NUMERICAL DETERMINATION OF HEAT TRANSFER CHARACTERISTICS OF SYMMETRICAL NATURAL PATTERN MINICHANNEL HEAT SINK

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ABSTRACT

In this work, performance of minichannels having natural leaf like structure is studied numerically .Previous studies shows that micro/minichannels having leaf like structure have advantages over conventional rectangular micro/minichannels. The secondary veins branching from primary, both are having converging passages improves heat transfer rate and requires less pumping power. In this paper effect of change in the bifurcation angle of secondary veins along with different aspect ratios on heat transfer is studied numerically. Bifurcation angles 15^o , 20^o and 27^o with aspect ratios 2, 3 and 4 are analysed numerically with heater input of 50 w and varying Reynold's number from 200 to 800.Flow is kept laminar. 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 15^o and aspect ratio 2.

Keyword: - *natural pattern, aspect ratio, bifurcation angle*

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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 70^o 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.

1.1Problems with conventional microchannel

conventional parallel micro/mini channel heat sink shows non-uniform temperature profile while cooling .

This behavior 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.

Gaikwad V. P. et. al [8] studied and numerically investigated heat transfer and pressure drop characteristics of single-phase flow through leaf pattern microchannel heat sink. Its cooling effectiveness is compared with conventional straight microchannel heat sinks through numerical simulations in ANSYS Fluent. Simulation results reveal a clear flow field difference between the conventional straight microchannel and leaf pattern microchannel. The velocity contours do not change along the length of conventional microchannel. velocity contours are not uniform along the length, the secondary channels disrupts the velocity profile at each entrance of the downstream channel and causes the hydrodynamic boundary layer development to reinitialize at every downstream secondary channel. This 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.

Rubio-Jimenez 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 profile where the maximum temperature occurs at the mid region. Secondary flows are also observed in nature like in leaf venation.

Sui 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.

Thundil Karuppa Raj 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.
Hence regard to single-phase cooling, due to the reduced feature size of micro/minichannels, high flow rates will cause a sharp increase in pressure loss. The coolant flow through micro/minichannels is always in laminar flow regime.

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1.2 Geometry of Mini channel

The Geometry is as shown in figure 1

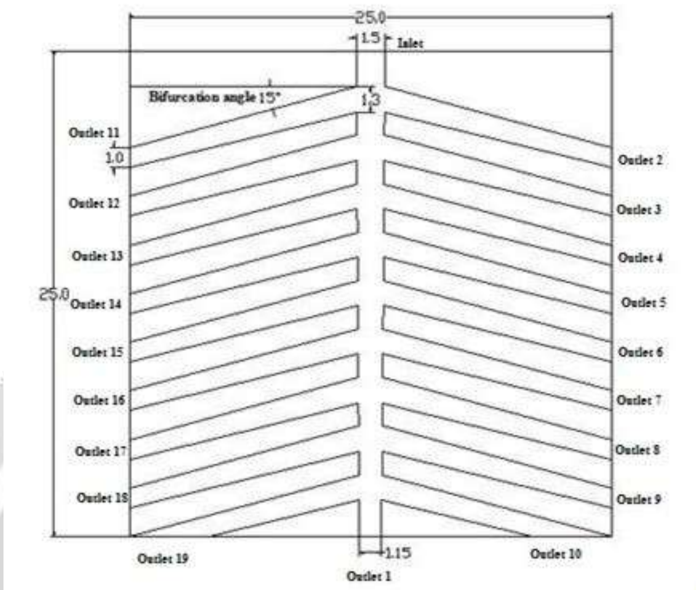

Fig 1 Geometry of Minichannel

1.2.1 Geometrical details natural leaf pattern mini channels

Characteristics	natural leaf pattern
Material	Aluminum
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.

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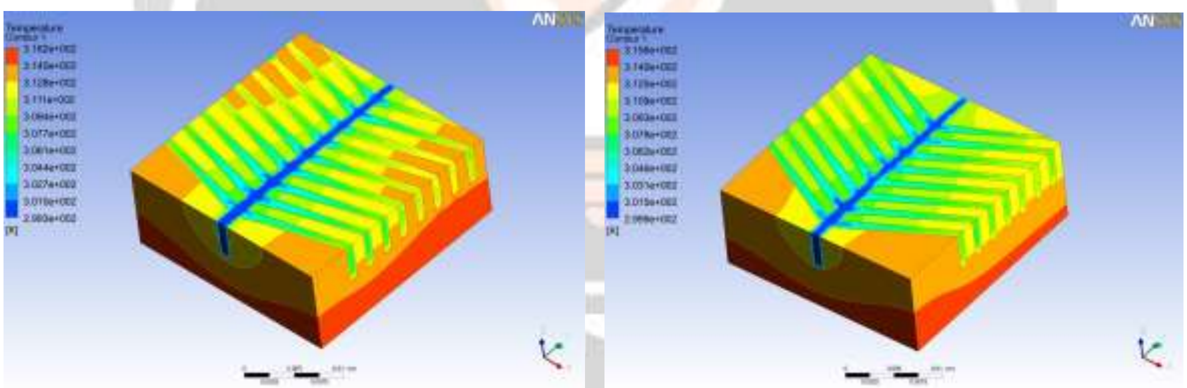
2. Numerical Analysis For Optimization of aspect ratio

Table 1 Test Matrix-I

Sr. No	Geometry	Aspect ratio (AR)	Heater input	Re
1	Parallel	2,3,4	50 w	800
2	Bifurcation angle $\alpha = 15^o$	2,3,4	50 w	800
3	Bifurcation angle $\alpha = 20^o$	2,3,4	50 w	800
4	Bifurcation angle $\alpha = 27^o$	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
ICEM CFD software 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 given
A uniform heat flux is applied at the base of minichannel which causes increase in the temperature of minichannel as well as that of water flowing through the primary and secondary veins. This temperature rise is combined effect of redevelopment of boundary layer and generation of secondary flow results in thinner boundary layer that leads to better heat transfer
The 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 Temperature Contours



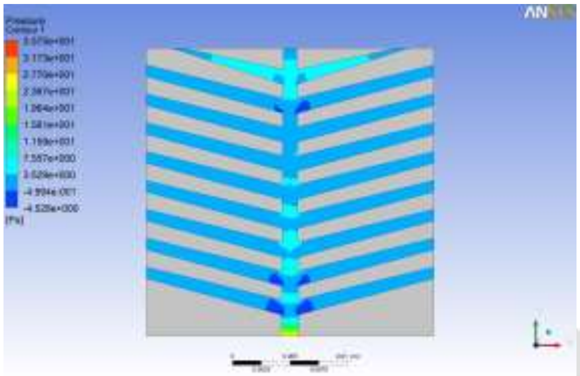
(a) Temperature Contour α 15^o AR 3**,** 50 w, Re 800 **(b)** Temperature Contour α 27^o AR 3**,**50 w Re 800

Fig 2 Temperature Contours for α 15^o ,27^o , AR 3 50 w , Re 800

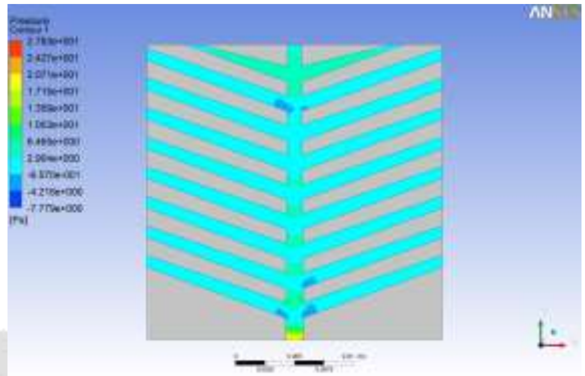
Figure 2 shows temperature contours for different minichannel geometries. From these contours following observations are made

1. From the temperature contour it is seen that the temperature is highest at the base.
2. There is not appreciable temperature rise of cooling fluid along the primary vein.
3. There is appreciable temperature rise of cooling fluid along the secondary veins due to which most of the heat transfer takes place.
4. This heat transfer is due to better fluid mixing due to secondary flow.

2.2 Pressure Contours



(a) Pressure Contour α 15 AR 3 , 50 w Re 800



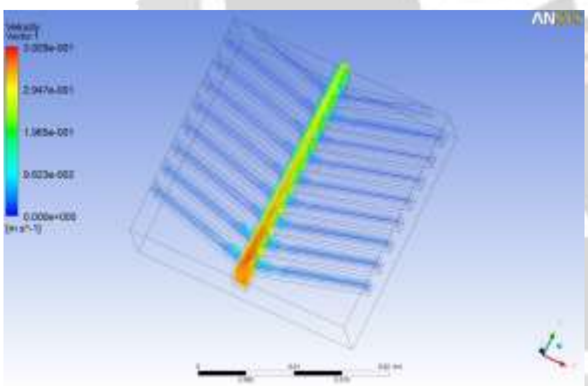
(b) Pressure Contour A α 20 AR 3 , 50 watt Re 800

Fig 3 Pressure Contours for α 15^{o} ,20^{o} , AR 3 50 w , Re 800

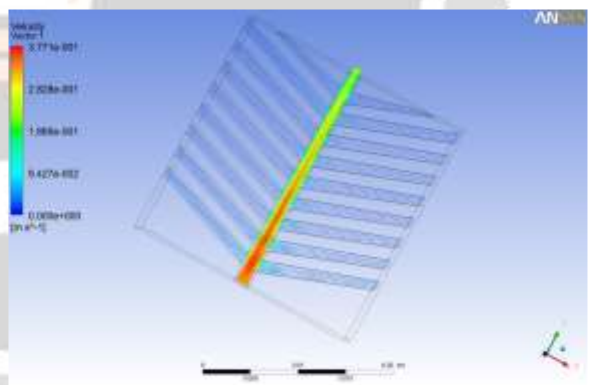
Figure 3 shows pressure contours for different minichannel geometries. Following observations are made

1. Pressure is highest at the inlet of primary vein
2. .Along the primary vein the pressure goes on reducing . while at the exit pressure is zero (atmospheric)
3. At the entry to the secondary vein the pressure reduces initially but there is recovery in pressure along the secondary vein.
4. At the exit the pressure is again atmospheric

2.3 Velocity vectors



(a) Velocity vector α 15^{o} AR 3, 50 w, Re 800



(b) Velocity vector , α 20^{o} AR 3 , 50 w, Re 800

Fig 4 Velocity vectors for α 15^{o} ,20^{o} , AR 3 50 w , Re 800

Figures 4 shows velocity vectors natural pattern minichannels with Bifurcation angles 15^{0} ,20^{0} and AR (aspect ratio)3

In both the cases velocity is highest at inlet of the primary vain as shown by velocity vectors and reduces along the primary vain due to fluid friction. The velocity values in secondary veins are less than those in primary vain as in the primary vain there is no obstruction to fluid flow while , when the fluid enters into secondary vain it has to change its direction of flow and due to fluid friction , sudden change in direction of flow velocity decreases .

2.4 Change in Nu with bifurcation angles for different aspect ratios

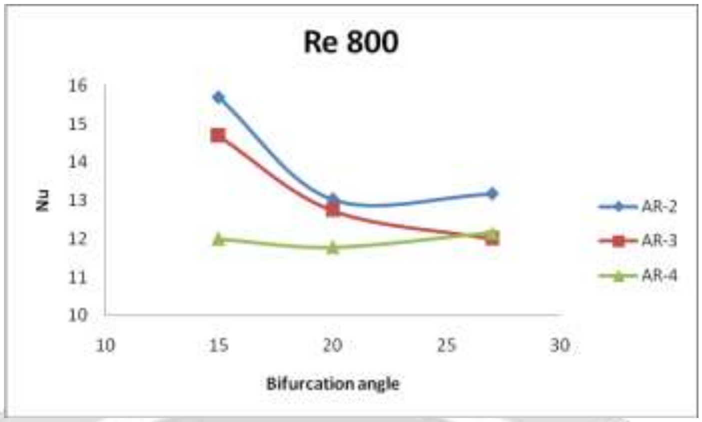


Chart 1 Change in Nu with bifurcation angles for different aspect ratios (AR)

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 2. 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^o	2	50 w	200,400,600,800
3	Bifurcation angle α=20^o	2	50 w	200,400,600,800
4	Bifurcation angle α=27^o	2	50 w	200,400,600,800

Numerical analysis of symmetrical; natural pattern minichannel hear sink having bifurcation angles of secondary veins 15^o , 20^o , 27^o 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 and Discussion

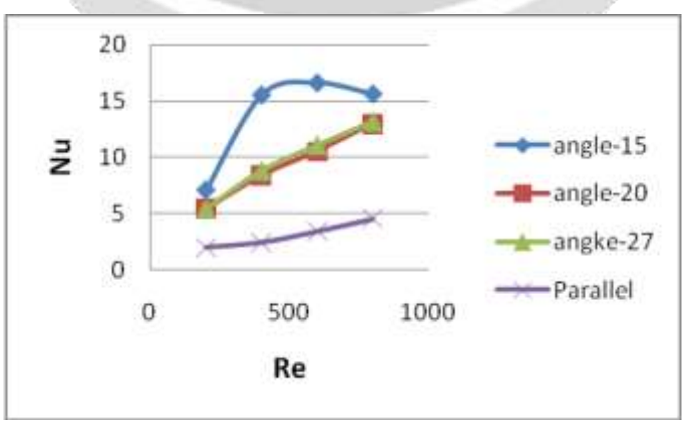


Chart 2 Nusselt number vs Re

From chart 2 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^o than the other two cases .
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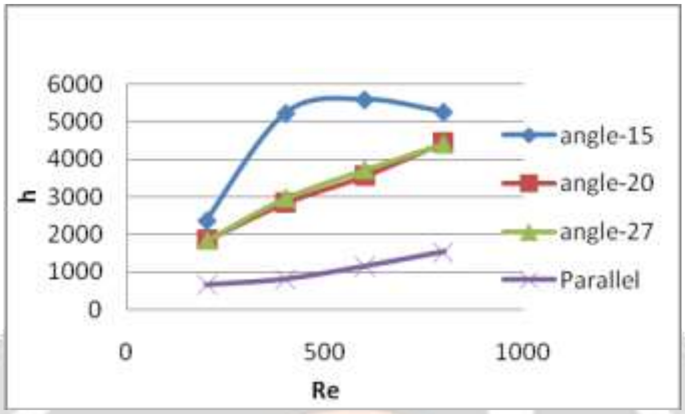

Chart 3. Heat transfer coefficient vs Re

From chart 3 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^o for all Reynolds numbers compared to the geometries with bifurcation angles 20^o and 27^o .

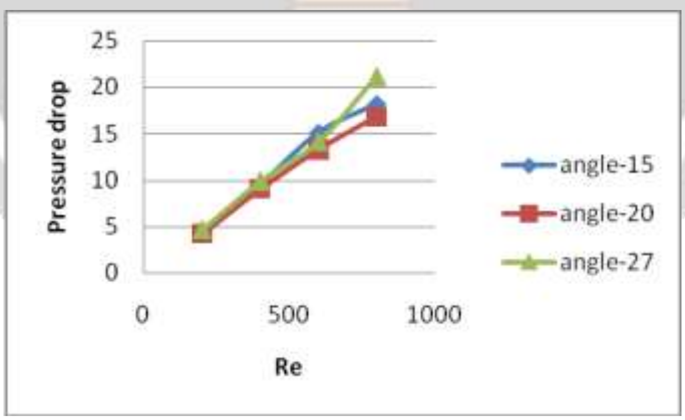

Chart 4 Graph of Pressure drop coefficient vs Re

Chart 4 shows comparison of pressure drop for different secondary bifurcation angles with Reynolds numbers. As the Reynolds number increases mass flow rate of coolant also increases which results in increase in frictional loss as a result pressure drop increases.

Also it is found that minichannel with secondary bifurcation angle 15^0 and aspect ratio 2 has higher heat transfer coefficient and Nusselt Number values compared to the other 8 cases.
Nevertheless, the heat transfer performance for the minichannel with leaf pattern is significantly higher than conventional heat sink. This remarkable enhancement in heat transfer is due to the combined effect of thermal

boundary layer redevelopment at the leading edge of leaf pattern minirochannel and the uniform secondary flows generated by flow diversion through secondary channels

4. CONCLUSIONS

Heat transfer and pressure drop characteristics of single-phase flow through leaf pattern minichannel heat sink are numerically investigated. Its cooling effectiveness is compared with conventional straight miniochannel heat sinks .Also leaf pattern minichannel are compared based on change in bifurcation angle and aspect ratios

The following 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^{o} with aspect ratio 2 and 3 has higher values of heat transfer coefficient and Nusselt number compared to the other cases of Bifurcation angles .
3) bifurcation angle 15^{o} with aspect ratio 2 shows best result among the cases investigated .
4) Demerits of leaf pattern minichannel heat sink include complex construction geometry, and a significant pressure drop across the primary channel.

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