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Research paper

# Effect of circumferential pin thickness on condensate retention as a function of vapor velocity on horizontal pin-fin tubes

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## HIGHLIGHTS

- Effect of circumferential pin thickness on condensate retention was reported.
- R-141b, water and ethylene glycol were used to simulate condensate.
- For EG and water, effect of velocity on pin-fin was less than integral-fin tubes.
- For R-141b, retention angle showed no change with changing velocity.

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## ABSTRACT

This paper reports the effect of circumferential pin thickness on retention angle as a function of vapor velocity on four pin-fin tubes (varying in circumferential pin thickness from 0.5 mm to 2.0 mm). Three fluids (namely water, ethylene glycol and R-141b) with high, intermediate and low surface tension to density ratios were tested. Experimentation was performed by providing downward air (to simulate vapor) through a vertical wind tunnel with velocities from 0 to 18 m/s. By providing small holes on the upper side of tube a continuous flow of condensate was ensured along the circumference of the test tubes. At low approaching zero vapor velocity; an increase in circumferential pin thickness caused a decrease in retention angle (an angle measured from top of test tube to the point of flooded flank in circumferential direction) in case of pin-fin tubes for all fluids tested. At high vapor velocity; the role of vapor shear was less effective on the upper half of pin-fin tubes when compared to the equivalent integral-fin tube (i.e. with same longitudinal fin spacing, tooth thickness, tooth height, inner and outer diameter as that of pin-fin tubes). This less effective role of vapor shear on the upper half of pin-fin tubes, when compared with integral-fin tube is thought to be due to the presence of trapped condensate in between the horizontal cuts (circumferential pin spacing) available on pin-fin tubes, which tends to resist the downward motion of the condensate. On the lower half of test tubes (as in case of test fluid R-141b) vapor velocity showed no effect on retention angle for all pin-fin tubes while for the case of equivalent integral-fin tube, retention angle was decreased with the increase of vapor velocity.



## 1. Introduction

Integral-fin tubes are being employed in industrial condensers for many decades. To optimize these tubes, researchers reported numerous experimental and theoretical studies which are summarized in Refs. [1,2]. The phenomenon that severely affects the thermal performance of integral-fin tubes is condensate retention; Katz et al. [3] first observed it experimentally. The extent of this condensate retention is defined as condensate retention angle; measured from the top of the tube to the point of condensate fully fills the inter-fin spacing.

For free convention condensation on integral-fin tubes, this problem of condensate retention has been studied by many researchers. Honda et al. [4] reported experimental data on three integral-fin tubes using R-113 and methanol as test fluids. Condensate retention was observed to decrease when experimentation was carried on same set of tubes using drainage strips. Furthermore, retention angle was found to be the same for both

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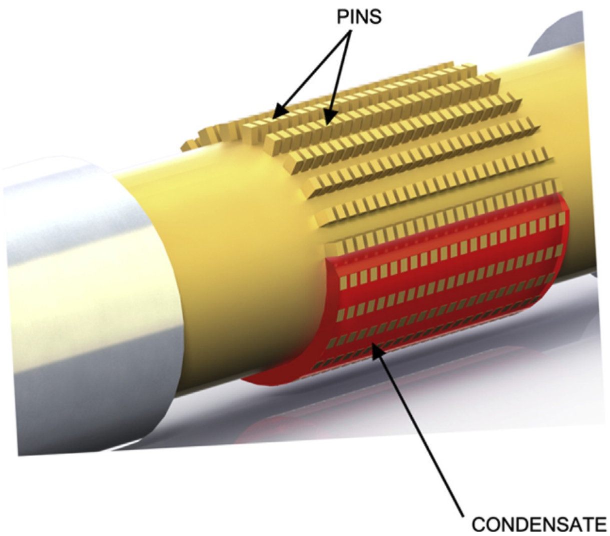


**Fig. 1.** Sketch of a 3-dimensional pin-fin tube.

real and static condensation. Rudy and Webb [5] obtained the same results when compared real and static condensation on integral-fin tubes. Yau et al. [6] tested drainage strips effects on condensate for integral-fin tubes. Tubes with drainage strips performed well (found to be less flooded) when compared with tubes having no drainage strips.

Based on experimental investigations (see for example [7–9]), many heat transfer models were developed to predict the free convection condensation heat transfer on horizontal integral-fin tubes [10–12]. In all these models, condensate retention angle was considered as a prominent factor effecting the heat transfer which was predicted as following equation reported by researchers [4,5,13],

$$\O_{f=}\ \cos^{-1}\left[\left(\frac{2\sigma cos\theta}{\rho gsR_o}\right)-1\right] \quad for\ s<2h \tag{1}$$

For forced convection condensation on integral-fin tubes, behavior of condensate retention under the influence of vapor velocity was experimentally reported by Fitzgerald et al. [14]. Results showed that when condensate was retained at upper half of tube, increasing vapor velocity decreased it considerably. However, when condensate was retained only on the lower half of tube, increasing vapor velocity decreased retention angle. A semi-empirical correlation for condensate retention angle accounting vapor velocity effect on integral-fin tube was later published [15].

Thermal performance of porous fins (wet) of different materials and shapes were studied by Hatami and co-workers [16–18], they used different analytical methods to study the temperature profiles of porous fins. Many other shapes of wet porous fins were also studied and their thermal performance analysis was reported in Refs. [19–22].

In recent decades, pin-fin tubes have received great attention for condensation heat transfer. A sketch of a 3-dimensional pin-fin tube with different geometric dimensions is shown in Fig. 1. A comprehensive experimental data for free-convection condensation heat transfer is now available for pin-fin tubes (see for example, [23–28]) which show that these tubes perform much better than 2-dimensional integral-fin tubes.

To further exploit the enhancing effects of pin-fin tubes for free convection condensation, it was pivotal to understand the condensate retention behavior on these tubes. A comprehensive experimental data for condensate retention (for free convection) was reported on 15 pin-fin tubes by Ali and Briggs [29]. Static method to create condensate was adopted to carry out experimentation. Pin-counting and photographic methods were used to analyze condensate and a comparison of both methods was found to be within ±5%. All pin-fin tubes were found to be less flooded than the equivalent integral-fin tubes. A semi-empirical model was

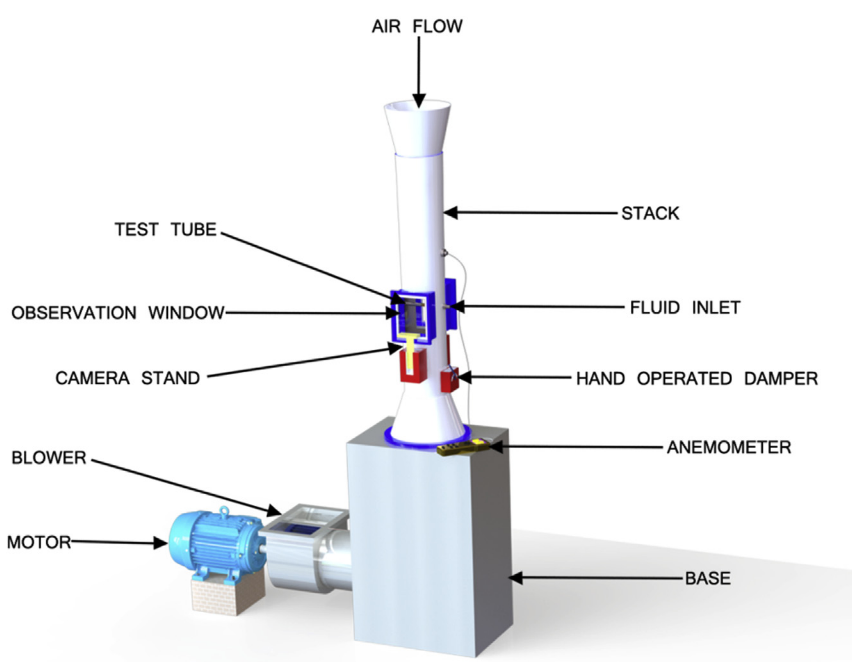


**Fig. 2.** Apparatus used for this investigation.