Effect of Condensate Inundation on Enhanced Tubes

Bryan C. W. Ng1*, S. Namasivayam2
1School of Engineering, Taylor’s University, Malaysia
*Email: bryan.ng7@gmail.com

Abstract— Enhanced tubes have effectively mitigated condensate inundation in tube bundles. This paper shows data mainly for wire-wrapped tubes but also includes data for smooth tubes, corrugated tubes and low-finned tubes. Thus far, results from previous researches have shown that enhanced tubes not only prevent inundation, but enhances the heat transfer coefficient of the tubes. The experiment was conducted using simulated artificial inundation technique where the inundation rate is controlled to simulate a depth of up to 30 rows of tubes. The results from this experiment shows that enhanced tubes suffers less inundation compared to smooth tube and the fin tube was the best performing tube among corrugated and wire-wrapped tubes.

Keywords— Condensation; Corrugated tube; Inundation; Low-finned tube; Tube bundle; Wire-wrapped tube

1.0 INTRODUCTION

The word inundation is used to portray the condensate falling from the upper tubes to the lower tubes of a horizontal condenser tube bundle. In the lower tubes, due to the increase of condensate film thickness by inundation, the heat transfer coefficient decreases. The condensate falls in various ways depending on the rate of condensation; droplets, columns or a continuous sheet. If steam is being pumped excessively into a shell and tube heat exchanger, the condensate would most probably fall from the upper tubes to the lower tubes in a continuous sheet; however, if steam is pumped in at a slow rate, the falling condensate would be in droplets [1,2].

The objective of this project is to study the effect of condensate inundation on enhanced tubes; wire-wrapped tubes, integral-fin tubes and corrugated tubes. By doing so, this research will aid in future designs of steam condensers to increase its efficiency.

There have been a number of researches done to evaluate the performance of wire-wrapped tubes in contrast to other enhanced tubes, namely horizontal integral-fin tubes (HIFTs), corrugated tubes and 3-Dimensional tubes. With this knowledge, wire-wrapped tubes can be utilized efficiently for applications such as condensers for Ocean Thermal Energy Conversion (OTEC) where finned tubes may not be so suitable [3].

The method of collecting data and analyzing results has much evolved since laminar film condensation for free-convection condensation was first investigated by Ernst Wilhelm Nusselt in 1916. The performance of a tube is measured in terms of heat transfer coefficient, α. The higher the heat transfer coefficient, the better the performance of the tube. The Nusselt formula is used to measure heat transfer coefficient.

2.0 METHODOLOGY

The experiment was conducted using simulated artificial inundation adapted from Murase et al. [4], where water is pumped into an inundation supply tube from both ends. The water then drops through the supply tube through holes at the bottom of the tube. The water is collected in an inundation distribution tube where the top half is removed to collect water and overflow onto the test condenser tube made of copper. The inundation rates used in the experiment are 0.1l/min, 0.3l/min, 0.5l/min and 0.8l/min. The inundation rates are as such to simulate the effect of inundation in a tube bank of approximately 20-30 rows deep. The whole setup was conducted over a measuring cylinder where water overflows from the tube into the cylinder. A stopwatch is used to time every minute to determine the inundation rate. The test condenser tubes used in the experiment consists of 1 smooth tube, 2 wire-wrapped tubes, 1 corrugated tube and 1 low-finned tube. The picture of the copper enhanced test condenser tubes and experimental setup is shown in the figures below. The specification of the 5 test condenser tubes are shown in the table below

<table>
<thead>
<tr>
<th>Type of Tube</th>
<th>Tube Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain copper tube</td>
<td>Length: 200mm, Outer Diameter: 12.7mm, Thickness: 1mm</td>
</tr>
<tr>
<td>Wire-wrapped tube</td>
<td>Length: 200mm, Outer Diameter: 12.7mm, Thickness: 1mm, Pitch: 4mm</td>
</tr>
<tr>
<td>Wire-wrapped tube</td>
<td>Length: 200mm, Outer Diameter: 12.7mm, Thickness: 1mm, Pitch: 8mm</td>
</tr>
<tr>
<td>Corrugated tube</td>
<td>Length: 200mm, Outer Diameter: 12.7mm, Thickness: 1mm, Loop: 8mm</td>
</tr>
<tr>
<td>Horizontal Integral-Fin Tube (HIFT)</td>
<td>Length: 200mm, Outer Diameter: 12.7mm, Thickness: 1mm, Fins density: 20fpi, Fin height: 1mm</td>
</tr>
</tbody>
</table>

3.0 RESULTS AND DISCUSSION

Results obtained from this experiment have shown that the heat transfer coefficient of enhanced tubes are significantly higher compared to smooth tubes in the graph below. Comparing the results of Murase et al. and the results obtained in this experiment, it is proven that enhanced tubes perform better than smooth tubes. Below are pictures of inundation on smooth tubes for 4 different inundation rates.

Figure 1. Photograph of simulated inundation on smooth tubes (a) Inundation rate: 0.1l/min; (b) inundation rate: 0.3l/min; (c) inundation rate: 0.5l/min; (d) inundation rate 0.8l/min
The figure above clearly illustrates the effect of condensate inundation on tubes and with it, the mode of falling condensates; (a) and (b) shows dropwise condensation while (c) shows column condensation and (d) shows a continuous sheet. As observed, the smooth tube is mostly covered in a film condensate preventing condensation whereas for enhanced tubes, the effect is much less. This can be seen in the pictures below. The results shown however, are only for 0.5l/min and 0.8l/min inundation rate, where the two highest rate tested in which the effect of condensate inundation is most apparent. This first set of results are pictures adopted from Murase et al. for wire-wrapped tube with winding pitch 4mm at 0.5l/min and 0.8l/min inundation rate.

Figure 2. Photograph of simulated inundation on enhanced tubes on wire-wrapped tubes with 4mm winding pitch. (a) Inundation rate: 0.5l/min; (b) inundation rate: 0.8l/min [1]

The second and third set of results shown below are obtained from the conducted experiment for 4 enhanced tubes for 0.5l/min and 0.8l/min inundation rates.

Figure 3. Pictures of simulated inundation on enhanced tubes at inundation rate of 0.5l/min where (a) Wire-wrapped tube 4mm pitch, (b) wire-wrapped tube 8mm pitch, (c) corrugated tube 8mm loop, (d) low-finned tube

From the results above, it is clearly seen that the effect of inundation is less in enhanced tubes than smooth tubes. The results obtained in this experiment are similar to that done by Murase et al. for the wire-wrapped tube with 4mm pitch. In addition, in both experiments, it was found that the fin tube was the best performing tube. However, in this experiment, where a corrugated tube was tested, it was found that the corrugated tube does not perform as well as the other enhanced tubes.

4.0 Error Analysis
The Kline and McClintock technique was used in this experiment. It was found that for a flow rate of 2l/min, there is a ±0.05l/min error. This would affect the outcome of the experiment.

5.0 Conclusion
The effect of condensate inundation was found to heavily affect the performance of a smooth copper tube. However, on an enhanced tube, this effect was less based on the results obtained even at a depth of 30 rows of tubes. The tube found with the least amount of condensate inundation was the low-finned tube. As for the wire-wrapped tubes, the performance of the tube improved when the winding pitch of the tube decreased. Lastly, the performance of the corrugated tube was almost similar to that of the wire-wrapped tube with 8mm winding pitch. However, results show that the heat transfer coefficient of corrugated tube is less than the wire-wrapped tube.

Acknowledgment
It is with immense gratitude that I acknowledge the support and help of my supervisor, Dr. Satesh Namasivayam whose patient guidance, steadfast encouragement and enthusiasm has made this research work possible.

References