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Numerical analysis of microchannel heat sink

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***Abstract*— Microchannels are used in a variety of applications like biochips, micro reactors, VLSI system where very high heat transfer performance is desired. These electronic equipments are virtually synonyms with modern life applications such as appliances, instruments and computers. The dissipation of heat is necessary for the proper functioning of these instruments. Microchannels provide very high heat transfer coefficients because of their small hydraulic diameters. Here, an investigation of fluid flow and heat transfer in microchannels is conducted. Fluid flow and heat transfer experiments were conducted on aluminium microchannel heat exchanger. A three-dimensional Computational Fluid Dynamics model was built using the commercial package, FLUENT, to investigate the conjugate fluid flow and heat transfer phenomena in a aluminium- based rectangular microchannel heat sink. This work focused on laminar flow (Re < 200) within rectangular microchannel. The influence of the thermophysical properties of the fluid on the flow and heat transfer, are investigated by evaluating thermophysical properties at a reference bulk temperature. The results indicate that thermophysical properties of the liquid can significantly Influence both the flow and heat transfer in the microchannel. Assumption of hydrodynamic, fully developed laminar flow is valid here on basis of Langhaar's equation.The hydrodynamics and thermal behaviour of a rectangular microchannel are studied here. The variation wall temperature, pressure drop in the channel and the friction factors calculated usingANSYS Fluent can well predict the experimental data. The effect of Re on the behaviour the channel are also studied. Its behaviour also have been analysed with the help of temperature, pressure and velocity contours.**

***IndexTerms*—Microchannel heat sink, Numerical simulation**

I. INTRODUCTION

The advantage of microchannels was first introduced by Tuckerman and Pease [1] for microelectronic cooling devices. Applications have since been expanded to other micro and nanotechnologies such as bioengineering, mini heat exchangers, aerospace and micro-electro mechanical systems.Due to the ever increasing needs for cooling of electronic components in the past decade, microfabrication has been one of the key research fields for heat transfer engineers. In spite of the rapid growth of the knowledge, the prediction of heat transfer in microchannel is not yet a well established engineering practice. Various investigators proposed heat transfer correlations, but there is hardly any consistency among them. Some investigators are attempting to interpret such discrepancies in terms of novel physical mechanisms which are claimed to be due to micro-scales encountered.

Microfluidics is a rather young research field, born in the early eighties. Its older relative fluidics was in fashion in the sixties to seventies. Fluidics seems to have started in USSR in 1958, then developed in USA and Europe first for military purposes with civil applications appearing later. At that time, fluidics was mainly concerned with inner gas flows in devices involving millimetric or sub-millimetric sizes. These devices were designed to perform the same actions (amplification, logic operations, diode effects, etc.) as their electric counterparts. The idea was to design pneumatically, in place of electrically, supplied computers. The main applications were the concern of the spatial domain, for which electric power overload was indeed an issue due to the electric components of the time that generated excessive magnetic fields and dissipated too much thermal energy to be safe in a confined space. Most of the fluidic devices were etched in a substrate, by means of conventional machining techniques, or by insolation techniques applied on specific resins where masks protected the parts to preserve. The rapid development of microelectronics put a sudden end to pneumatic computers, but these two decades were particularly useful to enhance our knowledge about gas flows in minichannels or mini pneumatic devices. As microfluidics concerns smaller sizes – the inner sizes of Micro-Electro Mechanical- Systems (MEMS) – new issues have to be considered in order to accurately model gas microflows. These issues are mainly due to rarefaction effects, which typically must be taken into account when characteristic lengths are of the order of 1 µm, under usual temperature and pressure conditions.

Microchannels are used in a variety of devices incorporating single-phase liquid flow. The early applications involved micromachined devices such as micropumps, microvalves, and microsensors. This was followed by a thrust in the biological and life sciences with a need for analyzing biological materials, such as proteins, DNA, cells, embryos, and chemical reagents. The field of micromixers further received attention with developments in microreactors, where two chemical species are mixed prior to introducing them into a reaction chamber. The high flux heat dissipation from high-speed microprocessors provided the impetus for studies on heat transfer in microchannels. The developments in the microelectromechanical devices naturally require heat removal systems that are equally small. Cooling of mirrors employed in high-power laser sys- tems involves cooling systems that cover very small footprints. Advances in biomedical and genetic engineering require controlled fluid transport and its precise thermal control in passages of several micrometer dimensions. A proper understanding of fluid flow and heat transfer in these microscale systems is therefore essential for their design and operation.

An MCHS contains many parallel microchannels containing the flow coolant. The heat generated by a device is carried away from the channel walls by the coolant. Air, water, ethylene glycol (EG), and engine oil (EO) are commonly used as coolants in MCHSs. However, the heat transfer performance of these coolants is limited because of their limited thermal conductivity. Hence, to improve heat transfer performance, it is necessary to increase the thermal conductivity of the coolants. This can be achieved by adding an appropriate amount of solid nanoparticles having high thermal conductivity to a base fluid for use as a coolant (i.e., using a nanofluid). Nanofluids were first proposed by Choi [2] at the Argonne National Laboratory, USA, who found that nanoparticles raise the thermal conductivity of the coolant, thus improving the heat transfer performance. Several researchers have demonstrated that nanofluids have a higher effective thermal conductivity than pure base fluids and therefore have great potential for heat transfer enhancement. Hence, it becomes desirable to develop an MCHS containing nanofluids for potential application in many electronic devices in order to improve the heat transfer performance.

Several recent studies have experimentally examined the use of a nanofluid as a coolant for an MCHS. For example, Xuan and Li [3] proposed a theoretical model describing the heat transfer performance of a nanofluid flowing in a tube and accounting for solid particle dispersion. Heris et al. investigated the laminar- flow forced-convection heat transfer of an Al_2O_3 –water nanofluid inside a circular tube with constant wall temperature. They found that increasing the nanoparticle concentration in the nanofluid improved the heat transfer coefficient. Chein and Huang [4] demonstrated that the heat sink performance of silicon microchannels improved greatly when nanofluids were used as coolants. Lee and Mudawar [5] assessed the effectiveness of nanofluids for single-phase and two-phase heat transfer in microchannels. Ho et al. [6] investigated the forced convective cooling performance of a copper MCHS with a nanofluid; they found that the nanofluid-cooled heat sink had a significantly higher heat transfer coefficient, markedly lower thermal resistance at high pumping powers, and a slightly higher friction factor. Wen and Ding [7] studied the laminar flow of nanofluids consisting of Al_2O_3 nanoparticles and de-ionized water through a copper tube. They observed considerable enhancement of convective heat transfer when the nanofluids were used and proposed that nanoparticle migration and the resulting disturbance of the boundary layer were the main reasons for the enhancement.

Koo and Kle- instreuer [8] suggested that MCHS performance could be improved by the use of carrier fluids having high Prandtl numbers, high volume concentrations of nanoparticles, microchannels with high aspect ratios, and channel walls treated to avoid nanoparticle accumulation. Chein and Huang [4] investigated the heat transfer performance of nanofluid-cooled MCHSs and found that they yielded better heat transfer performance than a water-cooled MCHS, and that a higher nanofluid bulk temperature could prevent particle agglomeration. Tsai and Chein [9] analyzed MCHS performance using Cu–H_2O and carbon nanotube–H_2O nanofluids and a porous media approach. They found that the nanofluid reduced the temperature difference between the bottom-heated wall and the bulk nanofluid. Jang and Choi [10] numerically investigated a nanofluid-cooled MCHS and found that the use of a water–diamond nanofluid enhanced the performance by about 10% compared with that of an MCHS with pure water. Li and Kleinstreuer [11] analyzed the thermal performance of nanofluid flow in a trapezoidal microchannel using pure water and a nanofluid. They claimed that the nanofluid measurably enhanced the thermal performance of microchannel flow, although a slight increase in pumping power was required. Specifically, the thermal performance increased with nanoparticle volume fraction, but the greater pressure drop somewhat decreased the beneficial effect.

Ghazvini and Shokouhmand [12] extensively investigated the effects of particle volume fraction and Brownian–Reynolds number on the temperature distribution and overall heat transfer coefficient, and the influence of different channel aspect ratios and porosities on a nanofluid-cooled MCHS. Fard et al. [13] numerically studied laminar convective heat transfer of nanofluids in a circular tube under constant wall temperature and found that the heat transfer coefficient increased with the particle concentration and Péclet number. Chen and Ding investigated the heat transfer performance of an MCHS with water–Al_2O_3 nanofluids having different nanoparticle volume fractions. The fluid temperature distribution and thermal resistance changed significantly in response to the inertial force effect. Christo Ananth et al. [14] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

Mohammed et al. [15] numerically investigated heat transfer in a square microchannel heat exchanger and found that nanofluids enhanced the thermal properties and performance of the heat exchanger while slightly increasing the pressure drop. Mohammed et al. [16] also investigated the heat transfer characteristics of a trapezoidal MCHS using various base nanofluids and substrate materials. They observed that the heat transfer performance of water-based nanofluids can be greatly enhanced in a heat sink having a steel substrate.

In summary, many interesting results indicating the potential of nanofluids to enhance the thermal performance of an MCHS have been reported. However, most of the studies in the open literature did not simultaneously examine the effects of various nanoparticles, base fluids, particle sizes, and substrate materials on the heat transfer performance of an MCHS based on the optimal geometric design.

II. COMPUTATIONAL FLUID DYNAMICS AND FLUENT

Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The numerical solver codes are well-established and thus provide a good start to more complex heat transfer and fluid flow problems. FLUENT provides adaptability to variation of thermo physical properties with respect to temperature effect. The fundamental basis of any CFD problem is the Navier-Stokes equations, which define any single-phase fluid flow.Some of the discretization methods being used are:

a)Finite volume method:

This is the "classical" or standard approach used most often in commercial software and research codes. The governing equations are solved on discrete control volumes. This integral approach yields a method that is inherently conservative.

b)Finite element method:

This method is popular for structural analysis of solids, but is also applicable to fluids. The FEM formulation requires, however, special care to ensure a conservative solution. The FEM formulation has been adapted for use with the Navier-Stokes equations. In this method, a weighted residual equation is formed.

c)Finite difference method:

This method has historical importance and is simple to program. It is currently only used in few specialized codes. Modern finite difference codes make use of an embedded boundary for handling complex geometries making these codes highly efficient and accurate. Other ways to handle geometries are using overlapping-grids, where the solution is interpolated across each grid.

III. COMPUTATIONAL FLUID DYNAMICS MODEL EQUATIONS

In this study the both the single phase models is used for solving the respective category problems. This model will calculate one transport equation for the momentum and one for continuity for each phase, and then energy equations are solved to study the thermal behaviour of the system. The theory for this model is taken from the ANSYS Fluent V16.

a)Single phase modelling equations:

The single phase model equations include the equation of continuity, momentum equation and energy equation (ANSYS Fluent V16). The continuity and momentum equations are used to calculate velocity vector. The energy equation is used to calculate temperature distribution and wall heat transfer coefficient.

b)Two phase modelling equations:

A large number of flows encountered in nature and technology are a mixture of phases. Physical phases of matter are gas, liquid, and solid, but the concept of phase in a multiphase flow system is applied in a broader sense. In multiphase flow, a phase can be defined as an identifiable class of material that has a particular inertial response to and interaction with the flow and the potential field in which it is immersed. Currently there are two approaches for the numerical calculation of multiphase flows: the Euler-Lagrange approach and the Euler-Euler approach.

IV. GEOMETRY MODELLING

The rectangular microchannel heat sink is modelled in solidworks software. The diamensions of the model are specified below.

Length of heat sink = 51 mm
Width of heat sink = 51 mm
Channel height = 1.7 mm
channel width= 0.25 mm
Fin thickness = 0.14 mm
Number of channels = 130

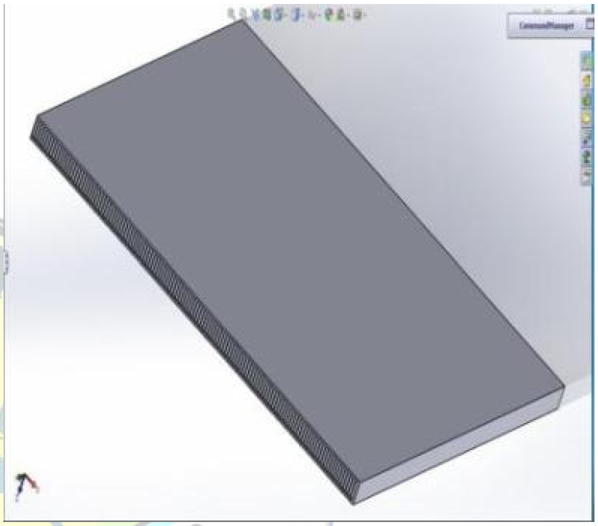

Fig 1-A microchannel heat sink

V. COMPUTATIONAL DOMAIN

Since the channels are symmetric in nature, a single channel is constructed and analysed which is taken as the computational domain.

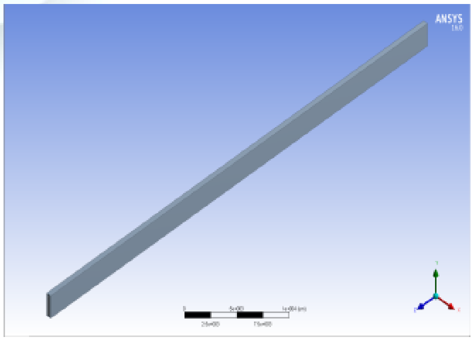

Fig 2-Computational domain

VI. RESULTS AND DISCUSSION

a)Aluminium as heat sink and air as coolant

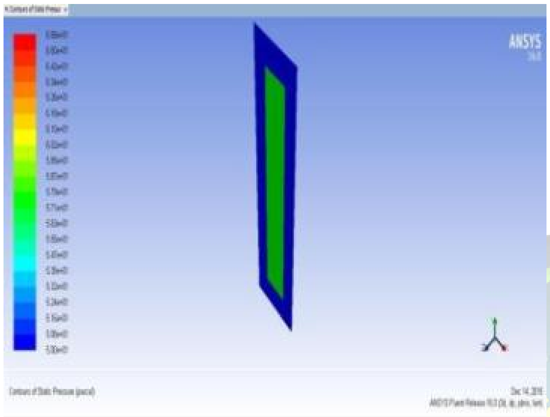

Fig 3-Countors of static pressure

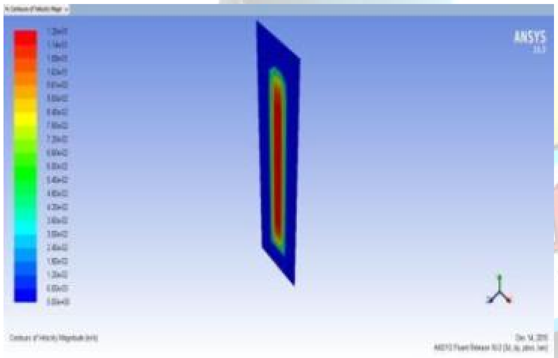

Fig 4-Countors of velocity magnitude

b)Aluminium as heat sink and water as coolant

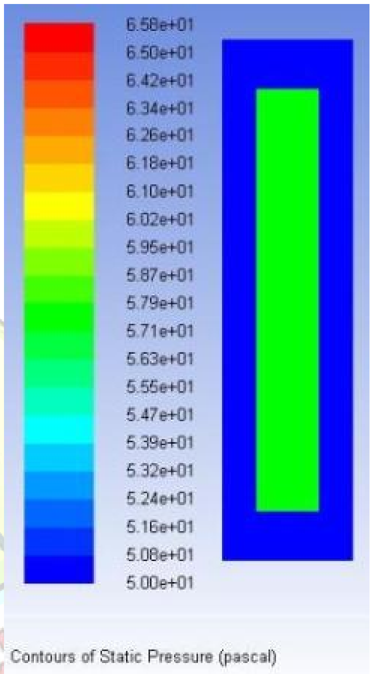

Fig 5-Countors of static pressure

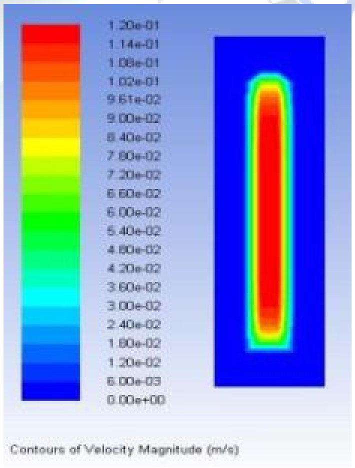

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Fig 6-Countors of velocity magnitude

c)Aluminium as heat sink and ethylene glycol as coolant

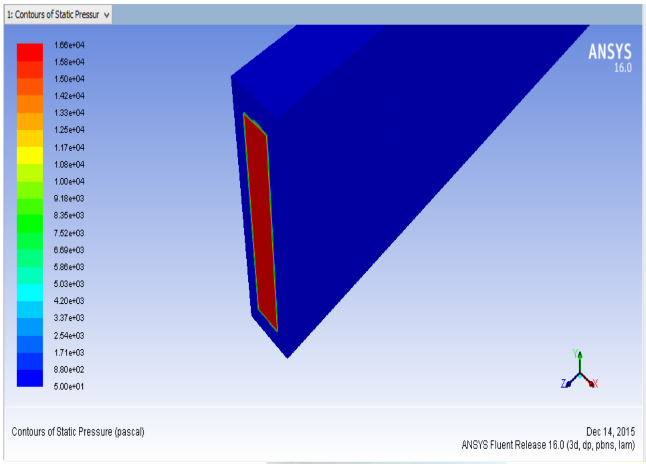


Fig 7-Countors of static pressure

d)Aluminium as heat sink and ethyl alcohol as coolant

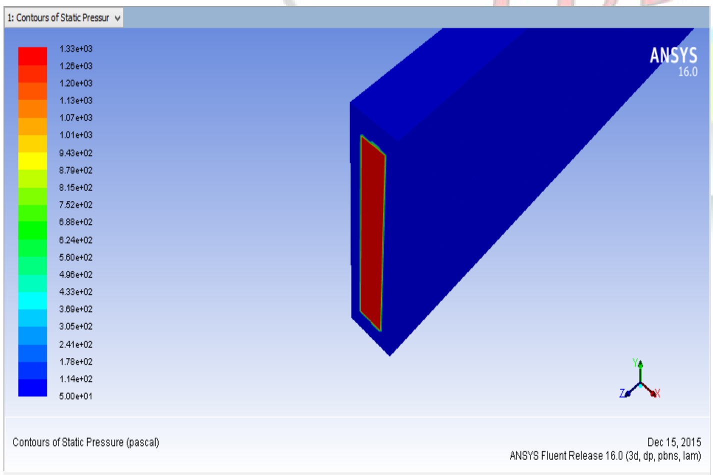
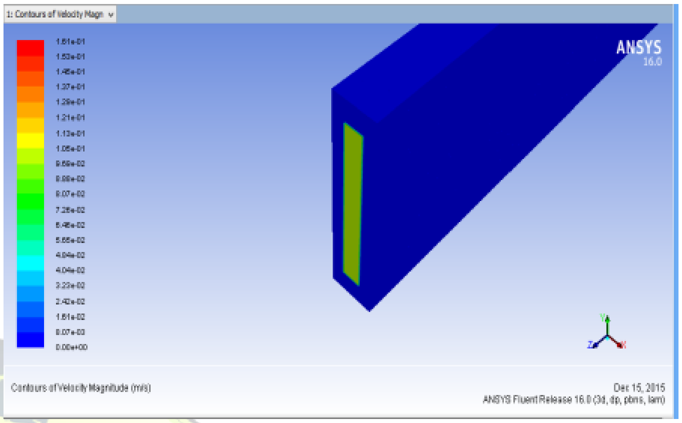


Fig 8-Countours of static pressure



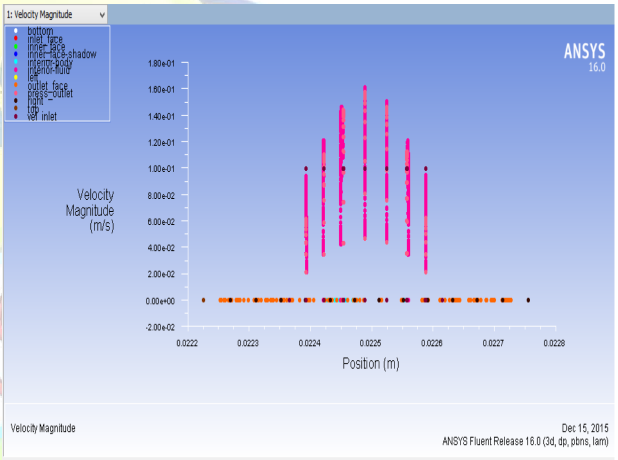


Fig 9-Countours of velocity magnitude

Fig 10- Plot of velocity magnitude

VII. CONCLUSIONS

The analysis performed, provides a fundamental understanding of the combined flow and conjugate convection–conduction heat transfer in the three-dimensional micro-channel heat sink. The model formulation is general and only a few simplifying assumptions are made. Therefore, the results of the analysis as well as the conclusions can be considered as quite general and applicable to any three-dimensional conjugate heat transfer problems.

A three-dimensional mathematical model, developed using incompressible laminar Navier–Stokes equations of motion, is capable of predicting correctly the flow and conjugate heat transfer in the micro-channel heat sink.

The combined convection–conduction heat transfer in the micro-channel produces very complex three-dimensional heat flow pattern with large, longitudinal,upstream directed heat recirculation zones in the highly conducting silicon substrate where the fluid and solid are in direct contact. Here we have compare of the numerical results with other published results and experimental data available in the literature for Reynolds numbers less than 200 based on a hydraulic diameter of Dh = 86 µm.

The influence of the geometric parameters of the channel and the thermophysical properties of the fluid on the flow and the heat transfer, are investigated with a temperature dependent thermophysical property. A correlation for the averaged Nusselt number with the Reynolds number is developed and discussed. The resultsindicate that variations in the way the Nusselt number is defined in different conditions.

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