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Research paper

# Experimental investigation of vapor condensation of iso-butane over single horizontal plain tube under different vapor pressures

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## HIGHLIGHTS

- Heat transfer coefficient (HTC) reduces with increase in wall sub-cooling temperature.
- HTC decreases as heat flux increases.
- Heat flux increases as wall sub-cooling temperature increases.
- For plain tube, Nusselt model underpredicts the experimental results at higher pressure.
- For plain tube, Nusselt model overpredicts the experimental results at lower pressure.

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## ABSTRACT

In this study, condensation heat transfer coefficients of refrigerant R-600a (iso-butane) over a single horizontal smooth tube of diameter 19 mm were measured at different vapor pressures and different wall sub-cooling temperatures. Like other refrigerants, condensation heat transfer coefficients of R-600a showed the same trend with wall sub-cooling that external condensation HTCs decrease as wall sub cooling temperatures increase. All data were taken under three different pressures of 0.52 MPa, 0.48 MPa, and 0.43 MPa of the refrigerant-vapor with wall sub-cooling temperatures of 5–12 °C on a plain tube of 19 mm outside diameter under a heat flux of 8–20 kW/m$^2$. Based upon the Data taken in this study, different graphs were plotted varying different parameters to show their dependency on other parameters. The experimental data were validated by comparing them against the standard model for condensation over plain tube. In this study, Nusselt's model was used as the standard model for validating the experimental results. The values given by Nusselt's equation were in the range of −10% to +12% of the experimental values.



## 1. Introduction

As CFCs deplete the ozone layer, various alternatives have been introduced in past years phasing out CFCs after Montreal protocol in 1987. Most of new alternatives have low ozone depletion potential (ODP) but higher global warming potential (GWP). After Kyoto protocol (1997), refrigerants having a low GWP have been emphasized. Hydrocarbons have zero ODP as well as low GWP, but the only concern is its flammability. In present days, design engineers have put remarkable efforts in designing advanced safe and compact systems thus reducing the risk of flammability. Therefore, use of hydrocarbons, which are known to have good thermodynamic properties as well as excellent environmental features, as alternative refrigerants is becoming widespread. In fact, pure and mixed hydrocarbons offer such advantages as low cost, availability, compatibility with the conventional mineral oil, and environmental friendliness. Iso-butane (R-600a) has dominated the European refrigeration sector and is being used in Japan and Korea as well at this time. Other countries like India and China also would like to use it in their own refrigerator sector.

Even though iso-butane is proposed as one of the alternative refrigerants, very few literatures are available and lot of work is still remaining in this area. The objective of this paper is to measure, compare and correlate external condensation heat transfer coefficients (HTCs) of iso-butane (R-600a) over single horizontal plain tube varying different parameters such as wall sub-cooling temperature and operating pressure.

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Many researchers have conducted experiments for vapor condensation of different refrigerants over horizontal plain tubes and there are plenty of experimental and theoretical studies in this area, but most of them have higher ODP and GWP whereas there are fewer on hydrocarbons such as propane, n-butane, iso-butane, and propylene and so many. Jung et al. [2] showed that dimethyl ether (DME, RE170) is a good alternate of R-12. DME which is flammable, showed good thermodynamic and environmental properties (ODP = 0 and GWP = 5). R-407C and R-410A are new alternatives to R22 which has R32 as one of its components. Jung et al. [3] performed experiments to calculate external condensation heat transfer coefficients (HTCs) of six flammable refrigerants of propylene (R1270), propane (R290), iso-butane (R-600a), butane (R600), dimethylether (RE170), and HFC32 over smooth tube of 19 mm diameter. They derived a general correlation by modifying Nusselt's equation based upon the measured data which showed an excellent agreement with all data exhibiting a deviation of less than 3%. The objective of this paper is to analyze the vapor condensation heat transfer coefficients of R-600a over plain tube within the operating range of condensing pressure. In the present scenario, the whole world is desperately attempting for saving and conserving energy, so the experimental data may help design engineers to design more energy efficient components in comparison to the data predicted by standard equation, since no single equation well predicts for all cases and conditions. Therefore in spite of Nusselt's equation well predicts the heat transfer coefficient for condensation of stationary vapor on single smooth horizontal tube, we also need experimental data for different cases and conditions. The motivation of this paper is to provide experimental data of vapor condensation of iso-butane over single horizontal plain tube under different vapor pressures so that it may help for design purpose.

## 2. Experiments

### 2.1. Experimental set-up

The experimental set-up fabricated for this study is illustrated in Fig. 1, a schematic diagram of the set-up, which comprised of major components like condenser, evaporator and data collection unit. The test condenser (5) is a stainless steel-304 cylinder of thickness 3 mm, inside diameter 100 mm and length 414 mm. The vapor of refrigerant is supplied through a dead end pipe (6) of 350 mm length and 6.5 mm diameter. This pipe has equally spaced 125 holes, each of 1 mm diameter, in a straight line. The test-section (3) (horizontal smooth copper tube) is fixed inside the test-condenser with the help of chuck nut assembly. The refrigerant-vapor generated in the evaporator (10) condenses over the test-section releasing latent heat of vaporization to the coolant (water), flowing inside the test-section, after conducting through the tube wall. Thus the temperature of the water rises, which is recorded with the help of data collection unit. The viewing window is provided in the middle of the test-condenser fitted with the Teflon glass to observe condensation. The vapor of liquid refrigerant is generated in the evaporator. The evaporator is a stainless steel-304 cylinder of thickness 3 mm, inside diameter 140 mm and length 670 mm. Three immersion heaters (12) each of 3 KW heating capacity are fixed in the bottom of the evaporator to transfer heat directly to the liquid refrigerant. The cylinder is closed by a flange (13), sealed with a 12 mm diameter hardened rubber O-ring and 8 holes of 10 mm hole diameter. At the top of the evaporator, a port is provided to supply the generated vapor to the test-condenser. Also at the top of the evaporator, another port is provided to monitor the evaporator pressure with a pressure gauge and pressure transducer. In the bottom part of the evaporator, a port is provided to feedback the condensate to the evaporator. The auxiliary condenser (2) is connected to the test-condenser. The auxiliary condenser is a stainless steel-304 cylinder of thickness 3 mm, inside diameter 120 mm and length 140 mm. Water is circulated inside the auxiliary condenser through a copper tube which condenses the residual vapor flowing out of the test-condenser and entering inside the auxiliary condenser through a port situated at the top of the auxiliary condenser. The condensate from the auxiliary condenser returns to the evaporator through port in the bottom part of the auxiliary condenser. The primary function of the auxiliary condenser is to keep the test-condenser free from non condensable. Since, the air is lighter than the refrigerant, it tends to accumulate at the top of the set-up which includes the test-condenser, and therefore, the auxiliary condenser is fixed approximately 45 cm above the test-

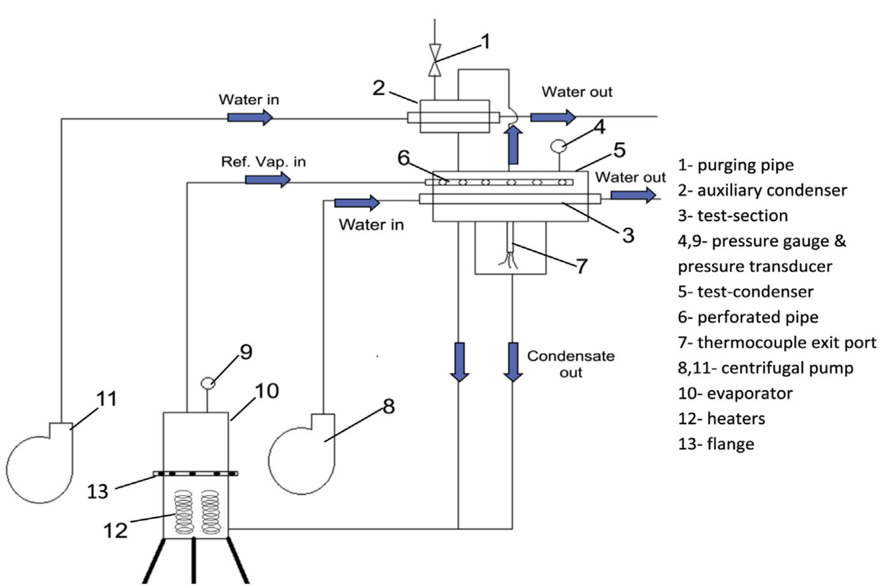


**Fig. 1.** Schematic diagram of the experimental set-up.