



# Frictional pressure drop during steam stratified condensation flow in vacuum horizontal tube



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## ABSTRACT

The frictional pressure drop of steam condensation flow in vacuum horizontal tube was studied experimentally. The steam saturation temperature changes from 50 to 70 °C, the steam mass flux varies from 2 to 10 kg/(m<sup>2</sup>·s), vapor quality range are from 0 to 1 and the temperature difference between steam and cooling water are 3, 5 and 8 °C respectively. 205 experimental data were obtained in the experiment and compared with 25 existing frictional pressure drop models in three different kinds. All the experimental conditions are stratified flow and the flow states are turbulent and laminar flow in steam and liquid phase respectively. The frictional pressure drop increases with mass flux and vapor quality. It decreases with saturation temperature and has less relationship with temperature difference. Five models with the highest prediction accuracy are Quibén's model, Chisholm's model, Zhang's model, Sun's model, Lee's model.

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## 1. Introduction

Steam condensation flow in horizontal tube is widely used in various industrial fields, such as chemical industry, air conditioning and desalination. A review of refrigerants condensation flow inside and outside tube was proposed by Cavallini et al. [1]. Later, Miyara [2], and Dalkilic [3] also gave comprehensive reviews of condensation flow, including the heat transfer, flow pattern, void fraction and pressure drop. Wang et al. [4] investigated the heat transfer characteristics of steam condensation flow in vacuum horizontal tube with inner diameter of 18 mm experimentally. Condensation heat transfer of vapor and noncondensable gas mixtures in horizontal tube with inner diameter of 27.5 mm when the inlet pressure is 0.2 MPa is shown in Wu and Vierow's study [5]. Similar experiment with inner diameter of 16 mm at the pressure 0.1 MPa was conducted by Ren et al. [6]. Thome [7] proposed a new condensation model for horizontal tube including two types of heat transfer mechanisms in the tube: film condensation at the top of tube and convective condensation at the bottom.

Two-phase flow is a very complex thermodynamic process. The frictional pressure drop of two-phase flow plays an important role in design and optimization of heat exchanger, especially for multi-effect evaporation desalination plant. The steam condenses in vacuum horizontal tube in multi-effect evaporation desalination plant, and the pressure drop of this process has a great influence on the

thermal performance of desalination system [8]. Kouhikamali et al. [9] investigated the pressure drop in the heat exchangers of multi-effect evaporation with thermal vapor compression system and showed that condensation pressure drop in the tube has most influence on the system performance among all different kinds of pressure losses. Considering condensation pressure drop in tube increases the specific heat transfer surface area by about 7% than neglecting it.

The frictional pressure drop of refrigerant condensation flow at high or atmospheric pressure has been studied extensively, but there are few studies about the frictional pressure drop of steam condensation flow under vacuum conditions.

The main factors influencing the frictional pressure drop are steam mass flux, vapor quality and saturation temperature. Many experiments [10–13] showed that the frictional pressure drop increased with the mass flux and vapor quality. Col et al. [14] investigated propane condensation flow in minichannel and found that the pressure drop increases with vapor quality and the increment increases with mass flux. Zhuang et al. [15] measured R170 condensation flow in a 4 mm diameter horizontal tube. The frictional pressure drop increases with mass flux and the effect of mass flux weakens as the saturation temperature increases. Quibén and Thome [16] measured the pressure drop of R134a, R22 and R410A experimentally. They found that the frictional pressure drop increased to the maximum firstly and then decreased with the increasing vapor quality. The mechanism of this phenomenon is the transitions of flow patterns. Charnay et al. [17] got the same experimental results with Quibén and Thome [16]. Zhang et al.

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