

INVESTIGATIONS ON HEAT TRANSFER CHARACTERISTICS OF POROUS TYPE COPPER HEAT SINK WITH BIFURCATIONS

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ABSTRACT

The lotus type porous copper heat sink has a higher heat transfer capacity as compared to micro channel heat sink for same size. Many studies on this heat sink show that its heat transfer capacity can be further improved by improving design of heat sink. This study investigates the heat transfer and flow characteristics of porous heat sink with different designs of internal bifurcations under both laminar & turbulent flow and studies the effect of such bifurcations on heat transfer of heat sink. The results of heat sink with bifurcations are compared with that of heat sink without bifurcations which show that for case of both laminar & turbulent flow, the heat sink with bifurcation showed better thermal performance as compared to heat sink without bifurcations.

Keywords: Porous Type Copper Heat Sink, Laminar Flow, Turbulent Flow, Bifurcations, Characteristic Curves.

INTRODUCTION.

For quite a long time, there has been focus on reducing the size and volume of electronic devices. On other hand with development of technology and need for more complex functions, there has been development on integrating different functions of electronic devices into single component. This has resulted in increasing the amount of heat released by such devices. Such situations call for design of cooling systems with good thermal performance but should be lesser in weight. This cannot be achieved by traditional methods of cooling such as use of fans with air as coolant as it occupies more space and there occurs more noise with increasing size. Thus, this emphasizes on need of such studies on increasing thermal performance of cooling systems such as heat sinks, heat exchangers etc.

Literature Review

Gongnan Xie et al [1] improved the thermal heat transfer characteristics of microchannel heat sinks by use of internal Y shaped bifurcations. Gongnan Xie et al also studied on effect of angle of arms of bifurcations and Y shaped bifurcation length on overall performance of heat sink. The results of study showed that the microchannel heat sink with bifurcations have a better thermal performance when compared with microchannel heat sink without bifurcations. With increase in velocity, the thermal performance of microchannel heat sink with bifurcations was found to decline sharply for corresponding velocities in microchannel heat sink without bifurcations. Thus, the study shows internal bifurcations is a possible method to increase their performance of a heat sink.

The work by Fengli Zhang et al [2] considered different structural designs of bifurcations for microchannel heat sink and investigated the heat transfer results for different inlet velocities ranging from 0.6m/s to 1.6m/s. The numerical results obtained from study show that heat sinks with multiple bifurcations have a better thermal performance compared with straight channel microchannel heat sink. The study by Zhang et al [2] showed that use of multiple bifurcations can help reduce thermal resistance of heat sinks. The results obtained from study thus show that proper design of bifurcation can help improve thermal performance.

A study on microchannel heat sink with multiple bifurcations under laminar flow was done by Shian Lie et al [3]. The bifurcation length of five different cases was considered and its thermal characteristics was studied.

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The study obtained local pressure profiles, velocity and temperature profiles are presented which show that heat sinks with long length bifurcations is better as compared to microchannel heat sinks without bifurcations.

D.R.S. Raghuraman et al [4] studied the effect of aspect ratio on thermal performance of rectangular shaped microchannel heat sink using CFD code. The optimum ratio at which heat transfer is maximum is obtained numerically. The thermal performance of heat sink with an aspect ratio of 20 was found to have superior as compared to other cases. At the same time the microchannel heat sink with aspect ratio of 20 was found to have a higher pressure drop as compared with other cases. The heat sink with aspect ratio of 30 was found to be optimum as it had higher heat removal rate.

Deborah V. Pence [5] conducted a study on reducing the pumping power and temperature of wall by use of fractal like branching networks. Fractal like heat sinks showed a 60% lower pressure drop and 30 degree Celsius lower temperature when compared to that of ordinary.

The study conducted by S.M. Senn et al [6] shows the importance of bifurcations and tree like nets on thermal performance of heat sinks numerically. The study shows that secondary flows are initiated at bifurcations which help to increase heat transfer characteristics by laminar mixing as compared to conventional serpentine structure without bifurcations.

Heng Ren [7] studied about effect of different types of structures in microchannel on cooling capacity of heat sink. Three types of microchannel designs were considered and temperature distribution and pressure drop on microchannel heat sink with different structures was investigated and it was found that heat sink with reverting structure was found to have considerable effect on temperature and pressure drop of heat sink. The use of reverting microstructure in heat sink was found to reduce maximum temperature and increase pressure drop in heat sink.

Xueye Chen et al [8] performed a numerical analysis of various types of micromixers based on fractal tree like network. The study showed that bifurcation angle is an important parameter that affects performance of heat sink with bifurcation. The numerical analysis results showed that bifurcation angle of 90 degrees was found to be optimum.

Yongping Chen et al [9] focused on studying effect of fractal branching channel network for heat sinks which showed that the effect of fractal branching network on pressure drop is negligible and it can increase the total heat transfer capacity of heat sink. Also a larger number of fractal network or larger length of fractal network can help increase magnitude of heat transfer appropriately.

Bladimir Ramos-Alvarado et al [10] performed numerical study on heat sinks with conventional and new flow channel configurations with flow regime as laminar. The study concludes that use of bifurcations on heat sinks helps to reduce temperature difference on heat sink per unit heat flux and a low thermal resistance.

The performance of an heat exchanger with tree like flow passages was examined by David Calamas and John Baker [11]. They found that the flow network caused by hierarchical bifurcating flow passages resulted in a pressure drop that is nearly two orders in magnitude smaller than traditional compact heat exchanger designs but resulted an increase in bulk temperature of fluid larger in magnitude as compared with microscale flow network that was studied. They also found that bifurcation angle had an important influence on pressure drop and wall temperature distribution because of flow separation and recirculation zones that are caused by such bifurcations.

A study was made on design of microchannel heat sink based on natural designs. Carlos Alberto Rubio-Jimenez et al [12] found that temperature contours obtained on heat sinks studied were non-homogeneous in nature. The design of heat sink corresponding to case 2-A was found to be most suitable design since the temperature distribution obtained on this design was found to be below the design point. A significant finding from this study is that the velocity of fluid can be increased by decreasing hydraulic diameter.

An experimental study was done by R.S.Mali et al [13] on heat sink with leaf like structure and found that leaf like structure resulted an increase in heat transfer capacity of heat sink. An important observation from the study is that the heat transfer capacity of heat sink with leaf like design is increased significantly for lower mass flow rates when compared with conventional type microchannel heat sink under the same conditions.

W. Escher et al [14] determined performance of bifurcating heat sink with that of parallel microchannel heat sink for same conditions and found that parallel microchannel heat sinks performance superior to that of bifurcating heat sink. The heat transfer capacity of parallel microchannel heat sink was found to be four times higher than bifurcating heat sinks along with a higher heat transfer coefficient because of dense packed nature of parallel microchannel heat sink thus allowing the heat sink to transfer heat more efficiently.

DESCRIPTION OF LOTUS TYPE POROUS COPPER HEAT SINK

The lotus type porous copper heat sink is a kind of heat sink similar to the microchannel heat sink with the exception that porous heat sink has long cylindrical pores as compared with long channels of a microchannel heat sink. The heat is absorbed by working fluids such as air flowing through pores. The heat sink is shown in figure 1. In reality the pores of copper heat sink are not exactly cylindrical in nature. Tetsuro Ogushi et al [15] showed that lotus type porous heat sink has a heat transfer capacity nearly four times as compared with conventional groove fins. It must be noted that to reduce computational time, only small size of heat sink has been considered in this study. Since heat transfer is a property dependent on area, with larger surface area, a better temperature gradient can be obtained.

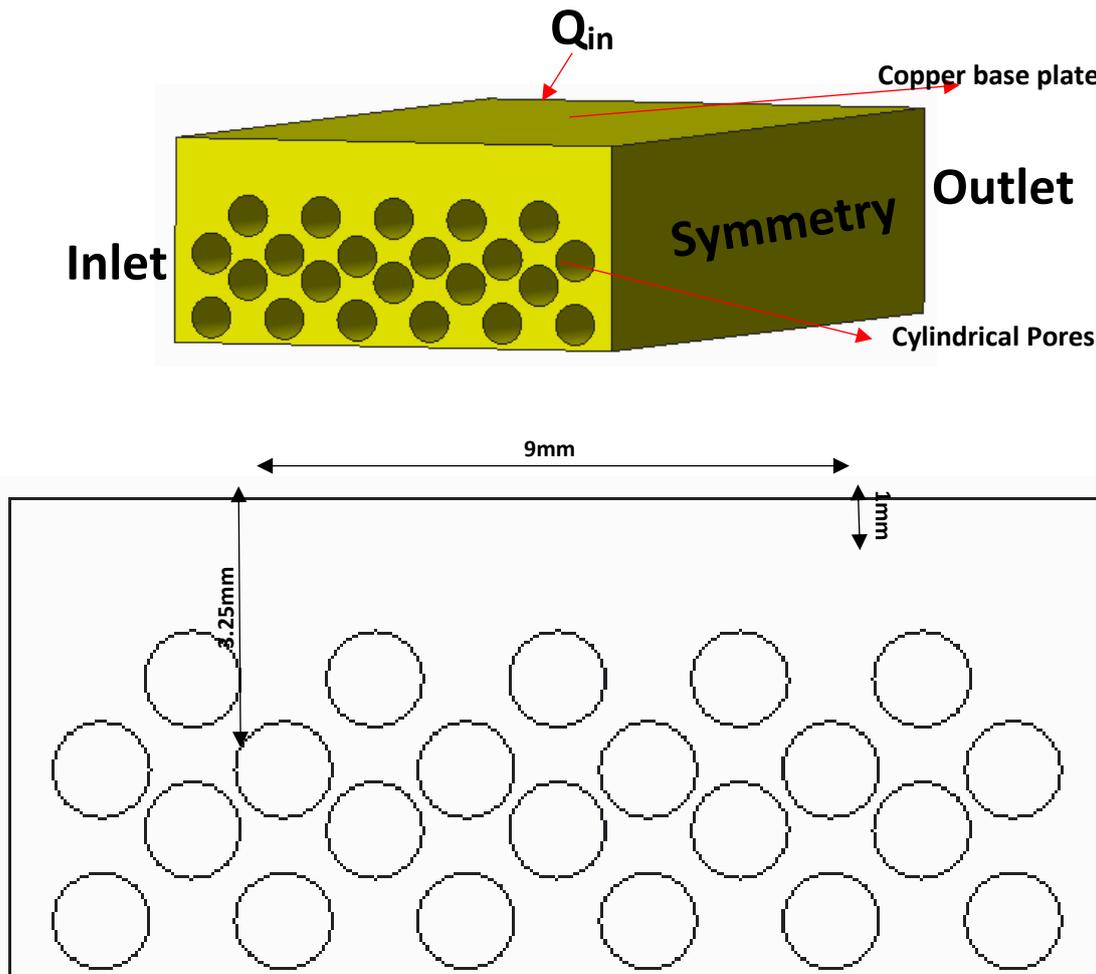


Figure 1. Lotus type porous heat sink used in this study along with dimensions and boundary conditions

Experimental Study

The specimen required for testing is prepared first by cutting required size of heat sink cut from ingot and then polishing it using Sic paper. After this process, the base plate made of copper is attached to lotus type heat sink using welding technique. Figure 2 below shows schematic diagram of experimental apparatus used in testing of lotus type porous heat sink. The experimental apparatus consists of two pipes which supply required fluid to cool the heat sink through use of pump. The heat sink is heated with the help of a heating unit. The temperature at base plate of heat sink was measured using T type thermocouple. The two junctions of thermocouple were stuck to surface of heat sink using adhesive. The heating unit consisted of a knob which could be adjusted to provide required level of heat flux to heat sink.

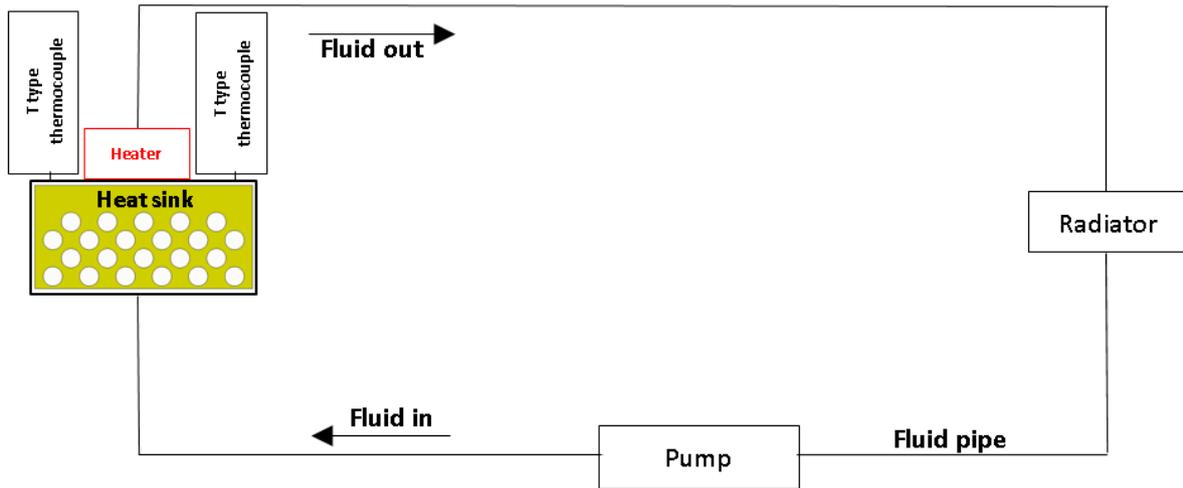


Figure 2. Schematic overview of experimental setup

The values of temperature obtained using experimental setup for both laminar and turbulent flow is tabulated in table 1 below. The error percentage between experimental and analytical results was found to be around 10%. This difference can be attributed to the fact that in real lotus type porous copper heat sink the pores are not completely spread throughout length of heat sink thus resulting in higher temperature values.

Table 1. Experimental value and numerical values of temperature for laminar and turbulent flows

Reynolds number	Temperature (K) Numerical results				Type: Laminar flow Temperature (K) Experimental results			
	Case a	Case b	Case c	Case d	Case a	Case b	Case c	Case d
	100	363	362	368	350	400	409	406
300	320	320	320	323	347	340	335	361
500	312	313	313	316	342	351	352	355
700	323	311	309	313	363	326	343	324
900	310	310	305	311	328	329	319	330

Reynolds number	Temperature (K) Numerical results				Type: Turbulent flow Temperature (K) Experimental results			
	Case a	Case b	Case c	Case d	Case a	Case b	Case c	Case d
	4100	329	317	321	398	360	342	366
4300	321	314	315	318	352	354	354	349
4500	314	313	310	312	335	350	337	335
4700	307	306	305	305	330	342	331	333
4900	303	302	302	302	318	321	326	322

NUMERICAL ANALYSIS

Model Description and Mesh Validation

The geometric model used in this study is shown in figure 2 above. In order to reduce the computational time and complexity of the problem, only a small portion of porous type copper heat sink is considered. The following are assumptions made in this study

- (1) The process is assumed to be a steady state process.
- (2) The physical properties of material remain constant and do not change with variables such as temperature.

- (3) Heat transfer due to radiation is neglected.
- (4) The effect of surface tension in liquid is neglected.
- (5) The material is homogeneous in nature and does not have any impurities.

The slip in velocity between fluid and solid is assumed to be zero. Uniform velocity and pressure distribution is assumed to be present at entrance of fluid into heat sink. The fluid is assumed to leave the heat sink with atmospheric pressure. A constant heat flux is provided at top wall of heat sink. It is assumed that side walls of heat sink have zero temperature and velocity gradients.

The side view of different designs of heat sink with bifurcations used in this study is shown in figure 3 below.

After importing geometry and meshing it, finite volume method and fluent code are used to solve corresponding governing equations with boundary conditions to get temperature and pressure fields. Convergence criteria is chosen in such a way that residual value is less than 10^{-6} . In order to avoid influence of mesh on results obtained a grid independence study was performed and results obtained are tabulated below. The study has been carried out with 3 million number of elements since the error percentage was found to be very less. A similar number of elements are used for both laminar and turbulent flow.

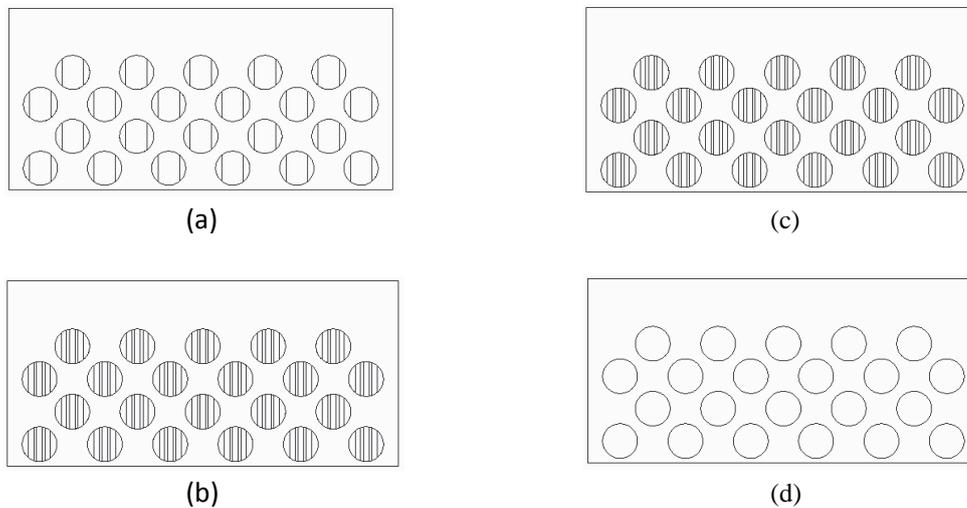


Figure 3. (a). Heat sink with single bifurcation, (b). Heat sink with multiple bifurcations with extreme bifurcations having depth of 0.0045m, (c). Heat sink with multiple bifurcations with centre bifurcation having depth of 0.0045m, (d). Heat sink with no bifurcations

Table 2. Mesh independence test results

Number of elements	Temperature	Error %
1.25 million	410K	-
2.5 million	404K	1.2%
3 million	400 K	0.9%

RESULTS AND DISCUSSIONS

Pressure Drop Characteristic -Laminar Flow

Fig .4 below shows the pressure drop characteristics of different designs of heat sink with bifurcations. As seen for the case of laminar flow, the heat sink with no bifurcations corresponding to case d has a lower pressure drop as compared to all other heat sinks with bifurcations. This is because the bifurcation causes the fluid to separate resulting in separation zones thus resulting in higher pressure drops. From the graph, it is also seen that with increase in Reynolds number there seems to be an increase in pressure drop as well and the velocity at which the pressure drop reaches maximum is based on design of bifurcation in heat sink and on physical properties of fluid.

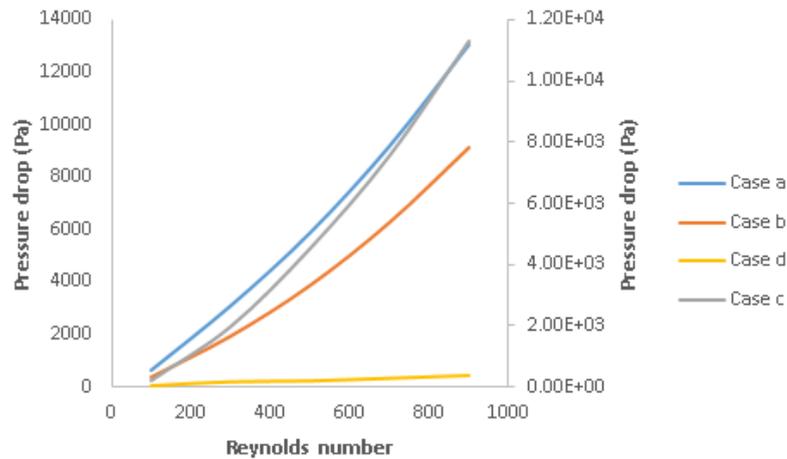


Figure 4. Pressure drop Vs Reynolds number graph for laminar flow

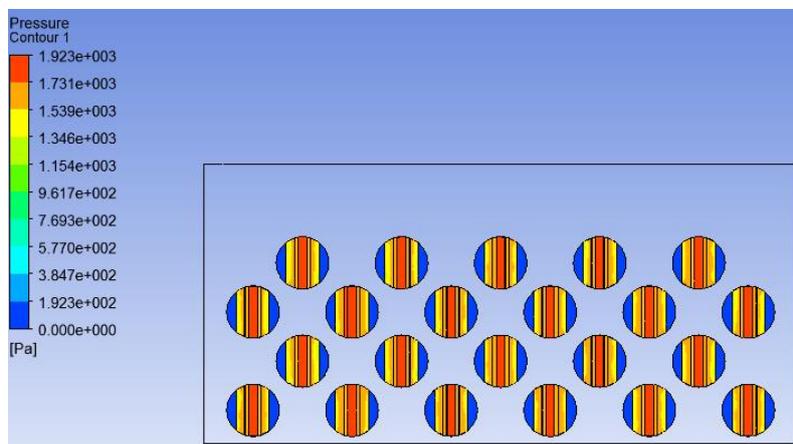


Figure 5. Pressure contours for Case d with velocity $v = 6\text{m/s}$

Thermal Characteristics- Laminar Flow

The thermal contours obtained for different cases is shown in fig. 5 below. The temperature seems to be maximum at velocity of 2m/s for heat sink without bifurcation. For call cases, it has observed that with increase in velocity of fluid, there occurs a steady drop in temperature. However, the temperature seems to reach a minimum value 305K for case c and 310K for case b at higher velocities. The heat sinks with bifurcations have a larger temperature gradient because the bifurcations result in boundary layer separations of fluid near its walls which causes an increase in heat transfer rate thus resulting in a temperature drop.

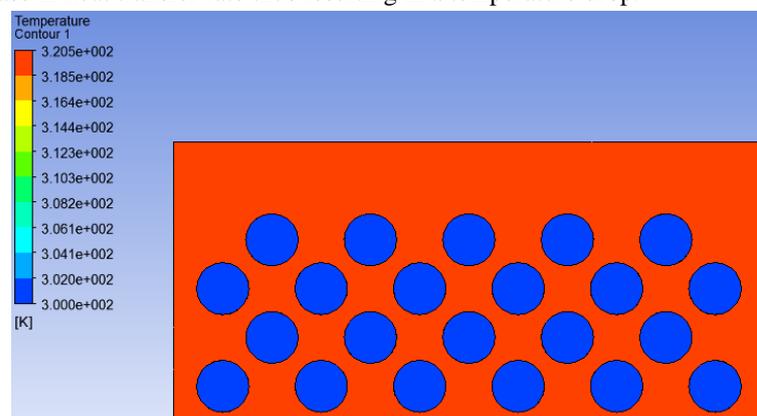


Figure 6. Temperature contours for Case b with velocity $v = 6\text{m/s}$

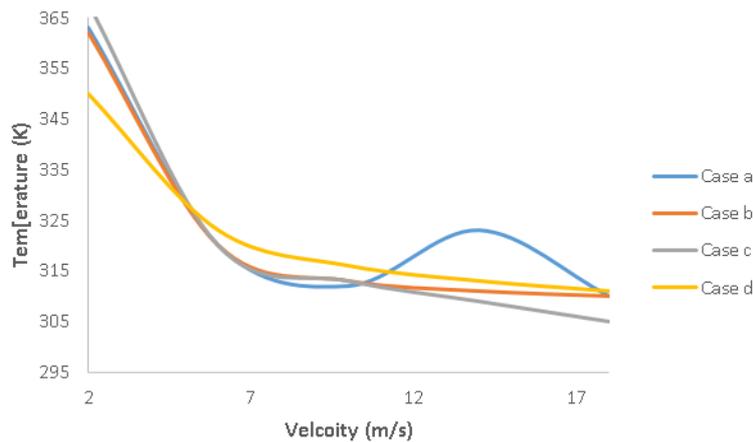


Figure 7. Temperature Vs velocity graph for laminar flow

Pumping Power - Laminar Flow

It can be observed from the graph that pressure drop has a strong correlation with pumping power. The pumping power increases linearly with increase in Reynolds number. The pumping power is found to be minimum for case d as expected because this heat sink does not have any bifurcations. The other heat sinks with bifurcations restrict the easy flow of fluid which causes an increase in pressure. The pumping power is found to increase more steeply for case a which has a single bifurcation and pumping power was also found to be maximum for this case since larger surface area of bifurcation causes a higher pressure drop. The pressure drop for other cases was found to be intermediate between two cases.

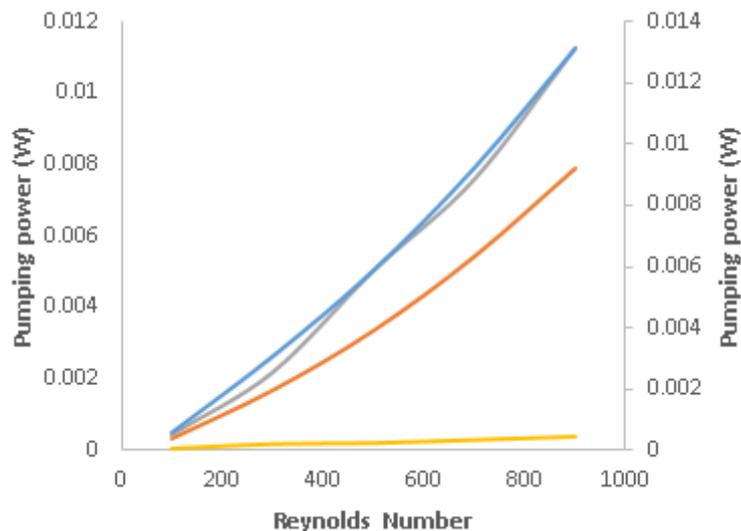


Figure 8. Pumping power Vs Reynolds number graph for laminar flow

Pressure Drop Characteristic -Turbulent Flow

Fig. 9 shows pressure drop graph for case of turbulent flow for all four cases. In graph the pressure drop increases with Reynolds number parabolically and reaches a maximum point. On further increasing the Reynolds number, the pressure drop begins to dip and reaches a minimum point. This nature of curve continues with further increase in velocity. Case d has a minimum pressure like laminar case as it does not have any bifurcations. An important observation to be made between pressure drop characteristics of laminar and turbulent flow is that for laminar flow, there is no dip in pressure drop with increase in velocity for laminar flow which is not the case for turbulent flow.

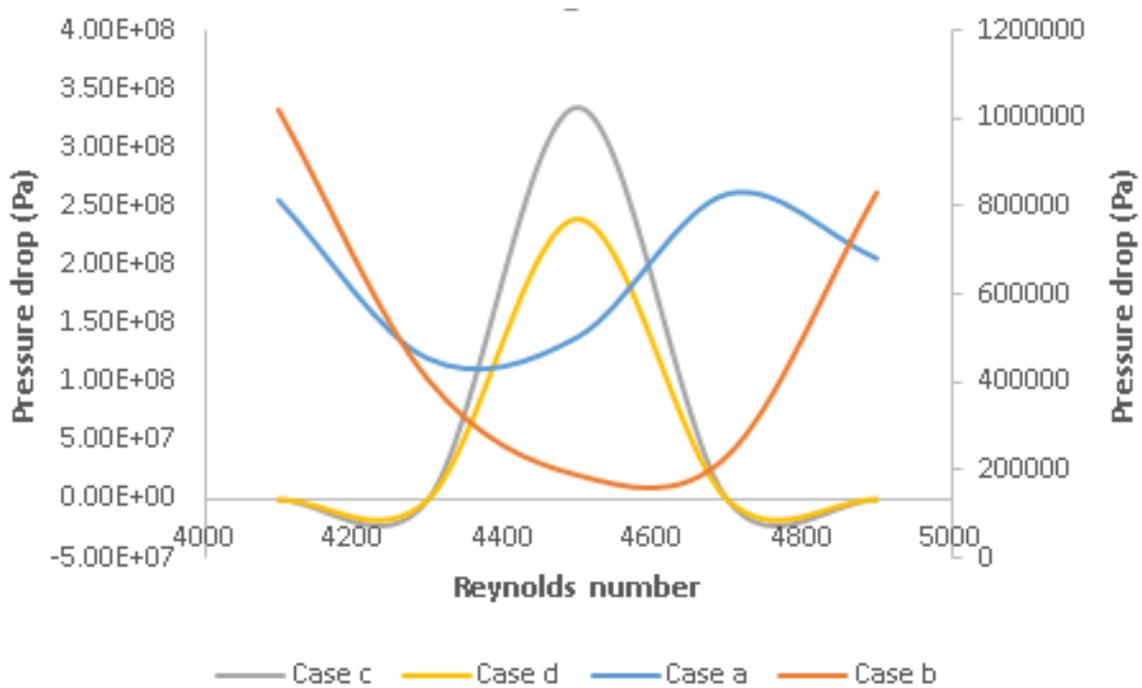


Figure 9. Pressure drop Vs Reynolds number graph for turbulent flow

Thermal Characteristic -Turbulent Flow

The thermal characteristics for turbulent flow were found to be similar to that of laminar flow with certain differences. For velocity of 82m/s, the heat sinks with bifurcations corresponding to cases a, b and c have a lower temperature while heat sink without any bifurcation has a higher temperature. The important difference between thermal characteristics of laminar and turbulent flow is that the temperature gradient in case of turbulent flow is more initially when compared to that of laminar flow. Also, it is seen that with continuous increase in velocity, all heat sinks approach towards a similar kind of temperature as the heat sink attains steady state. Although all heat sinks approach towards a similar kind of temperature with higher velocities, it is possible to take advantage of the fact that the heat sink with bifurcations that have a lower temperature at a lower velocity as compared to heat sink without any bifurcations. Case c was found to have a minimum temperature of 302K at higher velocity.

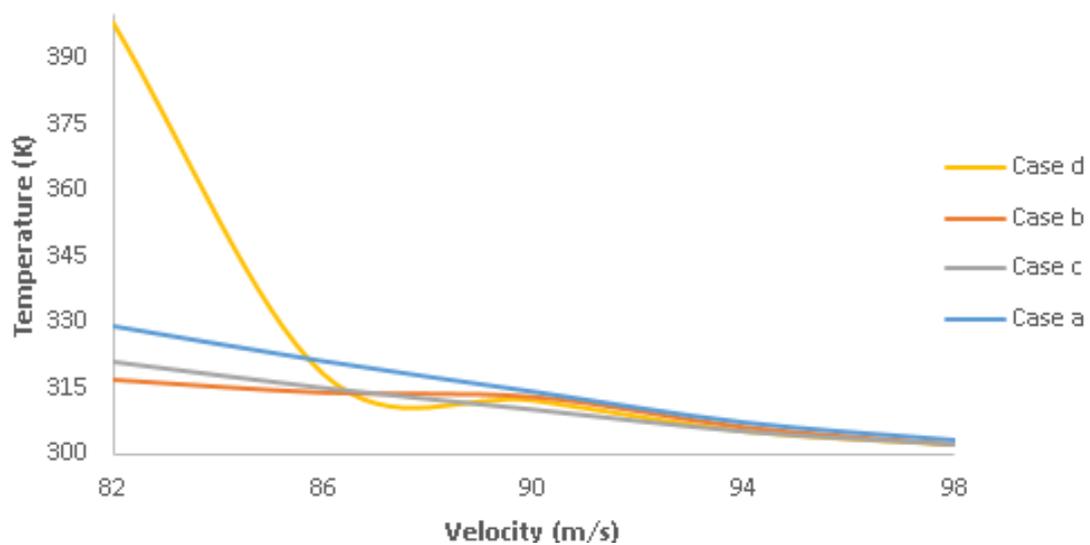


Figure 10. Temperature Vs Velocity graph for turbulent flow

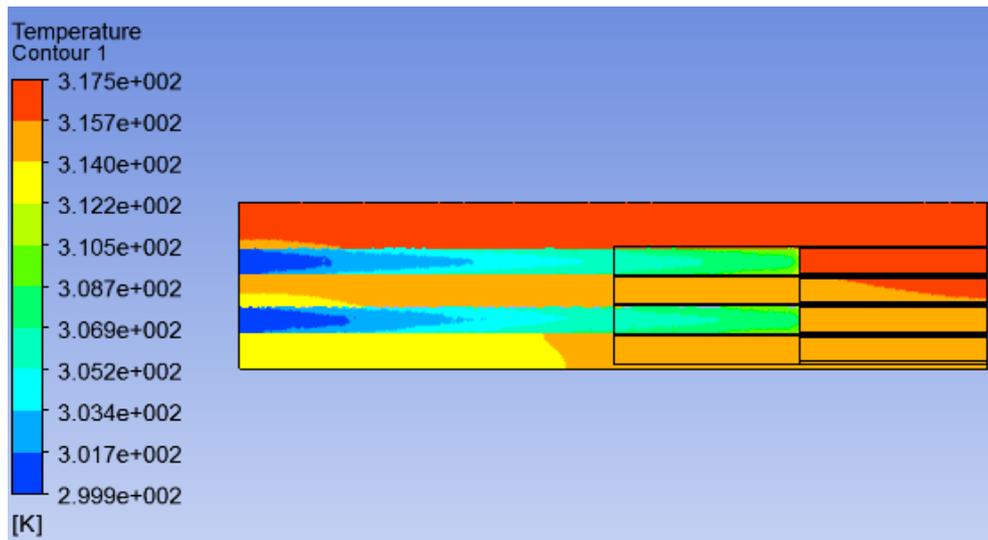


Figure 11. Temperature contours for case b with velocity 82m/s

Pumping Power – Turbulent Flow

As seen in fig. 11, for the case of turbulent flow pumping characteristics, like laminar flow the pressure drop of case d is less and thus it has a lower pumping power. Like pressure characteristics of laminar flow, there seems to be a maximum and minimum points at which pumping power reaches maximum and minimum values accordingly.

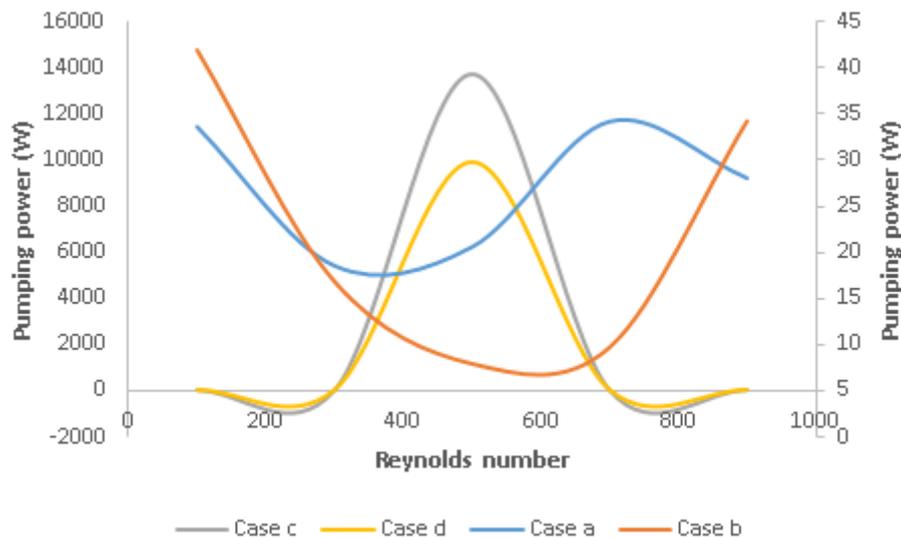


Figure 11. Pumping power Vs Reynolds number for turbulent flow

SUMMARY AND CONCLUSIONS

In this paper, bifurcations are designed for porous type copper heat sink. The effect of bifurcations on performance of porous type heat sink has been examined in this study for both laminar and turbulent flow. The following discussions could be concluded:

(1) The calculated results show that heat sink with bifurcations show a better thermal performance when compared with other heat sink without bifurcation. Thus, bifurcations provide a possible potential to further increase the heat transfer capacity of porous heat sink. A proper design of bifurcation can result in optimum pressure drop and pumping power thus resulting in optimum thermal performance.

(2) For both laminar and turbulent flows, the temperature drop increase with respect to increase in Reynolds number. However, for case of turbulent flow, the temperature drop is more as compared with that of laminar flow.

(3) The pumping power for case of laminar flow increases steeply for heat sinks with bifurcations while for case of turbulent flow, the pumping power attains a maximum value at certain velocity and reaches a minimum value at certain velocity which in turn is decided by design of bifurcation and properties of cooling fluid. A similar kind of observation was found for pressure drop as well for both cases.

CONFLICT OF INTEREST

None

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