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Experimental Investigation Of Heat Transfer Characteristics For Nanofluid Imparted Microchannel Heat Sink

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Abstract

Innovation in microcovective heat transfer along with use of nanofluids leads to dissipation of high heat in very small area. The semicircular section which is having the highest surface area to volume ratio is investigated theoretically and experimentally with carbon nanotubes and water nanofluids. Minimum thermal resistance and maximization of heat transfer coefficient methods are used to investigate theoretical analysis of microchannel heat sink. 0.2 mm hydraulic diameter semicircular microchannel of copper are experimentally analyzed with help of distilled water and carbon nanotubes having volume 0.01 to 0.1 % over laminar flow conditions. Heat Flux input and mass flows are simultaneously varied to investigate effect on heat transfer coefficient and pressure drop. The Reynolds number varied for theoretical design from 0-2000 and design heater watts are varied from 60-120. It was seen that experimentally heat transfer coefficient is increased by 36.29 % than distilled water due to presence of Multiwalled carbon nanofluid (0.1 % Nanofluid Concentration & 550 Reynolds number). Theoretical results are compared with experimental analysis along with correlations in journal papers and they are in good agreements. Heat transfer coefficient, pressure drop, friction factor are directly proportional to Reynolds number and input heat flux, concentration of nanofluids.

Keywords: *Pressure Drop, Multiwalled carbon nanotubes, Heat Sink, heat transfer enhancement.*

1. Introduction

The recent development in heat transfer is providing to achieve high heat transfer from one medium to another medium. Heat transfer enhancement with minimum power consumption is goal for recent heat transfer equipments. The technology advancement in nano and micro technology has made easy for designed compact heat exchangers. The application of microscale heat transfer along new class nanofluids will help to achieve highest heat transfer rate using small area. Within small period of time they become famous for heat transfer applications due to wide range applicability and reduced cost. Microchannel heat sink is classified as passive heat transfer method recently major studies concentrate on direct conversion heat exchangers for maintaining high heat flux removal. In that case heat transfer coefficient is function of surface area to volume ratio and microchannels in groove for high conductive material. The nanoparticles are characteristics substances that will enrich base fluid properties which will lead to heat transfer enhancement.

The thermal properties majorly of nanoparticles thermal conductivity, specific heat capacity have responsible to enhance the heat transfer coefficient enhancement. By dispersing the nanoparticles in the base fluids, will results increase in the pumping power but this pumping power rise is accepted if we can get high heat transfer coefficient and system performance improvement of the nanofluids as compared to conventional fluids. In this paper we have concentrated on microchannel heat sink parametric analysis. The theoretical design along with experimental analysis is carried out with and without carbon nanotubes mixed with distilled water. The comparison with correlations in journal paper is carried out.

Nomenclature

h = Heat transfer coefficient (W/m^2K)
Nu = Nusselt Number
Re = Reynolds number
Aeff= Effective Heat transfer surface area (mm^2)
Dh =Hydraulic diameter (mm)
k =Thermal conductivity (W/mK)
V = Velocity (mm/sec)
ø = % of Nanfluids
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)

2. Literature Review

Bahrami M et. al. [1] have worked to develop correlations for pressure drop across smooth mini and microchannels of fully developed flow laminar flow of Newtonian fluids in a various cross sections like circular tubes, parallel plates, and concentric annulus. The correlations developed for friction factor along with square root area are represented in terms of hydraulic diameter and polar moment of inertia.

Chein Reiyu et. al. [2] have carried out performance analysis of microchannel heat sink made up of silicon with using pure water and nanoscale Cu particles nanofluids as coolant with various volume fractions. They have also done theoretical and experimental analysis on parameters like heat transfer coefficient along with friction factor and pressure drop.

Choi SUS and Eastman [3] have investigated new class of nanoparticles with enhanced thermal conductivities and they have also done theoretical analysis on thermal conductivity of nanofluids with copper nano size materials and they have concluded that there are potential benefits of the fluids are obtained example there is dramatic reductions in heat exchanger pumping power

Copeland David [4] have worked on parametric analysis of power required to cool computers through Microchannel heat sink also they have worked for design of optimum dimensions of fin thickness and pitch and in order to minimize thermal resistance for a given application. Also they have investigated effect of fin pitch on thermal resistance and pressure drop and it is analyzed that fin pitch increases then pressure drop across microchannel decreases. They have compared the results obtained in theoretical analysis are compared with extruded, forged, bonded, corrugated, skived and other heat sink technologies.

Ebrahimi Sadollah et. al. [5] have investigated performance of microchannel heat sink with carbon nanotubes (CNTs) fluid suspensions with distilled water. They have done theoretical investigation to predict temperature contours and thermal resistance of a microchannel heat sink with MWCNTs dispersed in water.

Gaikwad V.P. [6] have explained about recent developments in the manufacturing technologies of microchannels. They found out manufacturing process for low cost, efficient microchannels, tolerances, less surface roughness to decrease the pressure drop and friction factor.

Ghazali Mohd Normah et. al. [7] have investigated that minimum the thermal resistance and pressure drop of a microchannel heat sink is requirement for efficient heat transfer and cooling systems with increasing high heat generation rate. The thermal resistance is inversely proportional to pressure drop. They have used environmentally friendly liquid ammonia as the coolant and used same number of microchannels per square cm and investigated that the thermal resistance for the circular channels is less by 21% at the least pumping power and lower by 35% at the more pumping power than the thermal resistance for the square microchannels

Kalteh Mohammad et. al. [8] has investigated the laminar convective heat transfer with alumina-water nanofluid flow inside a wide rectangular microchannel heat sink of silicon material having 94.3 mm length 28.1 mm width and 580 mm height. It is concluded that The Nusselt number is directly proportional to Reynolds number and volume concentration and inversely proportional to nanoparticles size.

Lee Poh Seng et. al. [9] have done experimental investigation to validate derived correlations for various geometry sections of microchannels to predict thermal performance in single-phase flow through copper 10 rectangular microchannels and deionized water with Reynolds number ranging from 300 to 3500. They have done numerical analysis for both developing flows in rectangular channels based on a Navier–Stokes equations analysis using both a full 3D conjugate approach and a simplified thin wall model. It is found that the numerical results were in good agreement with the experimental data

Muzychka and Yovanovich [10] has worked for developing simple model for prediction of Nusselt number for thermally developing flow Graetz problem in circular and non circular ducts of various shapes.

Tuckerman and Pease [11] both pioneer scientists are father of development of concept of microchannel heat sink. They investigated that microchannel heat sinks can dissipate high heat fluxes in small areas. Small channels with having parallel silicon fin acts as heat sink and experimentation is carried out in laminar flow and they obtained heat flux dissipation rate 790 W/cm^2 so that chip temperature is maintained below 110 °C.

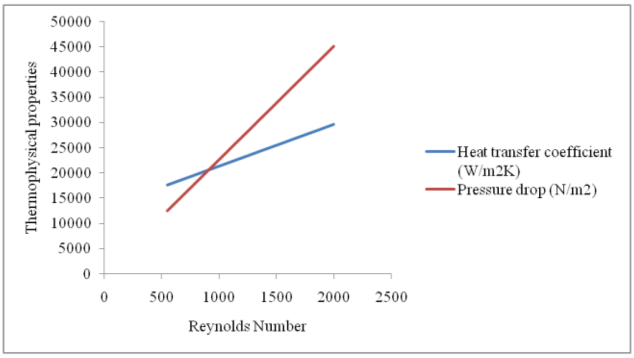
The literature review conducted for obtaining concept of microchannel heat sink along with design and parametric analysis. The experiential setup and analysis along with fabrication technologies of microchannel is made by evolution of different research papers. Since the major work has been carried out for rectangular and triangular profile of microchannel but circular microchannels are having high surface area to volume ratio so we have carried out analysis also extraction of nanofluids is emerging trend , we have gone ahead for analysis of semicircular microchannel with nanofluids. The theoretical results are in good agreement with experimental investigation which relates with theory in literatures.

3. Theoretical Analysis

The main objective behind this work is analysis of heat transfer characteristics of microchannel heat sink along with effect of nanofluids on its performance. The theoretical analysis is started with material selection for analysis and we have chosen copper which holds highest thermal conductive metal along with carbon nanotubes as nanoparticles which holds maximum thermal conductivity. The geometry is taken semicircular channel heat sink according to literature survey high surface area to volume ratio is obtained for semicircular shape so we have taken that into consideration with diameter 0.32 and microchannel heat transfer analysis is carried out for recent generation IC chip having dimension 3.75*3.2 cm and 0.5 cm depth also we have optimized 3 number of straight semicircular channels by analytical calculations. During analysis we considered the flow is steady, uniform & laminar. The analysis is carried out flow hyrdrodynamically fully developed and thermally developing flow which is used to provide maximum heat transfer coefficient. We have used minimum thermal resistance and entropy generation minimization model for analysis and in resistance model the conductive resistance due to base of IC is considered minor and the major contribution is convective resistance and fluid resistance so they are calculated and number of channels are varied also entropy generation is nothing but disorders in thermal systems so entropy generation model reflects on pressure drop since we are using laminar flow so there is no much pressure drop in the system. The Nusselt number is function of Reynolds number and Prandtl number since is replica for forced convection and we have calculated heat transfer coefficient by below Nusselt Number [9]

Nu= 1.953 (RePrDh/L)1/3 RePrDh/L ≥33.3 (1)

Nu= 4.364+ 0.0722 RePrDh/L RePrDh/L <33.3 (2)



Graph 1. Thermophysical properties Vs Reynolds Number

The objective functions for heat transfer coefficient and pressure drop are formulated in terms of hydraulic diameters. The parametric analysis is carried out for variation of Reynolds number 0-2000 which shows behavior of laminar flow and numbers of channels 0-93. The functions are of heat transfer coefficient is maximized and pressure drop is minimized for finding out optimum design for number of microchannels. The matrix arrays are solved by computational mathematics.

The properties of nanofluids used in this analysis were obtained using below equations [8]

Density:

$P_{NF} = (1-ø)*\rho_{BF} + ø*\rho_{NP}$ (3)

Heat Capacity:

$(\rho*C_P)_{NF} = (1-ø)*(\rho*C_P)_{BF} + ø*(\rho*C_P)_{NP}$ (4)

Thermal conductivity:

$K_{NF}=((K_{BF}+2*K_{NP}+2(K_{NP}-K_{BF})*ø)/$ (5)

$(K_{BF}+2*K_{NP}-(K_{NP}-K_{BF})*ø))*K_{BF}$

Viscosity:

$\mu_{NF} = \mu_{BF}*(1+2.5*ø)$ (6)

The Newton Rapshon method is used for finding out real roots of objective functions and we observed that first maximum optimization point for heat transfer coefficient function and pressure drop first minimum optimization point for pressure drop curve are approaching at number of channels 3 as per graph 1 and curve is smooth for Reynolds number 550, 650 & 750. These are optimized geometry dimensions best performance results for heat Sink. The optimized dimensions are prototyped on copper heat sink and carried out experimental analysis. The parametric analysis is carried out for distilled water and different concentrations of carbon nanotubes and comparison is done with theory.

4. Experimental Analysis

Fig 1 reflects detailed information about microchannel heat sink experimental analysis set up. The set-up consists of a test manifold which includes semicircular microchannel heat sink. The wire cut EDM manufacturing process is used for prototyping 200 μm hydraulic diameters microchannel. The manifold design is carried out for uniform flow distribution and Bakelite sheet is used for manufacturing it. The flow area is placed in front of fluid passage and system is made leak proof by using double coated rubber. The heat input is supplied to the base of a microchannel chip with help of cartridge heaters. In order to ensure complete compactness and avoid voids for heat transfer with IC chip we have used thermal grease during assembly of heater and microchannel heat sink. The digital temperature indicator (0-199 °C) and clamp meter, ammeters (0-5 A)are used for measurement of accurate temperature and electric inputs. The water flows through only microchannel and it adjusted by applying torques through bolt which is passes midway in Bakelite sheet.

The microchannel through which the water and nanofluids passes is made up of Bakelite sheet and it is covered by acrylics from top. Eurka Make glass tube rotameter (0- 10 LPH) and buermer make pressure gauges (0-15 Psi) with high accuracy are used flow measurement & pressure measurement respectively. The K type thermocouple sensors are placed at inlet, outlet and heater base for measurements of heat transfer coefficients

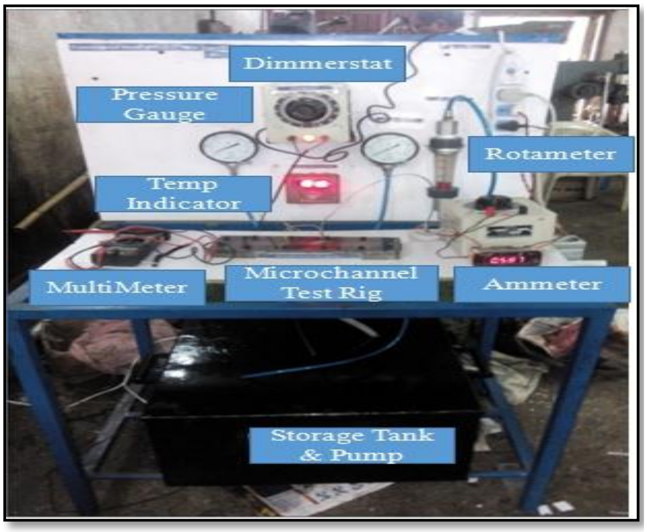
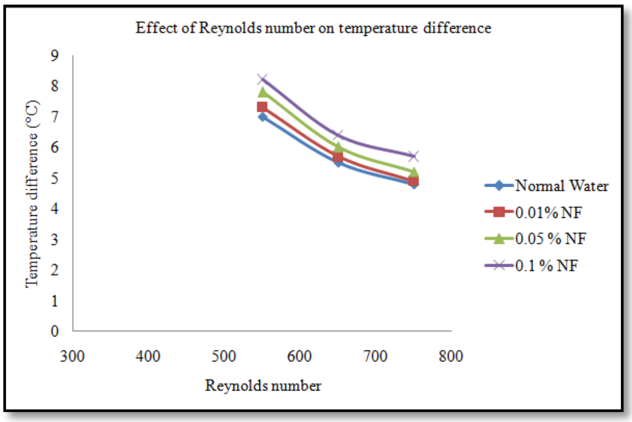


Fig.1 Experimental Set up

The two dimmerstats (0-240 VAC) are used for mass flow variation which is replica for variation of Reynolds number and second is for input heat flux. The cartridge heater (0-150 W) at bottom is supplying constant heat flux. The rotameter is used for flow measurement and it is cross verified through flask and stop watch method. The bottom side supply constant heat flux and top side is insulated properly. The microfilters are helping to keep water and nanofluids away from debris and making clean along with improve the efficiency, life of pump. Nusselt number correlations are used for calculating heat transfer coefficient at appropriate boundary conditions. The nanofluids of distilled water and carbon nanotubes are prepared with two step method. The firstly carbon nanotubes particles are mixed with distilled water and Magnetic stirrer is introduced complete mixing for 4-5 hours then solution is passed to ultrasonication for 2-3 hrs for complete dispersion of nanofluids. The nanofluid is used as soon as prepared with two step method and experimentation. We have kept heater input watt constant first and then varied Reynolds number and then for constant mass flow Reynolds number we have varied heater watts and experimentation is carried out. We have kept higher size of storage tank so that it can remove heat generated during experimental analysis and it will leads accurate results.



Graph 2. Temperature Difference Vs % of Nanofluids

As the measurement results show in graph 2 indicates that as % of nanofluids increase then it will leads rise to dissipation of more heat and increases heat transfer coefficient.

The theoretical, experimental results are compared with correlation in journal papers and they are in good agreements.

Experimental formulas to evaluation of microchannel heat sink [8]

$$Q=h*A_{eff}*(\Delta T)_{LMTD} \tag{7}$$

$$Nu=(h*D_h)/K_{NF} \tag{8}$$

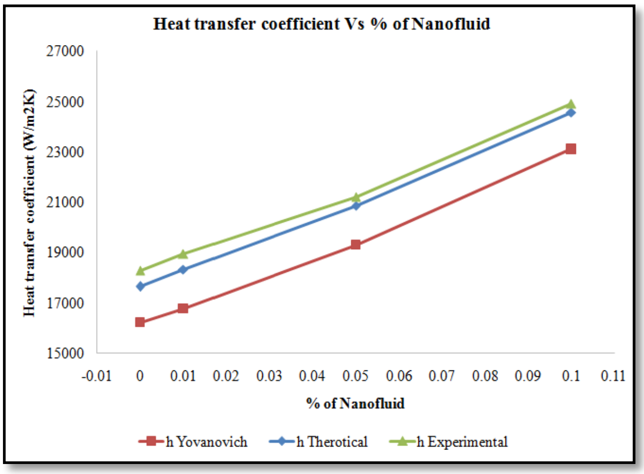
$$Re=(\rho_{NF}*V*D_h)/\mu_{NF} \tag{9}$$

$$(\Delta T)_{LMTD}=((T_b-T_{in})-(T_b-T_{out}))/(\ln((T_b-T_{in})/(T_b-T_{out})) \tag{10}$$

$$\Delta P=(\rho_{NF}\times f\times L_{ch}\times V^2)/(2\times D_h) \tag{11}$$

5. Results and discussions

From graph 3, it is observed that as % of nanofluids added to base fluid is increased then it enhances heat transfer coefficient. It is due to characteristics properties like thermal conductivity, specific heat capacity of nanofluids and particles concentrations. As nanofluid concentration increases, the molecular heat transfer increases and fluid is taken more heat from IC devices. Since in nanofluids heat transfer takes place at the surface boundary of particle so it will leads high size particles with high surface area are enhancing heat transfer coefficient. It is found that the heat transfer coefficient is increases by 36.29 % as compared to distilled water for 0.1 % of nanofluids at constant Reynolds number 550. It is concluded that carbon nanotubes are best candidate for enhancement of heat transfer coefficient with distilled water. The results are compared with journal papers correlation they are in good agreement.



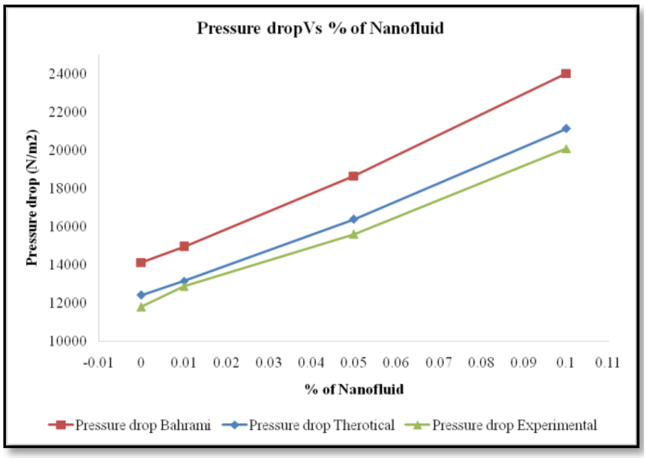
Graph 3. Heat Transfer coefficient Vs % of Nanofluids

Table 1. Results of heat transfer coefficient with and without nanofluid

Nanofluid %	0	0.01	0.05	0.1
h Theoretical	17641	18309	20868	24560
h Yovanovich	16206	16746	19297	23104
h Experimental	18275	18952	21211	24907

From graph 4, it is observed that as % of nanofluids added to base fluid is increased then pressure drop across microchannel increases. It is due to characteristics properties of nanofluids the density and clogging of particles due to viscosity rise But it is optimized for our system and we have done analysis till we get heat transfer coefficient enhancement is greater than pressure drop enhancement. The graph is drawn for constant 550 Reynolds number.

The results are compared with journal papers correlation they are in good agreement.



Graph 4. Pressure Drop Vs % of Nanofluids

Table 2. Results of pressure drop with and without nanofluid

Nanofluid %	0	0.01	0.05	0.1
Pressure Drop Theoretical	12413	13152	16384	21129
Pressure Drop Bahrami correlation	14112	14945	18643	24014
Pressure Drop Experimental	11800	12870	15600	20080

Conclusions

1) It is found that increase in thermal performance was obtained using carbon Nanotubes/distilled Water nanofluid as a coolant as compared to pure distilled water. It was successfully achieved to reduce and hold base temperature of microchannel heat sink at a constant level. Carbon Nanotubes/distilled Water nanofluid also minimizes the base temperature of microchannel heat sink to a more extent than pure distilled water. They are best useful media for heat transfer enhancement with minimum power drop in current IC cooling system
2) It is investigated that the heat transfer coefficient in experimental investigation is higher than theoretical analysis and journal correlation heat transfer coefficient is higher than experimental analysis. But they are within 2-3 % and it is due to suction manifold flow entrance effect and heat flux input via thermal grease packed voids between heater and microchannel heat sink.
3) From theoretical and experimental investigation result, it can be found that semicircular microchannel heat sink gives better result at Reynolds number from 550,650, 750 and carbon nanotubes % 0.01,0.05, 0.1
4) Microchannel heat sinks are good candidate for heat transfer enhancement along with nanofluids. Carbon nanotubes are having inherent properties highest thermal conductivity which can dissipate large amounts of heat with relatively little surface temperature rise and less surface area
5) As Reynolds number and flow rate are directly proportional to the heat transfer coefficient, pressure drop across microchannel and pumping power increases while in directly proportional to thermal resistance and friction factor factors
6) A significant improvement in the heat transfer coefficient i.e. 36.29 % is achieved using carbon nanotubes/Water nanofluid as compared to pure water at Reynolds number 550 and nanofluid concentration 0.1%.
7) If pressure drop rise is considered secondary candidate then % of nanofluids in distilled water are best performance risers for modern heat transfer equipment's.

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