CONDENSATE RETENTION AS A FUNCTION OF CONDENSATE FLOW RATE ON HORIZONTAL ENHANCED PIN-FIN TUBES

by

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The extent of condensate flooding as a function of condensate flow rate is measured on six horizontal pin-fin tubes (varying in circumferential pin-spacing) via simulated experimentation. Surface tension to density ratio is tested using three fluids namely water, ethylene glycol and R-141b. Results show that flooding was strongly effected by changing the condensate flow rate. An increase in flow rate caused a marginal decrease in flooding angle (an angle extracted from top of the test tube to the fully flooded flank). Similarly, circumferential pin-spacing also effected the retention angle and the effect goes on increasing by decreasing the surface tension to density ratio.

Key words: *condensate, retention, pin-fin tube, flow rate, heat transfer*

Introduction

The phenomenon of condensation has vital role in many engineering applications. Soon after the realization of heat transfer enhancement based on available surface area, simple plain condensing tubes were replaced by 2-D integral-fin tubes. However, due to surface tension effects, an adequate amount of condensate was observe to retain in between the fins, a phenomenon first observed by Katz *et. al.*, [1]. The extent of this flooding is measured by retention angle which is measured from top of the tube to the full flooded flank between the inter-fin spacing.

A comprehensive experimental data on heat transfer is available on integral-fin tubes [2-8]. Researchers also compared the measured retention angle in actual condensation with static condensation and no appreciable change was noted. Reasonable heat transfer models have also been reported [9-11] in which retention angle was found main parameter in the measurement of heat transfer.

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Retention angle measurement based on vapour velocity has also been reported on integral-fin tubes [4, 12] and a semi-empirical model was reported by Ali and Ali [12] which agree to data for water, ethylene glycol and R-141b to within ±20%.

After the advancement in tube geometry, trend shifted to more sophisticated 3-D tubes also known as pin-fin tubes. A reasonable heat transfer data is now available which shows the superior performance of these tubes over integral-fin tubes [13-21] and reports the effect of pin geometry over a range of fluids successfully. Recently Ali and Briggs [20] published an analytical model which predict most of the experimental data on pin-fin tubes to within ±15%. Ali also summarized the previous work on enhanced tubes successfully [22].

Effect of vapour velocity on condensate retention was studied systematically by Ali and Abubaker [23, 24]. Geometric parameters varied were circumferential pin spacing and circumferential tooth thickness. In all cases, pin-fin tubes were found less flooded when compared with equivalent integral-fin tube.

Eight horizontal tubes varying in fin spacing were tested under static condensation [25]. Three fluids namely water, ethylene glycol and R-141b were tested. Data showed the independence of the effect of mass-flow rate on the retention angle.

Based on the literature review available, only one study of Ali *et. al.*, [25] is available which reports the effect of condensate flow rate on integral-fin tubes. In this paper pin-fin tubes are tested under static condensation and the effect of mass-flow rate on these tubes is presented.

Methodology

Simulated experimentation was accomplished with small holes (about 0.4 mm in diameter) in between the rectangular fins in longitudinal direction. One end of the tube was connected to a fluid reservoir via a flexible tube and a needle valve to control the flow rate. The tube under test was located horizontally such that the small holes were kept right at the top. The schematic of experimental set-up and test tubes can be seen in figs. 1 and 2, respectively. Dimensions of the test tubes are given in tab. 1.

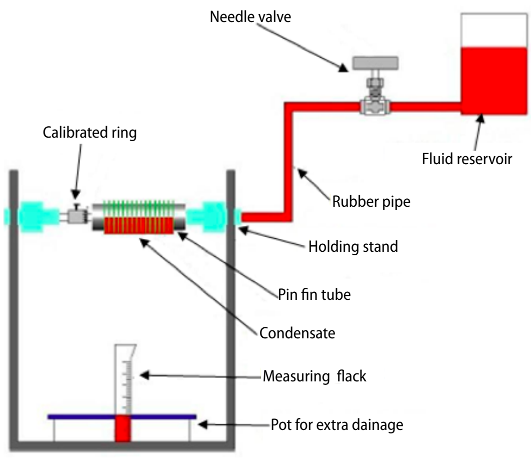

Figure 1. Schematic of Apparatus

Three fluids namely water, ethylene glycol and R-141b were tested. Colored dye was also mixed with first two fluids in order for quick recognition of the flooding point. The fact that measurements with almost zero condensate flow rate agreed closely with equation of Honda *et al.* [2], shows that adding small amounts of food coloring did

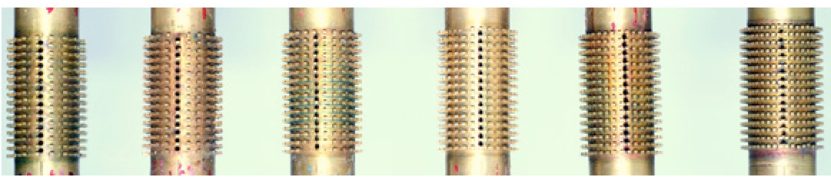

Figure 2. Pin-Fin tubes used in the present experiment

Table 1. Dimension of test tubes used in the present investigation in mm

Tubes	t_c (root)	t_c (tip)	s_c	t	s	h	d_r	d_0
T0	0.4	0.62	0.5	0.5	1	1.6	12.7	15.9
T1	0.36	0.62	0.75	0.5	1	1.6	12.7	15.9
T2	0.33	0.64	1.0	0.5	1	1.6	12.7	15.9
T3	0.28	0.65	1.25	0.5	1	1.6	12.7	15.9
T4	0.23	0.64	1.5	0.5	1	1.6	12.7	15.9
T5	0.22	0.74	2	0.5	1	1.6	12.7	15.9

not affect the surface tension significantly. As R-141b does not dissolve the dye, careful observation was made while locating the point to which fins were flooded.

Retention angle was measured using calibrated ring method. Pin fin tubes were mounted horizontally with a calibrated ring having angles from zero to 360° marked on it, fig. 3. This ring made up of aluminum was mounted on the finless portion of the tube. Ring had the inner diameter a 12.7 mm same as the fin root diameter with a small tolerance so that it may slide over the tube. Zero error was done by adjusting the small holes aligned with the zero degree of calibrated ring.

Once the error is removed the screw at the top of calibrated ring was tightened. The retention angle was then measured with the help of that ring as shown in fig 3. The results were also compared with photographic method and good agreement was found (see sample of photographs in figs. 4 and 5). The accuracy of calibrated ring method was around ±6°.

The flow rate was adjusted so that the fluid spilled steadily and uniformly over the tube surface. Photographs were taken for each tube at the flow rate starting from nearly zero

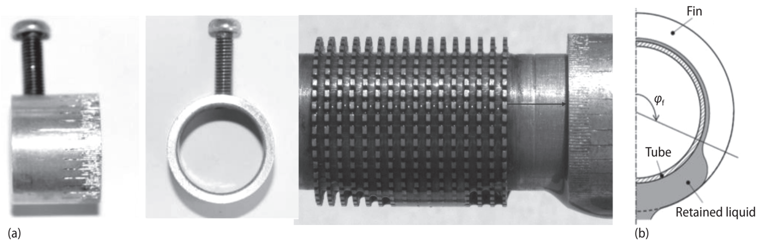

Figure 3. (a) Calibrated ring for the measurement of condensate retention angle, (b) condensate retention angle

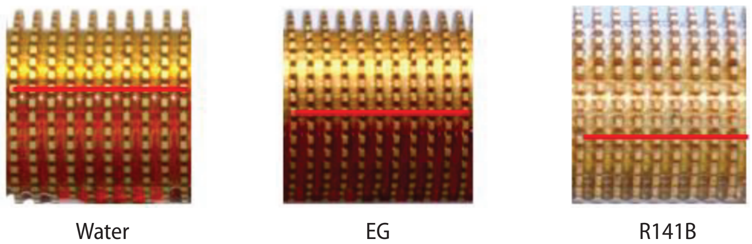

Figure 4. Photographs of test tube T0 with minimum flow rate (Lines show the retention angles)

Figure 5. Photographs of test tube T5 with minimum flow rate (Lines show the retention angles)

flow rate which was attained by spraying the condensate over the tube and measuring the retention angle, and ending at the flow rate at which the tube gets fully flooded. Measuring flask and stop watch were used to measure flow rate.

Results and discussion

Graphs for condensate retention angle versus condensate flow rate are shown in fig. 6. The difference in condensate retention angle between water and R141B at zero condensate flow rate is around 60 for circumferential pin spacing of 0.5 mm (T_0). However, this value reduces to around 40 for for circumferential pin spacing of 2 mm (T_5). It is interesting to note that variation in retention angle with changing circumferential pin spacing is more significant for liquids with higher surface tension to density ratio such as water. The results could also be used to estimate the condensate retention angles for liquids with different surface tension to density ratios at different condensate flow rates.

For all tubes tested the condensate retention angle has remained constant for a range of condensate flow rate (0-2 ml/sec). This highlights the importance and usefulness of pin fin tubes

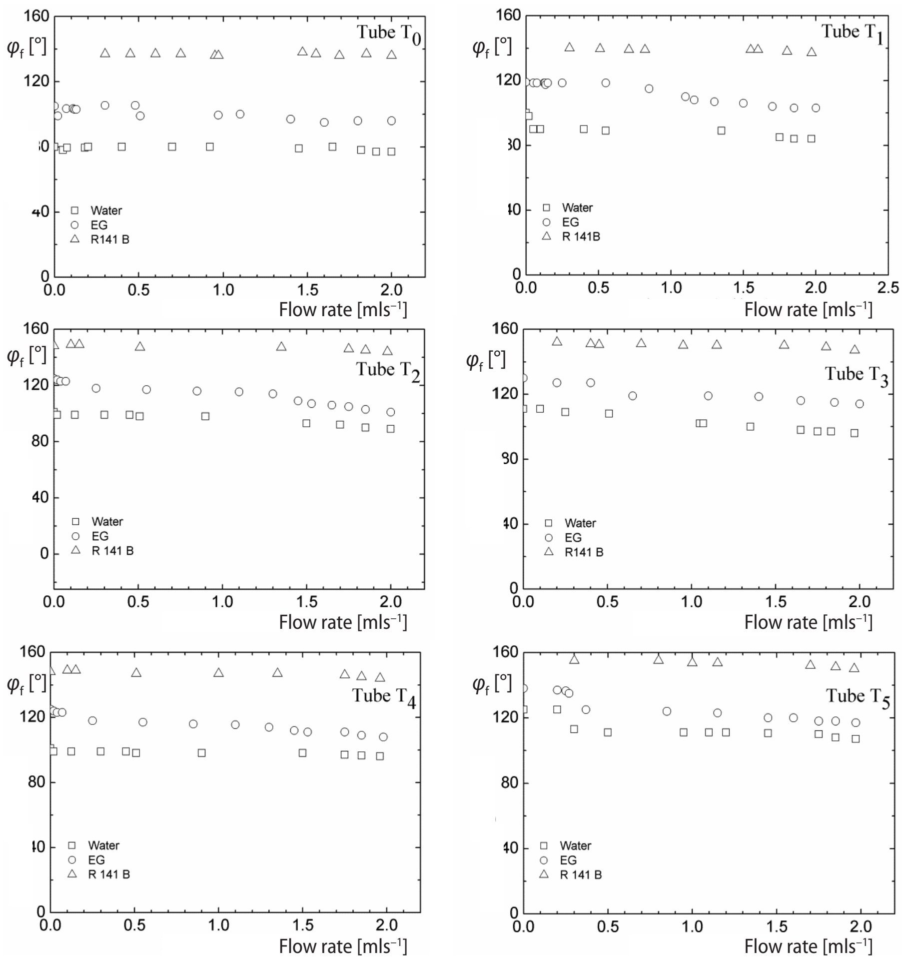

Figure 6. Effect of condensate flow rate on test tubes using water, ethylene glycol and R-141b as test fluids

in industrial condensers, where tube banks are used. For the case of smooth and finned tubes, significant degradation in heat transfer is obtained on the lower tubes in the bank. Firstly, higher condensate retention angles are obtained as lower tubes get thoroughly inundated with the condensate falling from the higher tubes. Secondly, condensate retention angles increase as vapour velocity is decreased, consequently shearing effect of vapour velocity is reduced.

Figure 7 shows the variation of retention angle with surface tension to density ratio. At a particular value of surface tension to density, variation in condensate retention angle is due to variation in circumferential pin spacing. Higher condensate retention angles correspond to higher circumferential fin spacing.

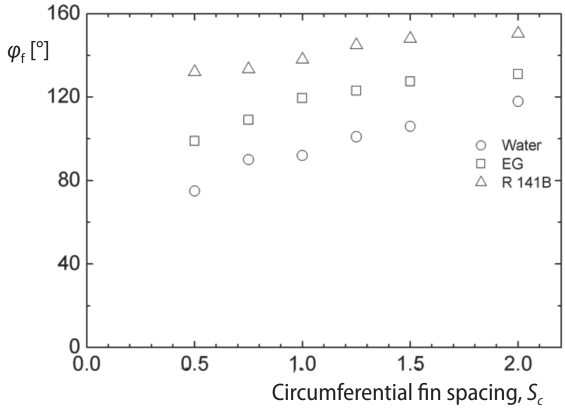

Figure 7. Effect of surface tension to density ratio on retention angle with minimum flow rate

This data could be used to determine the retention angle on pin-fin tubes for different liquids with a range of surface tension to density ratios.

Conclusions

New experimental data has been reported to determine the retention angle characteristics for simulated condensation of water, ethylene glycol and R141B as a function of condensate flow rate. Based on the findings it is recommended that the pin-fin tubes could be used in the bank of tubes that get thoroughly inundated. Since, no drainage mechanism is present for the case of smooth tubes, significant reduction in heat transfer is observed. Results for a range of condensate flow rates have been supportive of the fact that pin fin tubes could be used in the bank of tubes in general and lower the bank in particular.

Moreover, for optimised geometries, further investigation is needed to determine the retention angle and heat transfer characteristics for a range of condensate flow rates and geometries.

Nomenclature

d_0 – outer diameter
d_r – root diameter
h – pin or fin height
s – longitudional pin or fin spacing
s_c – circumferential pin spacing
t – pin or fin thickness
t_c – circumferential tooth thickness

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