別紙第１号様式　　　　　　　　　　　　No.1

博　士　論　文　の　要　旨

専攻名　システム創成科学専攻
氏名（ 本籍 ） Afdhal Kurniawan Mainil
(Indonesia) 印

博士論文題名
（外国語の場合は，和訳を付記する。）

Pressure Drop and Two-Phase Heat Transfer of Pure Refrigerant (R1234yf) and Mixture Refrigerant (R454B, R454C) inside Microfin Tube

（ マイクロフィン管内の純冷媒（R1234yf）および混合冷媒（R454B, R454C） の圧力損失と二相熱伝達））

要旨（２，０００字程度にまとめること。）

The method for improving heat transfer performance and reducing the charge of refrigerants is carried out by employing the mini diameter tube instead of the large diameter. This study analyzes the pressure drop and two-phase heat transfer performance of pure refrigerant (R1234yf) and mixture refrigerant (R454B and R454C) inside a 3.5 mm OD microfin tube. The effects of the experimental parameters such as mass velocity, saturation temperature, diameter, heat flux, and vapor quality were observed using parametric analysis of the experimental results. Furthermore, experimentally obtained heat transfer coefficients are compared with previously correlations in available literature by considering the working conditions and the refrigerant used, then analyzed. Some data from previous research with different diameters were added to further analysis.

The experiment was carried out using test equipment at the Miyara and Kariya Laboratory Saga University, Japan. The microfin test tube specifications are equivalent diameter (d_e) is 3.18 mm, tube wall thickness (δ) is 0.15 mm, fin height (h) is 0.10 mm, helix angle (θ) is 10º, apex angle (γ) is 35º and number of fins is 25. The test microfin tube has a total length of 852 mm and an effective heat transfer length of 744 mm.

In the experiment of adiabatic pressure drop, The effects of mass velocity, vapor quality, saturation temperature, and diameter of microfin were analyzed. As a whole, the increase of frictional pressure drop was observed with the decrease of microfin diameter. The smaller diameter of the microfin tube leads to increased shear stress due to the increase of velocity

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gradients. Further, the increasing vapor shear stress and friction between liquid and vapor phase at higher mass velocity and vapor quality increase the pressure drop. Some existing correlations of microfin tubes were used to assess the two-phase frictional pressure drop of experimental data. The previous correlations cannot well predict the experimental data. A new correlation was developed and the proposed correlation expressed the experimental data of 3.5 mm OD and 2.5 mm OD very well with a mean deviation of 12.2 %, average deviation of -0.6 %, and 92.3 % of the data points are within the deviation of 30%. Validation of the new correlation with 699 data points from other researchers gave good agreement with approximately 17.6 % of mean deviation. The newly developed correlation could broadly be applied to the microfin tube diameter of 2.5 mm to 9.52 mm and the wide range of mass velocity and several refrigerants.

Experimental study of condensation heat transfer coefficient of refrigerant R1234yf inside 3.5 OD horizontal microfin tube has been carried out. The effect of mass velocity, vapor quality, tube diameter, and saturation on condensation heat transfer coefficient was investigated. The results show the heat transfer coefficient decreases as the wetness increases for mass velocities of 3.18 mm and 2.17 mm equivalent diameter of the test tube. Also, the findings show that as the microfin tube's diameter is decreased, the heat transfer coefficient increases. The increase of saturation temperatures resulted in decreased heat transfer coefficient due to the refrigerant's changing thermal properties. Four correlations of the heat transfer coefficients for microfin tubes from the literature were used to predict the heat transfer coefficient. Hirose et al., 2018 correlation has good agreement with experimental data than other correlation. However, slightly overestimated, especially at low mass velocity. Therefore, the development of a new correlation of microfin tubes is required. The new correlation for heat transfer condensation was developed. The proposed correlation agrees well with the measured data with average deviation and mean absolute deviation is 0.19% and 13.34%, respectively and 90.74% data points are within 30%.

The presents study also experimental flow boiling heat transfer coefficients of R1234yf

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inside a microfin tube with equivalent inner diameter of 3.18 mm. Generally, the heat transfer coefficient rises slightly with vapor quality at low mass velocity. It rises with vapor quality at high mass velocity, reaches a peak, and drops at around 0.9 of vapor quality due to dry-out phenomena. In the low vapor quality region, the effect of mass velocity is not so remarkable, and the nucleate boiling dominates the heat transfer. On the other hand, forced convection is present and dominant in the heat transfer process in the high-quality region. The effect of heat flux was observed in the mass velocity 200 kg $m^{-2}s^{-1}$ and the impacts of heat flux are readily visible: nucleate boiling is the most crucial heat transfer mechanism.

This study also investigated the two-phase flow condensation and boiling heat transfer as well as adiabatic pressure drop of Mixture refrigerant R454B and R454C inside a 3.5 mm OD microfin tube. Experimental results were then compared with pure refrigerant. The frictional pressure drop of R454B is the lowest for each mass velocity, and R1234yf is the highest using the same microfin tube, where the results show that R1234yf has a frictional pressure drop value of 1.05 to 2.17 times greater than R454B and 1.06 to 1.32 times greater than 454C. A comparison between R454C and R454B shows that R454C is 1.01 to 1.64 times greater than R454B in the mass velocity range of 50 kg $m^{-2}s^{-1}$ to 300 kg $m^{-2}s^{-1}$. This phenomenon is caused by the thermo-physical difference between the three refrigerants.

Condensation and Boiling HTC's R454B is slightly larger than R1234yf, increasing 1.1 to 1.5 times enhancement in all mass velocities from 50 to 200 $kgm^{-2}s^{-1}$. With a sizeable R32 composition of about 68.9% in R454B, HTC's increase is relatively small. The condition is because of the degradation of HTC due to mass transfer resistance due to the presence of a temperature glide of zeotropic mixture refrigerant. Condensation and boiling HTC’s R454C is lower than R1234yf for all mass velocities with 1.1 to 1.7 degradation from

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氏名 Afdhal Kurniawan Mainil

R1234yf. The Degradation of heat transfer coefficient from this zeotropic mixture refrigerant due to mass transfer resistance during the condensation process due to the presence of a temperature glide of zeotropic mixture refrigerant.