ABSTRACT

Title of the Thesis: Investigation of Laminar Film Condensation of Pure Vapour over Horizontal Integral Fin Tubes

Investigator: P.S.S. Srinivasan (srini_pss@mailcity.com)
Supervisor: Dr. R. Balasubramanian (Dr_rbala@hotmail.com)

Condensation of pure, stationary vapour over single horizontal integral fin (HIF) tube is taken as the broad area of research. Such tubes having two-dimensional rectangular or trapezoidal circumferential fins are commonly used in horizontal surface condensers to enhance the shell-side condensation heat transfer. Earlier investigations have shown that heat transfer enhancements of 2 to 12 times is possible with the HIF tubes when compared to the plain tubes. Based on the literature survey, the present research program has been carried out with the following objectives:

- To study the effect of fin height during condensation of pure saturated steam over single HIF tubes to find the optimum fin height.

- To develop a better technique for reducing the condensate flooding at the bottom of the HIF tubes (especially for a high surface tension fluid like water) as the condensate retention adversely affects the condensation heat transfer performance.

- To study the condensate motion and heat transfer over finned surfaces under the combined action of surface tension force and gravity force numerically in order to understand the phenomenon better.

- To develop a simple and easy to use correlation to find the condensing-side heat transfer coefficient during condensation of vapour over single HIF tubes.
Experimental facility has been created and validated, and is used to find the optimum fin height during condensation of steam. Enough care has been taken to obtain accurate and reliable experimental data. Fin heights of 1.0, 2.0, 2.5, 3.0, and 3.5 mm are tested. The optimum fin height for steam is found to be 3.0 mm which is almost two times greater than that reported for refrigerants by earlier investigations. Thus, larger fin heights can be employed for steam applications than those are currently used in practice.

By making a narrow longitudinal slot at the bottom of the HIF tube and by orienting the tube little inclined with the horizontal, considerable reduction in the condensate retention level has been observed. Using a simple experimental setup, the slot widths of 1.0 to 3.0 mm and the tube inclinations of 1° to 5° are tested to study their effect. The slot width of 1.0 mm and the tube inclination of 5° with the horizontal are found to reduce the condensate retention level by 40%.

To get the impact of such technique in actual condensation conditions, heat transfer measurements are carried out using the existing experimental setup. The tube with 1.0 mm slot is found to provide the heat transfer augmentation of 30% over a similar HIF tube without such slot when kept inclined at 5° with the horizontal. The current technique is free from various problems associated with the use of drainage strips proposed by earlier investigators for condensate retention reduction purposes.

A modified Nusselt type equation for condensation over the unflooded fin surface has been numerically solved. The distribution of curvature of liquid-vapour interface, magnitude of gravity and surface tension forces, local condensate film thickness, and their impact on local and average heat transfer rate are predicted. Condensation of Steam, Ammonia, R-11, R-12, R-22, R-113, and R-152a are considered to cover a wider range of fluid properties. Effects of fin geometry and fluid properties are studied.
Numerical results are also obtained by making the gravity force zero while leaving the surface tension force alone to act and vice-versa. These results are compared with the results that are obtained by allowing both the forces to act simultaneously. This comparative analysis has indicated that the role of gravity force is less than 5.0 % in the total heat transfer process when both the forces simultaneously control the condensate motion. It has led to an important conclusion that by replacing the gravity force term \((\rho gd^3)\) in the Nusselt equation with the surface tension force term \((\sigma \rho)\), heat transfer process in the unflooded region of the HIF tube can be modeled in a non-dimensional form. The result of which is the new non-dimensional number \(\left\{ \frac{(\rho h_e)}{(\kappa \Delta T)} \cdot (\sigma \rho) \right\}\), which is named as “Surface tension number” and denoted as “Su”.

Using the non-dimensional parameters identified from the numerical study, a simple model with four non-dimensional equations and six empirical constants has been developed for predicting the heat transfer performance during condensation of vapour on single HIF copper tubes with rectangular or trapezoidal fins. The six empirical constants are obtained by correlating the 183 reliable experimental data including the present one. The data covers 75-tube geometry and three condensing fluids (Steam, R-11 and R-113).

The ability of the present model is tested with 392 data points covering 132 tube geometry, 7 fluids including the Ozone safe refrigerants from 20 investigations. The model predicts 80 % of the data within \(\pm 15\) % and 88 % of the data within \(\pm 20\) % of the experimental values. The effect of fin geometry (spacing, thickness and height) on the heat transfer performance predicted by the present model agrees well with the experimental observations and is relatively better than the predictions of the earlier models. This study is the first of its kind reported until recently on such a wider scope.

*****