Influence of condensate inundation on heat transfer of R134a condensing on three dimensional enhanced tubes and integral-fin tubes with high fin density

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Abstract

High performance integrally-finned tubes with external fin density of 54 and 56 fpi are designed and manufactured. The condensing heat transfer of R134a on five tubes with integral-fin density of 20, 37, 48, 54, 56 fpi and five different high performance three dimensional enhanced tubes are studied for their single horizontal tube. Condensate inundation experiment of the integrally-finned and three-dimensional enhanced tubes is also performed. The experimental results indicate that the specially-designed integrally-finned tubes No.4 and No.5 of high density show the highest overall heat transfer performance over the three dimensional enhanced tubes about 8%. For the lower fin density integrally-finned tube, the results show apparently no condensate inundation influence effect. For the higher fin density tubes, the heat transfer is firstly enhanced more or less with the condensate impinging from the above tube, then maintains nearly unchanged. For the 3-D enhanced tubes, the heat transfer is also enhanced with condensate inundation firstly except tube No.7, while it is all followed by a mild drop as the increase of condensate rate. As a whole, the performance of the integral-fin tube with high density is better than that of the 3-D enhanced tubes.

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1. Introduction

Experimental investigations on the condensation heat transfer of refrigerant outside horizontal enhanced tubes have been widely conducted in the recent decades. The enhanced tubes studied include two dimensional integral-finned tubes and three dimensional (3-D) finned tubes. Compared with the integral-finned tubes, the 3-D enhanced tubes are most widely used in shell and tube condensers. Recent investigations in this area are mainly concentrated in the experimental study of comparisons between different enhanced single-horizontal tubes [1–6], prediction or modeling of horizontal single tube and its bundles [7–12], and condensate inundation effect on condensing heat transfer [13–20].

The condensation in a bundle is different from the condensation on a single tube, chiefly due to the effect of condensate inundation. The relationship of bundle effect was firstly put forward by Nusselt based on the assumption of constant wall temperature and laminar flow of film, and the result was as follows:

\[ h_N/h = N^m \]

where \( N \) is the row number of vertical tube bundle from the top row. Nusselt’s theoretical analysis showed that \( m = -1/4 \), while the experimentally determined value of the exponent \( m \) ranged from \(-1/6\) to \(0\) according to [21]. This result indicates that the bundle effect of condensation is essentially negative, but specifically it is case dependent, and for different type of tube the effect may be significantly different.

Webb and Murawski [13] experimentally studied the row effect of four enhanced tubes with refrigerant R11. The enhanced tubes were low-fin tube with fin density of 26 fpi (fin per inch) and three 3-D commercially available enhanced tubes: Turbo-C, GEWA-SC and Tred-D. On a vertical rank of five horizontal tubes, their results of the integral-fin tube showed virtually no row effect. Tred-D showed lowest single tube performance and the largest row effect, and Turbo-C showed highest single tube performance and small row effect. GEWA-SC showed 80% of the single tube performance of Turbo-C but its row effect was lower than Turbo-C.

Honda et al. [14] studied the film condensation of R113 with six different fin geometries, two low-fin tubes (with fin density of 27 and 51 fpi) and four three dimensional tubes. Their experimental results indicated that with the increase of condensate inundation rate, low-fin tubes showed a slow decrease in the heat transfer performance, while a faster decrease was observed for the three dimensional tubes. The decrease was more significant for the in-line tube bundle and lower vapor velocity.

Cheng and Wang [15] tested the heat transfer characteristics of R134a on one plain tube, three low-fin tubes (26 fpi, 32 fpi and