (1988)	Freon	Triangular
Taylor and Pettigrew (2000)	Freon	Rotated Triangular and rotated square
Feenstra et al. (2000)	R-11	Parallel/triangular
Pettigrew et al. (2000)	Freon	Rotated triangular
Inada et al. (2000)	Air-water	Square
Marn and Catton (1996)	Air-water	Normal triangular, parallel triangular and rotated square
Funakawa et al. (1989)	Air-water	Square/triangular
Nakamura and Fujita (1988)	Air-water	Square
Goyder (1988)	Air-water	Triangular
Nakamura et al. (1986)	Steam-water	Square
Axisa et al. (1984)	Steam-water	Square
Pettigrew and Gorman (1973)	Air-water	Triangular/parallel, square and rotated square
Heilker and Vincent (1981)	Air-water	Triangular and rotated square
Nakamura et al. (1982)	Air-water	Square and rotated square
Remy (1982)	Air-water	Square

- Grover and Weaver [2] used a 19-tube array with only one tube flexible and the other was made rigid. They found out that vibrations induced by the fluid flow were responsible for the instability of the single flexible cylinder. They concluded that the mechanism which was responsible for the instability of a single flexible cylinder is the same mechanism leading to the instability of an entire flexible array.
- Huerta-Haurte and Gharib [6] carried out experiment on the side-by-side arrangement of the two flexible cylinders tubes. They carried out the experiment making one of the cylinders fixed in the side by side arrangement. They concluded that effect of making one of the tube fixed appears when tubes oscillate out of phase, leading to vibration amplitudes of larger value. Keeping the same phase angle, vibration amplitude was calculated for both inline and cross-flow, in which they found out that the amplitude of vibration, are practically same.
- Granger et al. [4] designed an experimental test facility and tested a square in-line tube bundle. To make tubes elastic in nature so were mounted on smaller diameter tubes. The latter were instrumented with strain gauges for measuring response due to flow. They performed many experiments and concluded that a measure of the modal parameter variations may be necessary to be utilized simultaneously with the critical fluid flow velocity information in order to gain insight into the intrinsic behavior of theoretical models.
- Hardik et al [7] studied flow induced vibration around triangular array of cylinders with two degree of freedom where the cylinders were allowed to vibrate in the longitudinal and transverse direction. They calculated the results in terms of amplitude of lift coefficients and drag coefficients with respect to Reynolds number. They found that when the Reynolds number increases, amplitude of lift and drag coefficient did not vary much but for downstream cylinder, lift coefficient increases and the drag coefficient decreases with increase in the Reynolds number.
- Chunlei et al [8] studied numerically the vortex shedding characteristic and forces acting on the tube in an inline cylinder array. They considered flow to be laminar and studied the effect of tube spacing on the array. Computations were carried out for a six row inline tube bank. They concluded that by increasing the spacing makes the flow more asymmetric and induces vortex shedding. Vortex shedding starts from the last cylinder and proceeding upstream.

B. Fluid Medium Used

Different types of fluid have been used for carrying out the experiments. Single phase fluid i.e. liquid and gas and multiphase fluid have been used. Summary of the fluids that have been used is shown in the table.

Table 1 Type of fluid and tube array arrangements used by the researchers [9].

C. Failure of Tube Phenomenon

Phenomenon mainly responsible for the failure of the heat exchanger tube is vortex induced vibration. Heat exchangers are designed considering the frequency responsible for the fluid-elastic instability. Many researchers have performed experiments to understand this phenomenon of vortex induced vibration.

- S. Pasto [10] performed the experiment on freely vibrating circular cylinder in turbulent and laminar flows. He performed the experiment in the wind tunnel by varying the roughness of the cylinder and mass damping parameter and studied the behaviour of the cylinder in terms of Reynolds number.
- P. A. Feenstra et al [11] conducted experiments on the model heat exchanger to determine the flow induced vibration response. The tube bundle consisted of a normal square array of 12 tubes subjected to cross-flow of refrigerant 11. They carried out experiments for both single phase and two phase cross-flow. They concluded that occurrence of vortex shedding in the model is similar to that of the previous results. They found out that the vibration amplitude of vortex shedding was

significantly reduced by the introduction of bubbles in the fluid flow.

- E. Longatte et al. [12] studied the numerical methods for investigating the effects of flow induced vibration on the tube bundle motion in presence of fluid at rest and single phase cross-flows. They used arbitrary Langrange Euler formulation for the fluid computation for simulating thermo-hydraulics and mechanics problem. The main purpose was to provide a numerical estimate of the critical flow velocity for the threshold of fluid-elastic instability of tube bundle without experimental investigation. They validated their results with the available experimental data obtained with same configuration.
- T. K. Prasanth et al. [13] investigated a pair of equal sized circular cylinders in inline and staggered arrangements in laminar flow regime. Both cylinders were free to oscillate in in-line and transverse direction. They utilized

a finite element method to compute in two dimensions. They concluded that the downstream cylinder vibrated with large amplitude compared to the single cylinder. Compared to inline arrangement, staggered arrangement of the cylinders was found to have significant effect on the flow.

III. DISCUSSION

This paper discusses the significance of the application of heat exchanger in different areas. It is observed that the failure of heat exchanger tubes occurs mainly due to the vortex induced vibration. Tubes are arranged in inline and staggered arrangement to understand the effect of vortex induced vibration on the tubes. The main aim of this review is to study the mechanisms responsible for the failure of the heat exchanger tubes.

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Biography

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