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Temperature Distribution in Mini Channel Heat Exchanger for the Development of a Portable Vaccine Carrier

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Abstract*: *Vaccine transport is of major importance in today's generation where there is a rapid population increase in the Philippines and it is most concerned in remote places where there is little or no available regular health support. Millions of Philippine pesos were lost due to the damages of vaccine materials being transported at unsuitable level of temperature. The idea of a portable vaccine kit is the best solution to this problem. The design of mini channel heat exchangers has attracted lots of attention in its application to localized heating and cooling system for miniature devices such as portable vaccine kit. The purpose of this study is to determine and simulate the temperature distribution of mini channel heat exchanger used as evaporator of a mini vaccine carrier kit. Experiments were conducted using mini channel heat exchangers of channel hydraulic diameters of 3.0mm. The total length for each channel is 640.0mm. The dimension of the mini channel heat exchanger is 100mm x 50mm x 20mm and the outside surfaces were machined to contain the needed fins. The mini channel heat exchanger is connected to a standard vapor compression refrigeration system. During each run of the experiment, the mini channel heat exchanger was placed inside a fabricated small wind tunnel where controlled flow of air from a forced draft fan was introduced for the cooling process. The experimental set-up of this study used data acquisition software and computer-aided simulation software. The software was used to simulate the temperature distribution of the evaporator before and after the experiment. The trend of the temperature distribution of refrigerant inside the mini channel heat exchanger is increasing. It was observed that the mini channel heat exchanger has a greater temperature drop compared to the temperature requirement of the portable vaccine carrier kit.

Keywords—mini channel heat exchanger, vapor compression refrigeration system, temperature distribution, wind tunnel

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I. INTRODUCTION

The application of mini channel technology is increasingly used to achieve high heat transfer rates with compact heat exchangers. Boiling and vaporization of refrigerant inside small hydraulic diameter tube and channels find many applications in compact heat exchangers for cooling electronic gadgets and other refrigeration systems. The adoption of mini channel also promotes the reduction of the refrigerant charged, which is beneficial to mass and energy conservation. Mini channel phase change may differ from the conventional channels due to differences in the relative influence of gravity, shear stress and surface tension. As dimensions of electronic components reduce at mini scale, it is necessary for us to use a cooling system which can apply to the same scale. Fluid flow inside mini channel is one of the efficient candidates for small scale cooling. According to Kandlikar, mini channels are classified based on the hydraulic diameter (D_h) of 200μm to 3 mm. There has not been any comprehensive study to determine the limits of macro channel correlations to smaller data[1]. There is a need for such a study and this paper attempts to fulfill this need to some extent.

II. METHODOLOGY

A. Refrigeration Vapor Cycle

The evaporator of a vapor compression refrigeration system is a heat exchanger that absorbs heat from the compartment or spaces in refrigeration system.

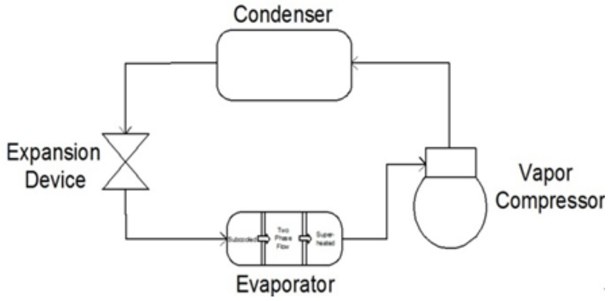

Fig. 1. Vapor compression refrigeration system

The evaporator receives low pressure refrigerant from the pressure reducing device, absorbs heat from its environment and delivers it to the compressor as a superheated gas. From the compressor, the refrigerant rejects heat in the condenser and enters back to the pressure reducing device.

The reduced pressure in the expansion device enables the evaporator to absorb heat from the environment at a lower and cooler temperature. Evaporators are devices that allows two-phase flow in the system which makes them difficult to calculate the exact coefficient of heat transfer and other thermodynamic parameters. It is normal for a conventional evaporator to experience two boiling regimes, nucleate boiling and convective boiling.

Fig.1 illustrates the fundamental set up of a conventional vapor compression refrigeration system. The mini heat exchanger is located at the evaporator of a refrigeration system or serve as the evaporator of a portable vaccine carrier kit.

There are two ways in which flow boiling in small diameter channels are expected to be implemented. They are, two-phase entry after a throttle valve and sub-cooled liquid entry into the channel[2]. Because of the requirement of the liquid flowmeter being used, this study belongs to the sub-cooled liquid entry into the mini channel. Sub-cooled liquid entry is an attractive option, because of higher heat transfer coefficients associated with sub-cooled flow boiling[2].

B. The Experimental Rig

The isometric diagram shown in Fig. 2, depicts the operational system of the experimental rig. The experimental rig consists the basic components of a vapor compressor refrigeration system. It has a 1/8 horsepower compressor from the smallest water dispenser available in the local market. It also includes the condenser of the dispenser that serves as the heat rejection device of the experimental set up. Capillary tube is used as the expansion device in this system so designed as to reduce the condition of the refrigerant to a sub-cooled region. To ensure a continuous supply of sub-cooled refrigerant, a small sub-cooler is mounted located just before the evaporator of the experimental rig.

Attachment sections were provided for easy removal and attachment of the different mini channel heat exchangers. Adaptor connections were provided in order to facilitate an easy and faster removal and mounting of another mini channel heat exchanger for testing.

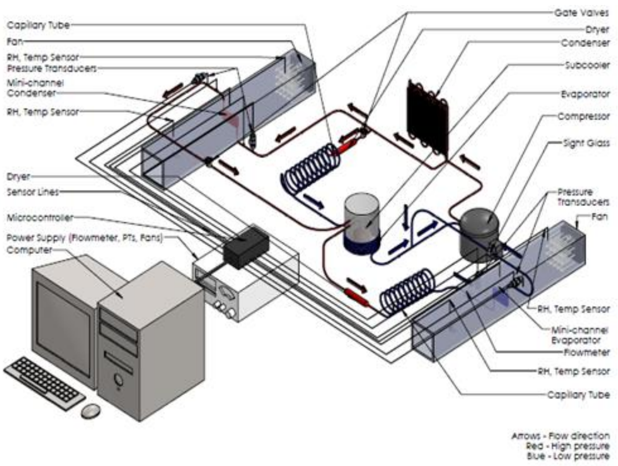

Fig. 2. Experimental set-up.

The mini channel heat exchangers are attached to a by-pass tubing that utilized a portion of the refrigerant that runs into the evaporator of the experimental rig or better called in this study as the mother evaporator. Regulating valve is installed near the inlet of the mini channel heat exchanger in order to maintain the pressure of refrigerant flowing inside the mini channel heat exchanger[8].

Fig. 3 shows the isometric view of the mini channel heat exchanger ready for the connection to the by-pass tubing. Adaptor fittings were fabricated to enable the mini channel heat exchanger easy connection to the mother evaporator. This mini channel heat exchanger is attached to the system and located inside of the wind tunnel. The wind tunnel is also fabricated component just to house and enclose the mini channel heat exchanger for data gathering.

C. Mini Channel Heat Exchanger

The mini channel heat exchanger is mounted inside the wind tunnel. The wind tunnel is equipped with a dc computer fan that serves as the blower of the ambient air. The refrigerant passing through the mini channel heat exchanger collects the heat from the ambient air and reject it to the condenser of the system.

The wind tunnel is made of thin galvanized sheets and insulated with composite insulating materials. The wind tunnel is equipped with humidity sensors and temperature sensors to monitor the changes in the humidity and temperature. These sensors are attached to a data logger in order to record the data at 30 seconds interval[8].

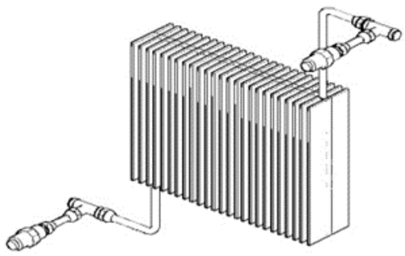

Fig. 3. Isometric view of the mini channel.

D. Fabrication of the Mini Channel Heat Exchanger

The mini channel heat exchanger is made from an ordinary copper bar available locally and considered as scrap metal from damaged electric transformer. The dimension of each channel is 100mm x 50mm x 20mm and the outside surfaces were machined to produce fins. The total length for each machined channel or machined tube inside the copper bar is 640.0mm. They were connected to a standard vapor compression refrigeration system in the experimental rig.

Fig. 3 shows the pictorial view of the interior part of the mini channel heat exchanger. A channel for the refrigerant to flow has been etched to the surface of the inner surface of the copper block. After the formation of the channel, the two copper pieces were welded together leaving the inlet and outlet of the refrigerant open. The inlet and outlet of the channel is then connected to a fabricated adaptor to join the fabricated adaptor in the experimental rig.

Provision for the attachment of the temperature sensor are made secure during the welding process and to ensure for the effective and efficient values of the data supplied by the sensors. Temperature sensors were also provided for the measurement of temperature half way of the channel.

Welded edges of the copper bars were made to a considerable thickness, to ensure that leakages of the refrigerant be avoided.

The dimension of the mini channel heat exchanger is 100 mm x 50 mm x 20mm and made of copper block. Fins were also fabricated on each face of the copper block and each face contains 24 fins with width of 2.0mm, length of 50.0mm and thickness of 5.0mm[8].

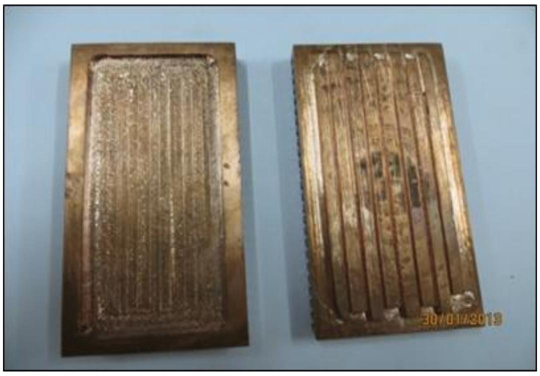

Fig. 4. Interior part of mini channel.

These mini channel heat exchangers were fabricated and joined together through oxy-acetylene welding. These heat exchangers were capable of operating at a maximum pressure of 1.0MPa[9].

E. Temperature Distribution Across the Mini Channel

The temperature sensors were installed at the inlet of the mini channel heat exchanger, another temperature sensor is mounted at the middle of the total length of the mini channel and a third temperature sensor mounted at the outlet of the mini channel heat exchanger. These temperature sensors were connected to the data logger so that data can be recorded every 30 seconds interval for every 60 minutes.[8] The heat absorbed or rejected by the refrigerant inside the wind tunnel can be calculated using the relation in equation (1),

$$Q = m_r\ (h_{out} - h_{in}) \tag{1}$$

where m_r is the refrigerant mass flow rate obtained directly from the flow meter, h_{in} is the enthalpy entering to the mini channel heat exchanger corresponding to a measured pressure and temperature, and h_{out} is the enthalpy leaving the evaporator corresponding to a measured pressure and temperature conditions.

The heat absorbed or rejected by the air passing through the wind tunnel, where the mini channel heat exchanger was mounted, can be calculated by the relation in equation (2),

$$Q = m_{cp}\ (T_{out} - T_{in}) \tag{2}$$

where m_{cp} is the flow rate of air obtained directly from the anemometer, T_{in} is the air temperature entering the wind tunnel and T_{out} is the air temperature leaving the wind tunnel.

Computer simulation for the temperature distribution inside the mini channel heat exchanger is introduced by defining the ambient conditions, thermodynamics parameters of the system and the materials being used. Fluid characteristics involved in the system and the refrigerant mass flow rates were also considered. The result on the computer simulation is used as basis for the improvement on the design for the revision of the new mini channel heat exchangers.

III. EXPERIMENTAL

An experimental rig was constructed to house all the refrigeration components and instrumentation sensors. A fabricated mini channel heat exchanger were used in the experimental set up by tapping a 1/8 horsepower vapor compressor.

The refrigerant passes through the mini channel heat exchanger with hydraulic diameter of 3.0mm. Leak tests were done to ensure that there will be constant flow of refrigerant in the system. The leak tests were done by permitting refrigerant to settle down the system to around 2.0 bars prior to start up. The system will then be charged with the refrigerant as the compressor starts up and to maintain a 0.7 bar suction pressure.

During the experiments, refrigerant flow rate was controlled by a by-passed valve from the main evaporator. To ensure that only liquid refrigerant enters the mini channel heat exchangers, a liquid receiver was fabricated and mounted before the mini channel heat exchanger. The refrigerant mass flow rate was measured at the inlet of the mini channel heat exchanger. The two temperature sensors and two pressure transducers was mounted on the refrigerant-side at the inlet and outlet of the mini channels. One temperature sensor was also mounted at the middle of the mini channel.

An insulated wind tunnel was fabricated and a forced draft fan was installed to guarantee sufficient supply of air across the mini channel heat exchangers. Two temperature sensors were mounted on the wind tunnel, one at the inlet and one at the outlet of the tunnel. The air velocity over the mini channel heat exchangers was measured using hotwire anemometer[9].

The temperature sensors, flowmeter and pressure transducers were connected to the data logger. The data logger was interfaced with the computer. Lab VIEW software had been used to operate the data logger and to store the data in the computer. The data logger was set to scan the data from the flowmeter, temperature sensor and pressure transducers at an interval of 30 seconds for a duration of 60 minutes[10].

IV. RESULT AND DISCUSSION

A. Temperature Distribution of the Mini Channel Exchangers

Each mini channel was mounted inside the wind tunnel where the same amount of airflow passed through it. Relative humidity, ambient pressure and temperature were recorded using data logger.

The results related to the temperature distribution and heat transfer coefficient were obtained from the readings of the three thermocouples, two pressure transducers, a flow meter and a handheld anemometer, installed in the different points in the test section.

The temperature distribution across the total length of the mini channel heat exchangers is depicted in Fig.5.

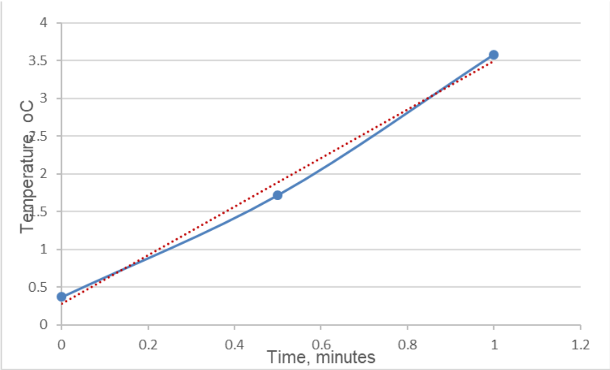

Fig.5. Temperature distribution inside the mini channel

Fig.5 shows the graph of the rise in the temperature of the refrigerant as it enters in the mini channel. The mini channel heat exchanger has an average inlet temperature of 0.37 ^{o}C, half way average temperature of 1.72 ^{o}C and an exit temperature of 3.58 ^{o}C. It is observed that there is a significant increase in temperature of refrigerant as it passes through the mini channel heat exchangers. The average temperature of the refrigerant inside the mini channel heat exchanger is 1.89 ^{o}C

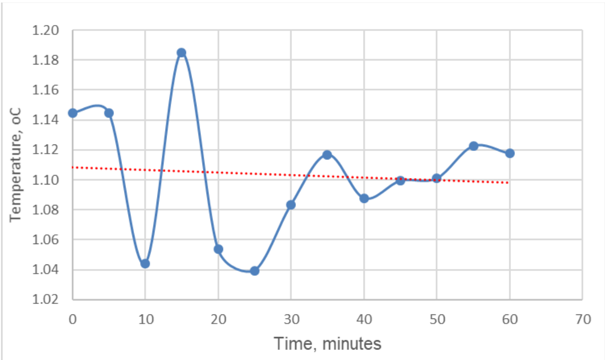

Fig.6. Temperature drop across the wind tunnel

It is evident in the gathered data that refrigerant passing through the mini channel heat exchanger have produced a lower value of temperature compared with the required temperature requirements of the portable vaccine carrier kit.

The temperature drops of air passing over the mini channel heat exchanger is shown in Fig.6. The temperature of air after it passed through the mini channel heat exchanger are recorded in the data logger. The behavior of the temperature of the refrigerant inside the mini channel heat exchanger when placed inside the wind tunnel is almost constant. The temperature of the air passing over the mini channel heat exchanger is also fluctuating but the general characteristic of the temperature distribution is constant.

The mini channel heat exchanger reduced the air temperature passing through the wind tunnel with an average temperature of 1.13 ^{o}C. It is shown in the above data that the mini channel has greater refrigeration effect compared to the requirement temperature of the portable vaccine carrier kit.

B. Simulation of the Temperature Distribution

Fig.7, shows result of the simulation of the temperature distribution of refrigerant inside the mini channel heat exchangers while subjected to air flows and connected inside the fabricated wind tunnel[8].

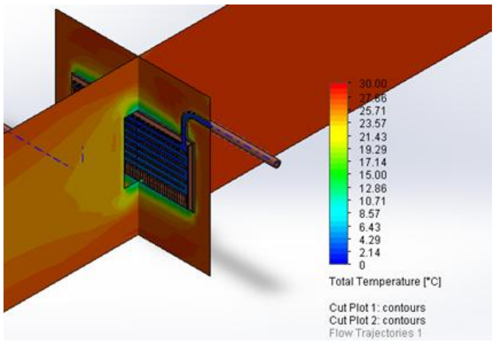

Fig.7. Temperature distribution for the mini channel heat exchanger from simulation

Fig. 7 shows the simulation view of the 3.0mm mini channel heat exchanger. The values of the simulated inlet temperature, midpoint temperature and the outlet temperature of the mini channel heat exchanger has an average error of 2.18% compared with the measured temperature values for the same mini channel heat exchanger.

The accumulation of the average error in the simulation software may be caused by the insufficient contact of the temperature sensor on the provided attachment surfaces. Better procedure of the mounting of the temperature sensors must be provided to ensure an optimum result of the data gathering.

The temperature requirement for the preservation of the vaccine is around 8.0 ^{o}C. The average temperature in the wind tunnel is more than enough to provide cooling system of the portable vaccine carrier kit.

V. CONCLUSION AND RECOMMENDATION

Based on the data obtained in this study, the following conclusions are drawn. The temperature distribution in the mini channel heat exchanger showed an increase in temperature from the inlet to the outlet of the mini channel heat exchanger. The simulated result of the temperature distribution in the mini channel heat exchanger inside the wind tunnel confirmed the validity of the measured data of the increase in the refrigerant temperature with slight discrepancy from the measured data. It was observed from the results of the simulation software that the heat absorbed by the refrigerant from the supply air in the wind tunnel becomes bigger as the time duration increases.

Though, these temperatures measured in the wind tunnel and the output of the simulation is more than enough to satisfy the 8.0 ^{o}C requirement in the design of a portable vaccine carrier kit, it is recommended that further study be done using smaller sizes of mini channel heat exchangers to compare the result of the current study.

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Comparison with s smaller mini channel heat exchanger such as the 2.0mm mini channel heat exchanger is highly recommended.

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