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Condensation heat transfer characteristics of zeotropic refrigerant mixture R407C on single, three-row petal-shaped finned tubes and helically baffled condenser

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Condensation heat transfer coefficients (HTCs) of zeotropic refrigerant mixture R407C on single horizontal petal-shaped finned (PF) tube and three rows of PF tubes with an in-line arrangement were experimentally measured. All measurements were taken at the vapour temperature 39 °C with the wall subcooling of 2–8 °C. The results showed that the average enhancement factor provided by the PF tube was about 5.02, and the effect of condensate inundation was significant for the PF tube. Furthermore, the experiments also were performed to compare the shell-side condensation HTCs of an integrally helical baffle condenser with PF tubes to those of that with low fin (LF) tubes at vapour temperature of 39 °C, the condensation HTCs of helically baffled condenser with PF tubes were about 1.56 times as large as that of helically baffled condenser with LF tubes at the same heat flux. Correlations have been suggested for both the shell-side condensation HTCs for the two condensers with different tube types and give very good agreement with experimental results. It is a promising route to use PF tubes instead of LF tubes for improving the performance of an integrally helical baffle condenser.

1. Introduction

Condensation of zeotropic mixtures is important in various industrial fields such as refrigeration, heat pumps, and chemical process industries [1–5]. One of the most common condenser technologies for heat pumps or refrigerant machines consists of a shell and tube heat exchanger in which the vapour condenses on the outer surface of the tube banks while the coolant flows through the inner passages of the tube banks. In order to apply zeotropic mixtures successfully in the condensers, their condensation heat transfer coefficients (HTCs) on the outside tubes need to be measured with their heat transfer characteristics analysed subsequently. Condensation of a zeotropic mixture differs from that of a pure fluid in only two ways [6,7]: Firstly, the effects of gliding temperature difference (GTD) can become apparent, and secondly the effects of mass transfer resistance are introduced. As the less volatile component is more liable to condense first the remaining mixture has a lower dewpoint temperature, thus causing the equilibrium temperature to fall. The practical significance of such a temperature fall, called “glide”, will be a reduction in temperature difference between the condensate and the coolant with a corresponding reduction in local heat transfer. Furthermore, the preferential condensation of the less volatile component causes a depletion of the less volatile component close to the interface. This means that the less volatile component must be transported through a film enriched by the more volatile component. A vapour diffusion layer appears between the bulk vapour and the condensate surface. This vapour film creates an additional mass transfer resistance to the condensation process.

In the last few decades, various types of enhanced surface tubes have been used to enhance the shell-side condensation of zeotropic mixtures. These enhanced tubes can be classified according to two types: two dimensional (2D) fin enhanced tubes with transverse plain fins and three-dimensional (3D) fin enhanced tubes with interrupted fins, spines (Turbo-C, Gewa C, Gewa SC, Tred-D and Thermoexcel C tubes, etc) [8–12]. When assessing the effectiveness of enhanced surfaces during heat transfer it is useful to define an enhancement factor (EF) which indicates the ratio of the condensation HTC of the enhanced tube over that of a smooth tube at the same wall subcooling $\Delta T = (T_{sat} - T_w)$. Jung et al. [8] measured the condensation HTCs of zeotropic mixtures of R32/R134a, R134a/R123 and R407C (R32/R125/R134a = 23/25/52 mass %) on a low fin (LF) tube and a Turbo-C tube. The results showed that, for all mixtures tested, the difference of EF between the Turbo-C tube and the LF tube was small. For R407C, EF was between 3 and 5 in the Turbo-C tube. Belghazi et al. [9] carried out experiments to

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determine the HTCs during condensation of R23/R134a on a Gewa C and an integral fin tubes, they found that the Gewa C tube gave no enhancement compared to the integral fin tube. Honda et al. [10] measured the row-by-row condensation HTCs of downward flowing R407C in a staggered bundle of horizontal finned tubes. Two kinds of conventional 2D LF tubes and three kinds of 3D fin tubes were tested. The results showed that the effect of fin geometry on the condensation HTC was not very significant. Generally, contrary to the pure fluid case, all 3D fin enhanced tubes tested give no significant enhancement compared to the 2D fin enhanced tubes for zeotropic mixtures, it means that EF is almost the same for 3D as 2D fin enhanced tubes. Therefore, novel enhanced tube and a high effective condenser must be developed to further improve the condensation heat transfer performance of zeotropic mixtures.

Very few studies on the condensation heat transfer of zeotropic mixture in a shell and tube condenser can be found in literature. Gabrielii and Vamling [13] investigate the change in the overall HTC when replacing R22 with R407C in a horizontal shell and tube condenser used as a full-scale test plant. The condenser has a cross-flow arrangement (TEMA X) with two tube-side passes. It consists of 263 LF copper tubes, arranged in a staggered layout. They found overall HTCs between 43% and 70% lower for R407C than for R22. Sajjan et al. [7] made an experimental and theoretical investigation to find out the reasons for the drop in shell and tube condenser performance when replacing R22 with a zeotropic mixture R407C, the results showed that the degree of mixing of the newly formed condensate on a tube and the drained condensate was a factor influential enough to explain the performance drop. Furthermore, they found that 3D finned tubes seem to have better mixing in the condensate than integral finned tubes. In large-scale refrigeration system, baffles were introduced on the shell side of condenser primarily to support the tube bundle and increase the cross-flow velocity for increased heat transfer within the allowable pressure drop. Recently, the helical baffle as one of the novel shell-side baffle geometries in shell and tube heat exchanger was reported in many literatures [14–17]. The baffle geometries mainly include a non-integrally and an integrally helical baffle arrangements. The studies on the shell-side heat transfer focused almost on the single phase heat transfer. For the shell-side condensation of mixtures, the helical baffle can offer many advantages over conventional baffled designs [18]. However, to the best of our knowledge, there are not available data on the condensation heat transfer of zeotropic mixtures in the shell side of a helical baffle heat exchanger in open literature.

Petal-shaped finned (PF) tube is a three-dimensional integral low finned tube with petal-shaped fin geometries on the outside surface invented by South China University of Technology in China for enhancing the heat transfer of the shell-side fluid [19,20]. The aim of the current investigation is to study experimentally the condensation heat transfer characteristics of R407C on in-line horizontal PF tubes. Furthermore, the condensation heat transfer performances of R407C in helically baffled condenser combined with PF and LF tubes are compared. In the paper, the experimental setup and procedure are described, the data reduction process detailed, and the results presented and discussed.

2. Experimental facility

For the experimental investigation on the condensation heat transfer characteristics of R407C on horizontal PF tubes, the layout of the experimental facility is shown in Fig. 1. The facility is composed of a condensation test section (condenser), an evaporator, a cooling water loop and a hot water loop. The condenser and the evaporator consist of a 6 mm thick horizontal cylindrical body and blind flanges made of stainless steel (AISI-316L). Both of them have an inside diameter of 150 mm and a total length of 650 mm.

The refrigerant vapour is generated by heating the pool of the refrigerant liquid by means of three immersed mechanically fabricated porous surface tubes using an in-line arrangement of three rows with the vertical pitch of 30 mm. These mechanically

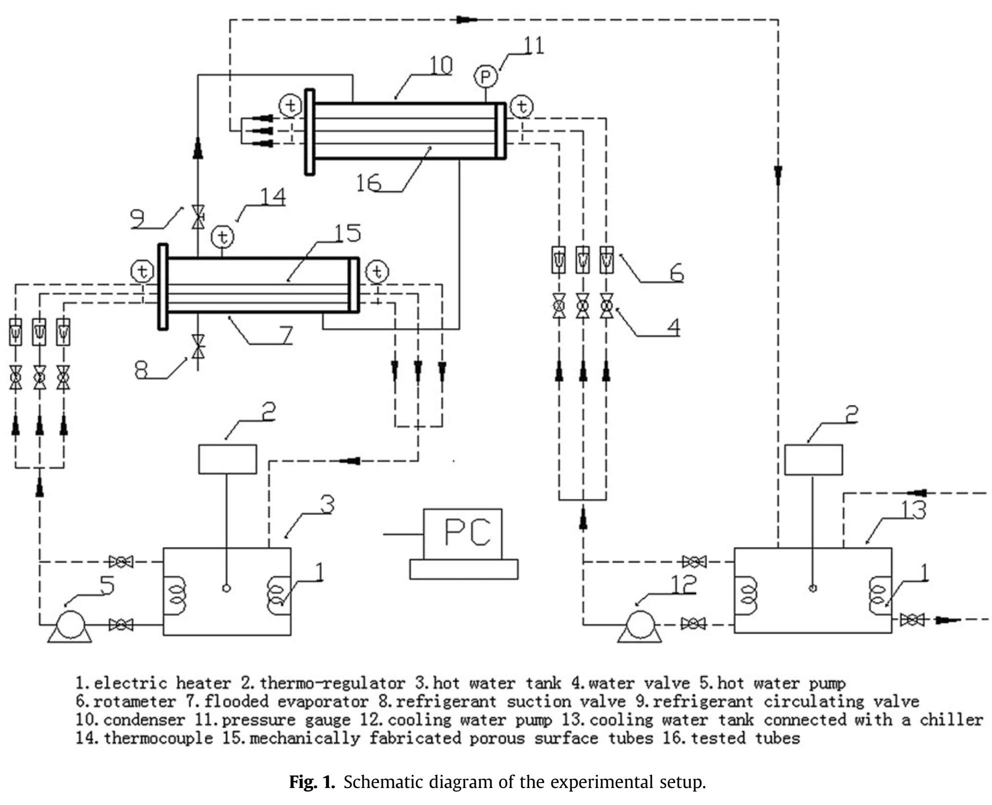

Fig. 1. Schematic diagram of the experimental setup.