IOP Conf. Series: Materials Science and Engineering **88** (2015) 012028 doi:10.1088/1757-899X/88/1/012028

Experimental Investigation and Flow Process Computer Simulation of the Single Mini Channel Condenser for Vapor Compression Refrigeration System

L L Pabilona[1] and E P Villanueva[2]

[1] Associate Professor II, College of Engineering & Architecture
Mindanao University of Science and Technology
Cagayan de Oro City, Philippines
E-mail: ll_pabilona@yahoo.com

[2] Professor VI,College of Engineering
Iligan Institute of Technology, Mindanao State University
Iligan City, Philippines
E-mail: ep_villanueva@yahoo.com

Abstract. This study is a computer simulation of the temperature profiles and experimental investigation of three 100 mm x 50 mm x 18 mm single mini channel condensers with hydraulic diameters of 3 mm, 2 mm, and 1mm. The mini channels which were made of copper were designed, fabricated and tested. Each unit was connected in a vapor compression cycle with R-134a as the refrigerant. The average refrigerant mass flow rates were varied from 1.296 - 69.471 g/s, and the average inlet and outlet condenser pressure variations were 102.5 - 121.8 kPa and 101.74 -121.23 kPa, respectively. Each condenser was placed inside a mini wind tunnel system where forced draft air was introduced to initiate convective heat transfer. Each condenser was tested and data were gathered every five minute interval for one hour using a Lab View Software. Computer simulations on the flow process were conducted using Solid Works software. The experimental results presented the inlet and outlet condenser pressures, and pressure drops. The experimental heat transfer coefficients were calculated at different mass fluxes during condensation. The values ranged from 3900 to 5200 W/m^2-°K for the 3 mm, 2600 to 9000 W/m^2-°K for the 2 mm, and 13 to 98 W/m^2-°K for the 1 mm. The heat transfer coefficients calculated from experiments were then compared with the computed values using the correlations developed by Dittus-Boelter and Lee-Son. The results showed increasing deviation as the diameter decreased. The discrepancies could be attributed to the appropriateness of the Dittus-Boelter and Lee-Son correlations in small diameter channels, complexities in the flow process which involved two phase flow heat transfer in very small tubes, and the difficulties in attaining very accurate measurements in small channels.

I. Introduction

The condenser in a refrigeration system is the heat sink of the system. The condenser is a major component in the cooling system. Its design, configuration and size greatly affect the performance of the refrigeration system. As the size of the condenser decreases, such as in a mini-channel, the mechanism of fluid flow changes as the capillary effect becomes more prominent. The heat transfer mechanism is also affected since it is very dependent on fluid flow.

Minichannels are increasingly being used with compact heat exchangers. Small hydraulic diameter channels find applications in compact heat exchangers for electronic equipment, in automotive condensers, and in refrigeration applications. The adoption of minichannel also promotes the reduction of the refrigerant charge, which is favorable specially if toxic or flammable refrigerants

[1] To whom any correspondence should be addressed.

IOP Conf. Series: Materials Science and Engineering **88** (2015) 012028 doi:10.1088/1757-899X/88/1/012028

are used. Phase change of refrigerants in minichannels may differ from the conventional channels due to differences in the relative influence of gravity, shear stress and surface tension. Design of small heat exchangers is a must as the size of heat generators such as electronic components reduces to miniscale. Fluid flow inside mini channel is one of the efficient processes for small scale cooling. According to Kandlikar [1], mini channels are classified based on their hydraulic diameters (D_h) of 0.5 to 3 mm. There are relatively few studies conducted as regards to mini channels condenser of a refrigeration system.

This study is about the designing, fabrication and testing of a mini channel condenser. Three mini channels of similar configurations but of different channel sizes and used as condensers were experimentally tested. The inlet and outlet pressures, and pressure drops were analysed. Measurements of the heat transfer coefficient were compared to existing correlations developed by Dittus-Boelter and Lee-Son. Finally, Computer simulations on the flow process particularly the temperature distribution inside the single channel condenser were conducted using the Solid Works software.

2. Theoretical Considerations

2.1 Vapor Compression Cycle

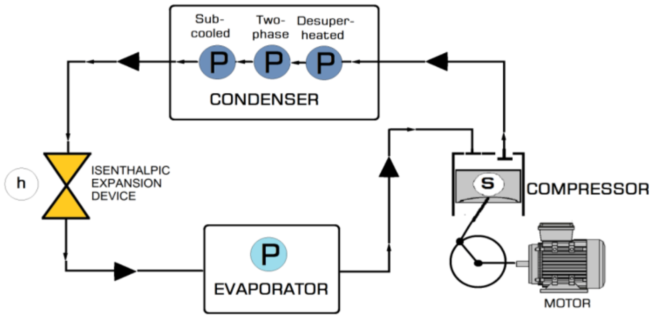

Figure 1. Analysis on the Condenser

The condenser is a heat exchanger that usually rejects all the heat from the refrigeration system. The condenser accept hot , high -pressure refrigerant ,usually a superheated gas, from the compressor and reject heat from the gas to some cooler substance . As energy is removed from the gas it condenses and this condensate is drained so that it may continue its path back through the expansion valve or capillary to the evaporator The condenser is divided into three regions characterized by the thermodynamic state: the de-superheated vapor, the change of phase (two-phase), and the subcooled liquid regions and the refrigerant condenses at a negligible temperature difference from the ambient.

2.2 Heat Transfer Coefficient

The Dittus-Boelter [2] correlation is a common correlation useful for many applications. This correlation is applicable when forced convection is the sole mode of heat transfer. This is an equation quite similar to McAdams [3] equation where the application as presented in the literature is not restricted to small diameters [4]. The equation is expressed below as

$$h_L = 0.023(\mathrm{Re})^{0.80}(\mathrm{Pr})^{0.40}\left(\frac{k}{D}\right)$$

Another correlation developed by Son-Lee [5] is the single-phase heat transfer coefficient (h_L), express as

$$h_L = 0.034(Re)^{0.80}(\mathrm{Pr})^{0.30}\left(\frac{k}{D}\right)$$

Where k is the thermal conductivity of R-134a, D is the hydraulic diameter, Re is the Reynolds number and Pr is the Prandtl number.

IOP Conf. Series: Materials Science and Engineering **88** (2015) 012028 doi:10.1088/1757-899X/88/1/012028

3. Description of the Experimental Work

Three 100 mm x 50 mm x 20 mm copper block mini channel condensers with 1 mm, 2 mm, and 3 mm hydraulic radius for each were fabricated and installed one at a time in the experimental rig as shown in Figure 2. Fins were machined on each face. Each had 24 fins with width of 2 mm, length of 50 mm and height of 5 mm. A fan was installed downstream of the heat exchanger to guarantee sufficient air flow across the condenser inside the insulated long duct used in the rig. Two temperature sensors and two pressure transducers were installed on the refrigerant-side at the inlet and outlet of the mini channel condenser. Another temperature sensor was also installed at the middle of the mini channel condenser. The refrigerant mass flow rate was measured at the outlet of the expansion valve. A valve that passed through the evaporator was used to control the mass flow rate. On the air-side, two thermocouples spaced equally were installed at the inlet and two at the outlet. The air velocity over the mini channel condenser was measured using a hot wire anemometer. Every start of the experiment, the system was vacuumed for about 30-40 min to remove air, followed by leak test before charging the system with the refrigerant R134a. The temperature, flow rate and pressure readings were automatically recorded, stored and processed by a data acquisition system using LabVIEW software. The data logger was set to scan the data at an interval of 5 minutes.

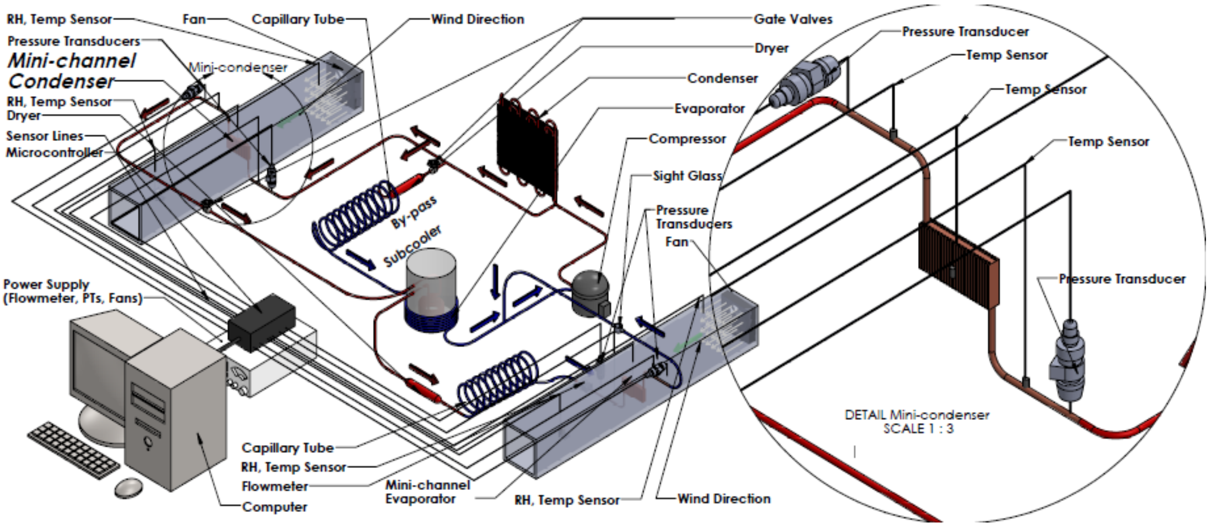

Figure 2. Experimental Set-up

4. Data Analysis and Evaluation of Heat Exchanger Performance

The results related to the heat transfer coefficient and pressure drop were obtained from the readings of thermocouples, pressure transducers, mass flow meter and anemometer, installed in the test section. The heat rejected in the condenser was calculated using the relation

$$Q = m_s (h_{in} - h_{out}) \tag{3}$$

Where m_s is the refrigerant mass flow rate and obtained directly from the flow meter, h_{in} is the enthalpy entering the mini channel condenser corresponding to measured pressure and temperature conditions, and h_{out} is the enthalpy leaving the condenser corresponding to measured pressure and temperature conditions.

The average values of experimental heat transfer coefficient were calculated at the average inside surface temperature of the condenser [6]:

$$Q = h_r A_i (T_{sat} - T_{si}) \tag{4}$$

Where h_r is the refrigerant side heat transfer coefficient, A_i is the inside area of mini channel, T_{sat} is the saturation temperature of refrigerant, and T_{si} is the temperature of inner wall surface.

The refrigerant pressure drops along the mini channel condenser were obtained from the difference in readings of transducer pressures between the inlet and outlet conditions.

$$\Delta P = P_{inlet} - P_{outlet} \tag{5}$$

5. Results and Discussion

The two parts of the heat exchangers before they were welded together are shown in figures 3. Figure 4 shows the finned exterior surface of the mini channel. The welded assembly was design to withstand pressure of up to 11 bars.

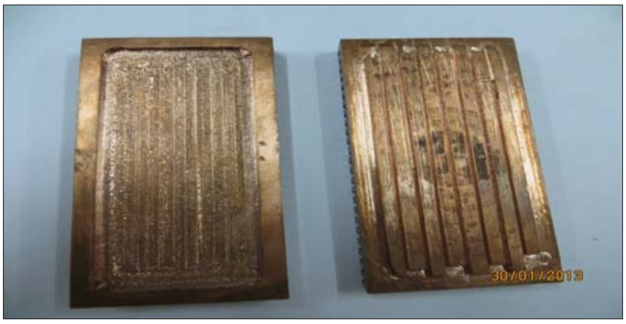

Figure 3. Interior part of mini channel (Unassemble)

Figure 4. Exterior Part of mini channel Parts

Figures 5, 6 and 7 show the inlet and outlet pressure for 1 hour observation of the different condenser sizes. The pressure readings tend to increase with increase in mass flow rate and decrease in diameter.

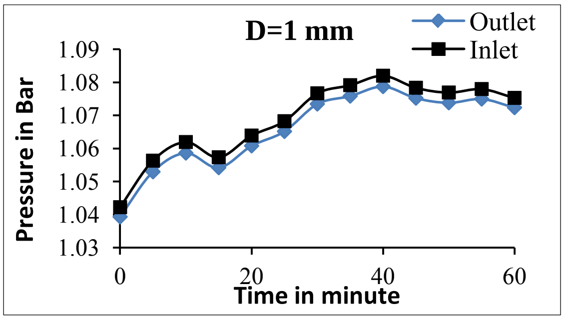

Figure 5. Variation of inlet and outlet Pressure with time for condenser size of 1 mm

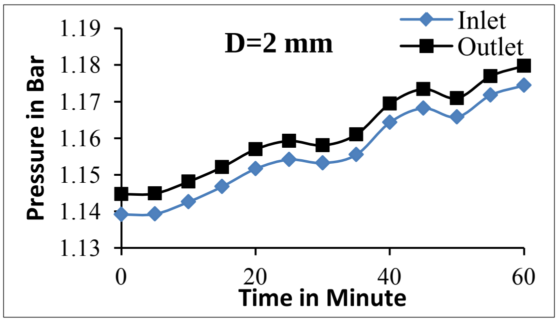

Figure 6. Variation of inlet and outlet Pressure with time for condenser size of 2 mm

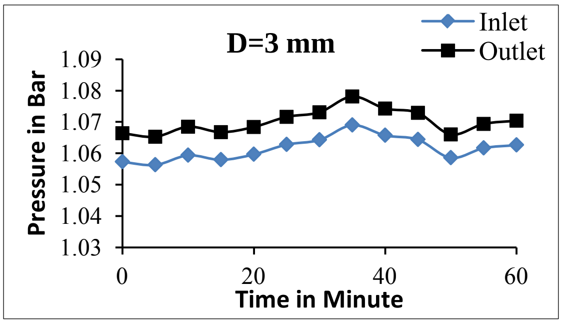

Figure 7. Variation of inlet and outlet Pressure with time for condenser size of 3 mm

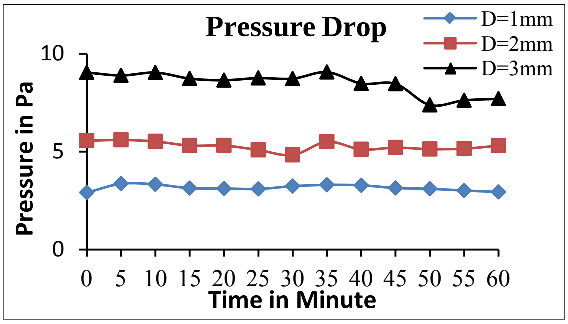

Figure 8. Variation of pressure drop with time for condenser size of 1 mm, 2 mm & 3 mm

Figure 8 shows the pressure drop of the three different sizes of mini channel condensers. The corresponding mass flow rates of size 1 mm, 2 mm and 3 mm are 2 g/s, 52 g/s and 58 g/s, respectively. The pressure drop is quite dependent on the mass flow rates, i.e., the higher the mass flow rate the higher is the pressure drop. However it is also dependent on the diameter. The pressure drop of the 1mm condenser although lower is not very far from the 2 mm and 3 mm condensers as correlated to their mass flow rates differences.

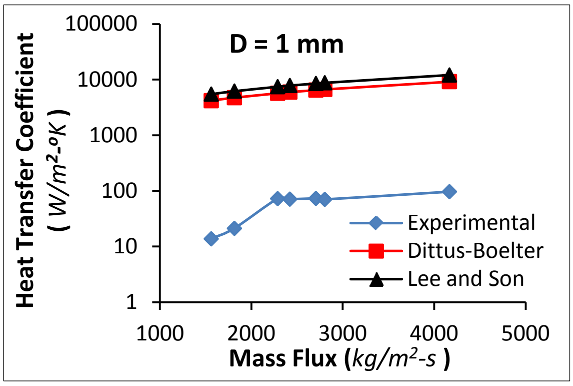

Figure 9. Variation of heat transfer coefficient with mass flux for condenser size of 1 mm

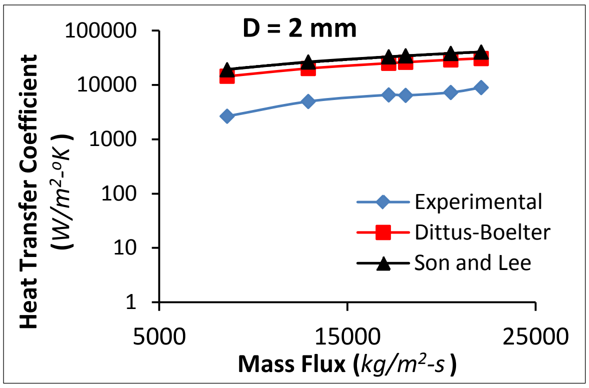

Figure 10. Variation of heat transfer coefficient with mass flux for condenser size of 2 mm

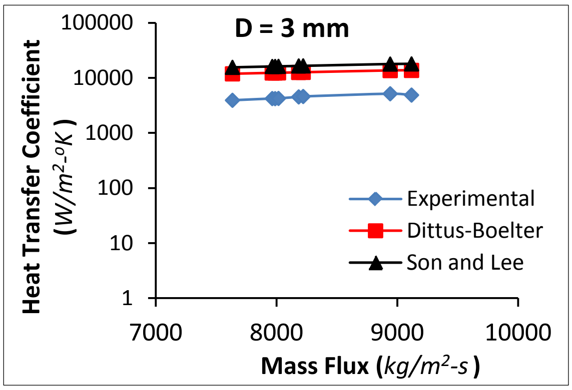

Figure 11. Variation of heat transfer coefficient with mass flux for condenser size of 3 mm

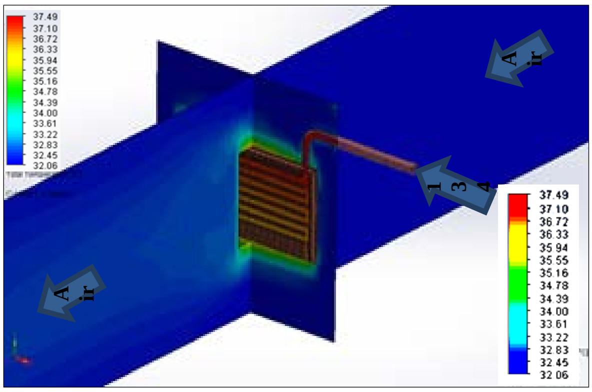

Figure 12. Temperature distribution of the mini channel condenser along the wind

The theoretical values of the average heat transfer in refrigerant side of R134a computed from Dittus-Boelter [2] and Lee-Son [5] correlations at experimental data were compared with experimental values of heat transfer coefficient from equation 4 as shown in figures 9 to 11. As can be seen in figures 9 to 11, the experimental heat transfer coefficients values ranged from 13 to 98 W/m^2-°K for the 1 mm, from 2600 to 9000 W/m^2-°K for the 2 mm, and from 3900 to 5200 W/m^2-°K for the 3 mm. The heat transfer coefficient is affected by the mass flux and the size of channel. The heat transfer coefficient is increased with R134a mass flux rising. Figures 9 to 11consistently show the calculated heat transfer coefficient values of both Dittus-Boelter [2] and Lee-Son [5] correlations which over-predicted the experimental results. Also from the same figures, deviations are shown from the existing correlations of heat transfer coefficient. The deviation of this heat transfer coefficient with this correlation appears to be related to difficulties in accurate measurements [7] particularly the 1 mm in size as shown in figure 9. The primary cause for these deviations are related to difficulties in accurate measurements of small flow rates in small channels, especially the 1 mm channel diameter having a mass flow of 2 g/s. It is worth to note that as the channel dimensions become small, the surface roughness and the measurement error become relatively more significant. Many authors have noted that precise measurements on smaller channels are very difficult and subject to error. Such researchers include Cavallini *et al*. [8], Bergles *et al*. [9], and Koyama *et al*. [10]. The difficulties are caused by very small flow rates and amounts of heat, and small dimensions of the test sections. Other matters to be considered as mentioned by Kandlikar [11] that are frequently neglected is the uniformity of the cross section dimensions along the channel flow length.If unaccounted, these errors significantly alter the results.

The result of the simulation as depicted in figure 12 demonstrates the temperature profile inside the mini channel condenser and the wind tunnel. The inlet and outlet temperatures at the refrigerant side are 37.15°C and 35.22°C, respectively. At the air side, the upstream and downstream temperatures are 32.07 °C and 32.36°C respectively. From the same figure, one can see that the fluid temperature changes along the mini channel condenser and along the wind tunnel during simulation. The simulation results show the temperature profiles along the flow paths of both air and the refrigerant. The colors indicate the increasing temperatures of air as it absorbs heat and the decreasing temperatures of refrigerant as it releases heat.

6. Conclusions and Recommendations

Based on the results of this study, the following conclusions are drawn.

1. The inlet and outlet pressure reading is dependent with the mass flow rates and diameter. The higher the mass flow rate and the smaller the diameter the higher is the pressure reading.
2. The heat transfer coefficient increases with increase in the mass flux in the experimental results and in the calculated values of both Dittus-Boelter [2] and Lee-Son [5] correlations. However the calculated values of both correlations over-predicted the experimental results. This indicates some deficiencies of the correlations in small channels that need further investigations.

The following are recommended for further studies:

1. Conduct more experimental runs using different refrigerants, pressure above 11 bars and hydraulic radii of 1.5 mm, 2.5 mm, and 3.5 mm
2. Conduct similar experiments using condenser made of materials of high thermal conductivity and designed and fabricated to withstand pressures beyond 11 bars.
3. Conduct a boundary layer analysis for small tubes and channels and the result plus the experimental data be used in the formulation of a new empirical equation for the calculation of heat transfer coefficient.

7. References

[1] Kandlikar S G 2006 *Heat transfer & Fluid flow in Minichannels & Microchannels* (1st ed. UK: Elsevier Science)

[2] Dittus F W and Boelter L M K. 1930 *Heat transfer in automobile radiators of tubular type* (University of California, Berkeley, Publications on Engineering Vol. 2, No.13) pp. 443

[3] McAdams W H 1954 *Heat Transmission* (3rd ed. McGraw-Hill Book Company,New York)

[4] Owhaib W 2007 *Experimental Heat Transfer, Pressure Drop, and Flow Visualization of R-134a in Vertical Mini/Micro Tubes* (Doctoral Theses, KTH, School of Industrial Eng'g. and Management , Energy Technology, Applied Thermodynamics and Refrigeration) pp.57-58

[5] Son C and Lee H 2009 *Condensation heat transfer characteristics of R-22, R-134a and R-410A in small diameter tubes* (Heat and Mass Transfer 45:1153–66)

[6] Suhayla Y H 2011 *Experimental Investigation of Condensation of Refrigerants R134a and R12 in Air Cooled Horizontal Condenser* (Journal Of Eng'g. And Dev. Vol. 15,No.4)

[7] Mirza M S 2010 *Heat transfer during condensation inside small channels : Applicability of general correlation for macrochannels* (Proceedings of the 14th International Heat Transfer Conference, August 8-13 2010 Washington, D. C., USA. : 125-134)

[8] Cavallini A *et al* 2006 *Local Heat Transfer Coefficients During Condensation in a 0.8 mm Diameter Pipe* (Proceeding International Conference Nanochannels, Microchannels and Minichannels,Limerick, Ireland) pp. 139-146.

[9] Bergles A E *et al* 2000 *Boiling and Condensation in Small Diameter Channels* (Heat Transfer Engineering) pp. 18-40.

[10] Koyama S *et al* 2003 *Condensation of Refrigerant in a Multi-Port Channel* (First Int. Conf. on Microchannels and Minichannels Rochester, NY,USA) pp. 193-205.

[11] Kandlikar S G 2003 *Microchannels And Minichannels– History, Terminology, Classification and Current Research Needs* (First International Conference on Microchannels and Minichannels)