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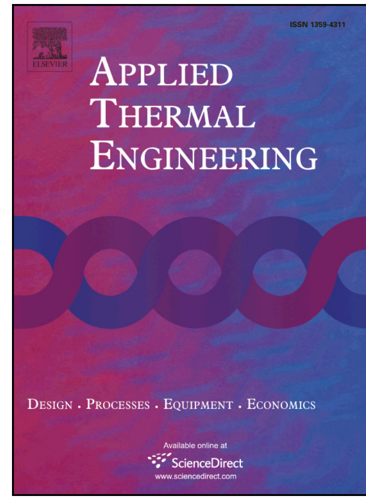

Research Paper

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ACCEPTED MANUSCRIPT

Effect of inclination on pressure drop and flow regimes in large flattened-tube steam condensers

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Abstract

This paper presents an experimental study of the inclination effect on pressure drop and flow regime during condensation of steam in a large flattened tube used in air-cooled condensers (ACC) for power plants. Steam with mass flux of about 7 kg m^{-2} s^{-1} was condensed inside a 10.7 m long, flattened test tube with inclination angle varied from horizontal up to 70^o. The original full-sized steel tube was cut in half along the centerline, and the removed part was replaced by a polycarbonate window to enable simultaneous flow visualization in situ with heat transfer and pressure drop measurements. A uniform velocity profile of 2.03 ± 0.12 m s^{-1} was imposed on the air side to extract heat from the steam in a cross flow direction. The experimental results showed that increasing the inclination angle led to reductions of pressure drop due to the improvement in the gravity-assisted drainage of condensate inside the test tube. At such low mass fluxes, tube inclination significantly influenced the flow pattern which was observed to be a well-separated stratified flow throughout the tube at all downward inclination angles. The separated flow pattern enabled the direct measurement of void fraction, and the traditional void fraction models using the newly-defined superficial quality successfully predicted the measurements within ±10%. The experimental data were converted to reflect pressure drop in a full tube based on the model that was developed to account for the differences in tube geometry between the full and test tube at the same operating condition. A prediction of pressure drop performance of the same steam condensing system under vacuum condition was also discussed. The negative dependence of total pressure drop on inclination angle also prevailed in both converted results in atmospheric condition and the predicted ones in vacuum condition.

1. Introduction

The rejection of waste heat is required for most industrial processes. Particularly, the thermoelectric power industry rejects waste heat at a rate of about twice of its electricity generation [1]. The water consumed to remove heat in these thermoelectric power plants made up about 45% of the total fresh water withdrawals in the U.S. in the year 2010 [2]. The ACC system, which was designed and developed to resolve the environmental impacts of thermoelectric power plants, requires zero water consumption and supply, but only 0.9% of existing thermoelectric power plant capacity in the U.S. uses such a system. Increasing the usage of ACC to 25% by 2035 could lead to a reduction of U.S. water withdrawal of 10.7% [3], but ACC's provide up to 10% less power production on hot days due to a higher steam condensation temperature and may cost up to five times more than traditional cooling tower systems. There is a great need to improve the overall efficiency of the ACC system, and characterizing pressure drop in ACC's is one of the approaches to deepen the fundamental understanding of the system.

Multiple factors, such as tube geometry, mass flux and tube inclination, influence the flow pattern, and thus heat transfer and pressure drop, in a convoluted manner. In the current design of the ACC system, steam is condensed in arrays of flattened tubes. This noncircular tube cross-section is not very common in industrial applications, and only limited studies are available to discuss the experimental results and correlations for two-phase pressure drop and void fraction in such a geometry. Coleman and Garimella [4] investigated flow regimes in round, sqaure and rectangular tubes during condensation of R134a. A comprehensive flow regime map was proposed for the condensation of R134a in different tube geometries, and was compared with existing results in the literature. Flow visualization showed that flow regime transitions were not very strongly dependent on tube shape and aspect ratio for the tubes with similar hydraulic

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