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Research Article

Design And Experimental Investigation Of Curved Face Heat Exchanger With FDM Printed Micro-Channel Fin Holders

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ARTICLE INFO **ABSTRACT**

In this work, we extend our heat transfer performance study on our proposed new and novel 3D printable micro channel fin holder of the heat sinks with geometrically complex structures relative to previously did flat face micro channel heat sink. Cooling of engine components is one of the critical challenges that the automobile industry is facing towards sustainable development. Aiming at lowering the surface temperature of the heat sink to limit thermally induced deformations, curved face channels are employed to improve the thermal and hydraulic performances of a heat sink. Design and experimental approach are carried out to study heat transfer rate, pressure drop, overall heat transfer coefficient parameters and to find out there the effect on curved face the heat sink.

Keywords: water cooling, Pressure drop, Curved face, 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
FMD	Fused Deposition Method
u	Overall heat transfer coefficient
C_P	Specific heat
K	Thermal Conductivity

1. Introduction

Conventional heat sinks come in different geometries such as cylindrical pin fins, strip fins, and plate fins [1]. Their hydraulic and thermal characteristics are well established [3]– [7]. Such heat sinks are manufactured with conventional manufacturing techniques such as die-casting, milling, and extrusion [7]. A new class of heat sinks that is based on cellular materials have been investigated. Cellular structures have shown high potential in enhancing heat dissipation. The high surface-to-volumes ratios that increase the heat transfer area and the tortuous fluid paths that enhance fluid mixing are among the characteristics that rendered cellular structures suitable for thermal management. Cellular structures are classified according to their interconnected network as either stochastic or periodic structures.

[2] 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. 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] Researchers discuss about the topology optimization. They study the relationship between the thermal hydraulic performances and the layout of cooling channels designed by topology optimization from the engineering perspective. Here they discuss about two type of topology optimization.

[4] This study numerically investigated heat transfer and fluid flow characteristics in a novel cylindrical heat sink with helical mini-channels for the laminar flow of fluid with temperature-dependent properties. A finite volume method was employed to obtain the solution of governing equations. The effects of helical angle, channel aspect ratio, and Reynolds number, which were regarded as main parameters, were determined. The overall performance of the heat sink was also analysed on the basis of the thermal performance factor and the augmentation entropy generation number. Results showed that a decrease in the channel helix angle and an increase in the channel aspect ratio and Reynolds number enhance the average heat transfer coefficient and pressure drop in the heat sink. The thermal performance factor and entropy generation minimization method revealed that an aspect ratio of 1.2 enables the best heat sink performance at all helix angles. When the helix angle decreases, performance increases, especially at low aspect ratios.

[5] Various AM processes and materials are available, but their capability to produce features desirable for microchannel heat sinks has received a limited assessment. Following a survey of commercially mature AM techniques, direct metal laser sintering was used in this paper to produce both straight and manifold microchannel designs with hydraulic diameters of 500 μm in an aluminium alloy (AlSi10Mg). Thermal and hydraulic performances were characterized over a range of mass fluxes from 500 to 2000 kg/m 2 s using water as the working fluid. The straight microchannel design allows these experimental results to be directly compared against widely accepted correlations from the literature. New design guidelines are needed to exploit the benefits of AM while avoiding undesired or unanticipated performance impacts.

[6] An approximate theory is derived to compute the thermal resistances of flat plate micro heat exchangers whose surfaces are heated with uniform flux. It is demonstrated that the thermal resistance can be minimized by proper selection of uniform conduit geometry. Further reductions in the maximum heated surface temperature and in the heated surface temperature gradients can be achieved by varying the conduit's cross-sectional dimensions as a function of the axial coordinate. This paper illustrates that a conduit's shape can be customized so as to achieve desired objectives.

[7] A full 3-dimensional (3D) conjugate heat transfer model has been developed to simulate the heat transfer performance of silicon-based, parallel microchannel heat sinks. A semi-normalized 3-dimensional heat transfer model has been developed, validated and used to optimize the geometric structure of these types of micro heat sinks. Under a constant pumping power of 0.05 W for a water-cooled micro heat sink, the optimized geometric parameters of the structure as determined by the model were a pitch of 100 μm, a channel width of 60 μm and a channel depth of about 700 μm. The thermal resistance of this optimized micro heat sink was calculated for different pumping powers based on the full 3D conjugate heat transfer model and compared with the initial experimental results obtained by Tuckerman and Pease in 1981. This comparison indicated that for a given pumping poser, the overall cooling capacity could be enhanced by more than 20% using the optimized spacing and channel dimensions. The overall thermal resistance was 0.068 °C/W for a pumping power of 2 W.

[8] The effect of geometrical parameters on water flow and heat transfer characteristics in microchannels is numerically investigated for Reynolds number range of 100–1000. The three-dimensional steady, laminar flow and heat transfer governing equations are solved using finite volume method. Three different shapes of microchannel heat sinks are investigated in this study which are rectangular, trapezoidal, and triangular. The water flow field and heat transfer phenomena inside each shape of heated microchannels are examined with three different geometrical dimensions. Using the averaged fluid temperature and heat transfer coefficient in each shape of the heat sink to quantify the fluid flow and temperature distributions, it is found that better uniformities in heat transfer coefficient and temperature can be obtained in heat sinks having the smallest hydraulic diameter. It is also inferred that the heat sink having the smallest hydraulic diameter has better performance in terms of pressure drop and friction factor among other heat sinks studied.

[9] In the present study, a novel multi-nozzle micro-channel heat sink (MN-MCHS) was proposed. The channel length, channel aspect ratio, rib width, pumping power, and heat flux were numerically investigated in detail. It was found that the MN-MCHS with a shorter channel length not only could significantly improve the temperature uniformity on the bottom wall and thermodynamic performance index, but it also could significantly reduce the overall thermal resistance. With the decrease in the channel length from 10 mm to 1 mm, the temperature uniformity was enhanced by approximately 10 times, the overall thermal resistance

improved 62% and the pressure drop was reduced approximately 12 times. This structure of MN-MCHS is really a promising structure of MCHS because it can improve thermal performance and reduce the pressure drop by optimizing its geometric dimensions.

[10] A three-dimensional analysis procedure for the thermal performance of a manifold microchannel heat sink has been developed and applied to optimize the heat-sink design. The procedure is robust and the optimal state is reached within six global iterations. Comparing with the comparable traditional microchannel heat sink, the thermal resistance is reduced by more than a half while the temperature uniformity on the heated wall is improved by tenfold. The sensitivity of the thermal performance on each design variable is also examined and presented in the paper. Among various design variables, the channel width and depth are more crucial than others to the heat-sink performance. The optimal dimensions and corresponding thermal resistance have a power-law dependence on the pumping power.

[11] A three-dimensional numerical model is developed and validated to study the effect of geometric parameters such as microchannel depth and width, manifold depth, and manifold inlet and outlet lengths on the performance of a manifold microchannel (MMC) heat sink. The deterministic analysis shows that the heat transfer performance of the MMC heat sink is optimal at a manifold inlet to outlet length ratio of 3. A comparison between the deterministic and probabilistic optimization approaches is presented for the unit-cell model. A probabilistic optimization study is performed for the porous-medium model and the results thus obtained are compared with those of the unit-cell model for a uniform heat flux distribution.

[12] This work presents the experimental design and testing of a two-phase, embedded manifold-microchannel cooler for cooling of high flux electronics. The ultimate goal of this work is to achieve 0.025 cm2-K/W thermal resistance at 1 kW/cm2 heat flux and evaporator exit vapor qualities at or exceeding 90% at less than 10% absolute pressure drop. While the ultimate goal is to obtain a working two-phase embedded cooler, the system was first tested in single-phase mode to validate system performance via comparison of experimentally measured heat transfer coefficient and pressure drop to the values predicted by CFD simulations.

[13] This 38-page document is a part of Wohlers Report 2016-2022 and was created for its readers. The document chronicles the history of additive manufacturing (AM) and 3D printing, beginning with the initial commercialization of stereolithography in 1987 to April 2015. Developments from April 2015 through March 2016 are available in the complete version of the report. An analysis of AM, from the earliest inventions in the 1960s to the 1990s, is included in the final several pages of this document.

[14] This paper reviews recent improvements in additive manufacturing technologies, focusing on those which have the potential to produce and repair metal parts for the aerospace industry. Electron beam melting, selective laser melting and other metal deposition processes, such as wire and arc additive manufacturing, are presently regarded as the best candidates to achieve this challenge. For this purpose, it is crucial that these technologies are well characterised and modelled to predict the resultant microstructure and mechanical properties of the part. This paper presents the state of the art in additive manufacturing and material modelling. While these processes present many advantages to the aerospace industry in comparison with traditional manufacturing processes, airworthiness and air transport safety must be guaranteed. The impact of this regulatory framework on the implementation of additive manufacturing for repair and production of parts for the aerospace industry is presented.

[15] This paper presents pressure drop and heat transfer results of flow through small, as produced channels that have been manufactured using the DMLS in an effort to better understand roughness. Ten different coupons made with the DMLS all having multiple rectangular channels were evaluated in this study. Measurements were collected at various flow conditions and reduced to a friction factor and a Nusselt number. Results showed significant augmentation of these parameters compared to smooth channels, particularly with the friction factor for mini-channels with small hydraulic diameters. However, augmentation of Nusselt number did not increase proportionally with the augmentation of the friction factor.

From The above literature review study concludes that 3D printing technologies are widely used for the production of polymer components from prototypes to functional structures with difficult geometries. The paper unveils the research gap that is required to widen the 3D printing technological field for sustainable growth of advanced industries. Compared to previous work conducted in the literature, this study's optimal heat sink geometry achieved a better response than the prior performance of other studies in terms of the thermal resistance and pressure drop. effectiveness, overall heat transfer coefficient and mass flow rate of curved face micro channel was examined in this study.

2. Methodology:

Methodology for the proposed paper work is given in following steps:
1.Review of Literature
2. Design and Manufacturing of 3-D printed headers of MCHX

3.. Experimental Investigation to Find Out Parameters
4. Result and conclusion

3. Design and Manufacturing of 3-D printed headers:

In the manufacturing technique of Curved shape micro-channel heat exchanger using 3-D printed headers we use the following method for design and manufacture this product the work flow is shown in figure below.

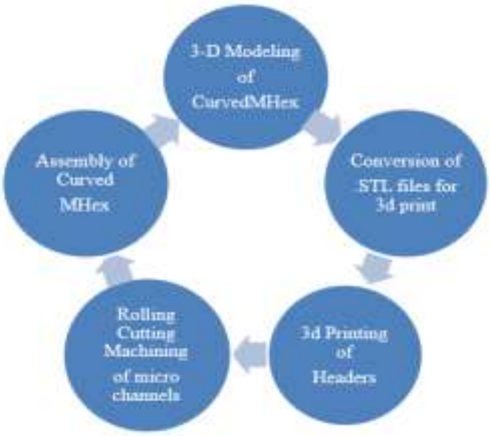


Fig.no.1 Manufacturing steps of 3D Curved MCHX Fin holder

3-d Modelling of the Curved Micro channel Heat exchanger (Schematic)

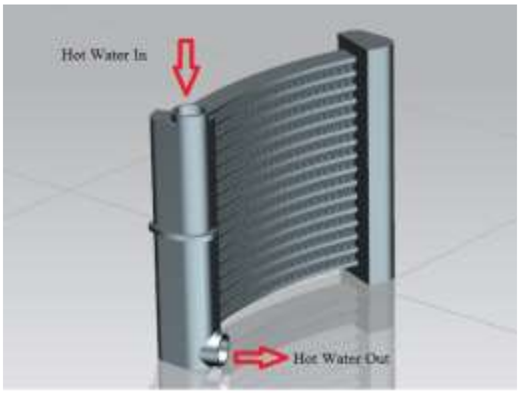


Fig.no.2 3D Modelling of the Curved Micro channel Heat exchanger

The 3-d modelling of the curved 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 Curved shape micro-channel heat exchanger

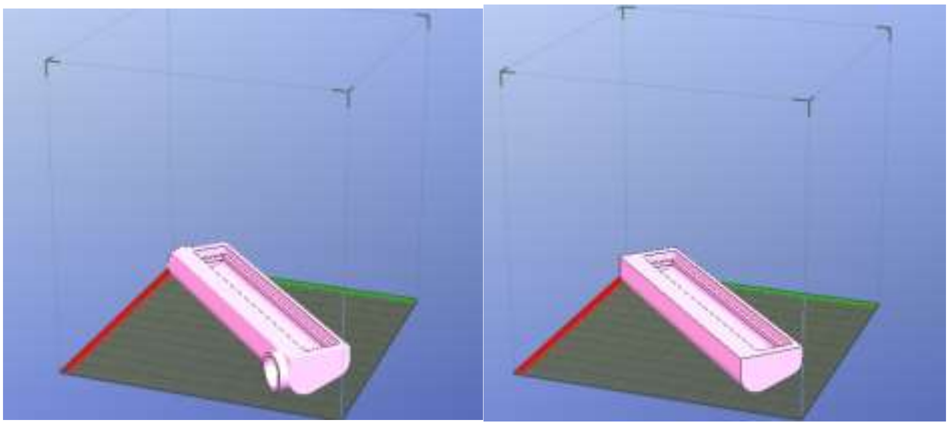


Fig.no.3 LH & RH Header

a. LH-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. RH-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.

c. Partition

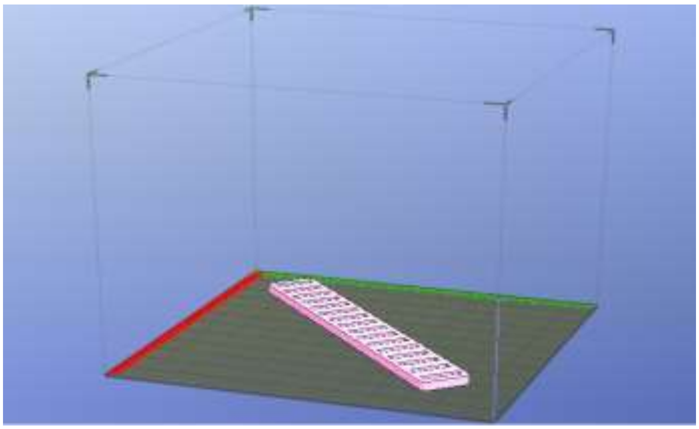


Fig.no.4 Partition view of the Curved Micro channel Heat exchanger

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

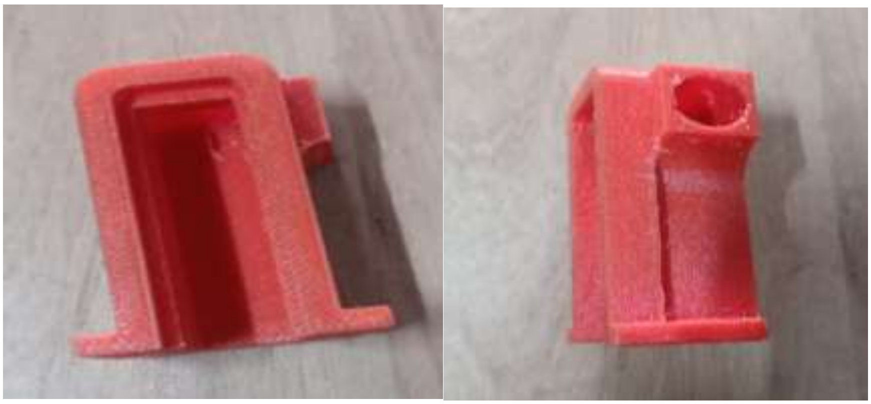


Fig.no.5 3D printed fin holders

Curved Heat exchanger: details with 3D model

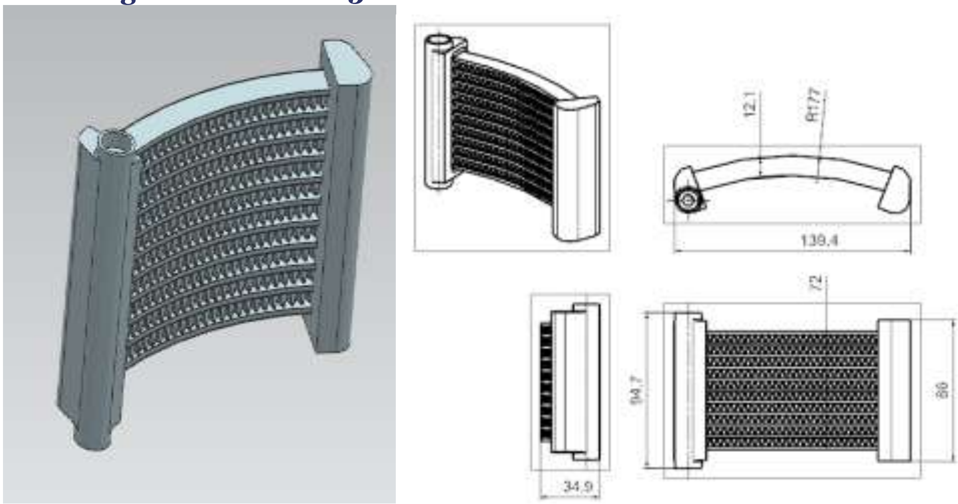


Fig.no.6 3D view with details of the Curved MCHX

Fig.no.7 curved face MCHE with headers assembly

4. Experimental set-up: Experimental test rig schematic diagram is given below.

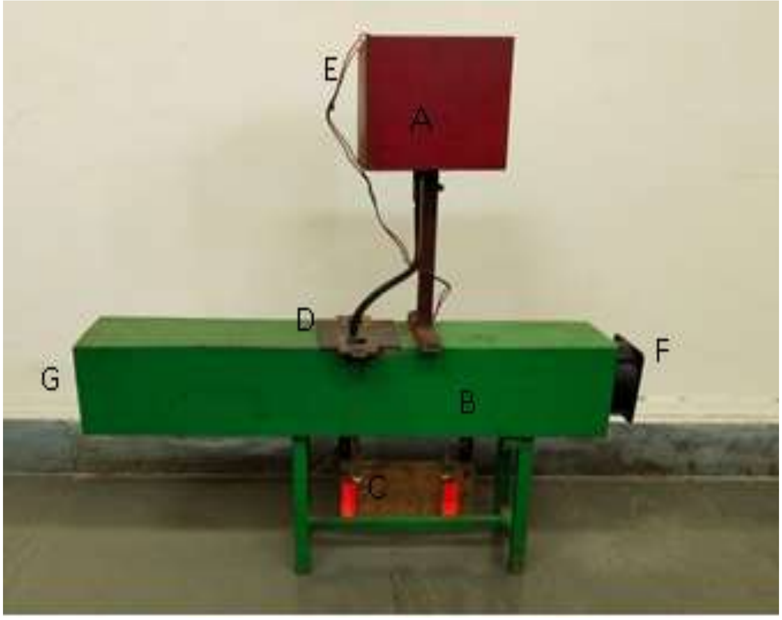


Fig.no. 8. Experimental set-up

Digital Temperature Sensor: Temperature range: Upto 100°C

Fig.no. 9. Temperature Sensor with flow measurement

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] Observations for Fan Speed:

Table no.1 Observations for Fan Speed

BLOWER SETTING	DISCHARGE M3/HR	AIR VELOICITY M/SEC	Air Flow rate Kg/sec
STAGE-1	51.5	2.3	0.14375167
STAGE-2	60.58	2.71	0.17953533
STAGE-3	71.27	3.19	0.20914944
STAGE-4	100.39	4.49	0.25171967
STAGE-5	117.3	5.25	0.28380161
STAGE-6	138	6.18	0.33315839

[2] Observations flow rate:

Table no. 2 Observations for flow rate

SR.NO	Mass flow set designation	Volume (ml)	Time (sec)	Mass flow rate (kg/sec)
1	MF-1	100	48	0.0021
2	MF-2	100	30	0.0033
3	MF-3	100	23	0.0043
4	MF-4	100	16	0.0062
5	MF-5	100	12	0.0082
6	MF-6	100	9	0.0100

[3] Observation Set -1 (Mass flow set designation MF-1)

Table no.3 Observation Set -1 (Mass flow set designation MF-1)

SR. NO	Air flow set designation	Hot water inlet (T_{h1})	Hot water Outlet (T_{h2})	Cold air Inlet (T_{C1})	Cold air Outlet (T_{C2})	Air outlet Velocity m/sec
1	Stage-1	84	50.4	31.9	35.8	2.3
2	Stage-2	84	51.9	31.9	40.8	2.45
3	Stage-3	84	52.4	31.9	43.4	2.62
4	Stage-4	84	53.3	31.9	45.9	3.81
5	Stage-5	84	54.4	31.9	46.1	4.56
6	Stage-6	84	57.2	31.9	48.8	5.02

[4] Observations for LMDT and Pressure Drop:

Table no.4 Observations for LMDT and Pressure Drop

Sr. No	Air Flow rate (kg/sec)	Water Flow rate (kg/sec)	LMTD	Heat Rejected by water(KJ)	Overall Heat Transfer Coefficient (W/m2K)	Pressure drop
1	0.14	0.0021	12.39692	0.288073	81.64959	0.088
2	0.18	0.0033	14.88811	0.44034	131.6859	0.117
3	0.2	0.0043	15.1918	0.565411	165.7086	0.288
4	0.25	0.0062	18.42643	0.789629	190.7972	0.392
5	0.28	0.0082	19.75563	1.015115	228.7781	0.449
6	0.33	0.0100	17.78482	1.225454	306.7875	0.511

Calculation of Heat transfer (Experimentally) through Curved heat exchanger $Q_{(curved\ )}$:

Governing Equation to calculate heat transfer,

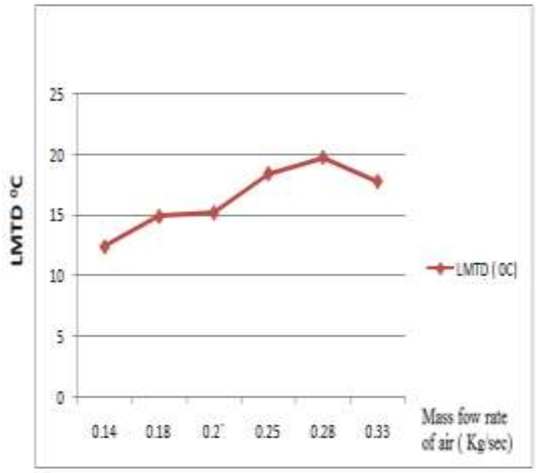
$Q_{(curved\ t)}$ Experimental = [U × A× ΔT = m × c × ΔT]

$Q_{(curved)}$ Experimental = 1.22 KJ ----------------- **(1)**

So, The experimental heat transfer through the heat exchanger = 1.22 KJ
From the reference observation table readings, different parameter graphs can be drawn are:
[1] Graph of LMTD Vs Mass flow rate of air
[2] Graph of Overall heat transfer Coeff. (W/m2K) Vs Mass flow rate of Air
[3] Graph of Pressure Drop across Heat exchanger Vs Mass flow rate of Air

[1] Graph: LMTD Vs Mass flow rate of air

[2] Graph: Overall heat transfer Coeff. (W/m^2K) Vs Mass flow rate of Air:



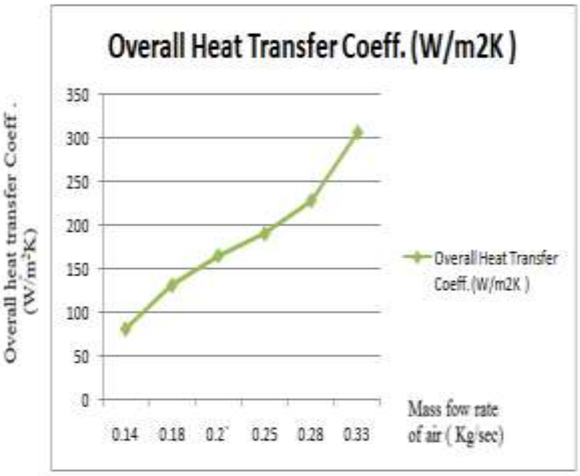


Fig.no.10 graph of LMTD Vs Mass flow rate of air
Fig.no.11 Graph of Overall heat transfer Coeff. (W/m2K) Vs Mass flow rate of Air

[3] Graph: Pressure Drop across Heat exchanger Vs Mass flow rate of Air:

Graph: Pressure Drop across Heat exchanger Vs Mass flow rate of Air

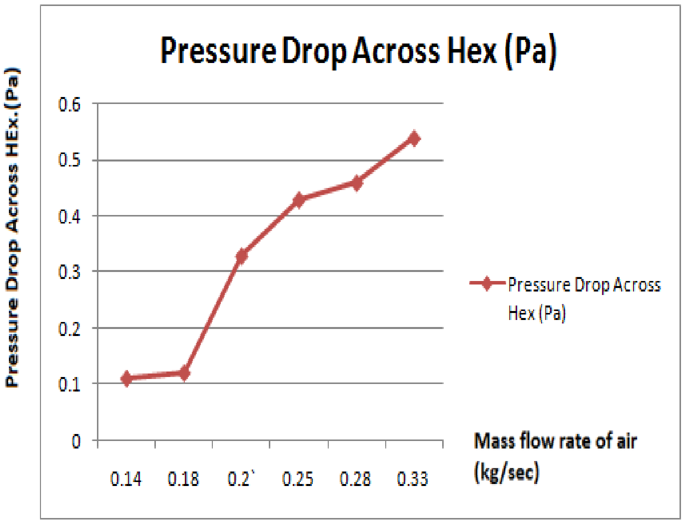


Fig.no. 12 Graph of Pressure Drop across Heat exchanger Vs Mass flow rate of Air

4.Result and discussion:

1. With reference to fig.no. graph of LMTD Vs Mass flow rate of air. observed that The LMTD of the heat exchanger is seen to increase in the mass flow rate at 0.28 kg/sec upto 200 C indicating the increase in heat transfer.
2. With reference to fig.no. graph of Overall heat transfer Coeff. (W/m2K) Vs Mass flow rate of air. observed that The Overall Heat Transfer Coefficient (81.64 to 306.7 W/m2K) of the heat exchanger is seen to increase in the mass flow rate 0.14 to 0.33 (Kg/Sec) indicating the increase in heat transfer.
3. With reference to fig.no. graph of Pressure Drop across Heat exchanger Vs Mass flow rate of Air. observed that The Pressure drop across the heat exchanger is seen to increase in the mass flow rate.
4. Heat Transfer Though Curved Heat Exchanger is 1.22KJ.

5.Conclusion:

In This Paper Study We Conclude That Rate of Heat Transfer Capacity of Curved Face Heat Exchanger Is Increased with Increase in Mass Flow Rate. Simultaneously Pressure Drop, Overall Heat Transfer Coefficient, LMDT Parameters Are Also Increases Significantly as Compare to Our Previous Flat Face Micro-Channel Study. We Observed That Air Drag Is Significantly Decreases in Curved Face Heat Exchanger as Compare with Flat Heat Exchanger, Hence Heat Transfer Performance Is Better Than Flat Face Heat Exchanger. the performance of 3D-printed heatsinks geometries is significantly superior to the classic designs making them an ideal candidate for designing further compact and efficient heat removal systems for automotive devices.

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