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Characteristics of Two-phase Flow Heat Transfer of R-22 and R-290 in Horizontal Circular Small Tube

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Keywords: R-22, R-290, Flow boiling, Heat transfer coefficient, Small tube

Abstract. Hydrocarbon refrigerants have been widely used to replace HFCs. As hydrocarbon, R-290 has no ODP (Ozone Depletion Potential) and negligible GWP (Global Warming Potential). This paper presents flow boiling heat transfer in small tube with R-290 and R-22. The test tube has inner diameter of 7.6 mm and length of 1.07 m. In order to determine the heat transfer coefficient, experiments were carried out for heat fluxes ranging from 10 to 25 kW/m^{2}K, mass fluxes ranging from 204 to 628 kg/m^{2}s, and saturation temperatures ranging from 1.87 to 11.9^o C. The study analyzed the heat transfer through the local heat transfer coefficient along the flow under the variation of these different parameters. In comparison with R-22, R-290 provides higher heat transfer coefficients. In the prediction of the heat transfer coefficients of R-22 and R-290, the correlation of Shah (1982) and Choi et.al. (2009) best fitted the present experimental result, respectively.

Introduction

New alternative refrigerants should not only have low ODP but should also have low GWP. R-290 is an alternative for the replacement of R-22 that is safe for the environment because it has a value of 0.0 ODP and GWP 8 (WMO, 1991, IPCC 1994).

There are some existing correlations for prediction of heat transfer coefficient in open literatures. Flow boiling equations introduced by Chen (1963) [1] consist of nucleate boiling and convective boiling. Copper (1984) [2] and Stephan and Abdelsalam (1980) [3] are widely used to predict nucleate boiling heat transfer coefficient. Jung et.al. (2003) [4] and Jung et.al. (2004) [5] conducted pool boiling experiment using pure halogen refrigerants and flammable refrigerants, respectively. Shah (2005) [6] conducted a study by comparing equations for the flow boiling process. Choi et.al. (2007) [7] investigated the flow boiling using CO_2 to vary the test diameter of 1.5 mm and 3 mm, length of 2 m and 3 m.

The study of flow boiling heat transfer using natural refrigerant in small tube is rarely done. This paper presents the flow boiling experiments using R-290 and R-22 with a heat flux from 10 to 25 kW/m^{2}K, mass flux from 204 to 628 kg/m^{2}s and saturation temperature from 1.87 to 11.9^o C. The heat is transferred to the test section uniformly. This study observe flow boiling phenomena of R-290 and R-22 by analyzing the heat transfer in 7,6 mm diameter tube. The present result is compared with some existing equations.

Experimental Apparatus and Procedure

The experimental facility as shown in Fig.1 consists of a condenser, receiver tank, gear pump, cooler, mass flow meter and test section. The test section has inner diameter of 7.6 mm and length of 1.07 m.

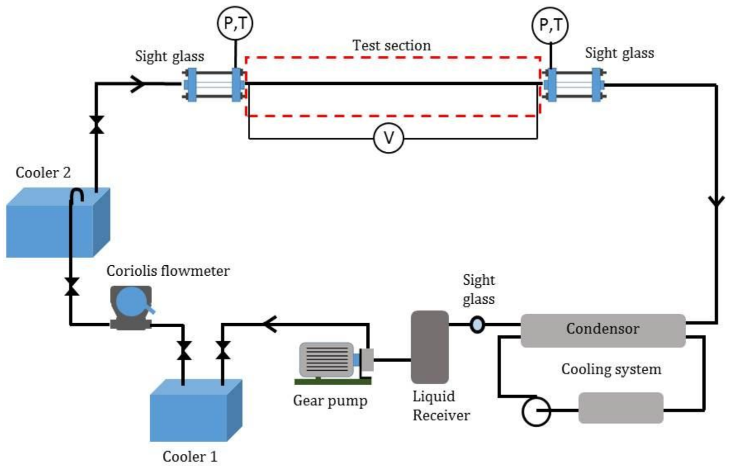

Fig. 1. Schematic diagram of the experimental facility

The condensed refrigerant enter the system in the liquid phase, then is accommodated in receiver tank to ensure that no vapor contained enter the next stage. The flow rate of refrigerant was measured using a coriolis flow meter with flow pressure generated by the gear pump coupled with an electric motor. Refrigerant enter the test section through a needle valve for adjusting the inlet pressure. Refrigerant temperatures are measured in the inlet and outlet of test section using thermocouples, as well as the tube wall temperatures. Pressure transmitter and bourdon tube pressure gauge are also installed in the inlet and outlet of test section to measure the local pressure which was used to determine the saturation temperature. Heat flux was provided by heater with variable AC voltage controller and voltage stabilizer. Test section was well insulated with glass wool and foam.

The local heat transfer coefficient in the boiling process is calculated using the following Eq. 1:

$$h = \frac{q}{(T_s - T_{sat})} \tag{1}$$

where *h* represents the local heat transfer coefficient during boiling process, T_s is the surface temperature, and T_{sat} is the saturation temperature. For data reduction accuracy, this experiment considered the subcooled length to determine the local heat transfer coefficient.

Result and Discussion

Effect of Heat Flux on Heat Transfer Coefficient. Figs. 2 and 3 show the effect of varying heat flux on the heat transfer coefficient of R-22 and R-290 in a horizontal small tube, respectively. Heat flux has a significant effect on the heat transfer coefficient. This trend agrees with the test results of some other researchers for the boiling of other refrigerants in small tubes (Saitoh et.al., 2005 [8]; Choi et.al., 2007 [7]; Choi et.al., 2009 [9]; Copetti et.al., 2011 [10]). Nucleate boiling is known to be dominant in this process, particularly at high heat flux condition. It caused increasing heat transfer coefficient with an increase in heat flux. Increasing heat flux caused an increase in emerged bubbles activity that indicates nucleate boiling increased. Thome et.al. (1994) [11] explained that the value of the radius cavity is inversely proportional to the difference of gas temperature to saturation temperature. It means that when the value of heat flux was high, the gas temperature also has a high value and the radius cavity becomes smaller, then a chance of bubble formation becomes greater.

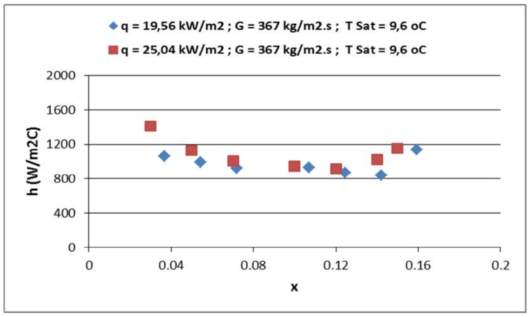

Fig. 2. The effect of heat flux on heat transfer coefficient of R-22

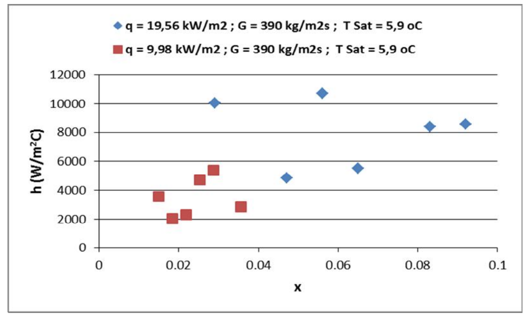

Fig. 3. The effect of heat flux on heat transfer coefficient of R-290

Effect of Mass Flux on Heat Transfer Coefficient. Fig. 4 shows the influence of varying the mass flux on the heat transfer coefficient of R-22 in a horizontal small tube. The change of the mass flux at low vapor quality has no significant effect on the heat transfer coefficient. It indicates that at low vapor quality the nucleate boiling heat transfer is predominant. At constant heat flux, an increase in the mass flux causes the vapor quality decrease. The decreasing vapor quality due to the rise of the pressed bubble with the increasing mass flux. The same result was also reported by Pamitran et.al. (2007) [12] using R-410 in mini channel, Choi et.al. (2007) [7], Copetti et.al. (2011) [10], Wang et.al. (2013) [13]. Hoo Kyu Oh (2011) [14] has conducted experiment of flow boiling in small tube for CO_2 and showed the result that the mass flux has no significant effect on the heat transfer coefficient at the low quality region. The result for R-290 as shown in Fig. 5 has the similar condition with the result for R-22.

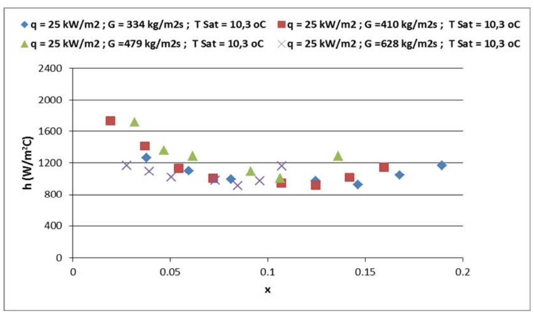

Fig. 4. The effect of mass flux on heat transfer coefficient of R-22

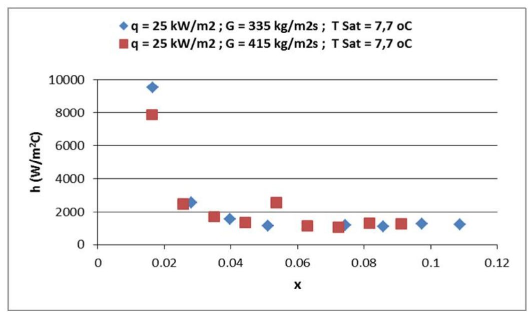

Fig. 5. The effect of mass flux on heat transfer coefficient of R-290

Effect of Saturation Temperature on Heat Transfer Coefficient. Fig. 6 explained that the heat transfer coefficient increases with increasing saturation temperature. It means the difference between wall temperature and saturation temperature (ΔT_{sat}) will become smaller, so that the value of heat flux is constant, the smaller ΔT_{sat} will have a greater heat transfer coefficient.

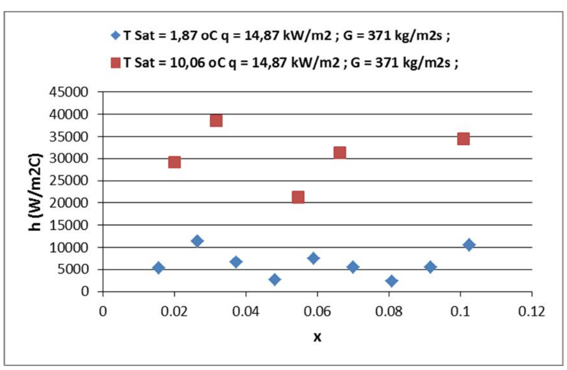

Fig. 6. The effect of saturation temperature on heat transfer coefficient

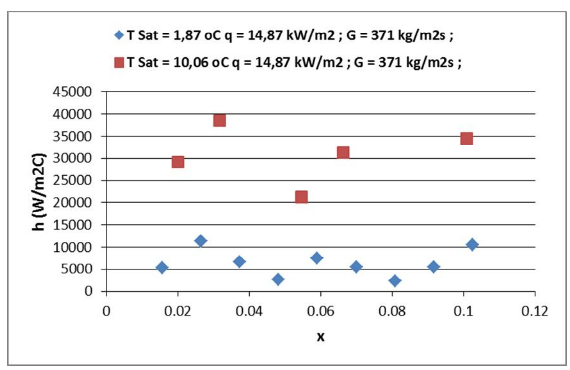

Fig. 7. Comparison of R-22 and R-290 on heat transfer coefficien

The higher saturation temperature will also change the fluid properties, which is the ratio between the density of the liquid and density of the vapor become smaller. When the density of vapor is greater in high saturation, the vapor velocity become higher, so that the detention nucleate boiling become faster. The value of surface tension become lower in high saturation temperature, it makes a greater chances of the forming bubbles and can be said that nucleate boiling is more dominant. Oh et.al. (2008) [15] reported that the forming bubbles and the bubble detachment increase at the high saturation temperature, then the nucleate boiling becomes dominant. Cooper (1984) [2] explains that the density of liquid and vapor decreased on increasing the saturation temperature.

Comparison of R-22 and R-290 on Heat Transfer Coefficient. A comparison between R-22 and R-290 is presented in Fig.7 with the same test facility and test condition. As shown in Fig.7 the heat transfer coefficient of R-290 higher than those of R-22. The higher boiling heat transfer coefficient of R-290 is caused by its high boiling nucleation. The fluid properties of R-290 such as a lower viscosity ratio, lower surface tension, and lower density ratio influences the high boiling nucleation. The viscosity ratio of R-290 at the same saturation temperature is lower than that R-22. These properties induce the liquid film of R-290 to be more easily broken. R-290 has a lower surface tension than R-22. This lower surface tension facilitates bubble formation, thus resulting in higher nucleation boiling. R-290 also has a much lower density ratio than R-22, which causes a lower vapor velocity for R-290. The lower vapor velocity can result in less suppression of nucleate boiling.

Comparison of Boiling Heat Transfer Correlation. There are some correlations to predict the local boiling heat transfer coefficient in a horizontal tube. Some of the correlations are presented by Chen (1963) [1], Shah (1982), Cooper (1984) [2], Gungor Winterton (1986) [16], Kwang II Choi (2009) [9], and Fang (2013) [17].

Table 1. Deviation (%) of the heat transfer coefficient comparison for R-22 and R-290 between the present data and the previous correlation

Refrigerant	Chen (1963)		Shah (1982)		Cooper (1984)		Gungor and Winterton (1986)		Kwang II Choi (2009)		Fang (2013)	
	AD	MD	AD	MD	AD	MD	AD	MD	AD	MD	AD	MD
R-22	-15%	78%	-31%	63%	39%	109%	198%	201%	58%	115%	-19%	67%
R-290	-36%	54%	-57%	58%	-16%	62%	52%	62%	- 3%	52%	-48%	58%

Table 1. shows the comparison of the experimental heat transfer coefficient for R-22 and R-290 with some existing correlations. Among these correlations, the correlation of Shah (1982) showed fairly good agreement for R-22, with a mean deviation of 63%. The correlation of Choi et.al.(2009) [9] howed fairly good agreement for R-290, with a mean deviation of 52%.

Conclusion

Experimental results for the flow boiling of R-22 and R-290 in a horizontal small tube under variations in the mass velocity, heat flux and saturation temperature were presented in this study**.** It was revealed that the boiling heat transfer of R-22 and R-290 at low quality region are affected by the heat flux and the saturation temperature. The boiling heat transfer coefficient of R-290 showed higher than those of R-22. For the prediction of the heat transfer coefficients of R-22 and R-290, the correlation of Shah (1982) and Choi et.al. (2009) best fitted the experimental result, respectively.

Acknowledgement

This study is funded by AUN/SEED-Net Project No. UI CRC 1401.

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