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INVESTIGATION OF THERMAL PROPERTIES OF MICROCHANNEL HEAT SINK WITH NANOFLUID

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ABSTRACT

Advancement in micro and nano fabrication technologies eases to manufacture compact heat exchanger devices. The compact heat exchanger and heat transfer devices performance can drastically improved by using microchannel arrays along with use of nanofluids. The parametric analysis of semicircular microchannel heat sink with distilled water and different concentrations of Multiwalled carbon nanotubes is carried out theoretically along with experimentation. The theoretical design is carried out for Minimum thermal resistance, maximum heat transfer coefficient, minimum friction factor and pressure drop along with minimum entropy generation. The microchannels with 200 µm hydraulic diameters are prototyped on accurate wire cut EDM. The effect of heat fluxes and Reynolds number is observed on heat transfer coefficient and pressure drop in laminar region. The performance of IC system is achieved best under Reynolds number 550 to 750. The heat transfer enhancement is observed 39 % over pure water with concentration of 0.1 % carbon nanofluids. The exact comparison theoretical calculation is done with experimental results and they are further validated with correlations in journal papers. Reynolds number increases then heat transfer coefficient, pressure drop, thermal resistance increases.

Keywords: IC cooling, microheat transfer, nanoparticles, Reynolds number, thermal resistance

I. INTRODUCTION

Heat transfer enhancement and equipment operational cost reduction are parameters taken as primary for design of new heat transfer equipments. The nanotechnology has opened facilities for production of microchannels and compact heat exchanges with high efficient operations. The high aspect ratio microchannel devices along with geometries with high surface to volume ratios will leads to high Nusselt number which is nothing but high heat transfer coefficient. The MCHE with nanofluid a new class fluids which leads to efficient working of heat transfer equipment. They improve convective heat transfer coefficient double, triple and more with marginal rise in pressure drop than base fluid performance. The microchannels are large applications in biological systems, in cooling of lasers, drug delivery systems, DNA analysis and telecommunications, IC cooling's.

In efficient cooling system liquid coolant is propelled to pour in microchannel array which is in contact with heat flux supply input. The heat is drain away by coolant and it leads to cool the source and it is continuously absorbs heat and it leads to efficient microchannel heat sink. The Tuckerman and Pease and developed this concept of microchannel heat sink. The area reduction and small size of the microchannel heat sink holds low cost so that it has taken attention in short time period. It has wide applications and it is enhancing heat transfer coefficient. They worked on reducing hydraulic diameter and it is noticed that if we reduce the hydraulic diameter then it will enhance heat transfer coefficient. The nanoparticles are innovation class fluids which will enrich base fluid thermal properties. The thermal conductivity, specific heat capacities have responsible to enrich Nusselt number and if pumping power is secondary criteria then nanofluids will be best candidate for heat transfer enhancement. So currently high heat dissipation devices need to prepare for existing IC devices. We have worked for design of microchannel geometry along and parametric analysis of microchannel heat sink with and without nanofluids. The results of theoretical investigation are compared with experimental analysis and correlations in journal papers and they are in good agreement.

II. LITERATURE REVIEW

Tuckerman and Pease [1] has worked for rectangular silicon microchannels for finding out optimum aspect ratio for heat transfer enhancement. The high aspect ratio in microchannel will leads to reduce the thermal resistance and as hydraulic diameter is reduced then heat transfer become dominant so they worked to reduce the area and diameter and achieved highest heat transfer coefficient. It is concluded that microchannel heat transfer can dissipate heat flux of range 790 W/cm^2 with only rise in substrate temperature rise of 71°C above the input distilled water temperature was measured. The further studies are carried out with imparting nanofluids along with variation in cross section, geometries also now a day's lot of research is carried out on boiling and condensation. It will allow digging out high power densities and definitely it will enhance the feasibility of ultrahigh-speed VLSI/ IC circuits

Bahrami [2] has worked on finding pressure drop correlations for arbitrary cross section and they have derived correlations based on parameters Reynolds number and geometrical parameters of the cross-section along with perimeter, area, cross-sectional polar moment of inertia, and channel length. The length scale is important to differentiate circular and arbitrary cross section. The collected pressure drop data was in good agreement with the proposed model and they have compared data with journal papers in hyperbolic contraction with rectangular cross-section.

P.S. Lee [3] has conducted experimental analysis to validate derived correlations for various geometries of straight rectangular microchannel sections of microchannels with width vary from .194 mm to .534 mm and aspect ratio 5 through copper 10 rectangular microchannels and deionized water with Reynolds number ranging from 300 to 3500. The various heat flux and Reynolds number with inlet temperature 90 °C are tested and he observed that expanding micro channel heat sink are better candidate for heat transfer performance enhancer than straight micro channel heat sink, under similar operating conditions. They have changed hydraulic diameters from .318 to .903 mm for experimental analysis over a range of flow rates under single-phase flows in the thermally developing laminar regimes.

Halelfadl Salma et. al. [4] worked for theoretical design of rectangular microchannel heat sink with aqueous carbon nanotubes based nanofluid as coolant with concentration 0.01%. They have calculated the thermal resistance and the pumping power in microchannel heat sink under laminar flow under genetic algorithm

(NSGA-II) optimization procedure. They have confirmed that optimized aspect ratio is low for the nanofluid smaller channel will leads to high heat transfer.

Hassan I. et. al. [5] have done the literature review on heat transfer enhancement requirement for IC cooling from 1990. They have collected various correlations for particular geometry and at particular boundary conditions for heat transfer enhancement and pressure drop investigations.

Mei Fang hua et. al. [6] has done analysis for efficient methods identifications of microchannel fabrication and assembly for metallic heat sink in less cost. The microchannels are fabricated with insertion molding under Inconel X750 and base material of copper and Aluminum 0.320 mm height 0.150 mm width 12.650 mm length of channels with 19 no of channels on 3.55* 3.55* 6.4 mm are used for experimental investigation. They have done parametric analysis for constant heat flux and different Reynolds number and they calculated different Nusselt number values for constant Reynolds number means flow which previously obtained from smoother Cu microchannels and they have concluded that surface roughness is increased of microchannel then heat transfer rate is increases. The literature review of fabrication along with experimentation is understood and used for investigation.

III. ANALYSIS WORK

The firstly we have focused on design of microchannel dimensions. The semicircular microchannels which is having high surface to volume ratio are investigated. The fin analysis equations are used to evaluate the thermal resistance and for the analysis distilled water properties are used and we have used below Nusselt number correlations for calculating heat transfer coefficient

$$Nu = 1.953\ (RePrDh/L)^{1/3} \qquad RePrDh/L \geq 33.3 \quad (1)$$

$$Nu = 4.364 + 0.0722\ RePrDh/L \qquad RePrDh/L < 33.3 \quad (2)$$

The new i7 core chip dimensions 1.48” *1.26” * 0.196” are used for analysis The objective was to enhance heat transfer coefficient with reduction in pressure drop. The pressure drop across microchannel is given by

$$\Delta P = (\rho_{nf} \times f \times L_{ch} \times V^2) / (2 \times D_h) \qquad (3)$$

All objective functions are displayed in terms of hydraulic diameter and optimization techniques are implemented. The optimization theory is used for maximization of heat transfer coefficient and minimization of pressure drop and it is converged at number of channels equal to three. The analysis is carried out for different concentrations of carbon nanofluids by using below equations

Density of nanofluids

$$\rho_{nf} = (1- ø) * \rho_w + ø * \rho_{CNT} \qquad (4)$$

Heat Capacity of nanofluids

$$(\rho * C_P)nf = (1- ø) * (\rho * C_P)_W + ø * (\rho * C_P)_{CNT} \qquad (5)$$

Thermal conductivity of nanofluids

$$K_{nf} = ((K_w + 2 * K_{CNT} + 2(K_{CNT} - K_w) * ø) / (K_w + 2 * K_{CNT} - (K_{CNT} - K_w) * ø)) * K_w \qquad (6)$$

Viscosity of nanofluids

$$\mu_{nf} = \mu_w * (1 + 2.5 * ø) \qquad (7)$$

The thermal properties are calculated such as velocity of flow, Reynolds & Prandtl number, heat transfer coefficient, friction factor, Nusselt number along with thermal resistance for distilled water along with different concentrations of nanofluids. The microchannels are fabricated with 0.2 mm hydraulic diameters under wire cut EDM. The manifold with Bakelite and acrylic tops for heat isolation and visualization are used and ensured that flow is carried through microchannels. The pressure drop connections and K type thermocouple sensor ports measure accurate pressure and temperature at different locations. The rotameter is used for flow measurement which is validated through time watch. The clamp meter and ammeter measures voltage and ampere which is calculates heat flux through cartridge heater. The nanofluid is prepared with two step method with concentrations 0 to 0.1% by volume in aqueous solution. The below figure shows layout of experimental set up

Fig.1 Experimental Set up

The flow of nanofluid is varied though pump which relates to increases Reynolds number. The heat flux is varied from bottom side through cartridge heater and dimmerstats are used to vary flow Reynolds numbers along with heater input. The carbon nanotubes are prepared with two step method with help of magnetic stirrer and ultrasonication and total process last 6 hrs and then they are used as earliest.

Experimental formulas to evaluation of microchannel heat sink [4]

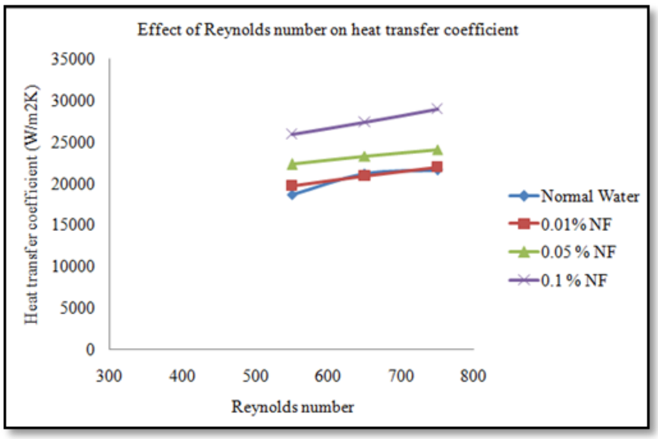
$Q=h*A_{eff}*(\Delta T)_{LMTD}$ (8)

$(\Delta T)_{LMTD}= ((T_b-T_{in})-(T_b-T_{out}))/$
$(\ln ((T_b-T_{in})/(T_b-T_{out}))$ (9)

IV. RESULTS AND DISCUSSIONS

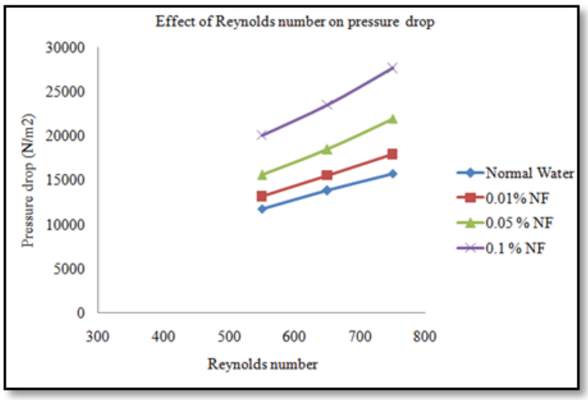
From graph 1, it is observed that as nanofluid concentration is increases then heat transfer coefficient increases and it is due to inherent characteristics of carbon nanofluids like thermal conductivity and specific heat capacity.

As the Reynolds number increases then molecular fluid velocity increases and exchange of heat dissipation increases. It is concluded that carbon nanoparticles are good candidate for enhancement of heat transfer coefficient and we have observed that average 39 % of heat transfer coefficient increases than distilled water at 0.1% concentration over normal water. We have compared these experimental results with theoretical and correlations in journal paper and they are in good conclusions.



Graph 1. Effect of Reynolds number on heat transfer coefficient

From graph 2, it is observed that as nanofluid concentration is increases then pressure drop increases and it is due to inherent characteristics of carbon nanofluids like dynamic viscosity and density. As the Reynolds number increases then molecular fluid velocity increases and friction factor decreases but pressure drop is directly proportional to square of velocity so pressure drop increases. It is concluded that carbon nanoparticles are good candidate for enhancement of heat transfer coefficient if we considered pressure drop as secondary candidate and we have observed that average 70 % of heat transfer coefficient increases than distilled water at 0.1% concentration over normal water. We have compared these experimental results with theoretical and correlations in journal paper and they are in good conclusions.



Graph 2. Effect of Reynolds number on Pressure drop

Nomenclature

h = Heat transfer coefficient (W/m^2K)

Aeff= Effective Heat transfer surface area (mm^2)

Dh =Hydraulic diameter (mm)

k =Thermal conductivity (W/mK)
Nu = Nusselt Number
Re = Reynolds number
V = Velocity (mm/sec)
ø = % of Nanofluids
T = Temperature (°C)
ρ =Density (Kg/m^3)
Cp= Specific heat at constant pressure (Kj/KgK)
µ = Dynamic viscosity (Ns/m^2)
f = Friction factor
ΔP = Pressure drop (N/m^2)
Q = Heat Input (W)
Lc= Length of channel (mm)

V.CONCLUSIONS

We have provided an overview of the research performed in analysis of microchannel heat sinks with carbon nanofluids. Currently lot of research is going on microchannel heat sinks with various applications and our research will helpful for development on new IC cooling devices. Heat transfer enhancement carbon nanotubes –water nanofluid flow inside semicircular microchannel heat sink is studied both theoretically and experimentally. It is concluding that microchannel heat sinks with nanofluid will best help for extraction of heat from modern heat exchangers and IC devices. The two function objective optimization validates the design the heat sink geometry and it is remarking that 0.1% nanotube concentration is referred as best concentration which will avoid particle clogging inside microchannel grooves and flow under laminar region will leads to uniform heat dissipation and main pressure drop rise is less which will ultimate proves less cost of equipment. The given application flow is best optimized at Reynolds number 550 to 750 and concentration 0-0.1% and performance improvement is observed. Further design with continuous variables such as fin width, fin heights, different new class coolant fluids, flux and wall temperature condition will emerge the field of microcovective heat transfer and microfluidic areas.

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