Influence of Vortex Excitation on the U-Tube Bundle

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Abstract: This contribution is devoted to causes of damaging tube bundle by fluid flow between tubes with U-bends inside a process boiler. Tube bundles are commonly used in process industry for heat transfer. Use of U-bends allows efficient space utilization and thermal dilatations of the bundle are compensated. Design of a tube bundle is strictly controlled by thermal-hydraulic design and strength design. Strength design includes flow induced vibration evaluation, which is done using simplified methods and cannot substitute fatigue assessment. This contribution studies influence of the fluid flow on the cyclic fatigue of the U-tube bundles.

Introduction

The U-tube bundles are mainly used in process heat transfer equipment such as heat exchangers, process boilers, coolers. These devices are designed by thermal-hydraulic calculations and stress calculations, however, usually only a static analysis is used for fatigue prediction. With good design and operation such devices can operate without major problems for many decades. However, there are many failures which are caused by fluid forces induced by vortex shedding.

One from many causes of cyclic fatigue of tube bundles is cross-flow of fluid around tubes. This flow distribution leads to terminal layer separation from each tube and creation of local reversed flow. A reversed flow generates vortices behind areas of terminal layer separation. As a result, there are many dynamic forces acting on tubes, which leads to fatigue. Described process is influenced mainly by following factors; U-tube bundle geometry, thermal-physics fluid parameters and fluid flow velocity. On the other side turbulent flow from the point of view of thermal-hydraulic design is considered positively, because laminar sub-layer separation intensifies heat transfer around the tubes.

Large influence on the generation of vortex has geometrical disposition of tubes in U-tube bundle. The tube arrangement according to schema 45° and 90° leads to low vortex generation in fluid flow. This disposition does not terminal layer separation on the all perimeter of tube and lead to smaller intensively heat transfer. On the other side tube arrangement according to schema 30° and 60° leads to higher vortex generation in fluid flow on the almost all perimeter. This disposition leads to terminal layer separation and consequently to intensive heat transfer. Vortices caused by intensive fluid flow lead to force responses on the tubes. These excitations lead to vibrations of tubes in the tube bundle and further to intensive stress on the tube bundle structure. In worst cases, tube excitation leads to resonation, which intensifies fatigue due to great inertia forces acting on the tube.

Flow induced vibrations of the tube bundle are also significantly influenced by the geometry of the bundle and supports. Inlets and outlets of U-tube bundle are commonly fixed to a membrane wall or a tubesheet. Usually, tube bundle is also supported in more areas, using simple supports (performed by anchoring of tube bundle) or pseudo-simply supports with clearance (performed by perforated plate, such as tubesheet or baffle). Generally, using more supports leads to more rigid state of the system, which is more convenient for reducing vibrations, but it also leads to greater thermal stresses.

Thorough evaluation of flow induced vibration fatigue is possible using coupled flow and structural transient analyses. This approach is computationally demanding, therefore it is used only in special cases, mostly for failure assessment. For design purposes, there are simplified methods that evaluate design using allowed frequencies and amplitudes, which do not lead to significant vibrations.

Proposed evaluation procedure

Proposed evaluation procedure uses CFD and FEM analyses. In order to get adequate results, it is necessary to use relatively detailed model in the CFD analysis. On the other hand, the tubes in the tube bundle for structural analyses can be sufficiently represented by beam (pipe) elements. The main disadvantage is that these CFD and FEM meshes are incompatible and it is necessary to create a procedure for boundary condition transfer between the models. This paper deals with boundary conditions from CFD to FEM models.

In the first part it is necessary to process the results from CFD analysis. Important results describe the dynamic pressure of fluid flow acting on the U-tube bundle surface. The suitable variable describing the response of fluid flow is force in node on the surface of geometry. This variable is represented by magnitude and direction. The above procedure is recording forces from fluid flow and forces from vortices at space between tubes. Generally, this procedure is supposed to describe duration, intensity and place of vortices. These variables can specify the measurement of variables force response on the other tubes. The values from these variables can be delayed due to distance between tubes and position of vortex.

Main part of this contribution is creation of software for processing force responses on the tube surfaces caused by vortices. This program performs evaluation of force responses and from these responses define duration, intensity and position and orientation of vortices. This information is necessary for fatigue assessment using cyclic stress cumulation, respectively damaging of U-tube bundle in supported areas.

Summary

Main goal of this contribution is to find important parameters influencing cyclic stress from vortex excitations on the U-tube bundle. That is necessary for complex design and assessment of U-tube bundles. Main part is creation of software which filters responses to common forces and finds only the important vortices. These vortices lead to damage cumulation on the U-tube bundle.

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