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Research Article

Performance Evaluation Of Flat Face Heat Exchanger With FDM Printed Micro-Channel Fin Holders

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ARTICLE INFO

ABSTRACT

Automobile engine cooling in case of two-wheeler vehicles is conventionally done using air cooling method, however, with the introduction of superbikes and motorcycles with engines larger than 200 cc, it was discovered that an additional approach, water cooling, was required to improve cooling efficacy. Traditional water coolers use a radiator-style setup that takes up a lot of room, volume, and weight. In an attempt to improve the performance of the radiator certain design changes are proposed through application of the FDM printed micro-channel fin holders and in this paper the flat face heat exchanger performance is evaluated. The flat face micro channel heat exchanger is made up of a brass hollow tube that is attached to the heat exchanger's surface and through which the hot water passes. This hollow tube makes touch with bent brass fins housed in an FDM (fused deposition technique printed) holder's micro-channel staggered array of holder slots. The fins are arranged in such a way that the heat exchanger has the most surface area in the least amount of space. The paper aims at comprehensive test and trial on the flat face heat exchangers that have been fabricated and testing has been done to evaluate performance parameters of the heat exchanger. As the temperature gradient grows, the overall heat transfer coefficient rises as a result of lower pressures and higher temperatures.

Keywords: Engine cooling, minimum air resistance, Flat faces, fused deposition method, Micro-channel fin holder.

Abbreviations and Nomenclatures

FMD	Fused Deposition Method
MCHX	Micro channel heat exchanger
MCHS	Micro channel heat sink
ΔT	Temperature Difference
3D	3 dimensional
A	Area
u	Overall heat transfer coefficient
cc	Cubic centimetre

1. Introduction

In an attempt to improve the performance of the radiator certain design changes are proposed through application of the FDM printed micro-channel fin holders. in this paper the flat face heat exchanger performance is evaluated. The flat face micro channel heat exchanger is made up of a brass hollow tube that is attached to the heat exchanger's surface and through which hot water passes. In an FDM (fused deposition technique printed) holder, this hollow tube is in contact with bent brass fins fastened onto a micro-channel staggered array of holder slots. The fins are arranged in such a way that the heat exchanger has the most surface area in the smallest amount of space.

[1] The thermal conductivity of the material with which they are printed is not the only limitation on the performance of 3D printed heat exchangers. It's important to work on increasing the printability of tiny

features and thin walls at the same time. The fundamentals of fluid flow in 3D printed, open micro channels created using fused deposition modelling (FDM) are explored.

[2] Printed micro channels are used in microfluidic devices and have potential applications in embedding electronics in plastic substrates. We also analyse the influence of print orientation on capillary flow, where micro channels printed in specific orientations are shown to exhibit different flow dynamics.

[3] Silver salt reduction on gold nanoparticle seeds by sodium borohydride was the basis for the design and construction of the molten modelling-based deposition-printed microfluid device for the production of core and metal-shell Au @ Ag nanoparticles. Fused Deposit Modelling, the most sophisticated 3D printing method, has been utilised to demonstrate that core-shell nanoparticles may be manufactured utilising microfluidic chips at minimal cost and in a short amount of time. We used spectroscopy and electron microscopy to validate the core-shell structure. Nanoparticles with core and shell are inserted into the modified carbon paste electrode to absorb the voltmeter for thiocyanate ions.

[4] It has been decided to use Pumping Power Flow as a new microchannel metric to compare the performance of normal and upgraded microchannels. When calculating the performance coefficient to show an increase in heat transfer, pumping power flux is combined with heat flux. For the same flow conditions, improved micro-channels provide a considerably higher COP. As a result, the better heat transmission outweighs the extra stress reduction generated by the improved microchannels.

[5] In microelectronics and high heat flux refrigeration, microchannels are used extensively. This study proposes a roadmap for improving thermal and manufacturing features of microchannels. Waterways with hydraulic dimensions of 10 to 200 m or less are known as microchannels. As a result of this pioneering effort, a wide range of sophisticated microfabrication methods have been created. Manufacturing technology is evaluated and classified, and numerous novel options for micro-channel construction are presented as results. Using current manufacturing methods, it is also feasible to create flow lanes with hydraulic diameters inside a micro-channel system.

[6] The performance of micro-channel heat exchangers with two stainless steel plates was examined experimentally in this research. Experiments suggest that MCHE may be used for energy recovery in integrated microstructure systems for thermal and chemical processes via the dehydration of ethanol.

[7] This research will help address present issues in the design, manufacture, and application of heat transfer structures using micro-channel heat exchangers, and it is expected that the technology will be extensively employed in the near future. We provide here a concise review of microchannel heat transfer and fluid dynamics. MCHX's benefits, drawbacks, and alternatives are explored in detail.

[8] On a PCHE made with the aid of micro photonic etching and diffusion bonding, we ran performance tests to see how well it worked. 6.8 percent greater heat transfer rate and 10 percent - 15 percent better heat transfer performance was reported in the resistance structure, respectively. The average heat transfer rate, heat transfer performance, and pressure drop all rose with Reynolds number. Heat transfer is not affected; however, pressure drop is marginally reduced within the investigated experimental range when input temperature is raised.

[9] Zigzag microstructures are excellent flow enhancers for passive heat transfer in microchannels because they easily induce helical fluid movement. When compared to a typical micro-channel, the heat transmission efficiency is quadrupled. When zigzag flow stimuli are present, we measure the drop in pressure that results. When considering the non-dimensional merit of heat transport, as well as the inverse rise of pressure decrease. Both computational and experimental approaches are used. When it comes to micro-channel heat sinks, it has been discovered that channel depth has a big impact on heat transfer efficiency The heat fluxes fell from 31.8 W / cm2 to 15.8 W / cm2 and the heat transfer rate rose from 113.3 W to 143.8 W when the channel depth was raised from 200 m to 900 m. Numbers and experiments agreeable, maximum error less than 6 percent.

[10] We created a new refrigerant after studying the old one. Inside the nozzle, two flat plates are inserted. Because of this, the speed and pressure of the nozzle drop. Temperature is closely related to pressure. Implementation/Improvement Prospects: In the radiator, this results in a drop in coolant heat. Coolant efficiency was improved by 5.37 percent using this new procedure rather of the conventional.

[11] Research has been done on a spiral radiator with aluminium perimeter wings as a test subject. On the other hand, coolant has been studied numerically. The heat transfer rate, Reynolds number, Nusselt number, capacity, total heat transfer coefficient, and average temperature difference of heat exchangers were analysed. According to the numerical simulation findings, the experimental results are in agreement. It was found that with the same water input temperature of 80 C, the helical coolant arrangement had an enhanced temperature decrease compared to the multi-pass coolant configuration.

[12] In this research, the radiator heat transfer rate was investigated using a coolant mass flow rate ranging from 4.00 litres per minute to 9.00 litres per minute. Heat transmission via an aqueous CuO nano-liquid coolant was calculated numerically using the Ansys workbench platform. CuO's heat transfer ability improves as the volume fraction of CuO rises, although an increase in pumping power may be noted as well. The appropriate length for improving heat transfer performance without compromising pumping power was discovered through experimental method design.

[13] The micro channel heat exchanger's compactness, reduction in weight and size along with heat transfer enhancement has showcased their promising and preferable choice in waste heat recovery and other

applications. Silicon carbide and alumina were found to be the cheaper materials than tungsten carbide and aluminium nitride. Their thermal and chemical stability for the extended period made them the best suited materials for high-temperature applications.

[14] The fabrication of a PDMS micro channel using a 3D printed mould technique has been successfully demonstrated and proven to be a viable technique. It took less than four hours to print 11 micro channel moulds. This includes a rough surface PDMS micro channel was produced as proven from the microscopic images and the large percentage differences between the replicated PDMS micro channel and drawn micro channel due to the spreading of the droplet

[15] The authors in their paper bring forth the parameters influencing the radiator performance and discuss various previous research on experimental, Numerical and CFD analysis of automobile radiators.

[16] The authors in this book focus on the recent advancement in micro-channel heat and mass exchangers, especially on the fundamental research results of practical significance. Leap advancements in micro-deformation, micro-machining techniques are seen to reduce the cost of fabrication at the same time improving the reliability of micro-channel systems.

[17] The authors developed a cylindrical micro-channel heat sink with inclined wings for the covered water cover, which reshaped the border layer at the top edges of the wings There was an overall decline in layer thickness, but the flow continued to evolve. Step. The authors performed an experimental and thermal performance analysis of the developed unit.

[18] Ethylene glycol flowing through the level containers of a vehicle coolant and 3D laminar motion and hotness move with two distinct nano-fluids, Al_2O_3 and CuO in a combination of water, have been concentrated mathematically to assess their predominance over base liquid. The hotness move coefficient and the nasalt number relationship of radiator level cylinders have better outcomes contrasted with the hotness exchanger heat structure. In the current work, 3D examination is utilized to concentrate on the cooling execution of copper-ethylene glycol nanofluid through the level containers of a vehicle coolant to survey its predominance over the base liquid. Mathematical recreation is performed by settling the laminar stream constantly, addressing the conditions of impetus and power.

[19] In this paper, the heat transfer and pressure reduction properties of distilled water and nano-liquid copper oxide based on distilled water flowing in a parallel circular tube under constant heat flow conditions are studied. It has been found that only certain properties are improved by a circular tube heat exchanger.

[20] In this paper, the implementation of water-based nano-TiO_2 and ethylene glycol as cryogenic coolant is experimentally solved. The heat transfer coefficient of the TiO_2 / EG-water nano-colour was estimated and compared with the data obtained experimentally. A flat plate heat exchanger with nano-liquid has been found to greatly enhance heat transfer efficiencies.

[21] Researchers are conducting a study in which the entire factor experiment and the accuracy of measurements of samples generated are evaluated. Depending on the model's form and proportions, there are two options available. Various 3D printer settings are used to process digital models. An estimation of the measured values is made using statistical techniques.

Based on the analysis above the research gap in optimizing micro heat sinks encompasses the exploration of novel coolants and materials, innovative design geometries, advanced modelling and optimization techniques, and a deeper understanding of thermal phenomena to achieve superior thermal management in miniaturized automobile parts, 3D printed fin holder needs to be developed to fulfil complex geometry with desire area enhancement. flat plate heat exchanger micro-channels with 3d printed fin holder for cooling performance was designed in this paper. Deionized engine water was selected as coolant, considering the various flow conditions, Experiments were carried out to investigate the heat transfer characteristics as effectiveness, overall heat transfer coefficient and mass flow rate. Finally, the fins are arranged in such a way that the heat exchanger has the most surface area in the least amount of space.

2. Methodology

Methodology for the proposed paper work is given in following flowchart.

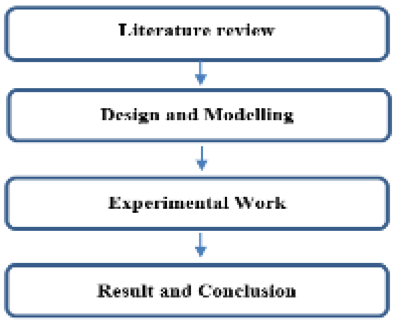


Figure. 1. Methodology for the proposed work

3. Design and Manufacturing:

Material Selection:
The copper and aluminum-gallium nitride will be use as workpiece material to study and investigation.

Material Properties:

Table no.1 Material properties of microchannel test section

Sr. No	Properties	Aluminum	Copper	Insulation material
1	Thermal conductivity, k (W/mK)	202	398	0.2
2	Density, ρ (kg/m^3)	2710	8850	300
3	Specific heat, Cp (J/kgK)	903	390	203

Table no.2 Properties of water and Air

Fluids	Thermal Conductivity	Specific Heat Capacity	Density	Viscosity
	K (W/m K)	Cp (J/kg K)	(kg/m^3)	kg/(m·s)
Water	0.6	4182	1000	0.001003
Air	0.024	1.012	1.225	1.81×10^{-5}

A. Manufacturing of Flat micro-channel Fin headers:
In the manufacturing technique of Flat shape micro-channel heat exchanger using 3-D printed headers, we use the following method for manufacture this product the work flow is shown in figure below.

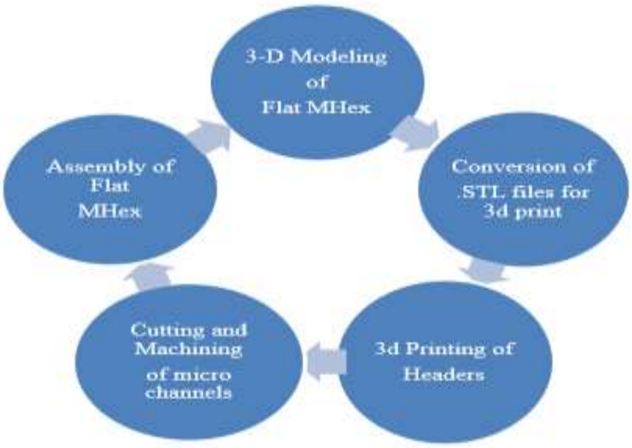


Fig.no.2 Manufacturing steps of 3-D Flat MCHX Fin holder

3-D Modelling of the Flat Micro-channel Heat exchanger (Schematic)

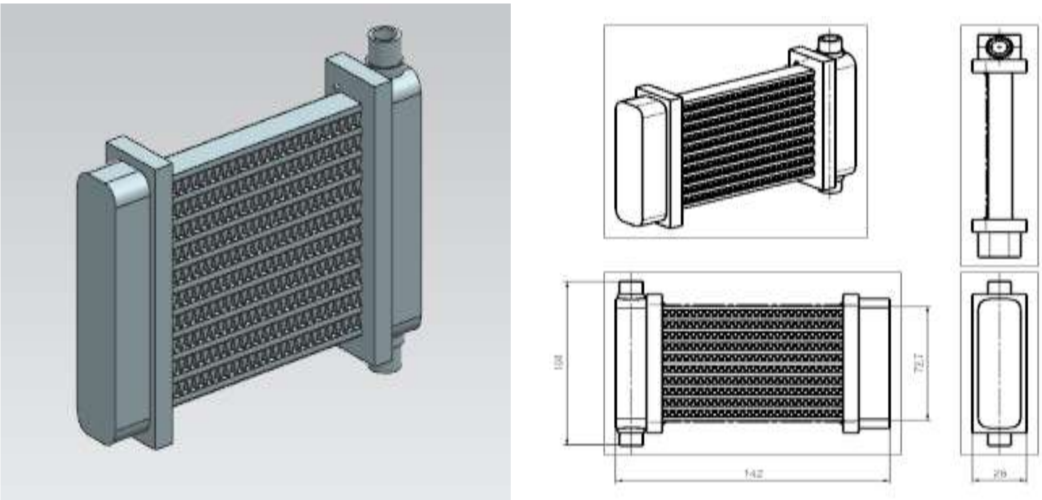


Fig.no.3 (a) 3-D Modelling (b) Dawning details of Flat face MCHE

The 3-d modelling of the flat shape micro-channel heat exchanger was done using solid modelling tool. Unigraphics NX -8. The 3-D model of the parts was further exported as the .stl files as input to the 3-Dprinting software UP mini.

3-D printing of the parts of the Flat shape micro-channel heat exchanger

a. Header **b. Partition**

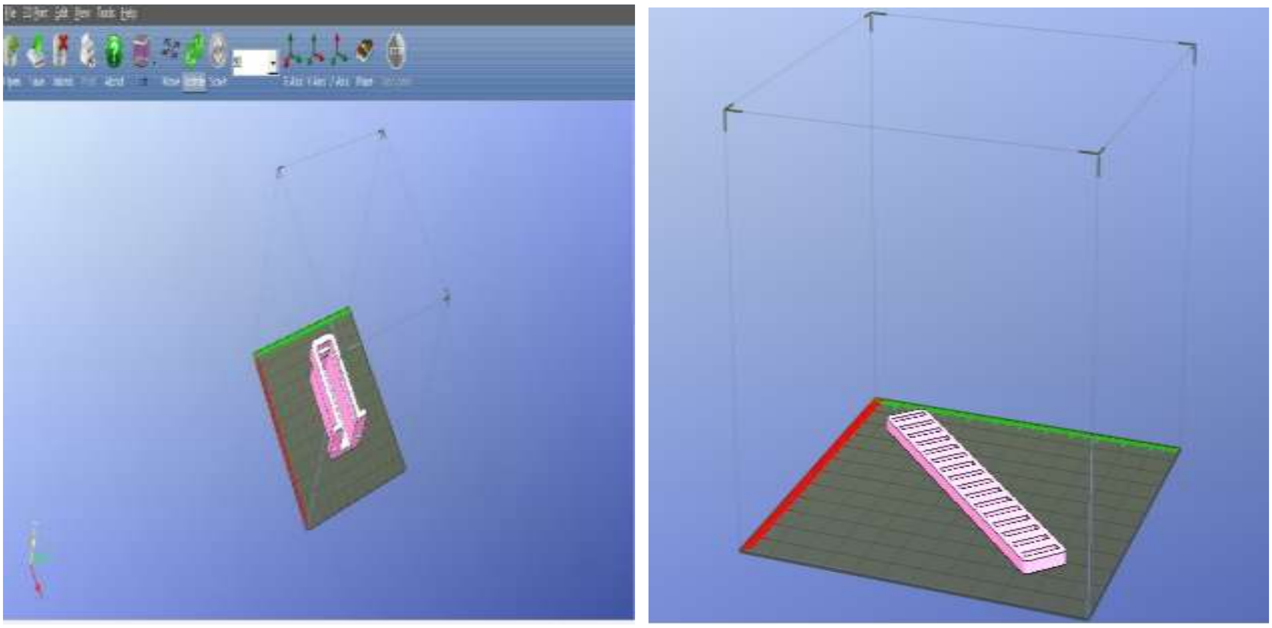


Fig.no.4 (a) Header of 3-D printing of the parts (b) Partition of 3-D printing of the parts

a. Header:

The. stl file was used for the 3-d printing of the headers of the micro-channel heat exchanger the GUI of the Up-mini Software is shown. Appropriate printing parameters were set and the 3-D printing was done.

b. Partition:

The. stl file was used for the 3-d printing of the partition of the micro-channel heat exchanger the GUI of the Up-mini Software is shown. Appropriate printing parameters were set and the 3-D printing was done.

Fig.no.5 (a) flat plate heat exchanger (b) 3D printed micro-channel fin holder

4. Experimental work: experimental test rig is given below.

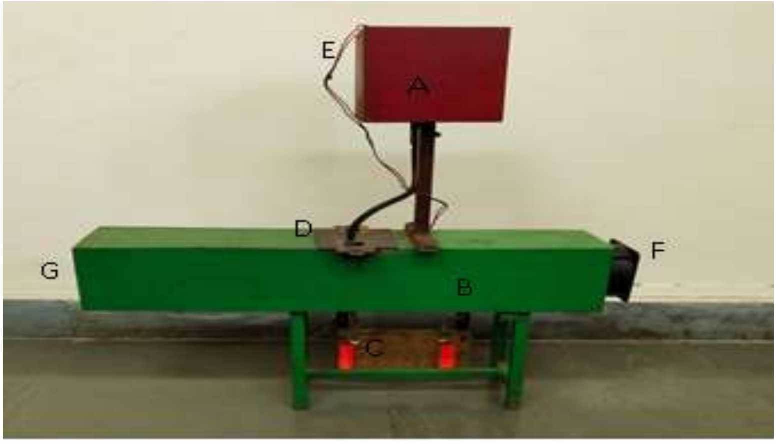


Fig.no. 6. Experimental test Rig

Digital Temperature Sensor

Fig. no. 7. Temperature Sensor with Mass flow and temperature measurement set up

A. Procedure of Trial:

1. Start the heater and let the temperature of water in overhead tank reach a suitable temperature say 90°
2. Start the flow control valve for hot water and let reach steady state
3. Start the air blow
4. Set air speed to stage-1
5. Note the flow rate and temperature of water using beaker, stopwatch and temperature sensor arrangement.
6. Note the air velocity
7. Check the air inlet's temperature.
8. Check the air inlet's temperature.
9. Switch the air blower to stage-2 and repeat procedure.

B. Observations:

1. Mass Flow Rate of Hot Water in flat shape heat exchanger

Observation Table 01: Mass Flow Rate of Water

Sr. No	Volume in Beaker (ml)	Time (sec)	Mass Flow Rate (kg/sec)
1	50	38	0.001204
2	50	32	0.001431
3	50	27	0.00168
4	50	23	0.001972
5	50	19	0.002309
6	50	15	0.003057

2. Temperature Readings for flat face heat exchanger

Observation table 02: Temperature Readings of Water and Air

Sr. No.	Cold air Inlet Temp. (T_{ci}) °C	Cold air outlet Temp(T_{ce}) °C	ΔTC Air °C	Hot water Inlet Temp. (T_{hi}) °C	Hot water outlet Temp.(T_{he}) °C	ΔTH WATER °C
1	28.6	28.9	0.3	82	76	6
2	28.6	29.5	0.9	82	71.8	10.2
3	28.6	30.2	1.6	82	64.7	17.3
4	28.6	31	2.4	82	60.6	21.4
5	28.6	31.5	2.9	82	56.3	25.7
6.	28.6	32.2	3.6	82	54.5	27.5

Calculation of Heat transfer (Experimentally) through flat heat exchanger $Q_{(flat)}$:

Governing Equation to calculate heat transfer,
$Q_{(flat)}$ Experimental = [U × A× ΔT = m × c × ΔT]

$Q_{(flat)}$ Experimental = 0.864 KJ ------------------ (1)

So, The experimental heat transfer through the heat exchanger = 0.864 KJ

1. Result and Discussion:

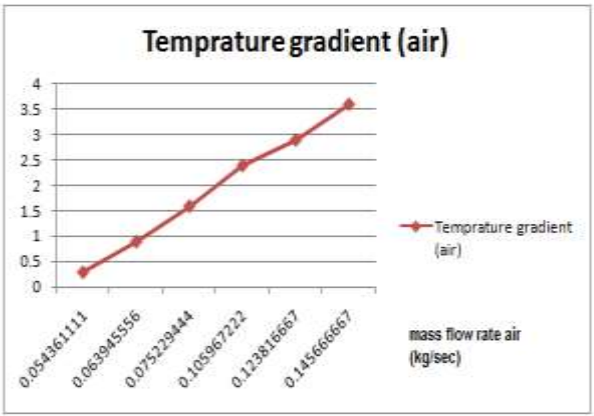
a. Result Table No. 1 (Effectiveness of Flat face Micro channel)

Sr.no.	mCpΔT (Hot Water) kw	mCpΔT (cold Air) kw	u w/ m2k	Effectiveness
1	0.01231	0.0165	291.84	0.0062
2	0.024841	0.058	196.41	0.0124
3	0.049835	0.121	221.99	0.025
4	0.073206	0.256	214.95	0.036
5	0.105171	0.361	258.56	0.053
6	0.143076	0.527	282.43	0.072

b. Result Table No. 2 (pressure drop across micro channel)

Sr. No	Inlet air Velocity	Outlet air Velocity	Pressure drop Across heat exchanger (mm of water)
1	2.3	1.9	0.00976
2	2.71	2.32	0.009278
3	3.19	2.78	0.010254
4	4.49	3.76	0.032507
5	5.25	4.46	0.03807
6	6.18	5.24	0.0539

With reference to result table, we can draw various parameters graphs:
1. Air temperature gradient vs mass flow rate in a flat-face heat exchanger graph
2. Graph of heat transferred to air vs mass flow rate of air in flat face heat exchanger



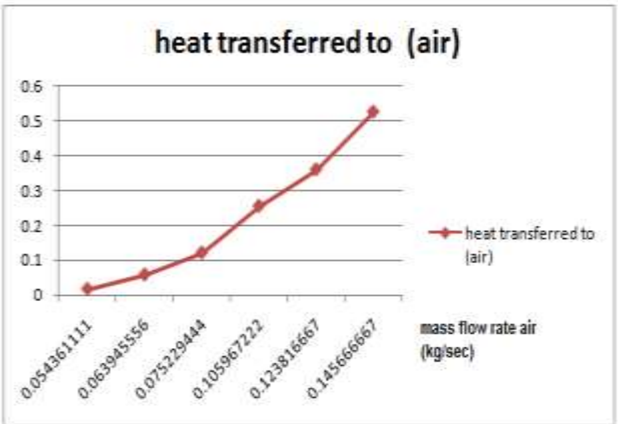
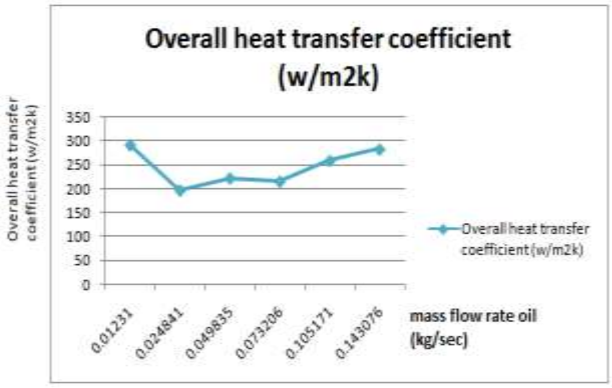


Fig.no. 8 Air temperature gradient vs air mass flow rate
Fig.no. 9 Heat transferred to air vs mass flow rate of air

3. Graph of Overall Heat transfer Coefficient Vs mass flow rate of Air
4. Graph of Effectiveness Vs Mass flow rate of air



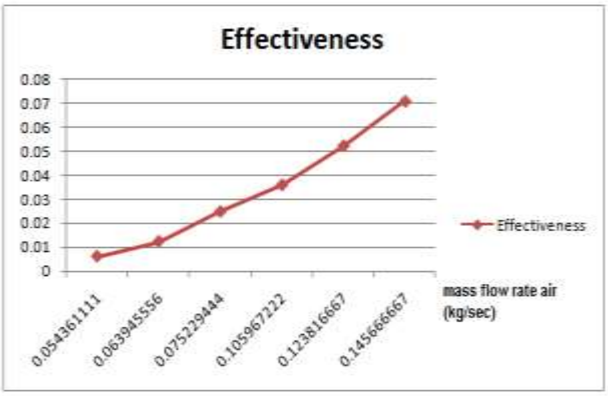


Fig.no. 10 Overall heat transfer coefficient vs. Mass flow rate of water
Fig.no. 11 Effectiveness Vs. Mass flow rate of air

5. Graph of Pressure drop across heat exchanger Vs Air velocity

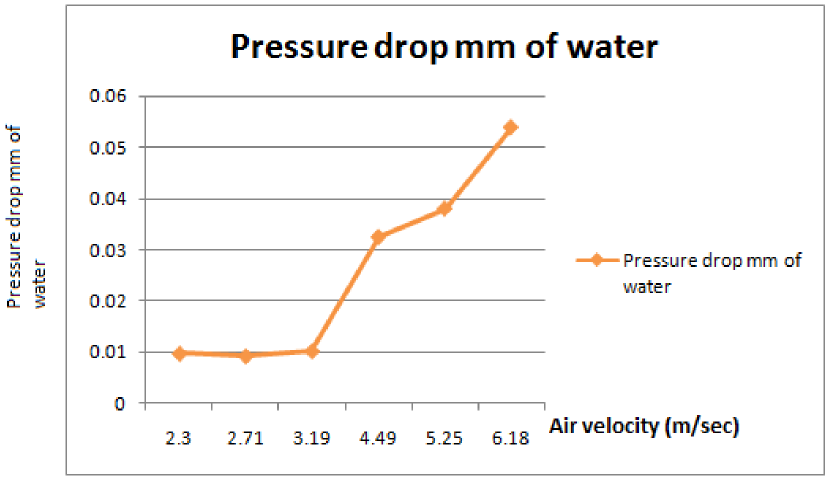


Fig.no. 12. Pressure Drop of water Vs. Air Velocity

1. From Result table no.1, it gives the values of effectiveness of flat face micro channel and overall heat transfer coefficient. It is found that overall heat transfer coefficient and effectiveness increases with increase in mass flow rate of air
2. From the air temperature gradient graph. Note that the flat-faced heat exchanger's air mass flow rate increases the air temperature gradient (Fig. 8), because as more air passes through the heat exchanger, it tends to bend. Increase the heat transferred from the heat exchanger so that the walls of the heat exchanger are also winged so that more heat is transferred, the maximum temperature gradient being 27.5 at the highest flow rate.
3. From Graph of heat transferred to air Vs. mass flow rate of air in flat face heat exchanger **(**figure no.9**),** noted that Heat taken away by the air is seen to increase with mass flow rate of air owing as more air passes through the heat exchanger will elevate the heat carried from the heat exchanger walls and also fins hence more heat is transferred to the air, the maximum heat transferred is seen to be 0.527 kw at the highest flow rate.
4. The total heat transfer coefficient (Fig. 10) is larger with a lower air mass flow rate because the walls are more effective at transferring heat of the heat exchanger tubes are in better contact and the wings transfer heat more easily as they are longer than the water. In contact with the walls, then the heat transfer coefficient is considered to be slightly reduced in total volume but stabilized by the increasing water flow velocity through the tube assemblies and the maximum observed heat transfer coefficient is 282.4 W / m2 K.
5. From the mass air flow rate (Fig. 11), it can be observed that the efficiency is higher with a lower flow rate as the walls of the heat exchanger tubes are in better contact and thus the wings transfer heat more easily as they have longer water time. With respect to the walls, the total heat transfer coefficient decreases slightly, but stabilizes as the water flow velocity increases through the tube assemblies, with a maximum observed heat transfer coefficient of 0.072.

6. From Graph of Pressure drop across heat exchanger Vs. Air velocity (figure no.12), noted that the pressure drop across the heat exchanger is seen to increase with the increase in air velocity and the maximum pressure drop observed is 0.0539 mm of water at stage-6 air velocity 6.18 m/sec.
7. Heat transfer through flat heat exchanger is 0.864 KJ.

Conclusion:

In this paper, a flat face micro-channel heat exchanger made of aluminium for investigating the heat transfer characteristics of micro-channel with 3D printed fin holder was designed and manufactured. The influence of various flow conditions on the cooling performance was studied experimentally. We seen that Effectiveness of flat plate heat exchanger increase with increase in overall hear transfer coefficient. But Pressure drop increases with increase in air velocity. So, pressure drop needs to be reduce by reducing pressure drag on wall surface of heat exchanger. Complex shape design and manufacturing is possible through 3d printing technology.

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