International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.6, pp 215-219, 2017

Reliability aspects of TiO_2 nano fluid coolants in Copper micro heat exchangers

D.R.S.Raghuraman[1]*, PK.Nagarajan[2], B.V.A.Rao[3]

[1]School of Mechanical and Building Sciences, VIT University, Vellore, India
[2] Mechanical Engineering Department, S.A. Engineering College, Chennai, India
[3]Visiting Professor, School of Mechanical and Building Sciences,VIT University, Vellore, India

Abstract: An experimental setup was developed to study the enhancement in heat removal and liquid flow in rectangular copper microheat exchangers with a hydraulic diameter of 29.4µm.The liquids used were de-ionized water and TiO_2-de-ionized water based nano fluids. Since the nano liquids with small volume concentrations of 0.1%,0.3% etc. have been used ,the reliability and life of the nanoliquids are discussed in the work.. The liquids when used with the nanopowders dissolved in it .exhibited stable liquid flows when used for a period of time ranging from 4-5 hours while collecting data for both the concentrations..The nanofluid exhibited instability characteristics (like deposition of nanoppwder at the bottom of the vessel after return collection of liquid after the above mentioned time). .Also the higher heat release at a temperature of 50-52 C, from the simulated electronic ICs (i.e. the heater) also has resulted in instability of the liquid.

Since the varying flows of the liquid were continually returning to the tank blockages or obstacles to the flow caused by the clustering of particles would be less as compared to other nano liquids and higher viscosity liquids like oils.The flows being laminar,volume concentrations of the nanpowder being less, erosion of the channels was not observed. Other researchers have observed erosion in Cu micro channels when using $Al_2 O_3$ nanoliquids.

Keywords : Micro heat exchangers, Nanofluid, fluid flow, instability, erosion.

1. Introduction

The high data transmission in the micro processors due to microelectronic devices has led to advances like fast ICs and inbuilt systems.Large quantity of heat and fairly high temperatures above normal have to be taken away. Traditional coolants like air or gases are not able to meet such challenges. Therefore liquids like water, ethylene glycol and oil were considered by various researchers for cooling purpose. But such efforts were not sufficient to remove the heat.

Heat exchangers have to become smaller and smaller in size before they can be used in cooling of electronic ICs.This means smaller hydraulic diameter of the micro heat exchanger .Hence larger bulk wall temperatures, low flows, low pressures, longer life without deterioration, indicates the use of special liquids like nanofluid instead of the conventional coolants.

Stephen Choi[1,2] was the first researcher to develop nano fluids in the Argonne National laboratory, U.S.A..This discovery revolutionized cooling technology in micro heat exchanger, since he proved that nnaoliquids performed better than the previously used fluids. Therefore such fluids were used in heat transfer applications like heat exchangers, refrigeration and lubrication. The plus point in such liquids is that these fluids have very good heat transfer capability but with less pressure drops. This is possible because by adding nano powders to the base liquid, its shear stress increases.

Larger sized particles (but micro sized) have been added to the base fluid in previous attempts by many researchers to improve heat transfer. The reliability of such micro particles was diminished by the blockages in the channel passages and deposition of the particles. So present day researchers are working on nanoparticle based liquids, since they are more stable (because of uniform dispersion in the base liquid) as compared to micro particle-based liquids used earlier.. In such cases for flows through micro channel or mini channels, heat transfer improves but at the cost of higher pressure drop for smaller sized passages in the channels. If stability of the nano fluid is assured for longer period, then we can assure better life Therefore the reliability of Nano fluids in small volume concentrations have enabled good thermal performance for longer hours..

The nanobased materials like nano powders, nanoporous materials[3], nanocarbons4, nanofilms etc have to perform as coolants, in drug delivery, for high level sensing, energy activation, environment protection etc.The use of nanotechnologies for high speed chips in computers and application of nano materials in data transfer and heat transfer envisages a requirement of frequent usage and long life.

Researchers have found that the high particle fractions of the nanopowder and the high temperatures affect the viscosity of the nanoliquid. Academics have found out that there is a critical point of the temperature above which the nanosuspensions begin to deteriorate. This phenomenon called as hysteresis or deterioration of the nanopowders (at high temperatures) puts a question mark on nanoliquids being used for enhanced heat transfer. If a very large amount of heat is generated say of the order of 790 W/cm^2 then life of nanoliquids would be affected, their viscosities would suffer and depositions may occur. Very few works have been carried out by the researchers on life and stability studies of nanoliquids.Stability studies would mean both short run and long run stability. Many of the research efforts have been directed towards studying the properties and behavior of the nanoliquids.

A Turgut,I.Tavman,M.Chirtoc,et.al[6] have measured the thermal conductivity and viscosity of TiO_2 nanoparticles (up to 3% volume fraction) experimentally..They have demonstrated that an increase in viscosity is there with increase in volume fraction. Also the increase in nanofluid viscosity is more than its improvement in thermal concudctivity.The authors[6] have also concluded that viscosity of the fluid decreases exponentially with temperature increase(similar to the base fluid).They have also proved that relative viscosity is dependent on the volume fraction of the nanoparticles. Mare e.t.al[21] performed research using Al2O3 water based nanoliquids and found the viscosity changes with temperatures at higher particle concentrations.Masuda et.al[22] were the pioneers in measurement of viscosity of nanobased fluids with temperature ranges from normal environment temperature to about 340 K.C.T.Nguyen et.al[23] in their paper have discussed the viscosity data for Al2O3 water based nano fluid and have concluded that at a critical temperature the particle suspensions change. This critical temperature is higher than the normal working temperature for such applications.

The experiments done in our setup relates to the performance of Titanium Oxide nanoliquids as coolants. We have found out during our experimentation that when bulk wall temperatures are higher around 50 C (because of high heat input), the return fluid after taking away the heat from the micro channel behaves differently as compared to the initial stage it was in. The nanoparticles settle down in the base liquid instead of retaining themselves as suspensions. Also this has happened after a time gap of 5-10 hrs between tests.

Experimental Apparatus

An assembly comprising of rectangular channels (122 in number) with an overall size of 31 mm length and 36.75mm width, has been machined from Copper. The channels have dimensions of 0.15 widths by 7 mm height each. The pictorial view of the channels is as shown in Fig 1.A 900 W plate type ceramic heaters is used with a rheostat for power control. This power source which can be varied, serves as the heat source analogous to heat emanating from the CPU. Pressure drop and flow are measured with suitable instrumentation.Thermocouples have been used for measuring the bulk wall temperatures and the inflow and outflow coolant temperatures through the micro heat exchanger. The other sketch Fig 2 shows the experimental layout showing pressure, flow and temperature sensors.

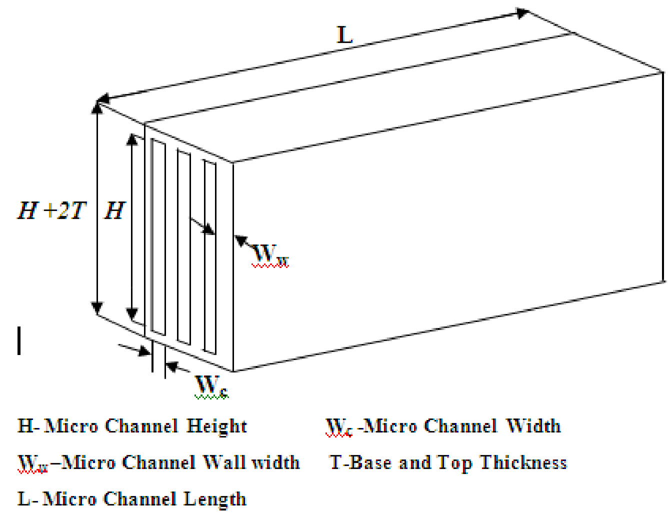

Fig 1.Micro channel Dimensions

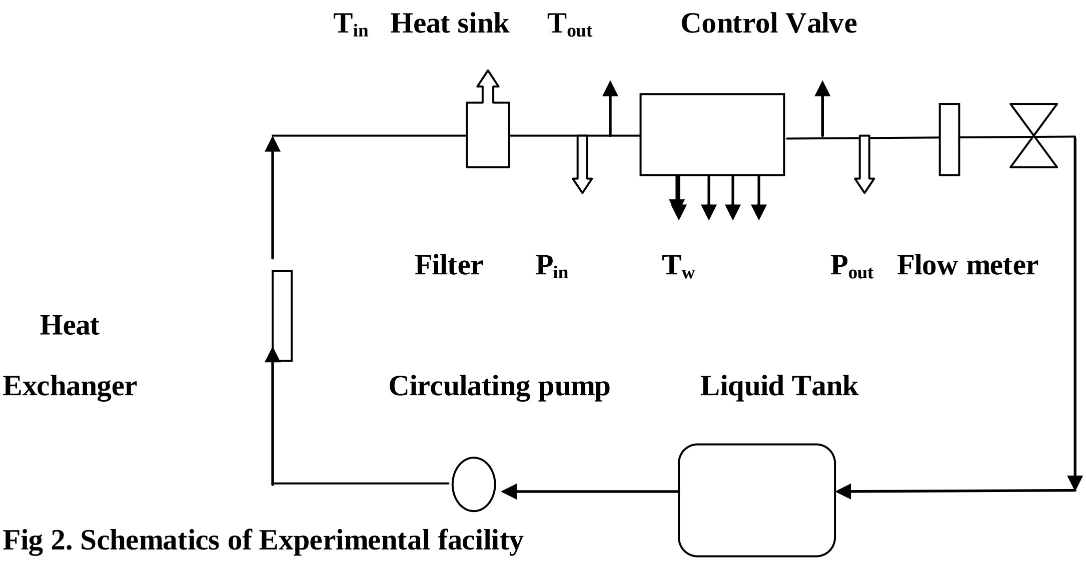

Fig 2. Schematics of Experimental facility

2.1 Description of Nanoliquids

Nano liquids are fluids which have mechanica; properties better than ordinary coolants viz.de-ionized water, ethylene glycol etc. Nano particles used as suspensions in the base fluids[12] help improve viscosity, density and thermal conductivity achieving better heat transfer performance, which results in good usage as cooling liquids in micro heat sinks. The increasing density and viscosity of nano liquids causes increase in pressure drop because of viscous friction .The increase in volume concentration of the nanpowder in the base liquid leads to changes in behavior of the liquid,clustering and clogging through the passages of the micro heat sinks. Low volume fractions of 0.1% and 0.3% TiO2 (which we have used) nanopowder in de-ionized liquid helps in improving the life of the nanoliquid by taking more amount of time for settling down as deposits as compared to the higher volume fractions of nanopowders which have been considered by other researchers[25]..Another interesting area to be considered is the reusability of the nanoliquid.Though sonification helps in improving the life of the nanoliquid,certain other factors like shelf life of the nanoliquid,high temperatures of beyond 50 C ,number of hours of usage whether cyclic or intermittent have to be taken into account for its reliability and its usage in IC cooling.

2.2 Basic Properties describing the Nanocoolant

The density ,viscosity,specific heat at constant pressure and thermal conductivities of the nano coolant having low volume fractions of 0.1% and 0.3% of TiO_2 nano particles are calculated from the formulae shown below from (1)-(4)

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \quad (1)$$

$$\mu_{nf} = \frac{1}{(1-\phi)^{2.5}}\mu_f \quad (2)$$

$$(\rho c_p) = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_p \quad (3)$$

$$k_{nf} = \frac{(k_p + (n-1)k_f - (n-1)\phi(k_f - k_p))}{k_p + (n-1)k_f + \phi(k_f - k_p)} \times k_f \quad (4)$$

			Greek Symbols	
C	specific heat at constant pressure ($Jkg^{-1}K^{-1}$)		ρ	density
k	thermal conductivity of heat sink ($Wm^{-1} K^{-1}$)		μ	absolute viscosity of fluid(kgm/s)
W	Width of micro channel(m)		ϕ	volume fraction (%)

3. Data Reduction

3.1 Thermal conductivity

The thermal conductivity of the nanoliquid of 0.1% and 0.3% volume fraction has been calculated based on the equation (4) and are higher than water.

3.2 Density

The corresponding densities of the volume fractions of the TiO2 nano powder are calculated using the equation (1). The values of density of the nano liquid are higher than that of water.

3.3 Viscosity

The viscosity of the nano coolants for 0.1% and 0.3% volume fraction are calculated using the equation (2).Their values turn out to be higher than water

4. Results and Discussion

4.1 Validation

As compared to the work by CT Nguyen[23] et.al, we have also found that above a certain bulk wall temperature of 50 C, the nano liquid suspensions behave differently than at temperatutres below that. We also found that when the flows were varied from 0.00005 m^3/s to 1.8 $x10^{-5}$ m^3/s the return flows to the tank were smooth without obstruction. This means that clogging and blockages are nonexistent because of moderate volume concentrations of 0.1% and 0.3% TiO2 nanopowder. Also since the thermal conductivity of 0.3% volume fraction TiO_2 - H_2O is higher than 0.1% volume fraction TiO_2 - H_2O and de-ionized water, heat transfer performance of the former is better than the latter .Clearly this indicates that having higher particle concentrations than 0.3%and with higher bulk wall temperatures,. the performance of the nanoliquid is affected. This has also been confirmed by CT Nguyen[23] et.al. The opinion of the authors, Reiyu Chein[22] et.al.in their research paper is that nanoparticle agglomeration cannot be prevented but delayed. Particle deposition is definitely going to be there but it has to be delayed as much as possible. Also Reify Chein[23] et.al. found that nanocoolant agglomeration could be prevented if nanoliquid has a higher bulk temperature. But this affects the behavior of the nanosuspensions in the nanocoolant, according to C.T.Nguyen[23] et.al. The authors [23] have also observed that the nanofluid viscosity increases with particle concentration. The authors [23] in their experimental studies have observed as mentioned earlier viscosity of the nanoliquid to be independent of temperature beyond the range of 22-40 C.Also though the authors have performed viscosity tests on Al_2O_3 nanoliquids, we have observed the similar results in our experiments on TiO_2 nanocoolants .Beyond a certain temperature above 48 C, the nanoliquid suspensions tend to behave differently. Along with above, we have also observed that prolonged intervals of 5-10 hours between experiments also results in deposition of the nano powder in the solvent. While observing such phenomena, we can state that nanoliquids can be used for effective heat transfer provided the bulk wall temperatures of the micro heat exchangers do not exceed the limits mentioned above. In addition, the nanopowder concentrations are not increased. Hence with low volume concentrations of 0.1% and 0.3% and wall temperatures not rising beyond 45- 48 C,TiO_2 –H_2O can be used effectively as a nanocoolant.Though the viscosities of the nanoliquids are higher than de-ionized water, they are not substantially high to cause problems while flowing through the micro channel passages.

References:

1. W.Yu, D.M.France, S.U.S.Choi, L.Routbort, Argonne National Laboratory, ANL/ESD/07-9, (2007)
2. Seok Pil Jang, Stephen U.S. Choi, Applied Thermal Engineering, (26), 2457 -2463, (2006)
3. Bull. Chem. Soc. Jpn. 85, 1 (2012).Chem. Soc. Rev. 41, 1677 (2012
4. J. Nanosci. Nanotechnol. 12, 2955 (2012).ChemSusChem 5, 456 (2012)
5. D.B. Tuckerman, R.F.W.Pease, IEEE Electron Device Letters -2 (5) 126 – 129, (1981)
6. A.Turgut, I.Tavman, M.Chirtoc H.P.Schuchmann, C.Sauter, S.Tavman,Springer Science + Business Media,LLC (2009)
7. Gian Luca Morini, International Journal of Thermal Sciences 43 631–651,
8. Mala, G. M. and Li, D. Int. J. Heat and Fluid Flow, Vol. 20, pp. 142−148 (1999).
9. C.J. Ho, L.C. Wei, Z.W. Li, Applied Thermal Engineering 30 96–103, (2010)
10. Ali Ijam, R. Saidur, Applied Thermal Engineering 32 76-82, (2012)
11. Dong-Kwon Kim and Sung Jin Kim, Proceedings of 6th Electronics Packaging Technology Conference, EPTC 569 - 574, (2004)
12. Sarit Kumar Das, Stephen U.S. Choi, Hrishikesh E. Patel, Heat Transfer Engineering, 27(10) 3–19, (2006)
13. D.A. Drew, S.L. Passman, Springer, Berlin, (1999).
14. H.C. Brinkman, Journal of Chemical Physics 20 571-581, (1952).
15. S.M. Yang, W.Q. Tao, Heat Transfer, third ed. Higher Education Press, Beijing,China, (1998).
16. R.L. Hamilton, O.K. Crosser, Industrial and Engineering Chemistry Fundamentals 1 182-191, (1962).
17. J. Lee, I. Mudawar, Int. J. Heat Mass Transfer 50 452–463, (2007).
18. W.M. Kays, A.L. London, Compact Heat Exchangers, McGraw-Hill, New York, (1984).
19. F. Incropera, D. Dewitt, Fundamentals of Heat and Mass Transfer, fifth ed., Wiley, New York, (2002).
20. Reiyu Chein, Jason Chang, Science Direct, International Journal of Thermal Sciences, 46, 57-66, (2007)
21. Mare,A.G.Schmitt,C.T.Nguyen,J.Mirie,G.Roy,Experimental heat transfer and viscosity study of nanofluids: water γ Al2O3,in: Proc.2nd Int.Conf.Thermal Engg,Theory and Applications,Paper No 93,January 3-6,2006,A1 Ain,United Arab Emirates.
22. H. Masuda, A. Ebata, K. Teramae, N. Hishinuma, Netsu Bussei4 (4) (1993) 227–233.
23. C.T.Nguyen,F.Desgranges,N.Galanis,G.Roy,T.Mare,S.Boucher,H.Angue Mintsa,International Journal of Thermal Sciences-47,2008,103-111.
24. Reiyu Chein,Jason Chang,Experimental micro channel performance studies using nanofluids,International Journal of Thermal Sciences-46(2007),57-66 .
25. Jason Lee,Isam Mudawar,Journal of Heat and Mass Transfer 50 (2007) 452-463.

*****