Forced Convective Heat Transfer Characteristics of Water Through a Minichannel at Higher Reynolds Number.

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Abstract--- Convective heat transfer coefficient and friction factor of water in circular minichannels were measured. An integrated system consisting of a single minichannel on one side, and one heater and four thermocouple temperature sensors along the channel on the other side were fabricated. Distilled water was used in experiments to investigate the effect of the Reynolds number to the convective heat transfer and fluid flow in minichannels. The convective heat transfer coefficient of the water in turbulent flow regime was measured to be increased by increasing the Reynolds number. The Nusselt number measured increases with increasing the Reynolds number in turbulent flow regime. We have measured the pressure drop and convective heat transfer coefficient of water flowing through a uniformly heated circular minichannel in the turbulent flow regime. The experimental results show that the data for water friction factor show a good agreement with analytical predictions from the Darcy's equation for single-phase flow

I. INTRODUCTION TO MINICHANNEL

Minichannel cooling has made the high heat flux removal in such applications as microprocessor cooling, cooling of high power electronic equipment, compact heat exchangers, and even compact fuel cells possible. The small hydraulic diameter increases the heat transfer coefficients in these passages. The application of minichannels to cool microprocessors is of particular interest. The majority of researchers working in this field realize the benefits of minichannel flow systems to meet the cooling requirements for high heat fluxes. The dimensions of the channel are very important as it defines the heat transfer characteristics. Channel classification based on hydraulic diameter is intended to serve as a simple guide for conveying the dimensional range under consideration. Diameters of minichannels are in between of 3mm and 0.2mm.

II. GENERAL INSTRUCTIONS

In the beginning of the 1980s, Tuckerman and Pease [1] conducted one of the initial experiments on water flow and heat transfer characteristics in micro channel heat sinks. This demonstrated that cooling of electronic components can be done by use of forced convective flow of fluid through micro channels, and opened a wide door in the field of electronics cooling and heat transfer in micro scale geometries. Wu and Little [2] reported higher heat transfer coefficients than predicted from the conventional correlations, and that the transition regime ranged from Re =1000 to 3000. Adams et al. [3, 4] investigated the heat transfer coefficient of turbulent water flowing in circular channels with Di ¼ 0:76 and 1.09 mm, they found that the Nusselt numbers for these channels were higher than those for macro channels. Yu et al. [5] conducted experiments with liquid water flowing in circular tubes having Di ¼ 19:2, 52.1 and 102 lm, measuring the heat transfer coefficients. They found that the heat transfer data at low Reynolds number agreed with those for macro tubes, while the values diverged as Re increased, in such a way that, with the micro tubes the values were higher. Mala and Li [6] experimentally tested water flow through micro tubes with Di from 50 to 254 lm. Their results showed that the deviation from the macro scale theory increases as the Reynolds number increases, and as the micro tube diameter decreases. They concluded also that there is an earlier transition from laminar to turbulent flow in micro channels. Palm [7] reviewed the literature regarding the heat transfer and pressure drop of single-phase flow through micro channels, defined as channels having a hydraulic diameter of 1 mm or less. It was concluded that the literature is inconclusive concerning the difference between heat transfer and pressure drop in micro channels compared to macro channels and that carefully designed experiments are necessary before final conclusions can be drawn.

III. DESCRIPTION OF EXPERIMENT

We deals with the friction factor calculation along a mini-channel for turbulent flow when water is flown through it. We will also determine the heat transfer characteristics (Nusselt number) for the above cases. We will compare the experimentally calculated friction factor values with the Darcy friction factor for a given Reynolds number and the experimental Nusselt number values with a theoretical correlation.

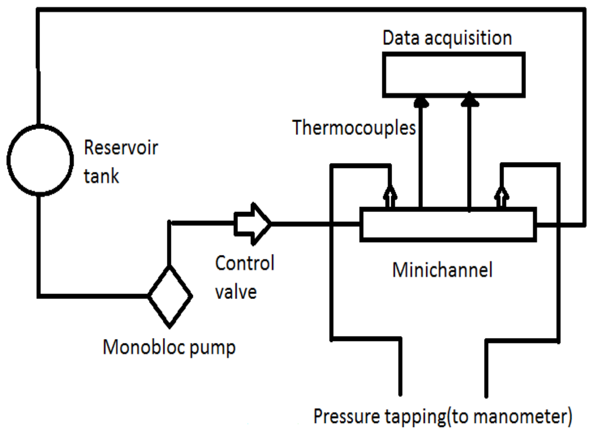

Fig. 1: Experimental setup of the experiment

IV. EXPERIMENTAL SETUP

Fig. 1 shows experimental apparatus for investigation on flow and convective heat transfer characteristics of water flowing through a circular minichannel with the constant heat flux in fully developed turbulent flow regime. It mainly consists of a test section, a pump, a reservoir tank, thermocouples, Manometer, and a data acquisition device. The straight minichannel with 1.41 mm inner diameter and 32 cm length is used as the test section. The minichannel surface is electrically heated by an AC power supply to generate constant heat flux and is insulated thermally by thick blanket to minimize the heat loss from the tube to the ambient. A heater is coiled on the minichannel to provide heat; whose voltage is regulated by a voltage variac. To measure the wall temperature of the minichannel four thermocouples (T-type) are soldered on at different places along the test section and inlet and outlet fluid temperature will be measured by thermometer. The pressure drop is measured by a mercury manometer at both ends of test section. A centrifugal pump controls the flow rate of the fluid according to the requirements.

Experimental friction factor is measured by calculating the pressure drop along the minichannel and the mass flow of the water. Experimental friction factor is calculated by

$$f_{\exp} = (2\times\Delta p\times g\times d)\div(l\times\rho_{water}\times U_m\times U_m) - (1)$$

Where Δp is the pressure drop measured along the minichannel, d is the diameter of minichannel, l is the length of microchannel, ρ_{water} is the density of water, and the U_m is the mean velocity of water coming out through the minichannel. U_m is measured by

$$U_m = M_{water}\div(\rho_{water}\times A_c) - (2)$$

Where A_c is the area of cross-section of minichannel, and the M_{water} is the mass flow rate of water. Theoretical friction factor will be calculated by Blasius equation given by

$$f_{theoretical} = 0.316/(\mathrm{Re}^{0.25}) - (3)$$

Where Re is the Reynolds number.Then we compared the theoretical value of friction factor with the experimental value of friction factor.

Wall temperature will be measured by calculating the average of four thermocouple readings. Fluid temperature of inlet and outlet will be taken by the thermometer. Heat flux will be measured by the

$$Q = M_{water}\times C_p\times(T_{inlet}-T_{outlet})\div(\pi\times d\times l) - (4)$$

Where Cp is the heat capacity of water. T_{inlet} and T_{outlet} are the temperature of water at the inlet and outlet of minichannel. With the measured wall temperature at the minichannel, the temperature of fluids at inlet and outlet, heat flux, and flow rate, the convective heat transfer coefficient of water under the fully developed condition of turbulent flow is calculated by

$$h = Q\div(T_{wall}-T_{bulk}) - (5)$$

T_{wall} is the minichannel wall temperature. Where T_{bulk} will be given by

$$T_{bulk} = (T_{inlet}+T_{outlet})\div 2 - (6)$$

With the measured convective heat transfer coefficient, diameter of minichannel, and the thermal conductivity of water, the Nusselt number of water under the fully developed condition of turbulent flow is calculated by

$$Nu = (h\times d)\div K_{water} - (7)$$

Where K_{water} is the thermal conductivity of water. Theoretical Nusselt number for the flow is is measured by the Gnielinski correlation for turbulent flow in pipes

$$Nu = ((f\div 8)\times(\mathrm{Re}-1000)\times\mathrm{Pr})\div(1+12.7\times(f\div 8)^{0.5}\times(\mathrm{Pr}^{2\div 3}-1)) - (8)$$

Where Re is the Reynolds number, Pr is the Prandtl number, and f is the Darcy friction factor, that is obtained by the Petukhov correlation for smooth tubes.

$$f_{petukhov} = (1.82\log(\mathrm{Re})-1.64)^{-2} - (9)$$

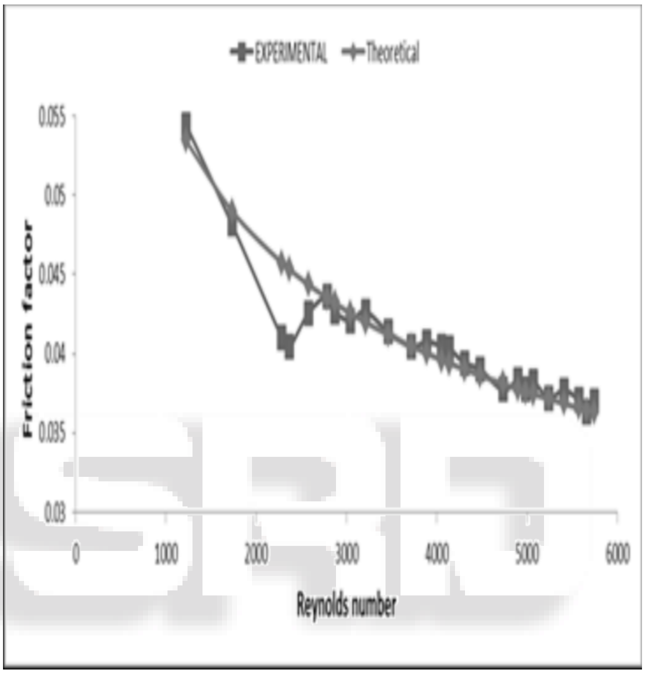

Fig. 2: Variation of Friction factor with Reynolds number for Experimental and theoretical case.

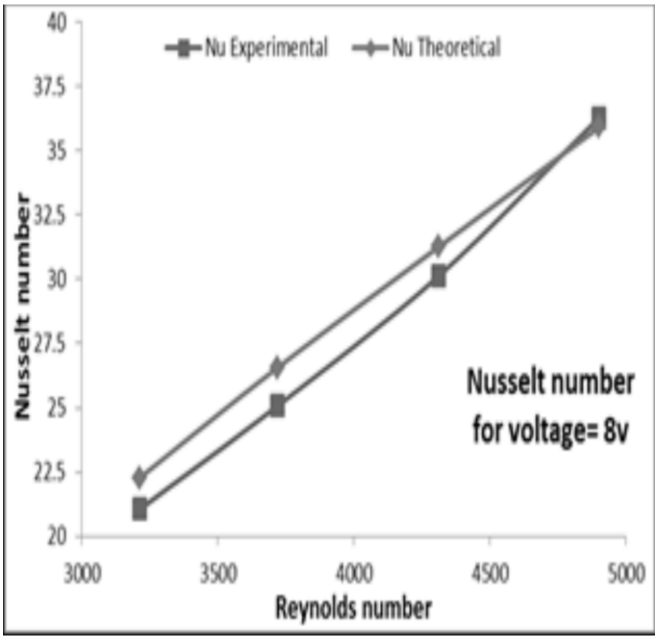

Fig. 3: Variation of experimental and theoretical Nusselt number with Reynolds numver for voltage=8V.

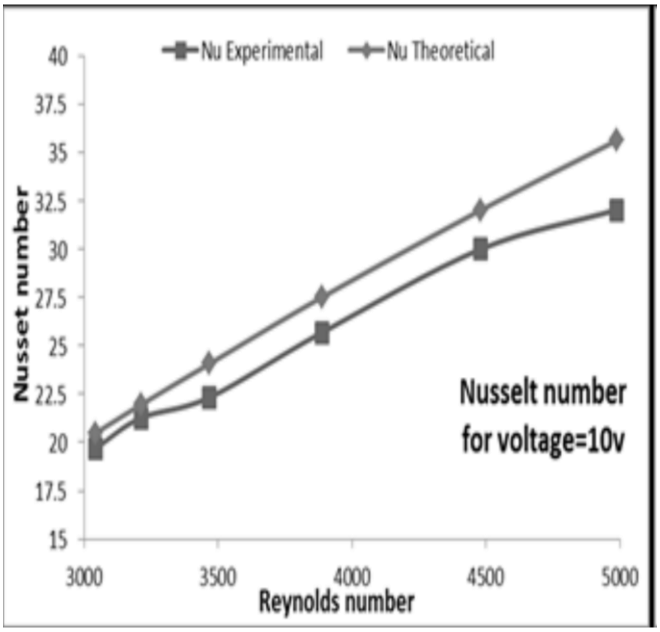

Fig. 4: Variation of experimental and theoretical Nusselt number with Reynolds numver for voltage=10v

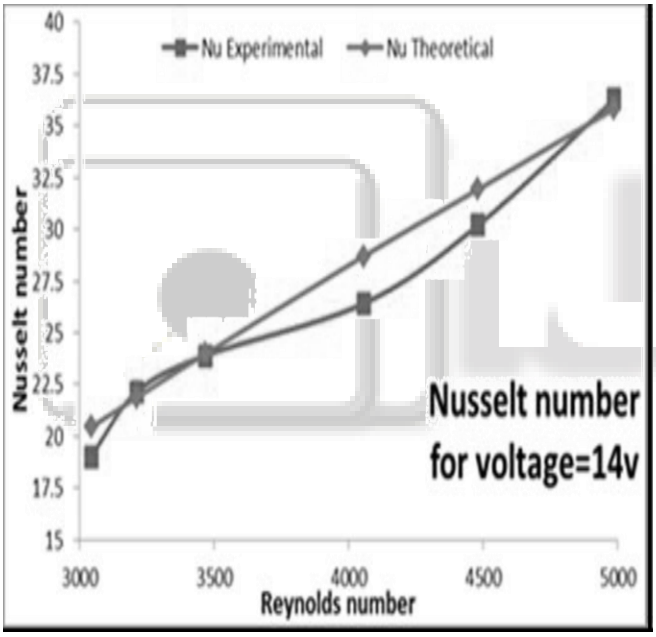

Fig. 5: Variation of experimental and theoretical Nusselt number with Reynolds numver for voltage=14V.

V. ANALYSIS OF EXPERIMENT

From the values of Darcy's friction (henceforth only friction factor) obtained from our setup, we can calculate the smoothness of the pipe and use the obtained value of 'f' for our Nusselt number analysis. It will be used for calculation of experimental Nusselt number. From the figure 2 we can see that the values of friction factor show an excellent correlation with the theoretical values using Blasius relation. The copper tube is a smooth pipe, and has very little to no scaling.

The variation observed between Reynolds number of 1700 and 2500 can be attributed to the transition zone between laminar and turbulent flow. Friction factor is observed to dip in this zone.

The petukhov equation is-:

We find the value of Nusselt number at different Reynolds number for 3 different voltages applied for heating. The 3 different voltage applied are 8v, 10v, and 14v. As can be seen from the values of Nusselt number obtained from the experiment in figure 3, 4 and 5, there is a clear conformance to the expected trend, but a small deviation from the theoretical values.

This is due to many factors, primarily improper insulation and an equipment restraint.

The improper insulation may be attributed to the impermanent nature of the setup, as it must often be removed to clean and ensure smoothness; the insulation is a loose covering of asbestos, cotton and jute fibers.

The equipment restraint deals with measuring the temperature at the inlet and outlet. The temperature at the inlet and outlet cannot be measured without human error, and least count of thermocouple was 1 degree, which given the slight variations in temperature led to difficulties in determining when a stable state was reached.

We can see that by increasing the Reynolds number value of Nusselt number continuously increase. This gives us that turbulent flow of a fluid through a minichannel gives better heat transfer characteristics at high Reynolds number.

We can compare these results to previously obtained results for laminar flow. There is marked increase in Nusselt number and heat transfer coefficient (h). This gives us the important results that turbulent flow of a fluid through a minichannel gives better heat transfer characteristics than laminar flow with a smaller increase in outlet temperature.

VI. CONCLUSIONS

Minichannel compact heat exchangers provide high performance within small space, which is desirable for all type of transportable systems, cryogenic and integrated to-phase applications. These minichannels have high heat transfer coefficients, high surface area, volume ratio and high heat transfer coefficients, high surface area, volume ratio and high heat transfer per unit volume. In order to design and optimize heat exchangers based on minichannels, design tools are needed. These tools should be able to correctly predict the heat transfer, pressure drop, and for evaporators, flow pattern and critical heat flux inside this minichannel heat exchangers. Since the flow is in thermally developing zone, hence the Nusselt number for water will increase with increase in Reynolds number.

integrated An experimental investigation of pressure drop in single-phase flow of distilled water through single circular minichannel having the inner diameter 1.41 mm and heated length of 320 mm was conducted. The experimental results are compared with Darcy friction factor. The experimental results are in good agreement with theoretical results. Hence, Conventional correlations for pressure drop are equally applicable in minichannels.

The experimental results of Nusselt number and heat transfer coefficient of water are plotted against Reynolds number for the minichannel of diameter of 1.41 mm. So, a correlation has been suggested for Nusselt number in turbulent flow through mini- channels.

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