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Research Paper

Nucleate boiling of pure and quasi-azeotropic refrigerants from copper coated surfaces

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HIGHLIGHTS

- Experimental analysis of pool boiling on a horizontal copper coated tubes has been presented.
- Pure (R-134a and R-600a) and quasi-azeotropic (R-410A) refrigerants have been tested.
- The effect of saturation temperatures or pressures and heat flux on heat transfer coefficient are considered.
- Experimental results are compared with existing correlations and also developed a correlation for present data.

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ABSTRACT

The present experimental study deals with boiling heat transfer enhancement over surfaces fabricated by gas flame spraying. The copper powder was used as a coating material applied to the outer surfaces of copper tubes of 25.4 mm diameter and an effective length of 116 mm. The surfaces having coating thickness of 42.2 µm and 95.4 µm were used. Pool boiling experiments for saturated refrigerants under pure fluid category R-134a and R-600a and, quasi-azeotropic mixture R-410A (mixture of R-32 and R-125) were carried out for heat fluxes ranging from 5 to 50 kWm^{-2} for their respective saturation pressure corresponding to temperature of 10 °C. A significant enhancement of boiling heat transfer coefficients due to coating were found for all three refrigerants. For R-600a, the nucleate boiling heat transfer coefficients were approximated 1.35–1.52 times and 1.09–1.2 times higher than those of R-134a and R-410A respectively. The experimental data for coated surfaces were correlated in terms of relevant parameters and also compared with the existing correlations in the literature.

1. Introduction

The current advancement in enhanced boiling heat transfer is one of the dynamic research areas to meet the challenges of the technological developments in refrigeration, chemical, power generation, and other allied systems. Comprehensive reviews on various techniques of enhancing boiling heat transfer have been described by Thome [1] and Webb [2]. Metallic powder coating on the substrate surface is one of the most commercially successful passive techniques that seem to be of great promise over active techniques due to ease of fabrication and non-employment of any external energy supply. There are various methods for fabrications of porous coating such as sintering, brazing of particles, electrolytic depositions and thermal spraying [3]. Few researchers [4–14] have investigated boiling of alternative refrigerants on thermal spraying metallic coated heating surfaces and observed significant enhancement of heat transfer coefficient. However, the results of these investigations are inconclusive as they do not consider the influence of operating parameters like saturated pressure or temperature, power input, pore size and coating thickness on boiling heat transfer coefficient. Metallic coating surface provides numerous numbers of active nucleation sites over the surface. This active nucleation site density is one of the important factors in nucleate boiling. However, the nucleation site density depends not only on the surface structure but also upon the thermo-physical properties of refrigerants. The effects of these parameters on nucleate boiling heat transfer were well described by Benjamin and Balakrishnan [15].

The United Nations 'Montreal Protocol' [16] proposed to reduce the production and use of the alternative refrigerants that have lower ozone depletion potential. The research and development effort on refrigerants have been developed over the past few decades. In recent years, the refrigeration and air conditioning industries are currently undergoing a massive conversion process from CFC(R-12 and R-22) to HFC(R-134a and R-410A) or HC(R-600a) refrigerants due to environmental issues. Among these alternatives, R-134a, R-600a and R-410A have been proposed as alternatives to the widely used refrigerants R-12 and R-22 because of its chemical

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and thermo-physical properties. Prediction of the nucleate boiling heat transfer coefficient depends upon knowledge of the mechanisms involved in heat transfer surface and refrigerants are being used. To date, few research efforts on the nucleate boiling heat transfer enhancement of R-410A and R-600a on gas flame coated surfaces have been reported in open literature. For successful application of R-134a, R-410A and R-600a as alternative refrigerants in flooded evaporators, boiling heat transfer coefficients have to be known. In the current study, porous metallic powder coating as an enhancement technique is applied on copper heating tube surfaces. The nucleate boiling heat transfer coefficient for alternative refrigerants R-134a, R-410A, and R-600a was measured and the predicted correlation for nucleate boiling heat transfer coefficients for these alternative refrigerants on present enhanced tubes was developed.

2. Experimental facility

2.1. Experimental set-up and procedures

The schematic of the single tube pool boiling apparatus is shown in Fig. 1. The setup includes a cylindrical vessel, heating surface, condensing loop, and power supply arrangements. A vessel was made up of stainless steel sheet (Type 304) of 3.4 mm thickness rolled into a cylinder with an internal diameter of 150 mm having a length of 490 mm. It also has an internal condenser, an auxiliary heater, a cartridge heater, a pressure gauge, thermocouples, and a test section. The boiling setup has two inspection windows on opposite sides to observe the boiling phenomenon.

The copper evaporator tubes fitted with a stainless steel flange at one end of the cylindrical vessel were 25.4 mm in outer diameter

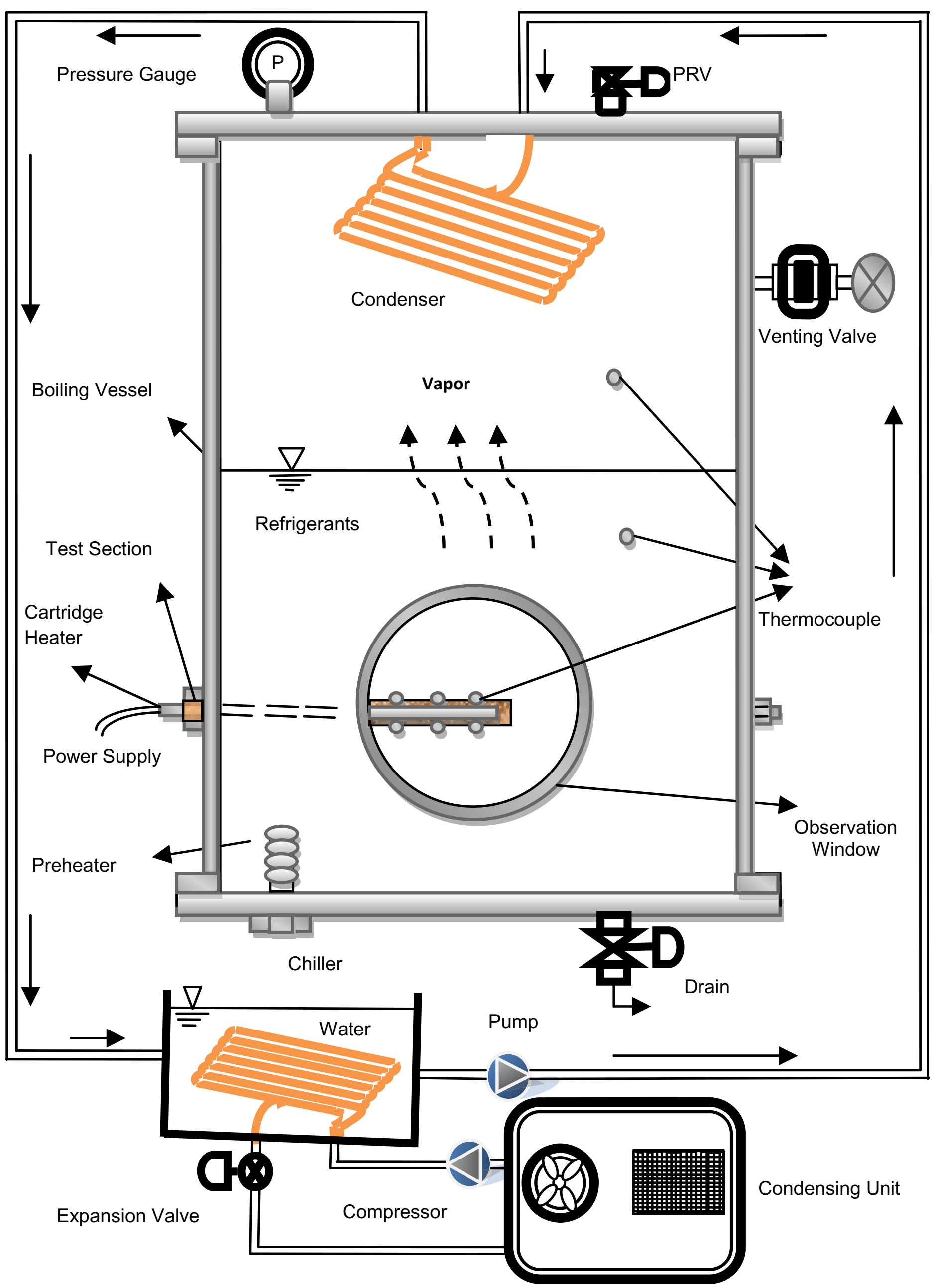

Fig. 1. Schematic diagram of a pool boiling apparatus.