Experimental Analysis of Performance Characteristics of Mini Channel Heat Exchangers

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ABSTRACT

The development of applications requiring cooling of components in a confined space has led to wide range of studies in the field of fluid flow and heat transfer in mini channel heat exchangers. The current study deals with the experimental evaluation of effectiveness of counter flow mini channel heat exchangers for circular cross sectional geometry. The heat transfer fluids used in the mini channel heat exchanger are oil (SAE20W40) and water. Low Reynolds number flow is found in the heat exchanger. The heat exchanger used have a hydraulic diameter of 5mm and a length of 500mm. The effectiveness of the heat exchanger with circular cross sectional geometry was found out experimentally. The Number of Transfer Units (NTU) Method is used here to calculate the rate of heat transfer, in the case when LMTD (Logarithmic Mean Temperature Difference) method cannot be used. The variation of effectiveness with Reynolds number was also made a subject of investigation.

Keywords: *Counter Flow, Heat Exchanger, LMTD, NTU, Reynolds Number.*

1. INTRODUCTION

Micro and mini channel heat exchangers are widely used in the heat flux removal in microprocessor cooling, compact heat exchangers, cooling of high power electronic equipment and even compact fuel cells. Mini channel heat exchangers are widely used in refrigeration and air conditioning sector. At present, efforts are made to improve the coefficient of performance of the system, reducing the total refrigerant charge in the system and reducing size of equipment.

The flow inside a mini channel is expected to be laminar due to small hydraulic diameter. Experimental and numerical study on a micro channel heat exchanger was done by Dang [1**].** The Nusselt number is constant as the assumption of fully developed laminar flow and the heat transfer coefficient in internal flows varies inversely with channel hydraulic diameter. In his study, Agostini [2**]** studied about the friction factor and heat transfer co efficient of R134. Hasan [3**]** in his study evaluated the influence of channel geometry on the performance of a counter flow mini channel heat exchanger. The friction factors, pressure gradients and heat transfer coefficients are quite high in micro channel flows because the available surface area for a given flow volume is high. Use of mini channels reduces internal volume of heat exchangers with a significant reduction in refrigerant charge.

1.1 Counter Flow Heat Exchanger

The two fluids in the counter flow heat exchanger flows in opposite direction. The temperature difference between the two fluids remains more or less nearly constant. Due to the counter flow this

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type of heat exchanger gives maximum rate of heat transfer for a given surface area.so this kind of heat exchangers are most favored for heating and cooling of fluids.

2. AIM OF THE STUDY

The aim of the work is to evaluate the effectiveness of circular channel heat exchanger. Also the effect of Reynolds number on the effectiveness of mini channel heat exchanger is analyzed by varying the Reynolds number of flow of hot and cold fluids in the mini channel heat exchanger.

3. HEAT TRANSFER ANALYSIS

Heat transfer in heat exchanger usually in the form of convection in each fluid and conduction through the wall between the two fluids. The use of mini channel heat exchanger for cooling purpose of electronic components was studied by Jemmy S. Bintoro [4]. The rate of heat transfer between the two fluids at a section in a heat exchanger depends on the magnitude of the temperature difference at that section, which varies along the heat exchanger. The main methods for the analysis of the heat exchanger are

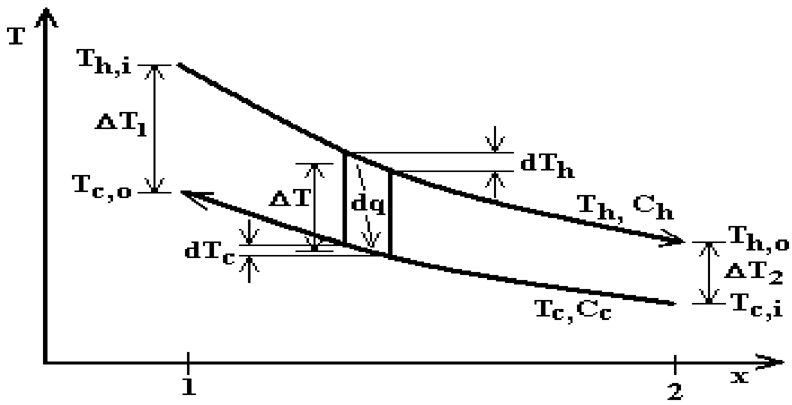

Fig. 1 Temperature Distribution in Counter Flow Heat Exchanger

3.1 LMTD Method for Heat Exchanger Analysis

Thermal analysis of any heat exchanger involves variables like inlet and outlet fluid temperatures, the overall heat transfer coefficient, total surface area and the total heat transfer rate. Since the hot fluid is transferring a part of its energy to cold fluid, there will be an increase in enthalpy of cold fluid and a corresponding decrease in enthalpy of hot fluid.

This may be expresses as,

$$q = C_h(T_{hi} - T_{ho}) = C_C(T_{co} - T_{ci})$$

Where, $C_h = mc_{ph}$ and $C_C = mc_{pc}$

In general, the temperature difference between hot and cold fluids varies along the heat exchanger and is convenient to have a log mean temperature difference ΔT_m

The heat transfer, $q = UA\Delta T_m$

Log Mean Temperature Difference (LMTD), $\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$

ΔT_1 *and* ΔT_2 Represent the temperature difference between two fluids at the two ends (inlet and outlet) of the heat exchanger.

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3.2 Effectiveness NTU Method for Heat Exchanger Analysis

This method is used to calculate the rate of heat transfer in heat exchangers when there is insufficient information to calculate log mean temperature difference. The heat transfer surface area of heat exchanger in this case is known but the outlet temperatures of hot and cold fluids are unknown. It is based on a dimensionless parameter called the heat transfer effectiveness, it is the ratio of actual heat transfer to maximum possible heat transfer [8].

$$\in = \frac{q}{q_{max}}$$

Actual heat transfer,

$$q = C_h(T_{hi} - T_{ho}) = C_c(T_{co} - T_{ci})$$

Maximum possible heat transfer in a heat exchanger is

$$q_{max} = C_{min}(T_{hi} - T_{ci})$$

Effectiveness, $\in = \frac{C_h(T_{hi} - T_{ho})}{C_{min}(T_{hi} - T_{ci})} = \frac{C_c(T_{co} - T_{ci})}{C_{min}(T_{hi} - T_{ci})}$

Where, $C_h = mc_{ph}$ and $C_C = mc_{pc}$

For $C_h = C_c$,

Effectiveness, $\in = \frac{(T_{co} - T_{ci})}{(T_{hi} - T_{ci})}$

$q = \in q_{max} = \in C_{min}(T_{hi} - T_{ci})$

So, the effectiveness of a heat exchanger enables to determine the heat transfer rate without knowing the fluid outlet temperatures. The effectiveness of a heat exchanger depends on the geometry of the heat exchanger and flow arrangement.

Effectiveness relation of the heat exchanger typically involve two dimensionless groups, Number of transfer units (NTU) and Heat Capacity ratio C, [9]

$$NTU = \frac{UA}{C_{min}}$$

NTU is proportional to A, for a specified value of U and C_{min}. NTU is a measure of heat transfer surface area A. Higher the NTU value larger will be the heat exchanger.

In heat exchanger analysis, it is also convenient to define another dimensionless quantity called capacity ratio as

$$C = \frac{C_{min}}{C_{max}}$$

It can be shown that effectiveness of a heat exchanger is a function of NTU and capacity ratio

For counter flow, $NTU = \frac{1}{c-1} \ln \frac{\epsilon - 1}{\epsilon C - 1}$

For C = 1, $NTU = \frac{\epsilon}{1 - \epsilon}$

4. PASSIVE ENHANCEMENT TECHNIQUES

Some basic techniques used for the passive enhancement include flow disruption, secondary flows, surface treatments, and entrance effects. [10] Several of these techniques can be easily implemented into a micro channel or a mini channel.

5. ACTIVE ENHANCEMENT TECHNIQUES

Active techniques involve the application of external input for heat transfer enhancement in the form of power, electricity, RF signals or external pumps. [10] Mainly used active enhancement techniques are vibration and electrostatic fields.

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6. EXPERIMENTAL SET-UP

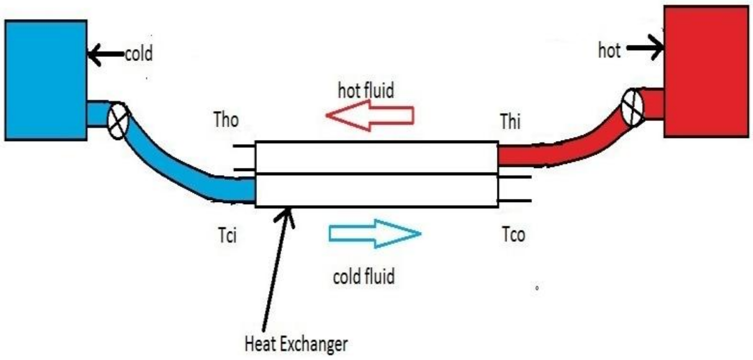

Fig.2 Schematic Diagram of Experimental Setup

Table.1 Properties of SAE20W40 oil

Properties of SAE20W40 oil	
Thermal conductivity	0.14W/mk
Density	850 kg/m^3
Dynamic viscosity	0.072 NS/m^2

To compare the performance of counter flow mini channel heat exchangers for circular cross sectional geometry, an experimental test was designed and constructed. The setup consisted of a counter flow mini channel heat exchanger, reservoirs for hot and cold fluids, valves for hot and cold fluids, conducting tubes and collecting tanks and a data acquisition system. The heat transfer fluids used in the experiment are SAE20W40 oil and water. Counter flow heat exchanger with circular cross sectional geometry is used as the channel for fluid flow. The heat exchangers were made up of copper. Each of them is having a hydraulic diameter of 5mm and a length of 500mm. The two reservoirs having a capacity of more than three liters were used for supplying hot and cold oil. The reservoir supplying hot fluids was provided with a heater and a thermo couple. The physical properties of SAE20W40 oil is as illustrated in the table.1.

Though both the reservoirs are having the same head, due to the higher temperature, hot fluid is having a greater Reynolds number than the cold fluid. The hot fluid and cold fluid are having a Reynolds number of 4. Figure 2 shows the actual experimental set up. The inlet and outlet temperatures of the oil supplied from the reservoir to the heat exchanger were measured by using j-type thermocouples and a Data Acquisition System (DAS). The heat exchanger surface was well insulated and the mass flow rate of oil through the heat exchanger was measured by using a measuring jar. The cold fluid was kept at ambient temperature of 303K and the hot fluid was at a temperature of 330K.The effectiveness of the counter flow mini channel heat exchangers were calculated from the temperature readings obtained from the data acquisition system.

7. EXPERIMENTAL OUTCOME

Experimental investigation of counter flow circular mini channel heat exchanger draws attention to many details. Experimental analysis was done with inlet temperatures of the hot and cold fluid at 330K and 303K respectively. The temperatures were measured by using the data acquisition system and mass flow rate of the oil through the heat exchanger was measured by using a measuring jar. From the mass flow rate, velocity of hot and cold fluids was found out. Due to the very low mass flow rate and high viscosity, the Reynolds number was found to be very low. The Reynolds number for hot and cold fluid was 6 and 4 respectively. The effectiveness was calculated using the inlet and outlet temperatures of the hot and cold fluids and the value of effectiveness is 0.45. The following graphs show the variation of effectiveness and NTU with Reynolds number.

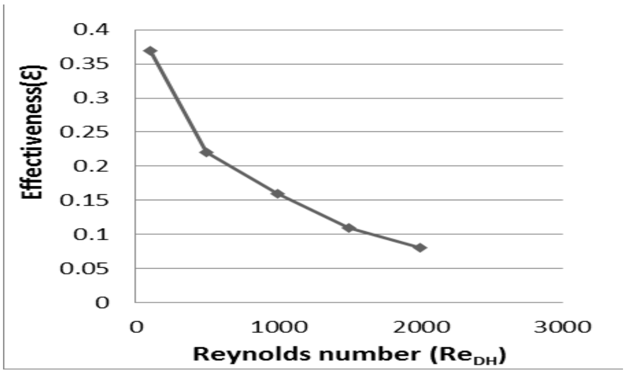

Fig.3 Variation of Effectiveness with R_e

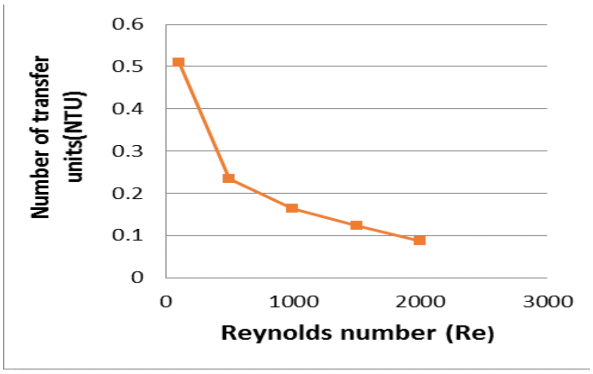

Fig.4 Variation of NTU with Reynolds Number

8. CONCLUSION

The effectiveness of the counter flow mini channel heat exchangers with circular cross section were determined experimentally. The study on the variation of effectiveness with Reynolds number was done and was found that effectiveness values are higher for lower values of Reynolds number and it tends to decrease with an increase in Reynolds number. A comparison between water and SAE20W40 oil was made and it was found that water served as a better heat transfer fluid than oil. Still oil will remain as a better option at higher temperatures at which water will vaporize.

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