Noise and Vibration Analysis of a Heat Exchanger: a Case Study

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Flow-induced vibration of heat-exchanger tube bundles often causes serious damage, resulting in reduced efficiency and high maintenance costs. The excitation mechanism of flow-induced vibration is classified as vortex shedding, acoustical resonance, turbulent buffeting, or fluid-elastic instability. This paper aims to identify the mechanism that causes flow-induced vibration in a specific heat-exchanger tube bundle with cross-flow and proposes a solution to this problem. This case is investigated through acceleration and sound pressure level measurements. Moreover, finite-element models are developed to view the acoustic models of the cavity and vibration modes of the tubes and plates. The layout pattern of the tube array, the spacing ratio, the Strouhal number, and the flow characteristics are used to determine the excitation mechanism.

1. INTRODUCTION

In cogeneration mills, the excess of energy generated can be transferred to an electrical system. In an attempt to improve the efficiency of these systems, some manufacturers have developed new heat exchangers in which the speed of the fluid flowing around the tubes has been increased; they have also changed their tube arrangements. The production cost of major heat-exchanger equipment is high. Also, since maintenance is necessary, the cost of the entire operation is quite high. According to the literature, many incidents of failure due to apparent flow-induced vibration in heat exchangers have been reported.

Flow-induced vibration and acoustical resonance have caused serious damage to the system integrity of heat exchangers. The four principal sources of vibration in cross-flow tube banks are vortex shedding, acoustical resonance, turbulent buffeting and fluid-elastic instability. All these mechanisms arise because of the various forces that act on a tube due to the shell-side cross-flow.

During the last decades, researchers were successful (in varying degrees) in better understanding the main sources of noise and vibration in different kind of heat exchangers. Distinct solutions have been proposed to control the noise and vibration problem in heat exchangers. In order to suppress acoustical resonances, a rigid baffle is normally placed inside a container and is parallel to the flow stream. It modifies the acoustical field and inhibits the instability. To avoid the vibration of the equipment, it is sometimes necessary to reduce the shell side flow rate, remove the tubes in the window area to form a bypass, and redesign and reinstall a new bundle.

However, it is difficult to find case histories presenting experimental analyses, finite element models, and a solution to the problem. Normally, the investigations are focused on excitation mechanisms, instabilities criteria, and methods to predict the problem.

2. EXCITATION MECHANISMS

Recently, a significant amount of research has been conducted to predict, understand, and resolve the mechanisms that cause flow-induced vibration in heat exchangers. The following four main mechanisms of flow-induced vibration in heat exchangers have been investigated.

2.1. Vortex Shedding

Flow across a tube produces vortices in the wake generated from the opposite sides of the tube. The oscillation frequency of a wake is proportional to the flow velocity and results in an oscillatory force on the tube. This phenomenon may excite vibration in a liquid flow or acoustical resonance in a gas flow.

When the frequency of the vortex shedding coincides with the natural frequency of the tube vibration, higher levels of vibrations and rapid tube damage may occur, especially for liquid flows. The velocity range over which the tubes exhibit high-amplitude vibrations is referred to as the “lock-in” range, as shown in Fig. 1. The lock-in conditions can be estimated from the following equation:

$$0.8f_n < f_v < 1.2f_n; \quad (1)$$

with

$$f_v = S_{lv} \frac{U}{D}; \quad (2)$$

where $f_n$ is the tube’s natural frequency, $f_v$ is the frequency of vortex shedding, $S_{lv}$ is the Strouhal number, $U$ is the gap velocity, and $D$ is the tube diameter.

Recent studies have shown that this excitation results from vortex shedding around the tubes. It occurs in the beginning of