A REVIEW ON CFD ANALYSIS OF MULTIPORT MINICHANNEL HEAT EXCHANGER USING WATER AS A WORKING FLUID

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ABSTRACT

In the conventional heat exchangers, pipes are larger in size which makes heat exchanger bulky. But in some typical applications such as closed loop gas turbine heat exchangers, cryogenic applications, heat exchangers used in PWR power plants, nuclear submarines, etc., size and weight are critical design constraints on the heat exchanger. Also for high pressure applications tubes are subjected to high bending stresses. To overcome these difficulties, compact heat exchangers can be employed. Mini channels heat exchanger is a type of compact heat exchanger in which mini channels are machined on metal plates and then such plates are bonded together. Such an arrangement provides high strength so that it can be used for high pressure applications. It has been observed that in mini channels, convective heat transfer coefficient is more than the tubes used in conventional heat exchangers. Hence, the length for same heat transfer is greatly reduced which results in reduced overall size and weight of the heat exchanger. Electronic device are in heavy demand for computer processor applications and generate large amount of heat. These high power device can be cooled off very effectively by either liquid or gas coolant flowing through micro or mini channels. Continuous research work is ongoing for developing high speed processor which generate high amount of heat. Cooling of such particular systems requires high amount of mass flow rate and compactness is also required. This compact heat exchanger can be used for cooling purpose of electronics device like silicon chip which would be used for microprocessor.

Keyword: - *CFD, Minichannel, Heat exchanger*

1. INTRODUCTION

Fluid flow inside the channel is heart of many natural and manmade systems. Heat and mass transfer is accomplished across the channel walls in biological system, such as brain, lungs, kidneys, intestines, blood vessels, etc., as well as many manmade systems, such as heat exchanger, nuclear reactor, desalination units, air separation units, etc. With the advancements in computing technology in the past few year decades, electronics have become faster, smaller and more powerful. This results in ever increasing heat generation rate from electronic devices. In most case, the chips are cooled through forced air flow. However, when dealing with components that contain billions of transistors working at high frequency, the temperature can reach a critical level where standard cooling methods are not sufficient.

In addition to high performance electronic chips, diode arrays and high energy mirrors. A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact [1]. In heat exchanges, there are usually no external heat and work interactions. Typical applications involve heating or cooling of fluid stream of concern and evaporation or condensation of single- or multi-component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperation. Common examples of heat exchanger are shell- and tube exchanger, automobile radiators, condensers, evaporators, air pre-heaters, and cooling towers.

1.1 Importance of Minichannel Heat Exchanger

Small channel diameters are at the heart of all biological systems. Fluid flow and mass transfer in the human body, for example, utilize the high heat and mass transfer coefficients associated with micro channels. Following nature's lead, many heat transfer devices are utilizing micro-channels in emerging novel applications, such as high heat flux cooling of lasers and digital micro-processors. Fig. 1 shows some key biological systems along with the progression of heat exchanger technology toward the micro scale arena. [2]

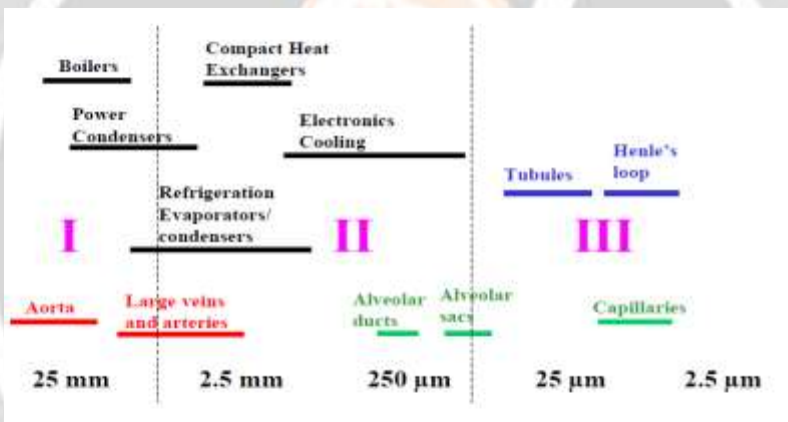

Fig -1: Ranges of channel diameters employed in various applications [2]

1.2 Kandlikar and Grande Channels Classification Scheme [2]

- Conventional Channels $D_h > 3$ mm
- Minichannels 200 µm $< D_h \leq 3$ mm
- Microchannels 10 µm $< D_h \leq 200$ µm
- Transitional Microchannels 1 µm $< D_h \leq 10$ µm
- Transitional Nanochannels 0.1 µm $< D_h \leq 1$ µm
- Molecular Nanochannels $D_h \leq 0.1$ µm

1.3 Construction of Multiport Minichannel Heat Exchanger

Multiport minichannel heat exchangers are usually built of thin plate. Minichannels are machined on surface of the plate by means of micro-fabrication technologies. Cold& hot plates are placed one over one such a way that C-H-C configuration is made so hot water gets cool faster & type of flow is counter flow. Total number of cold plates and hot plates are six & three respectively and top most plate is fixed plate. Material of plate is copper and working fluid is water. Computational model of heat exchanger are shown in Fig. 2.

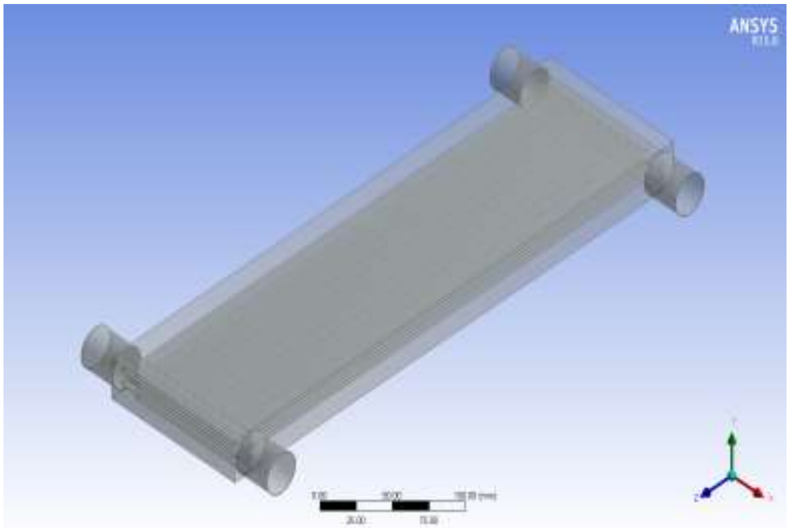

Fig -2: 3D Model of multiport minichannel heat exchanger

2. LITRETURE REVIEW

Nizar Ahammed et al. [3] has performed experiment on thermoelectric cooling of electronic devices with nanofluid in a multiport minichannel heat exchanger. In this study the performance of thermoelectric cooling of electronic devices with nanofluid in a multiport minichannel heat exchanger is experimentally investigated. The power transistor in the circuit board usually operates with the electric power ranging from 20W to 400W which is considered as the input power to the TEC. The aluminum oxide (Al_2O_3)–water nanofluid with volume concentrations of 0.1% and 0.2% is used as the coolant to remove the heat from the hot side of the TEC. The Reynolds number is varied from 200 to 1000.

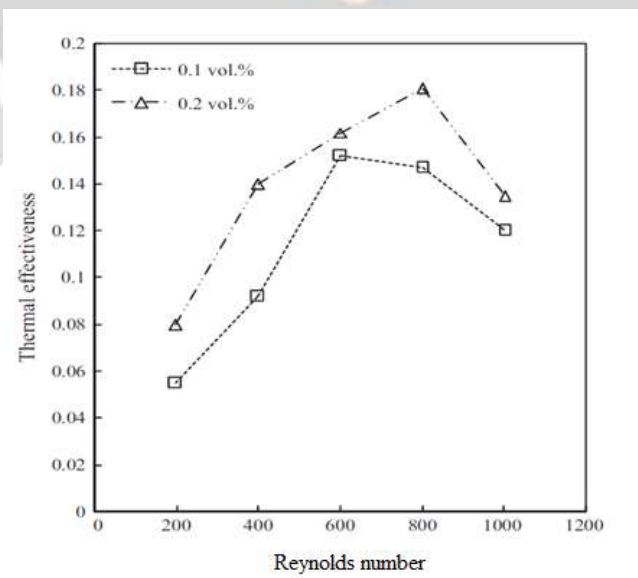

Fig -3: Thermal effectiveness as a function of Reynolds number [3]

The thermal effectiveness of the cooling system increases with increase in volume concentration as shown in Fig. 3 which makes the nanofluids as a promising coolant for electronic cooling applications.

Thanhtrung Dang et al. [4] in 2011 has done their experimental work on the effects of configurations on the performance of microchannel counter-flow heat exchangers. In this work the influences of configurations on the performance of microchannel heat exchangers were studied experimentally. The parameters associated with geometrical configuration consist of inlet/outlet locations.(1) case no.1 is for the case of increasing the inlet temperature of the hot side: the inlet temperature and the mass flow rate at the cold side were fixed at 22.5ºC and 0.2135 g/s respectively, at the hot side the mass flow rates were fixed at 0.2308 g/s and the inlet temperature were varying from 45 to 70 ºC (2) case no. 2 is for the case of increasing the mass flow rate of the cold side: the inlet temperature and the mass flow rate at the hot side were fixed at 70 ºC and 0.2308 g/s respectively, at the cold side the inlet temperature were fixed at 22.5 ºC and the mass flow rates were varying from 0.2135 to 0.401 g/s.

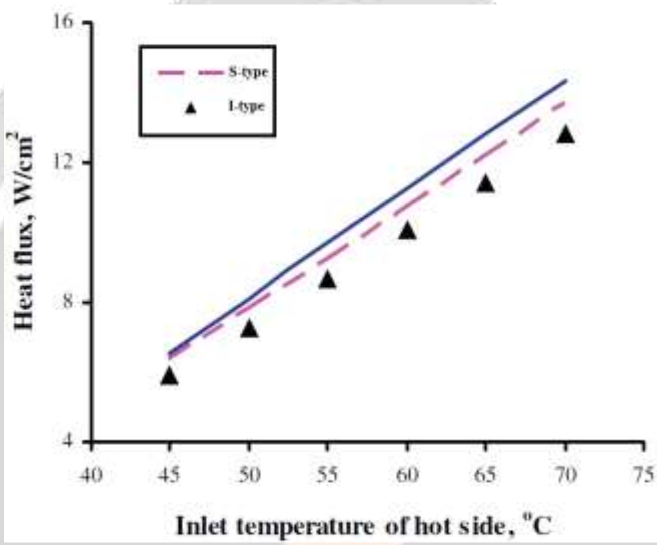

Fig -4: Heat flux versus inlet temperature of hot side [4]

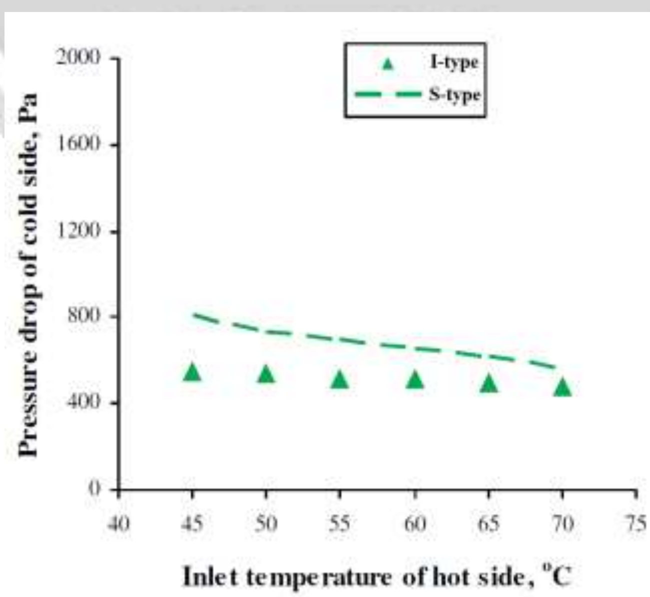

Fig -5: Pressure drop of cold side versus inlet temperature of hot side [4]

Regarding the effects of inlet/outlet locations, for two types (I-type and S-type) of the microchannel heat exchangers, the heat flux obtained from the S-type are higher than those from the I-type (as shown in Fig. 4) even though the performance indexes of both heat exchangers are essentially the same. The lowest pressure drop of 506 Pa was achieved for the heat exchanger with the I-type, as compared to those with the S-type as shown in Fig. 5.

Jyh-tong Teng et al. [5] has performed experiment on effect of flow arrangement on the heat transfer behaviors of a microchannel heat exchanger. In this study the results were obtained by both numerical simulations and experimental data. For the experiments carried out in this study, the inlet temperature and the mass flow rate of the cold side were fixed at 22.5 ºC and 0.2043 g/s, respectively. For the hot side, the mass flow rate was fixed at 0.2321 g/s and the inlet temperatures were varying from 45 to 70 ºC.

The results obtained from this experiment indicate that heat flux obtained from the counter-flow arrangement is always higher than that obtained from the parallel-flow one: the value obtained from the counter-flow is 1.1 to 1.2 times of that obtained from the parallel-flow. For the case of the counter-flow, the experimental results indicated that the total heat flux of 17.81 W/cm2 was achieved for water from the hot side of the device having the inlet temperature of 70 ºC and flow rate of 0.2321 g/s and for water from the cold side having the inlet temperature of 22.5 ºC and flow rate of 0.401 g/s as shown in Fig. 6 & 7.

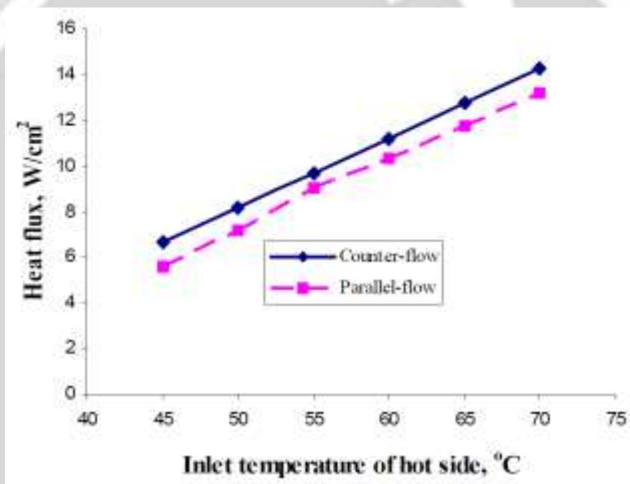

Fig -6: A comparison between counter- and parallel-flow cases for heat flux [5]

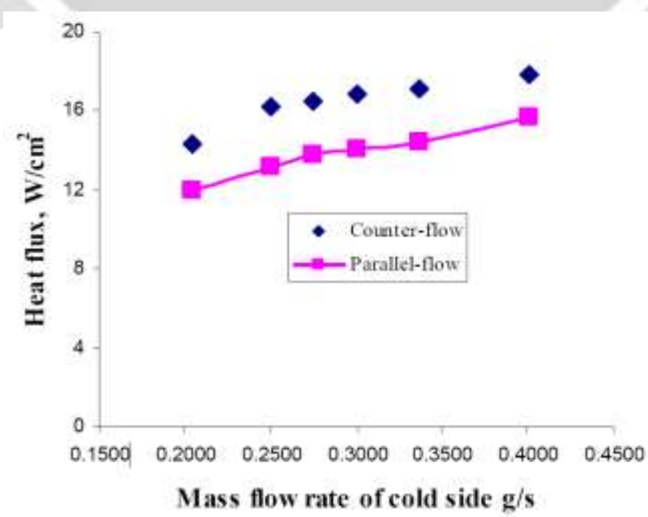

Fig -7: A relationship between heat flux and mass flow rates of the cold side [5]

Reiyu Chein et al. [6] has done their research work on numerical study of the inlet/outlet arrangement effect on microchannel heat sink performance. In this study, fluid flow and heat transfer in microchannel heat sinks are numerically investigated. The three-dimensional governing equations for both fluid flow and heat transfer are solved using the finite volume scheme. The computational domain is taken as the entire heat sink including the inlet/outlet ports, inlet/outlet plenums, and microchannels. The heat sink material is silicon and the working fluid is deionized water. The particular focus of this study is the inlet/outlet effects on the fluid flow and heat transfer inside the heat sinks. The microchannel heat sinks with various inlet/outlet arrangements are investigated in this study. Six types of micro channel heat sink D-, N-, S-, U-, I-type and V-type are used for investigation as shown in Fig. 8. All of the geometric dimensions of these heat sinks are the same except the inlet/outlet locations.

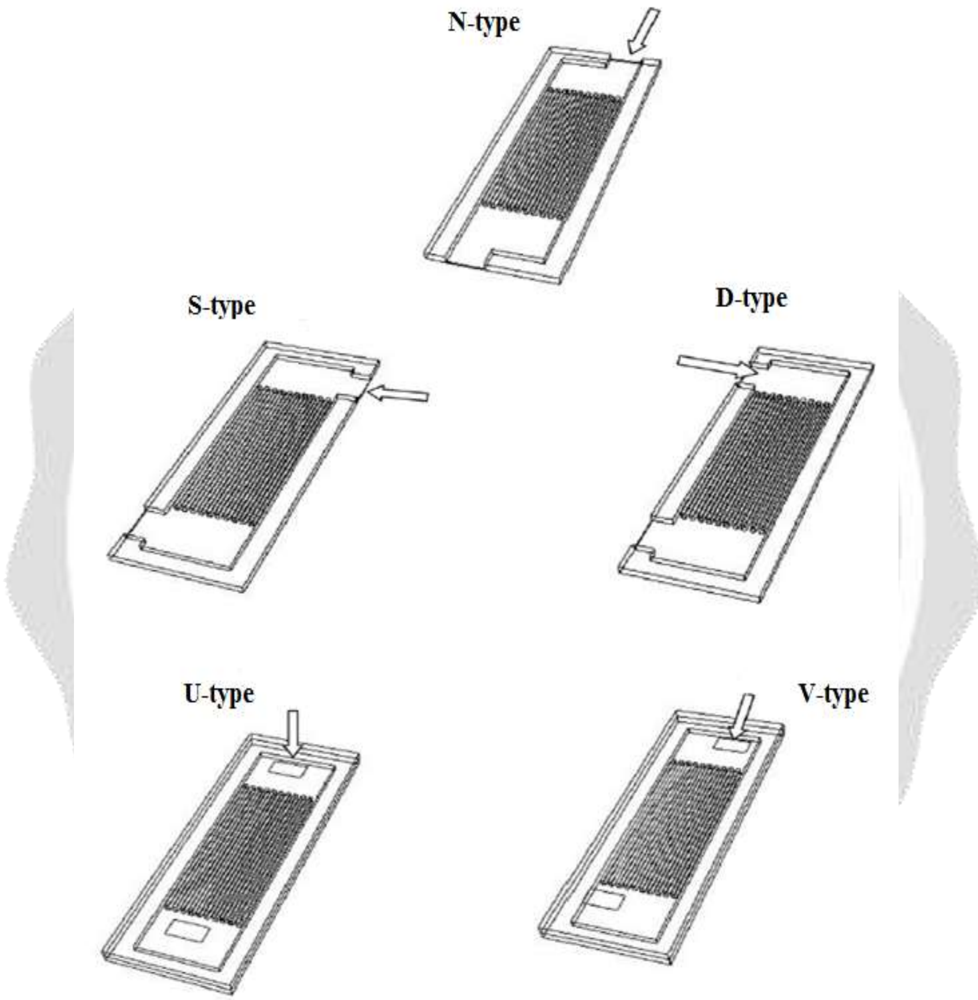

Fig -8: Geometric configurations of D-, N-, S-, U-, and V-type microchannel heat sinks [6]

The results obtained from this research work indicates that for the heat sinks with horizontally fluid supply and collection, i.e., the I-, N-, D-, and S-type heat sinks, the velocity maldistribution is more serious than heat sinks with vertically fluid supply and collection, i.e., the U- and V-type heat sinks. Because of velocity maldistribution, the flow rate in each heat sink channel is different. As a result, temperature nonuniformity is more serious in the heat sinks with horizontally fluid supply and collection. Using the overall heat transfer coefficient to evaluate the heat sink performance, it is found that the V-type heat sink has the best performance among the heat sinks studied as shown in Fig. 9.

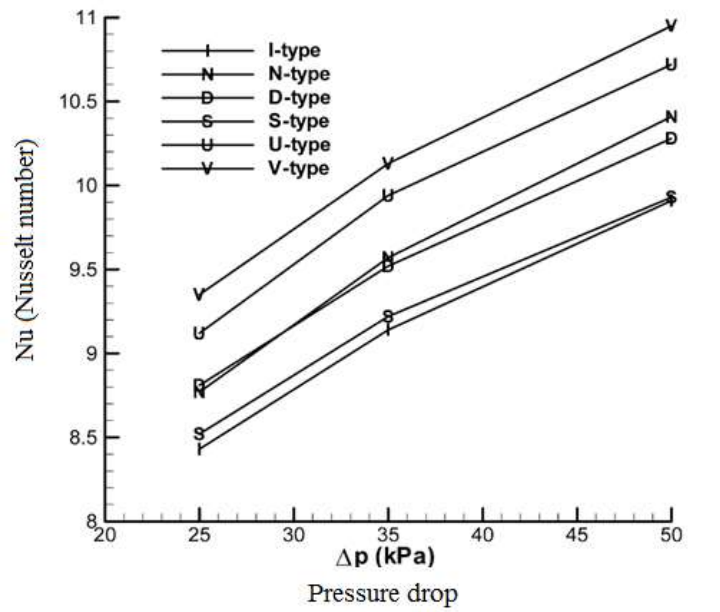

Fig -9: Overall heat transfer coefficients of microchannel heat sink as a function of pressure drop [6]

Nguyen Ba Chien et al. [7] has done their research works on convective heat transfer characteristics of single phase liquid in multiport minichannel tube: experiment and CFD simulation. This study demonstrated the single phase boiling heat transfer of water in horizontal multiport minichannels. The experimental data were observed in aluminum tube of 7.9 x 2.5 mm (width x high) with 7 rectangular channels and the length of 500 mm, the Reynolds number of 1400 – 4200, and heat fluxes of 3 – 6 kW/m^2. The detail setup of test section is shown in Fig. 10.

The result shows that the frictional factor is slightly higher for lower heat flux while the Nusselt number is higher with higher heat flux. Moreover, the transition of fractional factor was observer when the Re > 3000. Fig. 11 depicts the mean Nusselt number with non-dimensional axial length x*. The Nusselt number is high when x* < 0.06 and decrease and keep constantly as theory. The trend also shows that the Nusselt increase with the increasing of heat flux.

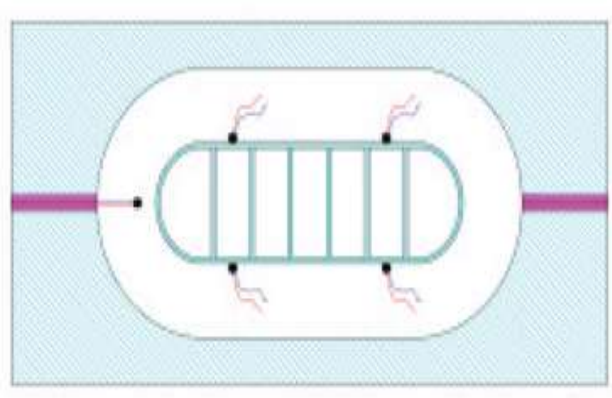

Fig -10: Test section [7]

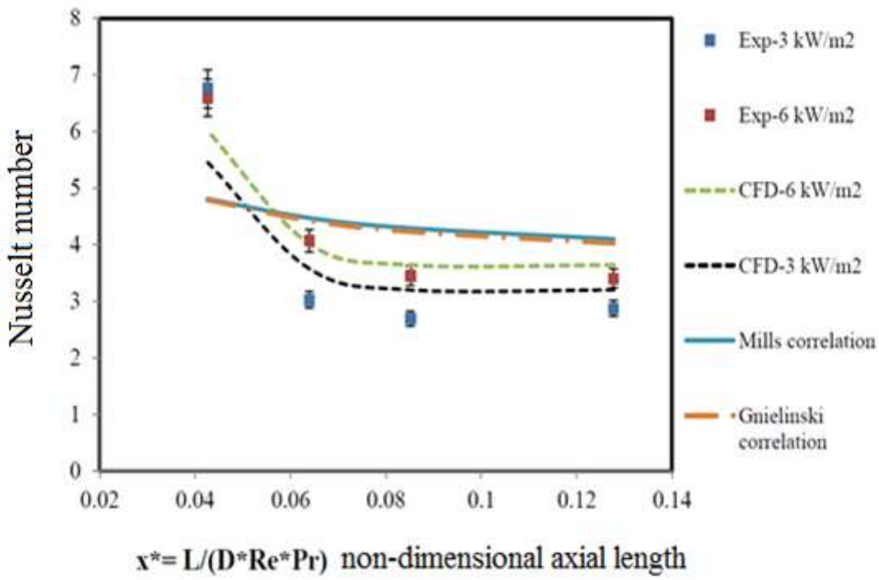

Fig -11: Variation of Nusselt number with non-dimensional axial length x* [7]

Somchaiet al. [8] has performed experiment on flow boiling pressure drop of R134a in the counter flow multiport mini channel heat exchangers. In the present study, the pressure drop characteristics during the boiling of R134a as it flows through the multiport minichannel heat exchangers are presented. The heat exchangers are counter flow tube in tube. The refrigerant flow runs through the inner tube, while the hot water flows through the 25.4 mm round tube at outer edge of the heat exchanger. Two inner test sections are made from aluminium tubing with hydraulic diameters of 1.1 mm for 14 channels and 1.2 mm for eight channels. The experiments were carried out at mass fluxes ranging from 350 to 980 kg/(mm^2 s), heat fluxes ranging from 18 to 80 kW/m^2 and saturation pressures of 4, 5 and 6 bar, at constant inlet quality of 0.05. The complete schematic diagram of the test section is shown in Fig. 12.

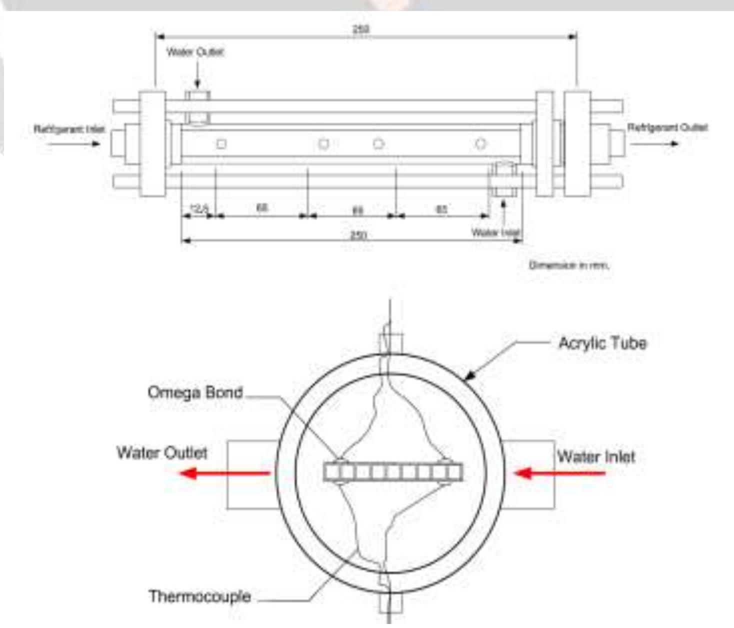

Fig -12: Schematic diagram of the test section [8]

Finally conclusion obtained from this experiment indicates that by comparisons of the frictional pressure drop of two types of heat exchange inner tubes, the frictional pressure drops of tube No. 1 are lower than those of tube No. 2 (i.e. approximately 10–20%) and frictional pressure gradient increases with increase in heat flux as shown in Fig. 13.

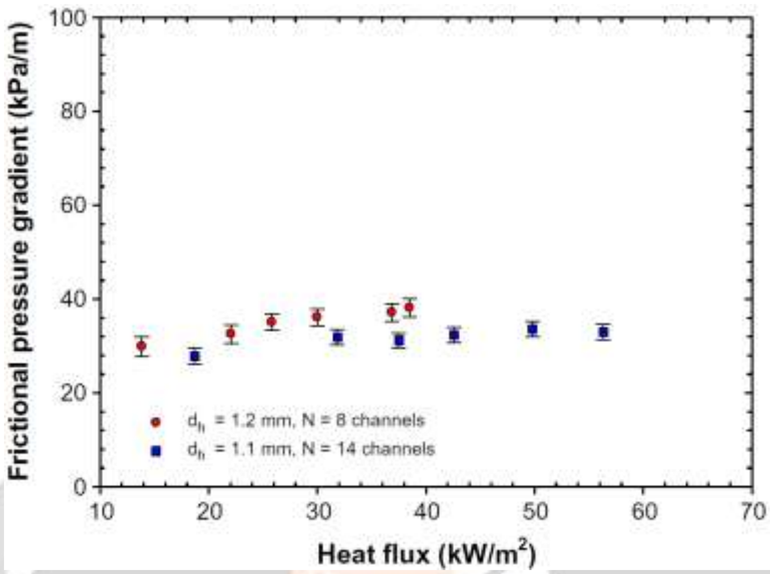

Fig -13: Frictional pressure gradient as a function of heat flux for different numbers of channels [8]

3. CONCLUSIONS

Performance of the minichannel heat exchanger that associated with the pressure drop and heat transfer rate is affected by the following parameters:

- Material of heat exchanger
- Working fluid
- Inlet / outlet location of both hot & cold fluid
- Flow arrangement
- Configuration of plates
- Number of plates
- Operating parameters

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