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A Review of Heat Transfer in Microchannels using Nanofluids

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***Abstract*— High performance heat exchanger devices with higher thermal conductivity of coolants are the need for micro industry, domestic and automobile industry. Thermal conductivity of coolants plays an important role in designing, selection, fabrication of high surface to volume ratio devices to extract higher heats from small spaces.Lower thermal conductivity of conventional fluids like water, ethylene glycol and oils has put a question on their credibility in small spaces high heat extraction devices.Nanofluids, suspensions have nano sized particles (upto 100nm) is seems to be promising solution of this problem. Furthermore, higher surface to volume ratio devices extract more heat than convention heat exchanging devices, microchannels stands by these constraints and proved a valuable asset for heat exchanger category.**

***Keywords*— Flow Rate; Heat Transfer; Nanofluid; Microchannel.**

I.INTRODUCTION

A lot of advancement has been made by microelectronics industry, resulting in development of high heat generating microelectronic devices. The heat generated by these devices which is an important issue for consideration of their use in industry or everyday activities. High heat buildup in microelectronic devices can not only hamper its performance but can also damage the device. Hence finding solution to this heat buildup is an important but challenging task. Now this heat disscipation task can either be achieved by increasing surface to volume ratio of heat exchangers or by employing better coolants or by both the methods. The problem here with conventional coolants like water, oils, ethylene glycols is that that they have been proved futile due to their low thermal conductivity that leads to poor heat disscipation and slows down the device.

In 1873,it was put forward by J.C Maxwell [1] that to increase the thermal conductivity of base fluid, very small solid particles must be added to the base fluid which can lead to higher heat disscipation. This happens due to higher heat capacity of very small solid particles as compared to base fluid and gives a boost to the heat capacity as well as thermal conductivity of base fluids. However experiments have also shown that addition of micro particles and millimeter sized particles to base fluids also leads to problems like abrasive wearing of pipeline, channel clogging, sedimentation and pressure drop. The above problems has put a restriction on their use in industry. To bypass these problems the use of nanoparticles was introduced.

II. STUDY OF HEAT TRANSFER THROUGH MICROHANNELS USING NANOFLUIDS

Microsized flow passasges having hydraulic diameter range between 10 micrometer to 200 micrometers are called microchannels. Microchannels consists of high surface area to volume ratio enabling higher heat transfer rates. Microchannels can fit in very small spaces owing to their small size.It can fit into small spaces where heat generation is more and where conventional methods fail to disscipate the heat. Many researchers have done experimentation for studying the heat transfer through microchannels using nanofluids The experiments carried out by these researchers have shown increased thermal conductivity upto 790W/cm2 and the maximum temperature can rise upto 710C higher than that of water. In the microchannels shown in figure 1.1 small channels which can be seen have hydraulic diameters ranging from 10mm – 200mm.Microchannels are generally manufacteured on silicon wafers because of simple process of stereo lithography and ease of manufacturing. Although this method is easier but it has a drawback related to manucaturing accuracy and thus it leads to discrepancy between theoretical and experimental results. Hence due to this drawback a new method of cnc wire cutting on aluminium is generally utilized. The revolutionary work of tuckerman and Pease[2] in 1981 gave a boost to the microchannels research. After this the research focus shifted to design implementation from 1986-1988.This was further followed by understanding the design fundamentals of flow of fluid through microchannels during the period of 1992-2002 and then the interest shifted towards practical application in 2002.

During the period after the focus shifted towards validating the research work which had already bee done. From the findings of Satish. G. Kandlikar [3] it has been found that for practical use more research needs to be done in microchannel area.

Wu et al. [4] did experiments using aluminium oxide – water based nanofluids and microchannels of silicon (hydraulicdia =194.5 nm and relative roughness = 2.2*10-5). They used spherical shaped nanoparticles. The mean size of the particles was 56 nm and the volume fraction they took for the work were .26% and .15%.The nanofluids were prepared by two –step method. The nanofluids were prepared by dispersing the nanoparticles in distilled water which acts as the base fluid. This mixture is then kept in ultrasonic ultrasonic oscillator and ultrasonic oscillation is done for 90 minutes. They kept the nanofluid for 10 days and after 10 days they examined the nanofluid for agglomeration. During this examination they found that no agglomeration had taken place and nanofluid was largely stable. the parameters they used for their work are a) Inlet temperature of the nanofluid (In the range of 250C – 350C) b) Flow rate (In the range of4.5*10-8 m3/sec – 2.6*10-7 m3/sec).The apparatus used for the work were sytem through fluid flow occurs, test section data acquiring system. They also studied how the factor such as volume concentration, Reynolds number and Prandtl number affected the heat transfer behavior, friction in fluid and pumping power required were studied. They found that the results obtained from the experiments were consistent with the results obtained from theoretical procedure. Hence this proved the correctness of the results obtained from the experiments. figure 2.6 shows the diagram of testing section. In case of zero heating power condition the flow was controlled by adjustment of liquid valves.

Yu et al. [5] Studied the nanofluids behavior and properties .From the studies performed they discussed in details the various aspects of nanofluids such as a) Application of nanofluids b) Various methods for checking the stability of nanofluids and c) Methods of preparation of nanofluids. They also discussed in detail about the one – step and two – step methods of preparation for nanofluids. In this discussion they have stated that one – step method for preparing the nanofluids provides better stability of nanofluids as compared to two – step method because of various factors such as a) No need for storage in one – step method b) The requirement to transport is avoided c) drying dispersion of nanofluid is also not required. Newer methods like phase transfer method, preparation of Cu nanofluids by continuous flow microfluidic microreactor. Methods to examine the stability of nanofluids:- a) Zeta potential method b) Sedimentation and centrifugation c) Spectral absorbency analysis. From the stated processes it was found that sedimentation and centrifugation is the best process to examine the stability of nanofluids. Applications of nanofluids have also been given. Stability enhancing methodologies have been described in detail.

Choi et al. [6] has written that fluids that provide high heat transfer rates are required in the area of highly efficient fluids for their progression. Choi et al performed experiments with copper – H_2O and Al – H_2O nanofluids as heatcoolants. They found that thermal conductivity of nanofluids as compared to base fluids is significantly better. Another observation was that the heat transfer rate could be doubled without much increment in pumping power needed to pass the nanofluid through heat exchanger.

Gunnasegaran et al. [7] for the research work took various geometries of microchannels with diffirent aspect ratios performed a numerical simulation on flow of fluid through each of them.From this study it was determined how various geometries of microchannels and aspects ratios influence the pressure drop as well as friction factor in the flow.In this numerical study finite volume method was chosen for numerical investigation with grid size of 2.5*105 cells.The different crosssections used in the study are triangular cross section,rectangular cross section and trapezoidal cross section.The variables in this study were:- a) For rectangular geometry: width of the cross section as well as height of the cross section, b) For trapezoidal geometry: width of the bottom,width of the top,height and length of the geometry and c) For triangular geometry: top width,triangular angle and height of the triangular geometry.Reynolds number varies directly with Poiseulle number.This direct variation is although not a straight line variation this is because of the reason that at low values of Reynolds no. higher amount of heat is transferred to the water which leads to reduced pressure drop as well as viscousity.In terms of poisuelle no triangular geometry ranks at the top and then follows trapezoidal geometry and rectangular geometry ranks third and last.For rectangular geometry poisueille no and friction factor varies directly with width to height rato.For trapezoidal channel the design variables of significance are ratio of height to top width,the ratio of bottom to top width and ratio of length to hydraulic diameter.The flow resistance varies inversely with the ratio of length to hydraulic diameter and varies directly as ratio of bottom to top width.The values obtained from numerical method is found to be consistent with the theoretical results.In this study a distinction has been made between the behavior of flow through different geometries of microchannels.

Singh et al. [8] performed experiments to study the heat transfer through microchannels using nanofluids.In this study two microchannels were used. One had hydraulic dia of 218 nm and the other has the hydraulic dia of 303 nm. Both the microchannels were manufactured by the process of wet ion itching on silicon wafer.In the apparatus there was facilities such as facility for temperature measurement of the lower wall as well as for providing the flow passage. The size of the nanoparticles are 45 nm. The various samples that were prepared for experimentation were 1 % by volume,.5% by volume and .25% by volume. These sample were stabilized by proper procedure.Water and ethylene glycol are used as fluids in which nanofluids are prepared. In this study emphasis was laid on viscousity as well as thermal conductivity. Dispersion is found to be characteristic of significance for which it was found that it occurred due to particle movement caused by shear. It was also observed that heat transfer behavior was directly related volume concentration and inversely related to viscousity of the base fluid.

Farsad etal**.** [9] numerically studied flow of nanofluids through microchannels and corresponding heat transfer. They conducted their numerical study on the commericial software FLUENT. In this study the input temperature was chosen as 220C and pressure for the input was chosen as 1 – bar. Only one rate of flow of volume was chosen for this study. The chosen rate of flow of volume in this study was .3 ml/min. The flow velocity was .212m/ sec. The different samples prepared of various concentrations are 0 %,2 %,4 %,6 %,8 %.Aluminium oxide – water based nanofluids are used in this study. Rate of heat transfer varies directly as rate of volume flow. Rate of heat transfer also varies directly with volume concentration. Heat transfer was better in case of metal nanofluids than the metal – oxide based nanofluids.

Mondragon et al**.** [10] performed experiments using silica - nanofluids, alumina – nanofluids and carbon –nanotubes. The parameters used in the study were specific heat, thermal conductivity and viscousity. Nanofluids were prepared by dispersing nanoparticles in water. In this study the most stable nanofluids were selected based on the value of prandtl number. These nanofluids requires lesser pumping power and thus higher pump efficiency and also they provided the best rate of heat transfer. Different samples were prepared with volume concentration in the range of .5% by vol – 5% by volume. The properties of samples were found at different temperatures of 40^0C,60^0C and 80^0C. Different models were used in this study. Low volume concentration of nanofluid did not affect the thermal performance much. Performance varies directly with concentration and the specific heat varies directly as temperature and varies inversely as volume concentration because of reduced thermal conductivity at higher volume concentrations. Increasing the temperature upto 600^0C resulted in increase in thermal performance but after 600^0C the performance starts to decrease. Viscousity of nanofluid varies directly as volume concentration whereas it varies inversely with temperature.

Salman et al**.** [11] conducted the experiments with silicon dioxide – water based nanofluids. They also studies these nanofluids theoretically. The size of the nanoparticles was 30nm.The volume concentration of different samples is in the range .5 vol % - 1% vol % .These calculations are based on a certain formulae. Two – step method was used for preparing the nanofluids. then 30 minutes of ultrasonication was done in the Ultrasonicator. Volume of each sample was 100 ml. After 5 hours nanofluids was examined for stability and it was reported that no agglomeration has occurred and nanofluid was largely stable. This study envoled finding how the nusselt no is affected by volume concentration as well as Prandtl no. A high pressure tank containing nitrogen was used to provide the flow of nanofluids. Heat was generated by a heater which consisted of 5k – type thermocouple. These thermocouples were spaced by an equal distance of 30mm.They were placed along the length of the tube. Their function was controlling the heat generated as well as measurement of temperature. Two thermocouple spaced by 3 mm were used to record the external temperature at both inlet as wellas outlet. The friction factor was also found for both aluminium oxide –water nanofluids as well as silicon dioxide – water nanofluids. The volume concentration for both the nanofluids sample was taken as 1 by vol %. The Reynolds no was from 90 to 800.The results were verified with theoretical model of full developed flow with nusselt no of 4.36.The heat generation is constant. A 22% increase in heat transfer rate was observed as compared to water.

Lin et al**.** [12] conducted experiments to find the heat transfer behavior aluminium oxide – water nanofluids. The mean size of the nanoparticles was 30 nm.Various samples were used in this study with different volume concentration. The volume concentration used in the study were 1 % by vol,2 % by vol,3 % by vol,4 % by vol. The microchannels used were dimple plus protruded as well as dimple. It was also observed that the factors such as volume conc., geometry of the microchannel, heat transfer behavior and velocity at inlet affects the results.

Kimet al**.** [13] conducted experiments using manifold microchannel heat sinks with forced air cooling. This research work envolved observing how microchannel geometry affects heat transfer through manifold microchannel heat sink. Thermal Resistance varies inversely as pumping power and thermal resistance dercreased when width of microchannel was reduced.

Chein et al**.** [14] experimentally found that in microchannel temperature of the wall was lower as well as rate of heat transfer was higher.In this study they used copper oxide – water nanofluids and did not use dispersion additives. Various samples were prepared with different volume concentration in the range of .2 % by vol to .4 % by volume. It was found that at lower flow rates the heat disscipation was higher for nanolfuids as compared to water. At higher flow rates the the disctinction is quite negligible. Value of temperature of wall was consistenet theoretically as well as experimentally. Pressure drop was higher for higher volume concentration.

Manay et al**.** [15] carried out a numerical study for finding out the heat transfer behavior and pressure drop in case of aluminium oxide nanofluids as well as copper oxide nanofluids. The samples of various volume concentrations used in this study were :- 0 %,.5 %,1 %,1.5 % and 2 %.The results obtained from numerical study were verified using results obtained from analysis of the literature.The method of finite volume was employed for solving the mathematical equations.Results are expressed in the form of Nu no,pressure drop and heat transfer.To validate the mixture model they compared this model with Eulerian method and agreement was found.The heat disscipation ability of nanofluids was significantly higher than that of base fluid.

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III. CONCLUSIONS

Many researchers have done work in the field of nanofluids nad microchannels.The available literatue sheds light on the behavior of nanofluids such as their thermal properties,their stability and also their applicability in various areas.A large quantity of work is available in the field of microchannels where emphasis has been on behavior of flow,boiling of flow and on validating the applicability of continuum theory to the flow of nanofluid through the microchannels.

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