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Numerical study of a power plant condenser tube arrangement

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ABSTRACT

The flow and heat transfer performance of a power plant condenser for a 300 MW unit was numerically analyzed using a porous medium model. Three typical tube arrangements were considered. The analysis indicates that none of these three tube arrangements satisfies the Heat Exchange Institute Standards (HEI Standards) with lower overall average heat transfer coefficients in the condenser and higher back pressures. A new tube arrangement was developed based on the modeling results for the velocity, heat transfer coefficient and air mass fraction distributions in the condenser. This tube arrangement gives better condenser performance than the HEI Standards.

1. Introduction

Power plant condenser (a huge complex shell-and-tube heat exchanger) is one of the most important auxiliary equipments in a power plant. Increases of the condenser heat transfer rate will increase the plant thermal efficiency by reducing the turbine exhaust pressure. A higher heat transfer coefficient will also reduce the condenser sizes.

A condenser has a large number of cooling tubes (a condenser for a 300 MW unit has approximately 20 000 tubes) with the condenser flow and heat transfer performance highly dependent on the tube arrangement. If the tubes are not well arranged, the overall heat transfer coefficient will be reduced and the turbine exhaust pressure, which is equal to the condenser back pressure, will be increased. Therefore, the tube arrangement must be optimized for a good condenser design. Many companies have developed high-performance tube arrangements. Some are now widely used, such as the cap-shaped tube arrangement developed by the Alsthom Corporation of France, the double-peak-shaped tube arrangement developed by the Balcke-Durr Corporation of Germany, the lozenge-shaped tube arrangement developed by Westinghouse of the USA, the church-window-shaped tube arrangement developed by ABB of Switzerland, and the AT-shaped tube arrangement developed by Toshiba of Japan.

The power plant condenser design is traditionally based on recommendations by the condenser manufactories founded on previous designs and experimental tests, often based on the standards developed by the Heat Exchange Institute (HEI Standards) [1]. However, this method does not take a number of factors that affect the heat transfer rate into account, including the tube arrangement. Improved computers and numerical simulations have now made it possible to solve for the fluid flow and heat transfer distributions in condensers numerically. In 1972, Patankar and Spalding [2] developed a calculational procedure based on the porous medium concept to analyze the transient behavior of shell-and-tube heat exchangers which greatly reduced the computing time as well as the storage, and provides an easy way of exploiting the extensive experimental data. Numerical simulations of the flow and heat transfer in condensers have now been conducted by many researchers. Davidson and Rowe [3] took into account the effect of non-condensable gases using a single-phase model. Al-Sanea et al. [4] and Bush et al. [5] used a two-dimensional two-phase model with comparisons to experimental data to show that the predictions agreed well with the experimental data in the lower half of the condenser but had some discrepancies near the top of the tube nest. Zhang et al. [6–9] did a series of studies from a two-dimensional single-phase model to a quasi-three-dimensional and two-phase model. Malin [10] used a three-dimensional approach in PHOENICS to model a marine condenser with the computed overall condensation rate in excellent agreement with measured data. Ormiston et al. [11,12] analyzed the convergence of condenser simulation models and found that new algorithms could obtain solutions in just a few time steps. Hu and Zhang developed a modified k-epsilon turbulence model for condenser simulations [13], and later assessed the effects of different closure correlations on the numerical simulations [14,15].

These models have been used for tube arrangement analyses. Sato et al. [16] numerically estimated the performance of an AT-

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