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Lockhart-Martinelli Correlation on RefrigerantR-134aPressure Drop in Mini Channel Evaporators

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ABSTRACT

Background: The design of minichannel heat exchangers has attracted lots of attention in its application to localized heating and cooling system for miniature devices. Heat exchangers with hydraulic diameter of 3mm to 200 µm are classified as minichannel heat exchangers. The behavior of the pressure drop across minichannel heat exchanger varies from the conventional heat exchangers in many aspects including the physics of fluid flow. In this study, minichannel heat exchangers were fabricated using copper blocks and a serpentine hole was machined in each of the three copper blocks. The dimension of each minichannel copper block is 100mm.x50mm.x20mm. and the outside surfaces were machined to have 24 fins on both sides. These fabricated minichannel copper blocks were then connected to a standard vapor compression refrigeration system utilizing R-134a as refrigerant. The three minichannel copper blocks were used as evaporator for a vapor compression refrigeration system with a total serpentine length of 640.0mm where the refrigerant R-134a flows through. During each run of the experiment, the minichannel copper block evaporator was placed inside a small wind tunnel where controlled flow of air from a forced draft fan was introduced for the cooling process. Laboratory experiments were conducted using three evaporator specimens of different channel hydraulic diameters (1.0mm, 2.0mm, 3.0mm). Pressure sensors were mounted near the inlet and the outlet of the minichannel copper blocks. The experimental set-up used data acquisition software and computer-aided simulation software. The pressure drop is lowest for 3mm minichannelevaporator at 0.29 bar, 0.63 bar for 2mm minichannelevaporator and 1.34 bar for 1mm minichannelevaporator**.**

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INTRODUCTION

Recently, there is a growing interest in the use of ultra-compact heat exchangers in various thermal systems because of their very high heat transfer density. The heat transfer and pressure drop characteristics in small and capillary tubes have been extensively investigated for various fluids such as air, water and some refrigerants (Kim *et al*., 2003). Temperature of today's computer chips are primarily cooled with conventional fans and "heat sinks," or metal plates containing fins to dissipate heat. Computer chips keep on increasing its capacity to cope up with the demand of high speed and performance, they will contain more transistors and other devices, and will generate far more heat than chips currently in use. As the electronics industry continues to churn out smaller and slimmer portable devices, manufacturers have been challenged to find new ways to combat the persistent problem of thermal management (http://www.nanowerk.com/nanotechnoly, 2015).

The previous century brought the miniaturization of electronics components and the development of systems towards micro and nano manufacturing and in time, more frequent and diverse applications occurred in other domains such as biomedical devices, MEMS and cooling nano technologies. Overheating of these micro components and micro devices led to the use of minichannels in the above mentioned technologies (Mihai, 2011). Minichannels are compact heat exchangers with hydraulic diameter from 3.0 millimeter down to 200 micrometer(Kandlikar *et al*., 2005). The aim is to eliminate as fast as possible the maximum heat quantity from these systems in order to ensure an increased reliability and functional stability (Kim *et al*.,2007).

With the present trend towards miniaturisation of devices and development of microscale processes,

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there is a need for microscale heat transfer equipment. Banton& Blanchet in 2004, indicated other possibilities regarding major cooling technology that would replace the conventional heat sink for computer and other electronicsgadgets (Banton *et al*., 2004). They indicated that aside from the microchannel cooling system, refrigeration with air chillers are the promising cooling technology for computer cooling system that ensure dissipation of increasingly larger power flows. And because of the portability issues of modern electronic gadget, a mini refrigeration system is one of the candidates for the solution of the rocketing heat dissipation problem of computer chips.

One of the pioneering technologies in the miniature refrigeration system for electronics gadgets is the ThermalTake. ThermalTake introduced Xpressar, world's first computer case with a DC inverter type micro refrigeration cooling system. And yet, the Xpressar is a quite big super tower case and weighs 22.2kg (http://www.dvhardware.net/article30006.htm,March ,2015).Miniaturization of the conventional vapor compression refrigeration system is a promising solution to the dissipation of high heat generation from high speed and more compact computer chips and portable electronics devices. A miniature refrigeration system, smaller than Xpressar, can be integrated into the electronics system to extract and cool the microchips. The minichannel heat exchanger can be designed and fabricated to serve as the evaporator for a miniature refrigeration system. A channel serves to bring a fluid into intimate contact with the channel walls and to bring fresh fluid to the walls and remove fluid away from the walls as the transport process is accomplished(Kandlikar *et al*., 2005). A reduction of the size of the evaporator and the corresponding pressure drop of R-134a may have an impact of the future designs of miniature refrigeration systems. Pressure drop requirementfor the mini refrigeration system plays an important criterion in the selection on the size of the needed compressor for the system.

This study is guided by the following objectives; 1.)to measure the pressure drop of refrigerant R-134a flowing through the minichanel heat exchangers with hydraulic diameters of 1.0mm, 2.0mm and 3.0mm.. and 2.)to compare the pressure drop of the three minichannel heat exchangers with the Lockhart-Martinelle correlation.

Refrigerant R-134a is chosen as the HFC refrigerant because, together with R-407C, they are regarded as the major substitutes for the phased-out refrigerant R-12 and R-22[8]. As a form of substitute, many vapor compression refrigeration systems will shift its usage to refrigerant R-134a. Since refrigerant R-134a belongs to the new generation refrigerant, the resulting experimental data will then be compared with the Lockhart-Martinelli pressure drop correlation (Lockhart *et al*., 1949).

The characterization of the pressure drops for the different sizes of small diameter tube will be useful in the design of a miniature air conditioning system for cooling of computers microchips and other electronics devices. Three(3) fabricated copper blocks minichannel evaporators is attached to a conventional vapor compression refrigeration system. These minichannel evaporators are the heat exchangers of the system and are used to absorb the heat from the surroundings or in this study, heat from the wind tunnel. This minichannel evaporator receives low pressure R-134a from the pressure reducing device, absorbs heat from the wind tunnel and delivers it to the compressor as a superheated gas. From the compressor, the refrigerant R-134a rejects heat in the condenser and enters back to the pressure reducing device where pressure is reduced to the minichannel evaporator pressure. The reduced pressure in the expansion device enables the minichannel evaporator to absorb more heat from the wind tunnel at a lower and cooler temperature. Evaporators are equipment that allows two-phase flow in the system which makes them difficult to calculate the exact pressure drops across the minichannel evaporator. It is normal for a conventional evaporator to experience two boiling regimes, nucleate boiling and convective boiling which complicate the thermodynamic process being involved (Incropera *et al*.,1996). Figure 1 illustrates the fundamental set up of a conventional vapour compression refrigeration system.

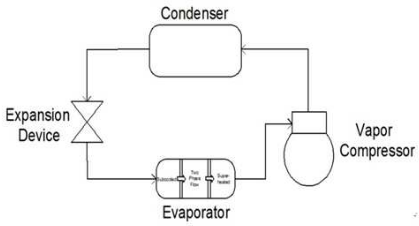

Fig. 1: Schematic diagram of vapor compression refrigeration system.

Theoretically, as plotted in a conventional R-134a pressure-enthalpy diagram, the pressure across any heat exchanger is always assumed to be constant for conventional evaporators. But in minichannel evaporator with the reduced hydraulic diameter, the refrigerant encounters high pressure losses due to friction on the inner surface of the tube or channel. For the two-phase flow, as in the case for the evaporation in vapour compression refrigeration system, the refrigerant R-134a will undergo a nucleate and convective boiling process. When the compressibility of the gaseous phase is neglected, and for both phases, the densities (ρl and ρg) and the friction factor remain constant over the length, the Lockhart-Martinelli model is the only model that would be useful for this study because the length ratio may be used in the absence of the quality of R-134a (Lie *et al*., 2008).

The Lockhart-Martinelli method is the basis for most of the recent methods to correlate two-phase frictional pressure drop (Mihai *et al*., 2010):

$$(dP/dl)_{TP} = \text{Ø}_l \ (dP/dl)_l \ , \quad (1)$$

Where Chisholm(Chisholm,1967)gave the following correlation to calculate the two-phase multiplier based on the liquid phase pressure drop:

$$\text{Ø}_l = 1 + (C/X) + (1/X^2) \quad (2)$$

The value of depends on the regimes of the liquid and vapour, and the Martinelli parameter X:

$$X^2 = (dP/dl)_l \ / \ (dP/dl)_g \quad (3)$$

With

$$(dP/dl)_l = f_l \ (2G^2(1-x)^2/d\rho_l) \quad \text{and}$$
$$(dP/dl)_g = f_g(2G^2x^2/d\rho)_g \quad (4)$$

Where f, ρ, x, G and D, are friction factor, density, length ratio, mass flux and the hydraulic diameter, the subscripts g and l denote the gas phase and the liquid phase, respectively.

2.0 Research design and methods:

There are five main parts of the study, the design component, the fabrication component, the experimental design and procedures, data gathering and the data evaluation.

There are four basic parts of a vapor compression refrigeration system, namely; compressor, condenser, expansion valve and the evaporator. The evaporator receives the low-pressure liquid refrigerant from the expansion valve and the refrigerant takes in heat from the high temperature surroundings. In the process, the low-pressure liquid refrigerant changes it phase from liquid to gas.

Since the study deals with a mini evaporator, a mini compressor, condenser and expansion valve are needed to complete the cycle. For the purpose of this study, the mass flow rate of refrigerant needed in the mini evaporator is relatively low due to the size of the minichannel. The required refrigerant is bled from the cold water dispenser refrigeration unit and returned back for compression as illustrated in Figure 2.

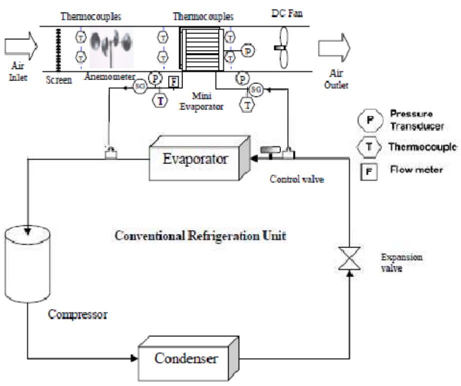

Fig. 2: Schematic diagram of the experimental rig.

Due to some limitations on measuring instrument used in the experiment and the difficulty encountered in the fabrication of minichannels, the investigation is focused only on the three minichannel evaporators with 1.0mm, 2.0mm and 3.0mm hydraulic diameter. These minichannel evaporators were fabricated using copper block and these minichannel evaporators have to be tested in the fabricated wind tunnel one at a time. The main system will be purged and the whole system will be subjected to vacuum pressure in order to remove the bound moisture of the system. The bound moisture of the system will cause difficulty of fluid flow and obstruction to the flow of refrigerant R-134a due to the reduced size of the minichannel.

The minichannel is connected using a tee-connector after the expansion valve and reconnected to the refrigeration unit before compression. Three copper blocks with the size of 100.0 mm x 50.0mm x 20.0mm were fabricated in a machine shop and were used as the experimental minichannel evaporators.

A fabricated minichannel heat exchanger shown in Figure 3, was used in the experimental test set up by tapping with a conventional 1/8 hp vapor compressor. The dimension of the minichannel is 100 mm x 50 mm x 20mm copper block. Holes of 1.0 mm, 2.0mm and 3.0mm in hydraulic diameter were machined in the copper blocks No.1, No.2 and No.3, respectively, with an overall length of 640 mm of small diameter tubes on each copper block and machined on the lengthwise direction and serve as the passage of the refrigerant R-134a. These minichannel evaporators were joined together through oxy-acetylene welding and were capable of operating at a maximum pressure of 1.0MPa. The refrigerant R-134a passes through these installed minichannels inside the fabricated wind tunnel.

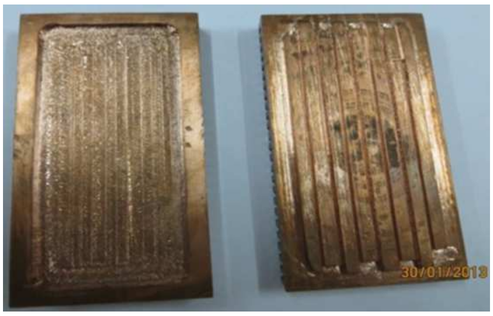

Fig. 3: Interior details of the fabricated minichannel evaporator.

Data collected from the experimental rig were fed and recorded directly by the software to the central processing unit. There were three minichannel evaporators used in this study and each minichannel evaporator had ten(10) separate and continuous experiments with a duration of sixty minutes for each experiment.

The data of the pressure taken by pressure transducer mounted near the inlet and outlet of the minichannel evaporator were used to calculate the pressure drop across the minichannel evaporator by incremental change. These data were used tocompare with the Lockhart-Martinelle pressure drop correlation (Lockhart,1949).

3.0 Results:

The experimental pressure drop on Figure 4 is the average of the ten trials conducted for 1.0mm, 2.0mm and 3.0mm minichannel evaporators. The values plotted in Figure 4 are the difference the of the pressure near the inlet and outlet of the three minichannel heat exchangers.

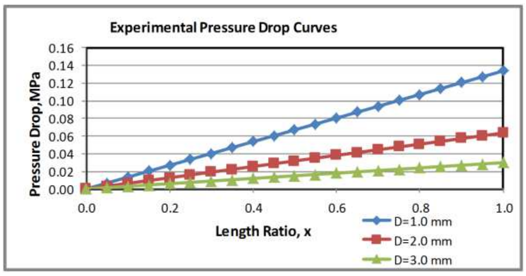

Fig. 4: Experimental pressure drop across the minichannel evaporator.

With these pressure differences, an incremental pressure drop was calculated to represent the pressure drop for every length ratio being considered. Each minichannel evaporator has a unique pressure drop compared to the other two minichannel evaporators. This unique pressure drop is depicted on Figure 4.

Figure 5 shows the plot of the experimental pressure drop of the 1.0mm minichannel evaporator and the Lockhart-Martinelli correlation. The Chisholm correlation to calculate the two-phase multiplier in eq. 2 and the Martinelli parameter X in eq.3 are being used to plot the pressure drop correlation. The resulting values of the pressure drop in eq.4 are used in eq.1 for final plot of the Martinelli correlation. This figure shows the behavior of the experimental pressure drop with respect to the Lockhart-Martinelle correlation with a slight gap near the outlet of the 1.0mm minichannel evaporator.

Figure 6 shows the plot of the experimental pressure drop of the 2.0mm minichannel evaporator and the Lockhart-Martinelli correlation. The Chisholm correlation to calculate the two-phase multiplier in eq. 2 and the Martinelli parameter X in eq.3 are being used to plot the pressure drop correlation. The resulting values of the pressure drop in eq.4 are used in eq.1 for final plot of the Martinelli correlation.

This figure illustrates the behavior of the experimental pressure drop with respect to the Lockhart-Martinelle correlation with a slight gap toward the outlet of the 2.0mm minichannel evaporator.

Figure 7 shows the plot of the experimental pressure drop of the 3.0mm minichannel evaporator and the Lockhart-Martinelli correlation. This figure portrays the behavior of the experimental pressure drop with respect to the Lockhart-Martinelle correlation with a minor gap toward and near the outlet of the 3.0mm minichannel evaporator.

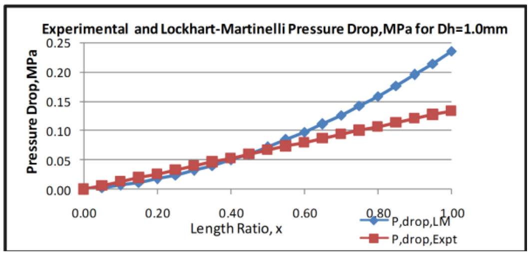

Fig. 5: Experimental and Lockhart-Martinelli pressure drop for Dh = 1.0mm.

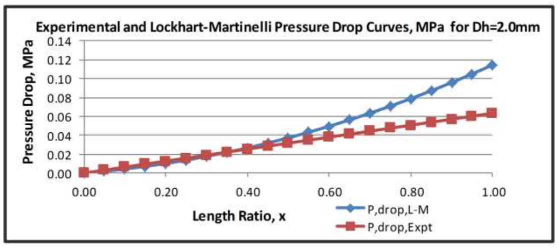

Fig. 6: Experimental and Lockhart-Martinelli pressure drop for Dh = 2.0mm.

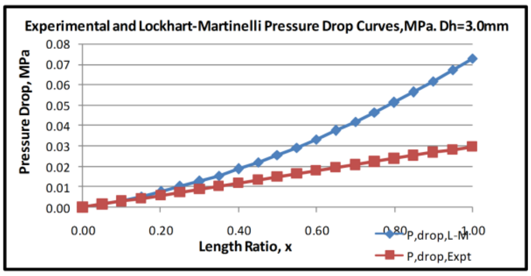

Fig. 7: Experimental and Lockhart-Martinelli pressure drop for Dh = 3.0mm.

Discussion:

Figure 4 shows the characteristic of the pressure drop across the minichannel evaporator. Each of these minichannel evaporators has two pressure transducers, one is mounted at the inlet and the second one is mounted at the outlet of the minichannel evaporator. Due to the limited number of the pressure transducers available for the data gathering, only two points were measured. It was observed that there were difficulties in maintaining the inlet pressure of the minichannel evaporator because the whole system must be purged with refrigerant R-134a everytime the test specimen was changed. The whole refrigeration system must be put into vacuum status to release air infiltration and bound moisture of the refrigeration system before a new refrigerant was adequately charged the system.

For the calculated data between the inlet and outlet of the minichannel evaporator, an incremental values were used based upon the total pressure drops across the whole length of the test minichannel. These incremental values are as follows: 6.69 KPa for 1.0 mm hydraulic diameter, 3.17 KPa for 2.0 mm hydraulic diameter and 1.49 KPa for 3.0 mm hydraulic diameter. The 1.0mm minichannel evaporator has the highest pressure drop with a total of 133.81KPa and the 3.0mm minichannel evaporator has the lowest pressure drop with a total of 29.81 KPa while the 2mm hydraulic diameter has a total pressure drop of 63.44 KPa for a total of 640 mm long of small diameter tube.

Figure 5 shows the variation of the Lockhart-Martinelli correlation with respect to the experimental data of 1.0mm as observed in the experiment. The experimental plot of the pressure drops were linear due to the limitation of pressure measuring points. Lockhart-Martinelli correlation have considered the presence of the void fraction of the system and the resulting curves are second degree curves and showed a little bit higher in pressure drop. At the outlet of the minichannel evaporator, Lockhart-Martinelli correlation has a value of 234.98 KPa while the experimental value has only 133.81 KPa. Comparing the experimental data of the pressure drop with the Lockhart-Martinelli as the standard correlation, there is a mean absolute deviation of around 0.18 % which is low and statistically acceptable.

For the 2.0mm minichannel evaporator and at the outlet of the minichannel evaporator, Lockhart-Martinelli correlation has a value of 114.52 KPa while the experimental value has only 63.44 KPa as depicted on Figure 6. Comparing the experimental data of the pressure drop with the Lockhart-Martinelli as the standard correlation, there is a mean absolute deviation of around 4.31 % which is a little bit higher than the 1.0mm but still statistically acceptable.

Figure 7 shows the experimental pressure drop of the 3.0mm minichannel evaporator and Lockhart-Martinelli correlation has a value of 72.72 KPa at the outlet while the experimental value has only 29.81KPa. Comparing the experimental data of the pressure drop with the Lockhart-Martinelli as the standard correlation, there is a mean absolute deviation of around 0.069 % which is the lowest among the three minichannel evaporator and statistically acceptable.

The discrepancy on the experimental values as compared to the Lockhart-Martinelli may be caused by the difficulty of connecting the pressure transducer as close as possible to the inlet and outlet of the minichannel evaporator. Roughness of the minichannel evaporator passageway contributed a lot on the pressure drop because of possible obstruction created during a particular flow regime as observed by Schmitt and Kandlikar in 2005 (Schmitt *et al*., 2005).

There is also a significant increase in pressure drops among the three minichannel as the mass flux were increased. This observation was also observed by Lie and *et al*., in their study in the comparison of the frictional drop between R-134a and R-407C (Lie *et al*., 2008).

Conclusion:

Vapor compressor refrigeration system has the highest coefficient of performance for all conventional refrigeration system. In this study, vapor compression refrigeration system is used to measureexperimentally the pressure drop of R-134a for the three minichannel evaporators.

The pressure of the refrigerant R-134a at the inlet and the outlet of the minichannel evaporators were measured as the refrigerant flows inside the three minichannel evaporator. This thermodynamic parameter was measured using pressure transducers connected to a data logger and the collected data were stored in computer using LABVIEW software. This parameter is very essential in finding the correct capacity of compressor and the amount of refrigerant R-134a needed by the minichannel evaporators. Calculation of pressure drop caused by the reduction of the hydraulic diameter of the minichannel evaporators is the deciding factor in specifying the correct size of vapor compressor for miniature refrigeration system.

The three minichannel evaporators showed an increase in pressure drop as the length ratio increases. The calculated pressure drops based on Lockhart-Martinelli over predicted the values near the outlet of the minichannel evaporator. The 3.0mm minichannel evaporator has the lowest pressure drop and displayed a superior performance in terms of the capability of allowing the refrigerant R-134a to pass through the minichannel evaporator with lesser pressure drop and eventually lesser power requirement of the vapor refrigeration compressor. Even with the reduced hydraulic diameter of the three evaporators, Lockhart-Martinelli correlation can still be used for the pressure drop correlation. From this study, the 1.0mm has the highest pressure drop while the 3.0mm has the lowest pressure drop based from the experimental data of the three minichannel heat exchangers.

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