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FLOW AND HEAT TRANFER ON ALCOHOL IN MICRO-CHANNEL

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ABSTRACT

The objective of the current experimental program is to generate data for liquid flow through micro-channels. The channel dimensions are 1.5 mm deep x 0.75 mm width. Rectangular 47 micro-channels were cut on a stainless steel substrate (230 mm x 160 mm) by Electro Discharge Machining (EDM) technique. The use of micro channels is recent topic of investigation. Micro channels are used to remove high heat fluxes from smaller area. Such as electronic components like printed circuit board (PCB), chip, space, laser applications etc. It is proposed to design and fabricate micro channels and to study the heat transfer characteristics, such as heat flux, liquid temperature, wall temperature and Nusselt number correlation. However the single phase forced convective heat transfer and flow characteristics of alcohol in micro channels structures plates with small rectangular channels and distinct geometric configurations are to be investigated experimentally. Finally experimentally obtained values will be compared with the theoretical or predicted values.

Keywords: *Experiments, Laminar, Friction factor, Nusselt number and Micro-channels.*

Nomenclature

C	empirical constant {no units}
c_p	specific heat, J/kg-K
d	diameter, m
f	friction factor, {no units}
H	height of the channel, m
h	heat transfer coefficient, W/m^2-K
k	thermal conductivity, W/m-K
l	length of the channel, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number, {no units}
p	pressure drop, Pa
Pr	Prandtl number, {no units}
Q	heat transfer rate, W
q”	heat flux, W/m^2
Re	Reynolds number, {no units}
T	temperature, ^{o}C
v	velocity, m/s
W	width of the channel, m
z	no. of channels

Greek symbols

Δ	Difference
μ	Viscosity, Pa s
ρ	Density, kg/m^3

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Subscripts

eq	equivalent
fi	fluid inlet
fo	fluid outlet
fm	fluid mean
wm	wall mean

I. INTRODUCTION

Fluid flow through micro-scale flow geometries is encountered in numerous engineering systems such as cooling of electronic devices and compact heat exchangers. Experimental Investigation of flow and heat transfer in micro-channel [1]. Micro-channel flows have been used for liquid dosing and flow measurement [2]. The literature sources are more recent to the extent that micro-scale flow passages are concerned. Tuckermann & Pease [3, 4] were, perhaps, the first to conduct a systematic research into micro-scale flow and heat transfer. Several investigations ensued which dealt with flow of gases [5] and liquids [6, 7, 8, 9,10] through micro-geometries. Issues pertaining to micro-channel heat exchangers were dealt with by [11,12,13]. Theoretical approaches to fluid flow and heat transfer were also reported [14, 15]. Water, methanol and n-propanol were used as liquid media and nitrogen, helium, argon and hydrogen as gaseous media for experiments. The test section geometries varied from a fraction of a μm to a few 100s of μm. There had been only one study with mixtures of fluids [16]. The substrates used were silicon, glass, copper and stainless steel. Based on these studies provide evidence to prove that flow and heat transfer in micro-channels need to be addressed differently compared to conventional channels. It appears that, firstly, the transition from laminar to turbulent flow takes place at a low Reynolds number and secondly, friction factor and heat transfer cannot be described by the empirical relations used for normal geometries. There is a need for more experimental data on a variety of fluids and flow geometries so that some generalized conclusions can be evolved.

II. FABRICATION OF MICRO-CHANNELS

Micro-components are mostly fabricated using etching, deposition and photo-lithographic techniques. There are numerous techniques available and also being innovated to meet the requirements of specific formations on various substrates. Non-circular geometries are often adopted because of their relative simplicity in fabrication as compared to circular channels. The conventional techniques, which have been administered for the fabrication of heat sinks and heat exchangers, include a) precision sawing or cutting and b) micro machining. The latter is an offshoot of bulk and surface chemical machining processes widely used in microelectronics industry. Other techniques for producing micro-channels include [17]: i) spark erosion or EDM ii) laser machining iii) stereo lithography and iv) LIGA (Lithography, Galvanoformung, Abformung) electroforming, a process developed initially in Germany [18]. It was reported that with a precision EDM dimensional tolerances up to 0.5 μm could be obtained.

In the present case, a channel of 1.5 mm deep and 0.75 mm width was cut by using EDM on a 230 mm x 160 mm x 1.6 mm stainless steel plate. Figure 3.1 shows the micro-channel dimensions typical (47 channels). The surface roughness measurement of test section was done to check the uniformity of the channel. The flow passage is formed by the machined plate and another stainless steel plate of thickness 1.6 mm on top. The inlet and outlet conduits were attached and brazed together with the two plates.

III. EXPERIMENTS IN MICRO-CHANNEL

Normally as a consequence, it is expected from experiments on micro-channels are, the prediction of (i) the zone of transition between the laminar and turbulent regimes (ii) the magnitude of friction factor and (iii) the magnitude of heat transfer rate. The objective of the current experimental program is to generate data on the friction and heat transfer characteristics in rectangular micro-channels.

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The schematic experimental setup is shown in figure 2. It consists of liquid reservoir/sump (capacity ~ 10 lit) to supply fluid to the test section. A diaphragm operated pump is used to pump fluid to the test section through a micro-filter (~ 100 micron) built-in in the main line to

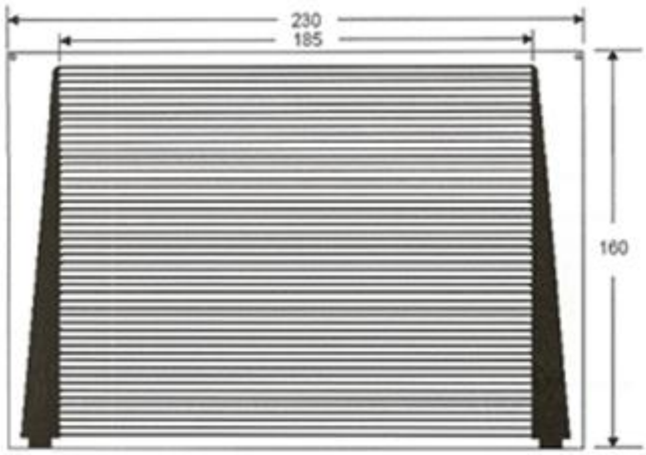

Fig. 1: Typical micro-channel test section

avoid any dirt that may enter into the test section. In the absence of micro-filter poor measurement data could be resulted due blockage of the channels to the flowing fluid. It is provided with by-pass line and control valves to establish the required flow rate in the test section and as well the pressure drop, measured with the aid of U-tube differential mercury manometer.

The flow medium used to test was filled in the reservoir. To start the experiment all the required precautions were taken into consideration. The pump is switched on while keeping the by-pass valve in open position and control valves to test section closed. The required discharge flow rate of the pump is obtained through stroke adjustment in the pump system. Control valve was somewhat opened allowing the flow to take place in the test section. Further, the control valve was tuned to set the required pressure drop indicated by the U-tube manometer. Corresponding to a pressure drop, flow rate through the test section was measured by collecting either known volume of liquid or a known period of time. Several trials were carried out and the average value is taken to evaluate flow rate in terms of cc/min basis. The average value of flow rate was taken from several run to reduce the measurement uncertainty. However, it may be noted that flow rate was based on manual measurement, as the flow meter put in the setup does not have instrument (display unit). The manometer system accuracy is about ±0.25 mm. The experiment was repeated for various values of pressure drops (range ~ 1 to 250 mm of Hg). The time intervals for flow rate measurement are carried out depending on the flow rate. Experiments were conducted at room temperature (~ 34^{o}C). Figure 3.2 shows plot of pressure drop *vs* flow rate data.-

In case of heat transfer experiments, fluid and wall temperatures are measured using thermocouples located at appropriate places in the test section (see Fig. 2 and 3.1) in addition to the above flow rate and pressure drop data. Electrical foil heaters mounted on either side heated equally the test section. This entire assembly of the test section is insulated on all sides to minimize heat loss to the surroundings. The wall temperatures were measured at 6 Locations which are located at a gap of 40mm.

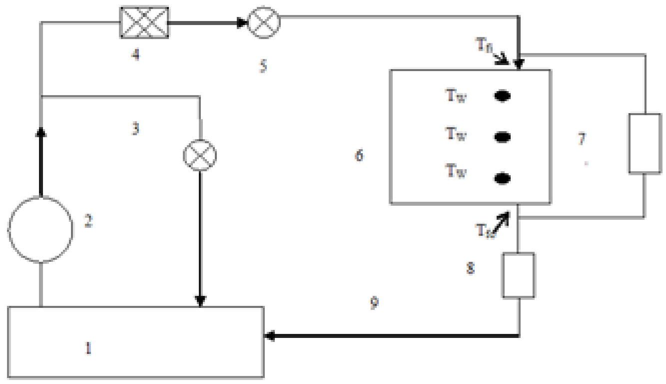

Fig. 2: Schematic experimental setup fluid flow and heat transfer

Legend: 1-Sump 2-Pump 3-By-pass control valve 4-Micro-filter 5-Flow control valve 6-Test section 7-Differential pressure gage 8-Flow meter 9-Return line to sump. T_w- Thermocouple location on wall and $T_{fi/o}$- Thermocouple location for fluid inlet/outlet.

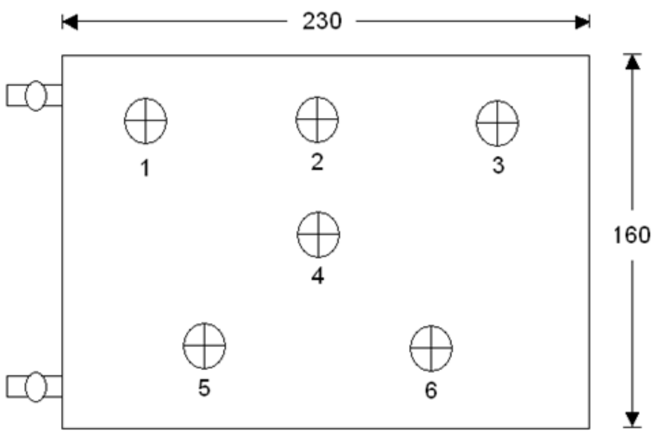

Fig. 3.1: Arrangements of Thermo couple points in micro channel

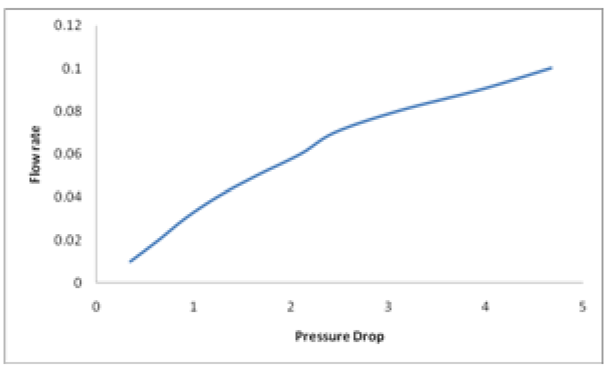

Fig. 3.2: Plot between pressure drop Vs Flow rate

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IV. FLUID FLOW DATA REDUCTION

The primary objective of this flow experiment is to obtain the friction factor *versus* Reynolds number relation. The friction factor 'f' is deduced from the raw data using Darcy-Weisbach formula [18] given below:

$$\frac{\Delta p}{\rho} = f \left(\frac{l}{d}\right) \frac{v^2}{2} \qquad (1)$$

Where, Δp is the pressure drop, ρ is the density, f is the friction factor, l / d is length to diameter ratio and v is the velocity. The Reynolds number is defined in the conventional way Re = $\rho vd/\mu$. The velocity v (average) is calculated from flow rate based on the cross-sectional area of the channel. For non-circular ducts, diameter d is replaced by equivalent diameter defined as, d_{eq}= 2 WH/(W+H) where W and H are width and height of the channel respectively. The thermo physical properties were evaluated at inlet temperature of the test fluid neglecting the viscous heating effect in the channel. Table 1 and Table 2 shows the Experimental and calculated values of Thermo physical properties of methanol.

Table 1: Experimental data

Pressure Drop in bar (Δp)	Flow rate (lpm)	Room temp. Ta (oC)	Fluid temperature (oC)		Wall temperature (°C)						
			T_{fi}	T_{fo}	T_1	T_2	T_3	T_4	T_5	T_6	T_{avg}
0.35	0.01	34	33	51.1	42	69	55	73	66	66	61.83
0.64	0.02	34	33	49.7	42	68	54	72	65	65	61
0.91	0.03	34	33	48.6	42	67	53	69	64	63	59.67
1.24	0.04	34	33	47.5	42	66	53	69	64	63	59.5
1.65	0.05	34	33	46.8	42	65	52	68	63	61	58.5
2.1	0.06	34	33	46	42	65	51	67	63	61	58.17
2.45	0.07	34	33	45.4	42	64	51	66	62	60	57.5
3.1	0.08	34	33	44.3	42	63	50	63	60	59	56.17
3.95	0.09	34	33	44	42	62	50	63	60	58	55.83
4.67	0.1	34	33	43.5	42	62	50	63	59	58	55.67
0.35	0.01	34	33	51.1	42	69	55	73	66	66	61.83

Table 2: Calculated data

SL no	Mass flow rate (kg/s)	Flow velocity V (m/s)	Reynolds number (Re)	Friction factor		Nusselt number (Nu)	h	Heat flux q
				f_{exp}	f_{the}		(W/m^2k)	(W/m^2)
1	0.0001	0.1481	212.79	0.3651	0.3008	9.54	0.1717	0.016
2	0.0003	0.2963	425.59	0.1669	0.1504	13.5	0.2429	0.0215
3	0.0004	0.4444	638.38	0.1055	0.1003	16.53	0.2975	0.0269
4	0.0005	0.5926	851.18	0.0808	0.0752	19.09	0.3435	0.0286
5	0.0007	0.7407	1063.97	0.0688	0.0602	21.34	0.384	0.0328
6	0.0008	0.8889	1276.77	0.0608	0.0501	23.38	0.4207	0.0346
7	0.0009	1.037	1489.56	0.0522	0.043	25.25	0.4544	0.0376
8	0.0011	1.1852	1702.36	0.0505	0.0376	26.99	0.4858	0.0409
9	0.0012	1.3333	1915.15	0.0509	0.0334	28.63	0.5152	0.0435
10	0.0013	1.4815	2127.95	0.0487	0.0301	30.18	0.5431	0.0446

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4.1 Results and discussion

The friction factor data obtained from the present experiments for the test section is shown in figure 4, as plot of friction factor *vs* Reynolds number (f-Re). Normally, the flow experiment results give an initiative to identify flow regimes (laminar, turbulent and zone of transition). Further, friction factor dependence on Reynolds number could be established. The experimental values are compared with conventional theory and earlier correlations. Pattern characterizes the 'f' theoretical value in laminar regime (i.e.; f = 64/Re) and pattern stands for smooth pipe turbulent regime by *Blasius* relation [19],

$$f = \frac{0.316}{Re^{0.25}} \qquad (2)$$

It is customary in pipe flow; the laminar flow regime is identified as friction factor 'f' varies inversely to Reynolds number (typically as f = 64/Re for tubes). The laminar flow is continued up to Re ~1200. In the test section in view of the limitation constrained by the differential pressure gauge (maximum 250 mm Hg) used. Consequently, the experimental data for the laminar region fitted in the friction factor relation of the form f = C/Re, yielded the constant C value 75.73 for methanol with regression coefficient (R^2) of 0.95 is observed as in figure 4. Therefore it appears that these micro-channels are preferred at low pumping power with high heat flux rate applications such as electronic cooling.

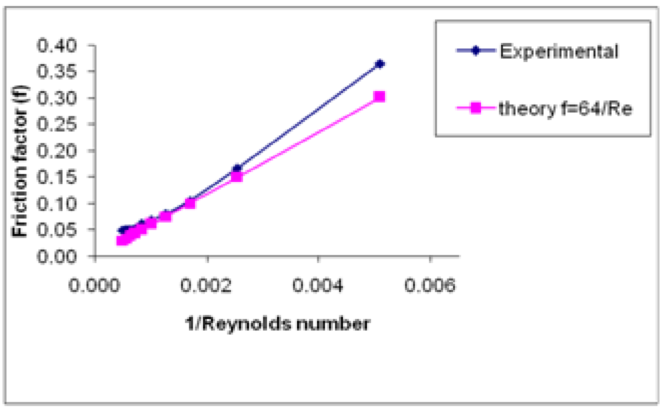

Fig. 4: Plot of friction factor Vs 1/Reynolds number

V. HEAT TRANSFER DATA REDUCTION

From the measured flow rate and temperatures various parameters are evaluated to obtain heat transfer rate and Nusselt number. The total heat transfer rate is obtained from energy balance of the fluid between inlet and outlet in the micro-channels as heat gained,

$$Q = \dot{m}\, c_p \left(T_{fo} - T_{fi}\right) \qquad (3)$$

The heat flux q" and heat transfer coefficient 'h' are calculated from the total heat transfer rate Q as

$$q'' = \frac{Q}{z2L(W+H)} \qquad (4)$$

$$h = \frac{q''}{T_{wm} - T_{fm}} \qquad (5)$$

The average Nusselt number is evaluated as

$$Nu = \frac{h\, d_{eq}}{k} \qquad (6)$$

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5.1 Results and discussion

The experimental average Nusselt number variation in the present experiment is depicted in figure 5 as a plot of Nusselt number *vs* Reynolds number. In general the data distribution is complex.

$$Nu = 0.00222\,\mathrm{Pr}^{0.4}\,\mathrm{Re}^{1.09} \quad (7)$$

$$Nu = 0.00805\,\mathrm{Re}^{4/5}\,\mathrm{Pr}^{1/3} \quad (8)$$

It is seen that the empirical relations given by equations (7) and (8) have not fit to the present data but be placed on either side. In view of the less experimental data available, at present it is not possible to either evolve a correlation or any supposition on heat transfer in micro-channel.

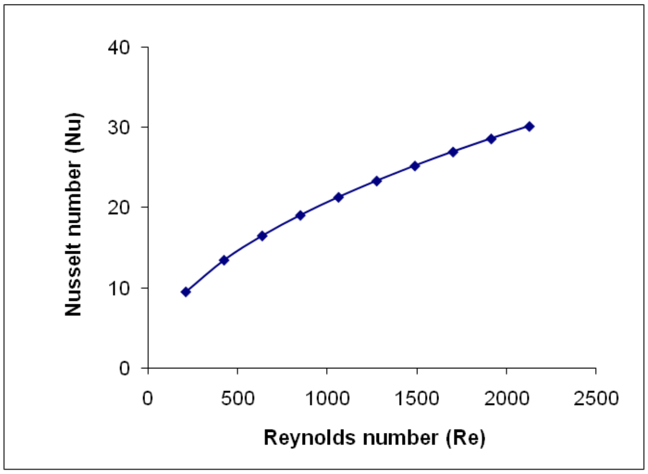

Fig. 5: Plot of Nusselt number Vs Reynolds number

VI. CONCLUSION

The present experiment investigation was carried out in a test section with micro-channel dimensions 1.5 mm deep x 0.75 mm width having each 185 mm long and 47 channels. The working fluid used in this experiment is methanol. Hydraulic diameter and aspect ratio are an important in micro-channel plate design. Hence we achieved by micro-channel design calculation for present study. In friction characteristics, pressure drop and flow rate are used to evaluate friction factor in the micro-channel. A plot of f vs. Re is obtained. The results have shown that the friction factor is higher than that of the conventional channels for laminar flow. More experiments and accurate results are required to identify the zone of transition in the case of micro-channel. In heat transfer characteristics, laminar data indicates that behavior in micro-channel is as normally sized channels and behaves with less pressure drop than that of smooth conventional tube flow.

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