Comparative Analysis of Heat Transfer Characteristics of Symmetrical Natural Pattern Minichannel Heat sink

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***Abstract*: In this paper, performance of minichannels having natural leaf like structure is studied numerically and experimentally. Here the effect of change in bifurcation angle of secondary veins along with different aspect ratios on heat transfer is studied numerically. Bifurcation angles 15º , 20º and 27º with aspect ratios 2 3 and 4 are analysed numerically with heater input of 30w , 40w ,50 w and varying Reynold's number from 200 to 800. Their performance is also compared with conventional parallel mini channel it is found that maximum heat transfer coefficient and Nusselt number is obtained for the geometry having bifurcation angle of secondary veins as 15º and aspect ratio 2. The results are then verified experimentally with conventional parallel minichannel with aspect ratio 2 and natural pattern minichannel having bifurcation angle of secondary veins 15º and aspect ratio 2 are tested for heater input of 20 w, 40 w, 50, w and Re 100, 200, 300, 400 , 500 and 550. The values of heat transfer coefficient and Nusselt number values are found experimentally and numerically for both the minichannels and are found close to each other with experimental values are found slightly lower than values got by numerical analysis. Also it is found that there is improvement in heat transfer coefficient and Nusselt number values for natural pattern minichannel heat sink compared to straight minichannel heat sink thus showing heat transfer enhancement.**

***Keywords*: natural pattern, aspect ratio, bifurcation angle**

1. INTRODUCTION

With technological development and increase in the speed of ultra fast computers and compact electronic circuits, the problem of heat dissipation is ever increasing as the compact electronic circuit generates more heat. The maximum allowable temperature for these devices is 70º C .Above this temperature the device fails.
So for better performance and for increasing the life span of these devices a better and effective heat dissipation method is required. The answer is micro/mini channel heat sink with liquid cooling. . The concept of micro-and mini channels heat sinks was at first proposed by Tuckerman and Pease [1] about three decades ago.
The following is the classification based on channel hydraulic diameter

Conventional Channels: D_h>3 mm
Minichannels: 3 mm $\geq D_h$> 200 µm
Microchannels: 200 µm$\geq D_h$> 10 µm
"D_h", being the hydraulic diameter
As the channel hydraulic diameter decreases, heat transfer coefficient increases. This is the main reason of using micro/mini channel heat sinks for heat dissipation where high heat dissipation is required in limited space.

1.1 Problems with conventional microchannel

Conventional parallel micro/mini channel heat sink shows non-uniform temperature profile while cooling .This behaviour shows a specific pattern: a low temperature at the zone where the fluid is entering the heat sink, increasing along the channel in longitudinal direction until reaches a maximum temperature at the outlet zone of the channel which results in hot spot.
One way to achieve this criterion for uniform temperature distribution can be obtained from natural forms of leaf. Those forms present a general appearance: a main channel which decreases its hydraulic diameter and branches out at a specific position into two or more channels with smaller hydraulic diameter.

A number of heat transfer enhancement techniques in microchannel heat sink have been explored by researchers to overcome the above mentioned issues. Steinke and Kandlikar [2] reviewed the passive and active enhancement techniques. The passive techniques include (a) flow disruptions by using the sidewalls to obstruct the flow, or placing obstacles in bulk of microchannel, (b) channel curvature, (c) re-entrant obstructions, (d) secondary flows by adding smaller channels between main channels, (e) out of plane mixing, (f) fluid additives, and (g) surface roughness. The effective techniques include (a) vibration, (b) electrostatic field and (c) flow pulsation.

Satish Kandlikar, et al. [3] proposed branching in the microchannel a phenomenon observed in nature to reduce the non-uniform temperature profile. The branching was based on two laws: Biomimetic tendency and Allometric law. The temperature profile in these microchannels showed a different non uniform temperature profilewhere the maximum temperature occurs at the mid region. Secondary flows are also observed in nature like in leaf venation.

Mohite S.S.et. al [8] studied and numerically compared heat transfer and pressure drop characteristics of single-phase flow through leaf pattern microchannel heat sink.with conventional straight microchannel. Simulation reveals that the velocity profile at each entrance of the downstream channel and causes the hydrodynamic boundary layer development to reinitialize at every downstream secondary channel. which results in the boundary layer thickness reducing significantly in comparison with the conventional straight microchannel. Thus, the velocity profile is maintained in the developing region for this leaf pattern, thereby enhancing the heat transfer. Due to the secondary flow and entrance effect in leaf pattern microchannel, superior convective heat transfer performance is achieved, and these results in a uniform and lower surface wall temperature compared to conventional straight microchannel. Thus the leaf pattern heat sink generates secondary flow which enhances its heat transfer performance yet maintains a comparable pressure drop compared with conventional heat sink ΔP.

Duryodhan V.S. et. al [7] experimented and numerically studied single phase liquid flows for heated diverging and heated converging microchannel .and found that higher heat transfer in converging microchannel compared with diverging microchannel. It is further observed that less pumping work is required in diverging and converging microchannels as compared with uniform cross-section microchannel.

Lee P.S**.** et al. [4] employed wavy microchannels of rectangular cross section to cause Dean Vortices to enhance convective fluid mixing and heat transfer. They concluded that for the entire range of Reynolds number and wavy amplitude considered the enhancement in heat transfer always moderately or significantly exceeds the pressure drop penalty.

B. V. A. Rao et.al.[12] Carried out numerical study to investigate the heat transfer enhancement and fluid flow characteristics for aspect ratios20,30,46of rectangular micro channel heat sinks .The working fluid considered for the analysis is water. The channel size optimization has been carried out numerically to obtain the effective heat removal from the micro channel heat sinks. Considering the various operating parameters such as pressure drop, friction factor, Nusselt number, thermal resistance, and pumping power the micro channel heat sinks with aspect ratio 30 is preferred since it could remove more amount of heat keeping the other parameters at optimum level .
The flow in the micro/mini channel is predominantly laminar because of tiny size of the channels which does not allow the flow to transit to the turbulent regime Also high flow rates (or equivalently, high Reynolds numbers) will cause a sharp increase in pressure loss and hence pumping power.

1.2 Geometry of Mini channel

The Geometry is as shown in figure 1

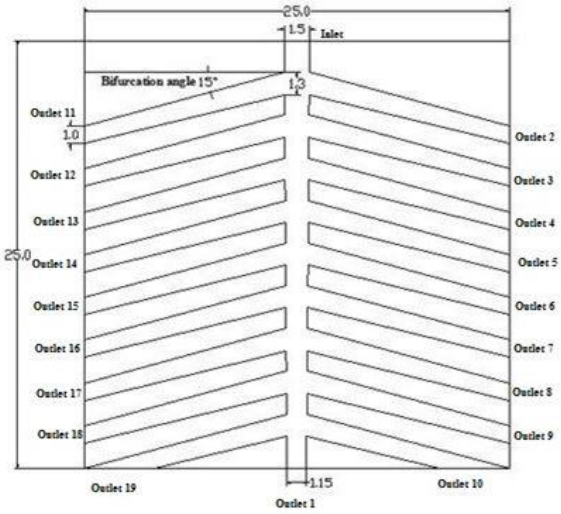

Fig. 1 Geometry of Minichannel

1.2.1 Geometrical details natural leaf pattern mini channels

Table 1

Characteristics	natural leaf pattern
Material	Aluminium
width x length (mm x mm)	25 x 25
Height mm	10
Primary channel start width mm	1.5
Primary channel end width mm	1.15
Aspect ratio (AR)	2 , 3 , 4
Secondary channel start width mm	1.3
Secondary channel end width mm	1
Secondary channel gap	1.2
Bifurcation angle α (°)	15 , 20 , 27

It consists of primary vain running along the length of minichannels while secondary veins are branching out from primary veins. Primary and secondary veins are converging in nature. This helps in improving the heat transfer and requires less pumping power.

2. Numerical Analysis For Optimization of aspect ratio

Table 2 Test Matrix-I

Sr.No	Geometry	Aspect ratio (AR)	Heater input	Re
1	Parallel	2,3,4	50 w	800
2	Bifurcation angle α= 15°	2,3,4	50 w	800
3	Bifurcation angle α= 20°	2,3,4	50 w	800
4	Bifurcation angle α= 27°	2,3,4	50 w	800

Conventional parallel minichannel and Minichannels with bifurcation angles varying from 15^0 , 20^0 and 27^0 and for each case of bifurcation angle with aspect ratios 2 , 3 , 4 different geometries are generated using ICEM CFD and is used to study the flow and heat transfer. Deionised water is used as a cooling liquid for minichannel with Re 800. And 50 watt heater input is givenThe heat transfer coefficients and Nusselt number for different 9 geometries , the results are compared to get the optimised aspect ratio for which values of Heat transfer coefficient and Nusselt number are highest amongst the cases analysed.

2.1 Change in Nu with bifurcation angles for different aspect ratios

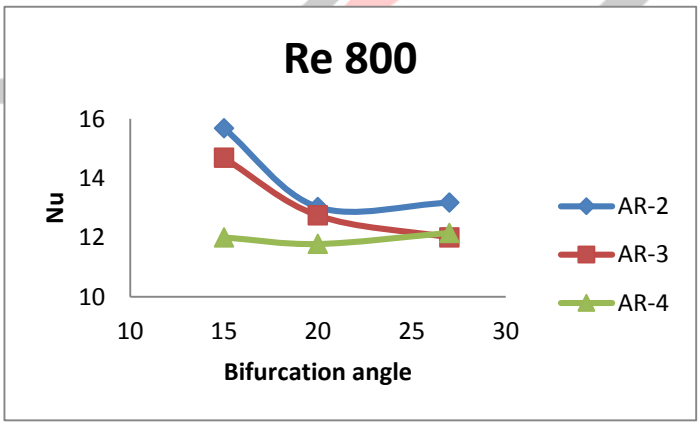

Fig. 2 Change in Nu with bifurcation angles for different aspect ratios (AR)

It is seen from figure 3.14 that minichannels with three cases of bifurcation angles and having aspect ratio 2 have higher values of Nusselt Number compared to channels with aspect ratios 3 and 4. Thus geometries having aspect ratio 2 have been selected for further analysis

3. Numerical analysis to find optimized geometry having aspect ratio (AR) 2

Table 3 Test matrix II

Sr. No	Geometry	Aspect ratio	Heater input	Re
1	Parallel	2	50 w	200,400,600,800
2	Bifurcation angle α=15°	2	50 w	200,400,600,800
3	Bifurcation angle α=20°	2	50 w	200,400,600,800
4	Bifurcation angle α=27°	2	50 w	200,400,600,800

Numerical analysis of symmetrical; natural pattern minichannel hear sink having bifurcation angles of secondary veins 15° , 20° , 27° with aspect ratio 2 is done to find the geometry with highest Nusselt number values and heat transfer coefficient among the cases analysed. Heater input is 50 watt while Renolds number is varied from Re 200 ,400 , 600 , 800.Following results are obtained

3.1 Results

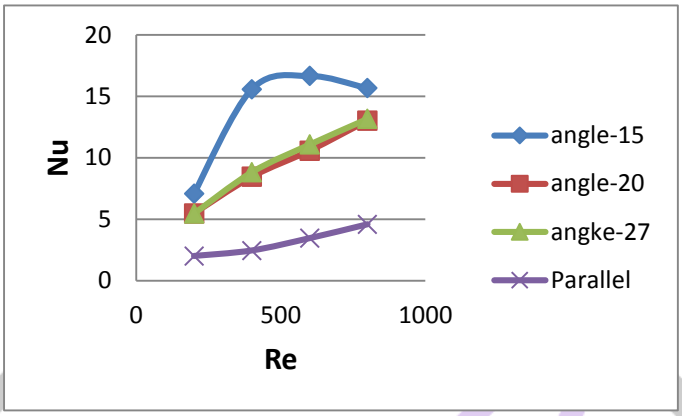

Fig. 3 Nusselt number vs Re

From fig 3 it is seen that the Nu for minichannel heat sinks increase with Reynolds number because the thermal boundary layer thickness decreases with increased fluid velocity.
It is seen that Nusselt number is higher for bifurcation angle-15° than the other two cases.

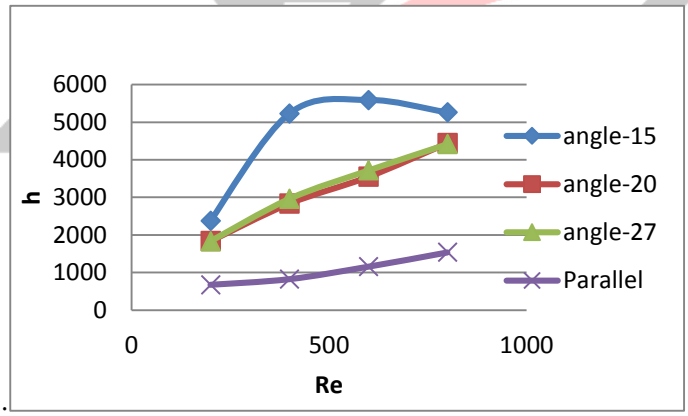

Fig. 4 Heat transfer coefficient vs Re

From fig 4 it is seen that heat transfer coefficient increases with increase in Reynolds no as the mass flow rate of the coolant liquid increases with increase in Reynolds no. ,value of heat transfer coefficient is higher for geometry having bifurcation angle 15°for all Reynolds numbers compared to the geometries with bifurcation angles 20° and 27° .

4 Experimental analysis

4.1 Minichannels for experimentation

Fig.5 and 6 shows minichannels manufactured for experimentation.

Fig. 5 Parallel minichannel

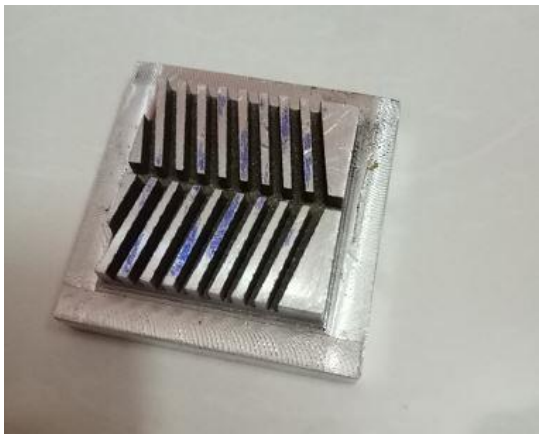

Fig. 6 Natural pattern minichannel

4.2 Experimental setup

Experimental setup consist of minichannel assembled in backlite manifold. The inlet of manifold is connected to micro pump which takes water from water tank. Thermocouples attached to the minichannel to measure surface temperature of minichannel and thermocouples used to measure the temperature of outlet water are connected to data logger. Electric supply is given to electrical heater through dimmerstat which can be varied by dimmerstat and is adjusted for 20w, 40w, 50wattage which can be recorded or measured by voltmeter and ammeter.

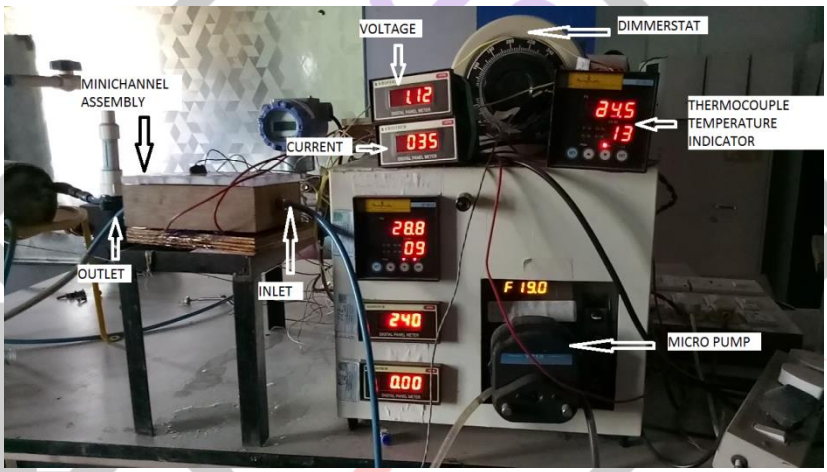

Fig. 7 Experimental setup

4.3 Equipments specification;-

Heater Range 0 to 50 watt
Micro pump – 0.001lpm to 0.2 lpm
Thermocouples – K type least count 1° c
PT -100 RTD least count 0.1°c
Data Logger – Universal Data logger

4.4 Experimental Assumptions:

1) The fluid flow and heat transfer are in steady-state.
2) The fluid flow and heat transfer are three-dimensional.
3) The fluid is in single phase and flow is incompressible, laminar.
4) The effects of gravity and other forms of body forces are negligible.
5) The fluid properties are set as piecewise-linear function of water temperature

Table 4 Test Matrix III

Sr No	Geometry	Aspect ratio	Heater input	Reynolds No
1	Parallel	2	20 w , 40 w ,50 w	100, 200, 300, 400, 500, 550
2	Natural pattern	2	20 w ,40 w, 50 w	100, 200, 300, 400, 500, 550

4.5 Experimental procedure

Water from tank is pumped by the micro pump passes through the minichannel where it absorbs heat which causes its temperature to rise. This heated water exits the minichannel and is stored in another water tank. Initially conventional parallel minichannel heat sink is tested for which flow of micro pump is so adjusted so as to get Re 100.AC supply is given to the heater through dimmerstat and is so adjusted to get 20watt heater input to minichannel which is shown by ammeter and voltmeter readings. The thermocouples are connected to data logger and are used to measure inlet temperature of water, outlet temperature of water and surface temperature of minichannel. Temperatures are noted down after each 10 minutes.This is done till the steady state is reached when there is no change in consecutive set of readings the final temperature readings are noted down for that particular state. For the next state heater input is increased to 40 watt Reynolds no is kept constant i.e Re 100 and the same procedure is repeated and the readings are noted down.Then the heater input is increased to 50 watt and the same procedure is repeated and the readings are noted down for Re 100.All the above procedure is repeated for Re 200, Re 300, Re 400, Re 500, Re 550 for 20 watt, 40 watt and 50 watt and the readings are noted down..Now after taking readings for conventional parallel minichannel the same procedure is repeated for natural pattern minichannel for the same mass flow rate and for same heater input i.e 20watt, 40watt and 50watt and the readings are noted down.

Experimental results and graphs for Nusselt Numbers vs. Re, Heat transfer coefficients vs Re, friction factors vs. Re, ΔT vs. mass flow rates are discussed for both Natural pattern minichannel and Straight minichannel heat sink. Results are also compared with values obtained from CFD analysis and thus validation is done

5 Results and Discussion

5.1 Effect of change of Re on Nusselt number

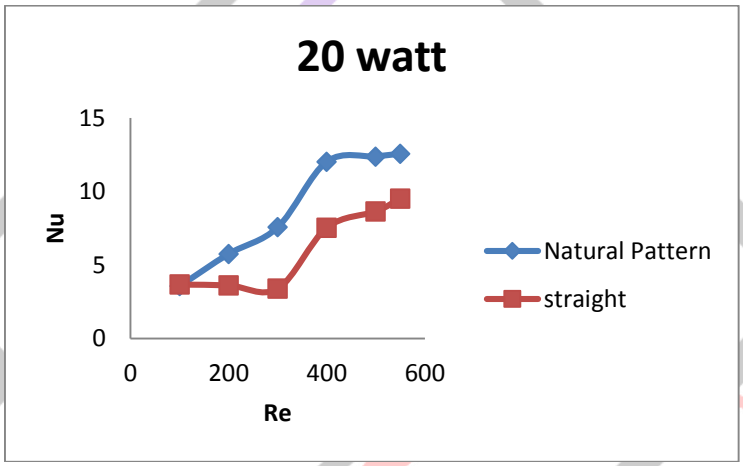

Fig. 8 Nu vs. Re for parallel and natural pattern (20 watt)

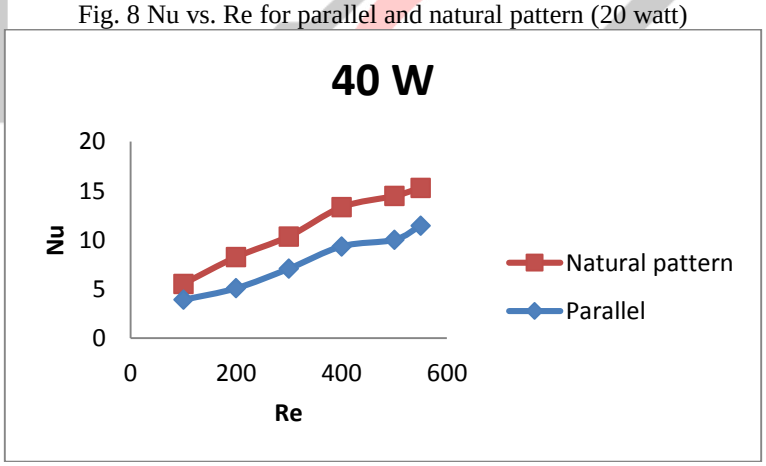

Fig. 9 Nu vs. Re forNatural pattern and straight minichannel 40 watt

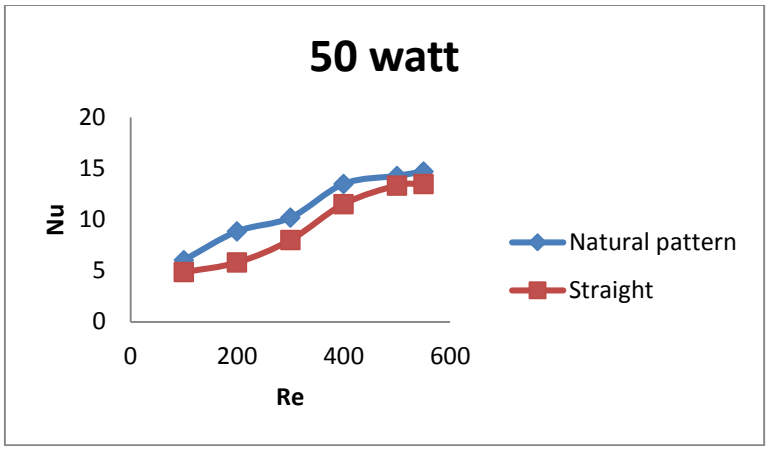

Fig. 10 Nu vs Re for parallel and natural pattern

Fig 8,9 and 10 shows comparison between Natural pattern and conventional parallel minichannel heat sinks for experimental values Nusselt number vs. Re for 20 watt and 40 watt and 50 watt of heater input. The graph shows that as Reynolds number increases Nusselt number values also increases as mass flow rate of water increases with increase in Reynolds number for both parallel and natural pattern heat sinks.

It is also seen that values of Nusselt numbers for natural pattern minichannel heat sink are higher than those for parallel minichannel heat sink. It shows almost 20.003% increase in the value of Nusselt number which shows improvement in heat transfer. This is due to the combined effect of redevelopment of boundary layer and generation of secondary flow results in thinner boundary layer that leads to better heat transfer performance in case of natural pattern minichannels compared to conventional parallel minichannels.

5.2 Nusselt number as a function of Reynolds number for Numerical and Experimental values of Natural Pattern Minichannel

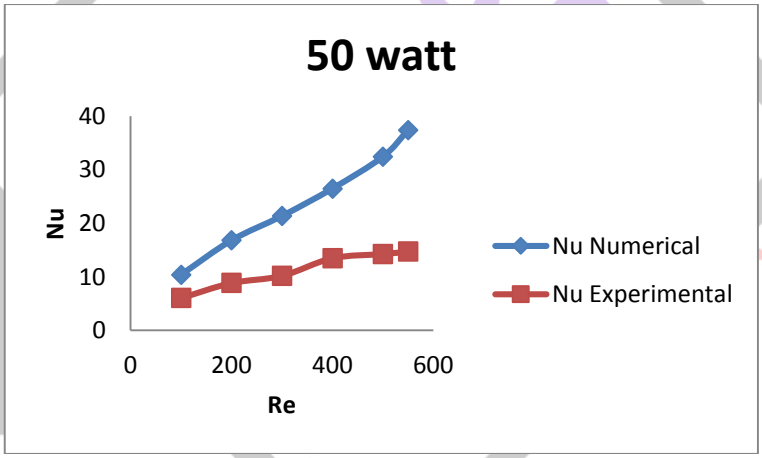

Fig. 11 Nu vs Re for Natural minichannel(Numerical and Experimental)

Fig 11 and shows graphical comparison of experimental and numerical values of Nusselt number against Reynolds number for 50 watt heater input for Natural pattern minichannel heat sink. The values of heat transfer coefficient and Nusselt number values are found experimentally and numerically for both the minichannels and are found comparative. For 50 W heat input Re is varied from 100 to 550 , the values of Nusselt number varied from 10.37 to 37.634 numerically and from 6.04 to 14.44 , experimentally. The experimental values are found less than theoretical values which is as expected due to practical inaccuracies.

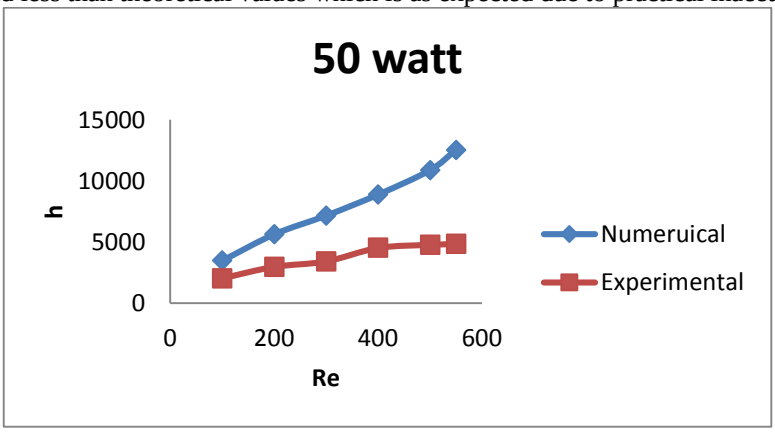

Fig .12 h vs. Re for Natural minichannel (Numerical and Experimental)

Fig 12 shows graphical comparison of experimental and numerical values of Heat transfer coefficient against Reynolds number for 50 W heater input for Natural pattern minichannel heat sink. The values of heat transfer coefficient values are found experimentally and numerically for both the minichannels and are found comparative

For 50 W heat input Re is varied from 100 to 550, the values of h varied from 3479.17 w/m^2 k to 12527 w/m^2 k numerically and from 2025.07 w/m^2 k to 4843.6 w/m^2 k , experimentally . Thus the experimental values are less than theoretical values.

5.3 Enhancement factor and Thermal enhancement factor as a function of Reynolds number

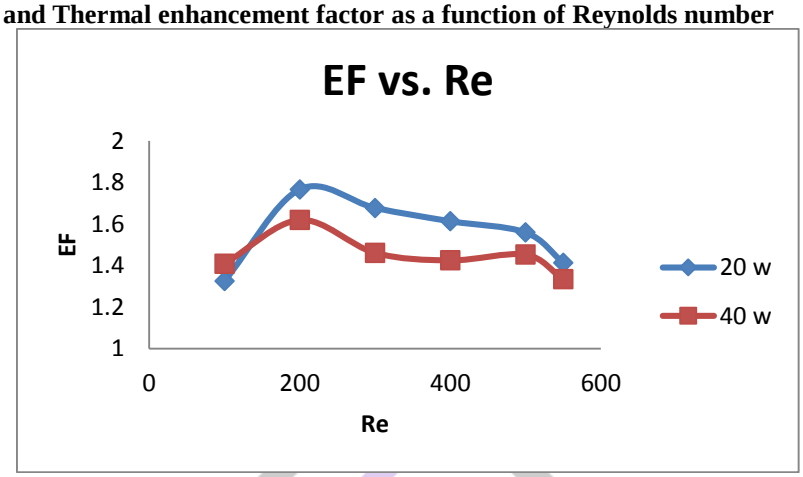

Fig. 13 Enhancement factor vs Re

Fig 13 shows graph of Enhancement factor versus Re for 20 W and 40 W heater input. It has been found that the thermal enhancement factor initially tends to increase with the rise of the Reynolds number and then decreases with the further rise of the Reynolds number for all cases.

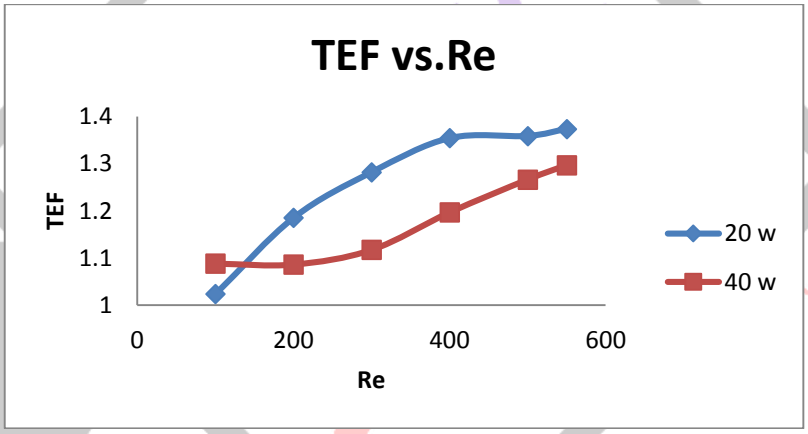

Fig. 14 TEF as a function of Reynolds number

Fig 14 shows graph of Thermal enhance factor plotted against Reynolds number for 20 w and 40 w heater input.As the Reis increased, it can be observed that the hydrodynamic boundary and thermal boundary layers are thinned. This results in significantly enhanced thermal performance.

6. CONCLUSIONS

Heat transfer and pressure drop characteristics of single-phase flow through natural pattern minichannel heat sink are numerically and experimentally investigated. Its cooling effectiveness is compared with conventional straight minichannel heat sinks. Also natural pattern minichannel are compared based on change in bifurcation angle and ARs The following key conclusions are drawn

1) The combined effect of redevelopment of boundary layer and generation of secondary flow results in thinner boundary layer that leads to better heat transfer performance and higher pressure drop. in case of natural pattern minichannels compared to conventional parallel minichannels.

2) Leaf pattern with bifurcation angle 15° with AR 2 and 3 has higher values of heat transfer coefficient and Nusselt number compared to the other cases of Bifurcation angles namely 20° , 27°.

3) α 15° with AR 2 shows best result with highest values of heat transfer coefficient and Nusselt number

4) For 50 W heat input Re is varied from 100 to 550 , the values of Nusselt number varied from 10.37 to 37.634 numerically and from 6.04 to 14.44 , experimentally for natural pattern minichannel.

6) For 50 W heat input Re is varied from 100 to 550, the values of Nusselt number varies from 4.55 to 13.49 for straight minichannel.

5) Nusselt number values for natural pattern minichannel heat sink are higher than those for parallel minichannel heat sink which shows almost 20.003% increase.

4) There is almost 43.44% increase in the value of heat transfer coefficient of pattern minichannel compared to straight minichannel thus showing heat transfer enhancement .This is due to better fluid mixing and secondary flows.

6) The values of heat transfer coefficient and Nusselt number values are found experimentally and numerically for both the minichannels and are found comparative

REFERENCES

[1]**Tuckerman D B. ,Pease R F W**., "High-performance heat sinking for VLSI" ,IEEE Electron Device Lett 1981;2:pp126–9.

[2]**Steinke M E, Kandlikar SG**" Review of single phase heat transfer enhancement techniques for application in microchannels, minichannels and microdevices." Heat Technol (2004) 22

[3]**Carlos Alberto Rubio-Jimenez, Abel Hernandez-Guerrero, Jose Cuauhtémoc Rubio- Arana, Satish Kandlikar**, "Natural Patterns Applied to the Design of Microchannel Heat Sinks", Proceedings of the ASME 2009 International Mechanical Engineering Congress & Exposition, IMECE2009

[4]**Y. Sui, P.S. Lee,, C.J. Teo**, "An experimental study of flow friction and heat transfer in wavy microchannels with rectangular cross section", International Journal of Thermal Sciences 50 (2011) pp 2473-2482

[5]**H. A. Mohammed, P. Gunnasegaran, and N. H. Shuaib**, "Influence of channel shape on the thermal and hydraulic performance of microchannel heat sink," *Int. Commun. Heat Mass Transf.*, vol. 38, no. 4 ,2011, pp. 474–480,

[6]**A. Sakanova, C. C. Keian, and J. Zhao**, "Performance improvements of microchannel heat sink using wavy channel and nanofluids," *Int. J. Heat Mass Transf.*, vol. 89, 2015,pp. 59-74

[7]**V.S. Duryodhan , Abhimanyu Singh , S.G. Singh , Amit Agrawal**, "Convective heat transfer in diverging and converging microchannels" , International Journal of Heat and Mass Transfer 80 (2015) 424–438

[8]**V.P. Gaikwad, S.D. Ghogare and S.S. Mohite** , "Numerical Study on Microchannel Heat Sink with Asymmetric Leaf Pattern" , Springer Techno-Societal 2016 pp 495-507

[9]**Morteza Khoshvaght-Aliabadi ,Farnaz Nozan**, "Water cooled corrugated minichannel heat sink for electronic devices: Effect of corrugation shape" , International Communications in Heat and Mass Transfer 76 (2016) pp188–196

[10]**M. Khoshvaght-Aliabadi , M. Sahamiyan, M. Hesampour, O. Sartipzadeh** , "Experimental study on cooling performance of sinusoidal–wavy minichannel heat sink" , Applied Thermal Engineering 92 (2016) pp50–61

[11]**Karan Ghule, M.S. Soni** , " Numerical Heat Transfer Analysis of Wavy Micro Channels with Different Cross Sections", Energy Procedia 109 (2017) pp 471 – 478

[12**] D. R. S. Raghuraman, R. Thundil Karuppa Raj, P. K. Nagarajan, and B. V. A. Rao**, "Influence of aspect ratio on the thermal performance of rectangular shaped microchannel heat sink using CFD code," *Alexandria Eng. J.*, vol. 56, no. 1,2017, pp. 43–54,

[13]**Seyed Ebrahim Ghasemi , A.A. Ranjbar , M.J. Hosseini** , "Experimental and numerical investigation of circular minichannel heat sinks with various hydraulic diameter for electronic cooling application", Microelectronics Reliability 73 (2017) pp 97–105