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Numerical analysis of micro-channel heat sink using ethylene glycol based nanofluid in case of electronics cooling

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Abstract. As size of Integrated circuit is goes on decreasing and number of elements per chip increases, the heat dissipation per unit area of IC increases. Therefore, nanofluid forced convection cooling using an micro-channel heat sink is introduced as new research topic for efficient cooling of IC devices. In this manuscript, ethylene glycol base nanofluid has been studied by using five different oxide nanoparticles including Al_2O_3, TiO_2, CuO, SiO_2 and ZnO and varying their concentration from 0 to 10% volume fraction. Single phase model has been considered in simulation analysis using ANSYS Fluent 13.0 software and the results obtained from simulation have been validated with previous experimental and simulation work. Furthermore, several aspects of parameters such as local thermal resistance, pumping power and local heat transfer coefficient are presented in below manuscript. From the result it is analysed that ethylene glycol base nanofluid increases the heat transfer parameters very effectively. Further, as concentration of nanoparticle sis increases the convective heat transfer coefficient and pumping power increases. Also, CuO-EG nanofluid cooled electronics devices more efficiently compared to other nanofluid which are considered in this study.

1. Introduction

Although there has been significant improvement in electronics device for past years, but still there are some problems respect to cooling of electronics devices as there heat flux goes on increasing. Hence number of researcher have interest in forced convection nanofluid cooling using mini or micro channel heat sink, as study find out that addition of nanoparticles in base fluid increases the heat transfer coefficient of base fluid significantly. Moreover, some literature study are reviewed in this manuscript which are as follow; Saeedinia et al. [1] experimentally studied the nanofluid by taking CuO nanoparticles in oil based fluids and measures the heat-transfer parameters and pressure loss in pipes for different coils and shape, concentration of nanoparticles. It was noted that the increase in heat-transfer coefficient by 45 percent, and the pressure drop by 70 percent. From the literature review, it is observed that there may be further research is required in case of some points like comparison of heat transfer enhancements using various concentration of different nanoparticles in base fluids. Therefore, in the present analysis this particular aspect will be analysed numerically. M. R. Sohel et al. [2] analysed the thermal characteristics performance and also second law in Al_2O_3 –water base nanofluid for cooling purpose in mini-channels heat sink. It was observed that nanofluid is more effectively than common fluid flow for cooling in mini-channels heat sink. It was also studied that entropy generation is less in case of nanofluid. Dongsheng Wen et al. [3] performed experiment using Al_2O_3 nanoparticles in water base fluid for laminar fluid flow in circular shape tube and studied that

local heat-transfer coefficient increase up to 47% for 1.6% concentration. N. Putra et al. [4] studied the used of TiO_2 and Al_2O_3 nanoparticles in water base fluids for a heat-pipe as the coolant and it linked with thermoelectric cooling system. When results are compared with conventional cooling method, this collective cooling method shows higher declination in electronics chip temperature. It analysed that it also decreases thermal resistance of a system.

From above study conclusion can be made that although sufficient study have been carried out using nanofluid but their only few studies which was focussed on wide range of oxide nanoparticles and their concentration. This was happen mainly, because it is difficult to considered wide range of nanoparticles and their concentration in experimental study. Hence here numerical approach is consider to study wide range of five oxide nanoparticles by varying their concentration from 0-10 % volume fraction in ethylene glycol base fluid. Furthermore, commercially available CFD software ANSYS Fluent 13.0 is used for simulation purposed.

2. Physical Model

2.1. Heat Sink Model

Figure 1 demonstrated rectangular micro-channel heat sink which was made of Aluminium material as Aluminium have low weight and required conduction coefficient for this case. Furthermore, the upper wall was considered to be made of glass and IC dissipated uniform heat flux q to the bottom wall of heat sink as shown in figure. The size of IC was consider to be 1 cm x 1 cm (L_hxW_h). The inlet temperature of nanofluid was assume to be 293 K. Here three different size of heat sink are considered as discuss in Table 1. For validation purpose Case 0 and case 1 dimensions was considered and Case 2 dimensions are used for further results. In our study simplified single micro-channel is considered as studying whole heat sink model is difficult, time consuming and it take more memory in ANSYS Fluent software. Moreover, micro-channel from centre heat sink model is considered as it gave actual heat transfer from IC which is not happen in case of outer micro-channel where heat dissipation might be less than actual heat flux or zero.

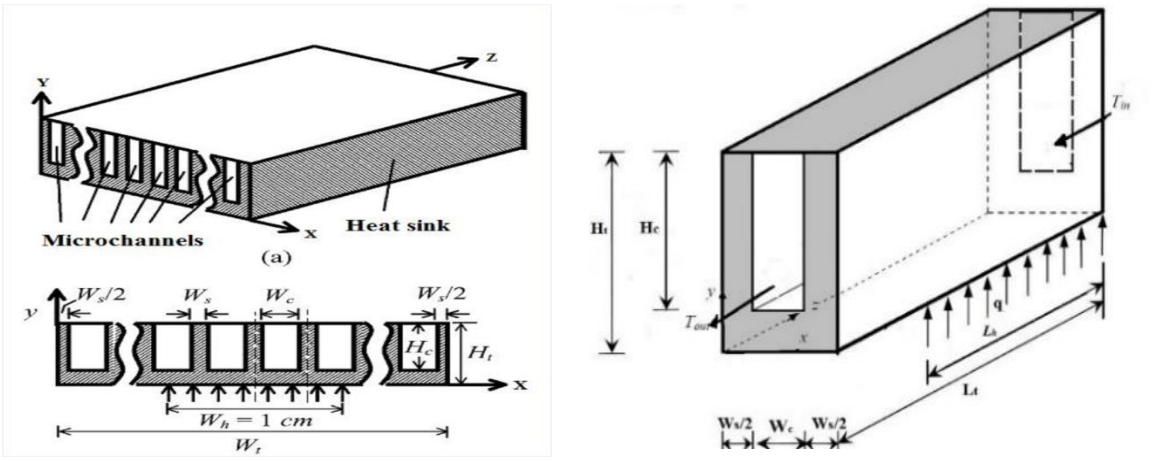


Figure 1. (a) Diagram of sink; **(b)** view of micro-channel

Table 1. Dimension for three different sets of micro-channel

Cases / **Parameters**	0	1	2
Micro-channels length L_t (cm)	2	1.4	1.4
Heat sink width W_t(cm)	1.5	2	2
Micro-channel width W_c(μm)	64	56	56
Width of single heat sink W_s (μm)	36	44	44
Sink height H_t (μm)	489	533	533
Micro-channel height H_c (μm)	280	320	420
Flow rate $\dot{Q}^a(cm^3/s)$	1.277	4.7	4.7
Heat flux q (W/cm^2)	34.6	181	90
Number of channels in sink	150	200	200

2.2. Thermo-physical Properties

From help of Table 2 equations thermo-physical properties of nanofluid was find out. Further, thermo-physical properties of nanoparticles, base fluid and heat sink material are considered to be constant.

Table 2. Thermo-physical properties equations of nanoparticles

Properties	**Author**	**Equations**
Density (kg/m^3)	Xiang-Qi et al. [5]	$\rho_{eff} = \frac{\rho_b V_b + \rho_p V_p}{V_b + V_p} = (1-\emptyset_b)\rho_b + \emptyset_b \rho_p$ $\emptyset_b = \frac{V_p}{V_f + V_p}$ is the volume fraction of nanoparticle
Specific Heat (J/Kg.K)	khalil et al. [6]	$c_{eff} = \frac{(1-\emptyset_b)\rho_f c_f + \emptyset_b \rho_p c_p}{\rho_{eff}}$
Viscosity (kg/m.s)	Batchelor et al. [7]	$\mu_{eff} = (1 + 2.5\emptyset_b + 6.2{\emptyset_b}^2)\mu_f$
Thermal Conductivity (W/m.K)	Purohit et al. [8]	$k_{eff} = \frac{k_p + 2k_f + 2(\frac{k_p}{k_f})\emptyset_b}{k_p + 2k_f - (\frac{k_p}{k_f})\emptyset_b}$

Table 3. Thermo-physical properties of nanoparticles

Type of Nanoparticles	$[\rho_p]$ **(Kg/m³)**	$[c_p]$ **(J/kg.K)**	$[k_p]$ **(W/m.K)**
Al_2O_3	3970	791	40.00
TiO_2	3900	692	8.40
CuO	6400	551	32.90
SiO_2	2200	745	1.40
ZnO	5600	495	13.00

Table 4. Thermo-physical properties of base liquids

Type of base Liquid	ρ_b **(Kg/m³)**	c_f **(J/kg.K)**	μ_f **(kg/m.s)**	K_f **(W/m.K)**
Ethylene-Glycol	1111	2415	0.01570	0.252

Table 5. Thermo-physical properties of heat sink materials

Solid	$[\rho_s]$ (kg/m^3)	$[c_s]$ (J/kg.K)	$[k_s]$ (W/m.K)
Aluminium	2719	871	202.4

Following equations are used to find out heat transfer parameters,
Local thermal resistance,

$$R = \frac{T_{max(z)} - T_{in}}{q} \quad (1)$$

Hydraulic diameter,

$$D_h = \frac{4A}{P} = \frac{2H_c W_c}{H_c + W_c} \quad (2)$$

Reynolds number,

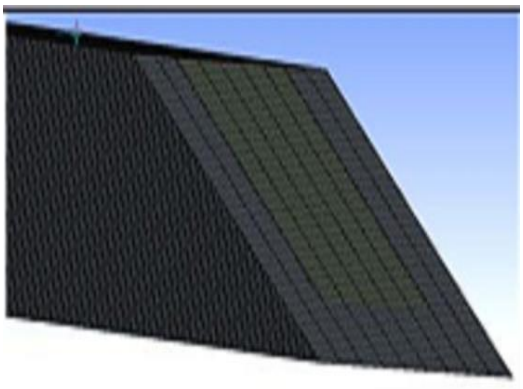
$$Re = \frac{\rho w_{avg} D_h}{\mu} \quad (3)$$

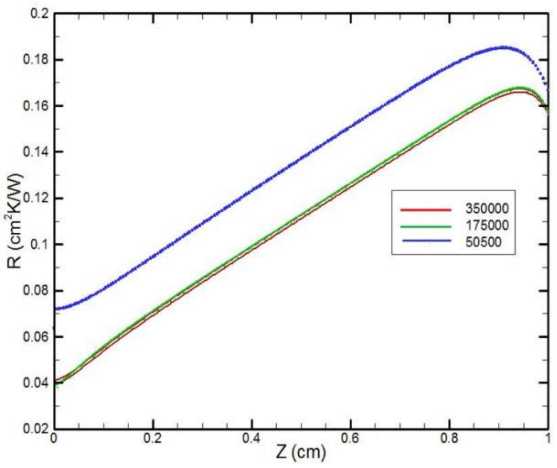
Pump power,

$$P_{pump} = \Delta p \; x \; \dot{Q}^a \quad (4)$$

2.3. Governing equations, Numerical Method & Grid Independency Test

Here cartesian tensor system is used, for more detail information of governing equation is found from K.C. Toh et al. [9] research article. Furthermore, numerical analysis is performed on ANSYS FLUENT 13.0, Solver is specified at simple pressure based with absolute velocity formation. For simulation design solution, Standard Viscous-Laminar model is opted with initial iteration value of 0.3 is taken as relaxation factor. Further second order upwind spatial discretization is considered for momentum and for other species. The residuals energy equation is set at $1x10^{-4}$, for momentum and the other component equations it is and $1x10^{-6}$ for continuity equations $1x10^{-3}$. The grid size used for the simulations should be such that it not only increases the accuracy of the results but also decreases the computational time as well. Keeping this in mind the number of grid elements taken in the study after studying Figure 2b has been near about 175000 elements.





(a) (b)

Figure 2. (a) Grid model Sectional view; (b) Grid Independency Test

3. Results and Discussions

3.1. Validation of Model

For validation of models the results get from simulation has been compared with previous data from literature article [9]-[10] as shown in Figure 3 (a) and (b). The simulation results are in good agreement with experimental data; there is little deviation seen because of the some assumption which have been made during study such as here top wall of heat sink considered as adiabatic wall but in experimental study the top wall has been made of glass which form convection phenomena in between glass wall and surrounding air. In this study only single micro-channel has been studied but in experimental study of Tuckerman et al. [10] entire heat sink was studied this might be some reason for some devotions between simulation and experimental study.

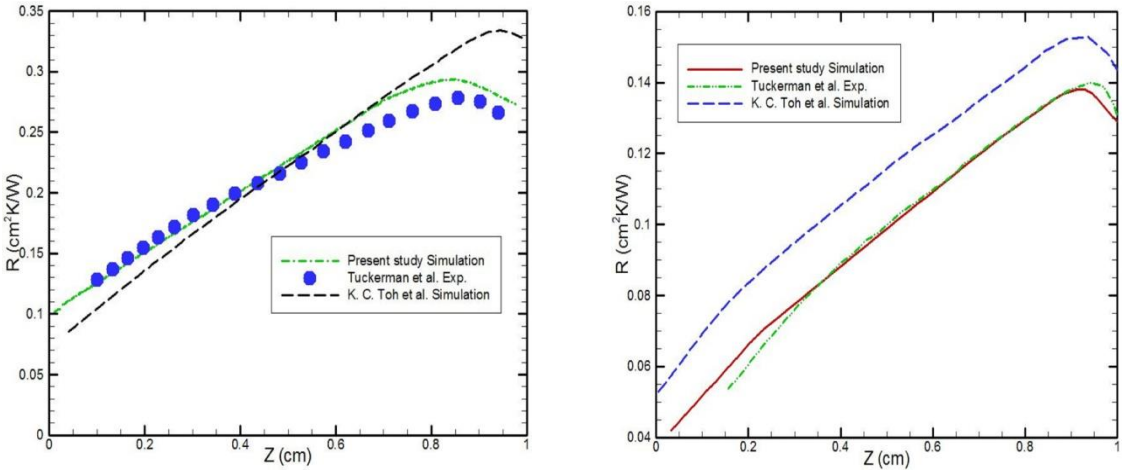


Figure 3. Correlation between experimental and present study for local thermal resistance parameters along fluid flow: (a) for case-0; (b) case-1

3.2. Analysis of Varying Concentration of Nanoparticles in Ethylene Glycol Base Nanofluid.

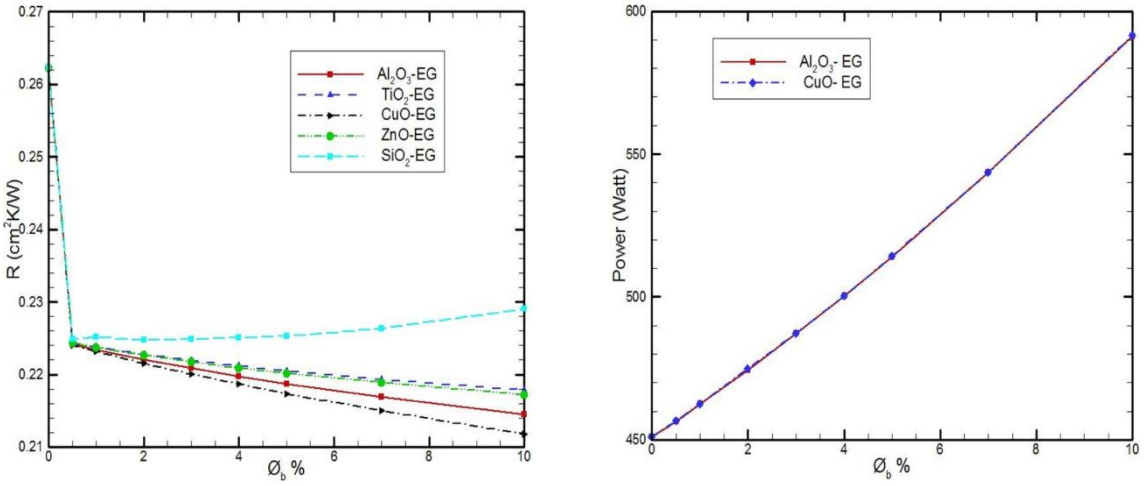
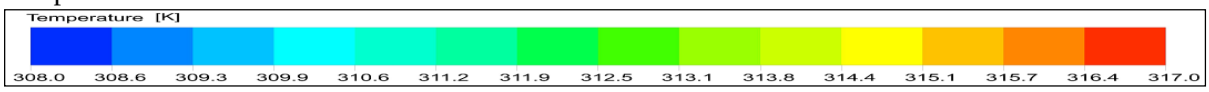


Figure 4. Effects of nanoparticles varying concentration in EG at z =0.9 cm plane: (a) On local thermal resistance; (b) on pump power [$\emptyset_b$%=Percentage concentration of nanoparticle]

From Figure 4a it have been evident that in case of flow of pure ethylene glycol in micro-channel, local thermal resistance at Z=0.9 cm was 0.2623 cm^2K/W observed. But when 0.005 volume fraction of oxide nanoparticle has been mixed with ethylene glycol and flow through micro-channel; the local thermal resistances is decrease up to 0.2242 cm^2K/W except in case of SiO_2 it was 0.2248 cm^2K/W. There have been drastic decrement in local thermal resistance up to 14.56 percentages even for small addition of nanoparticle. Moreover, thermal resistance decreases further as concentration of nanoparticle increases, but it observed that in case of CuO nanoparticle the drop was more compare to other nanoparticle, the reason for that is the CuO nanoparticle have higher heat capacity (ρc_p) compare to any other nanoparticle. Initially the drop in thermal resistance has been more but concentration of nanoparticle increases the decrement in thermal resistance have been less because of increasing viscosity which reduce the velocity of fluid and hence it further affect convection phenomena between sink and nanofluid. In case of SiO_2-EG nanofluid the thermal resistance goes on increases as nanoparticle concentration increase the reason for that been the SiO_2 have low thermal conductivity and heat capacity and at same time it generate more viscosity in that which further reduces the heat transfer phenomena.

Temperature contour interval



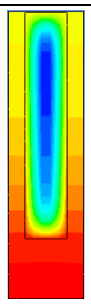
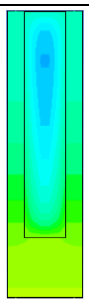
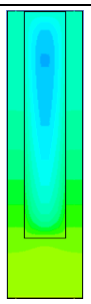
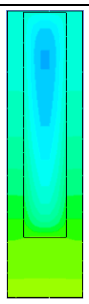
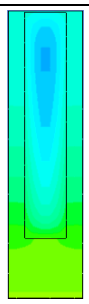
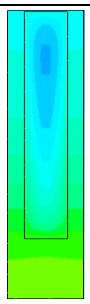
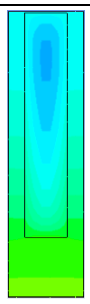
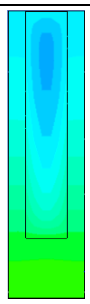
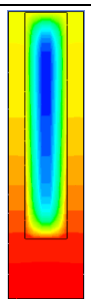
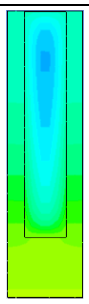
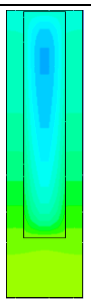
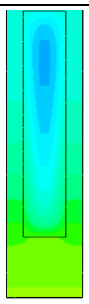
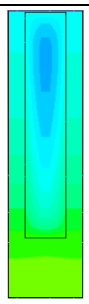
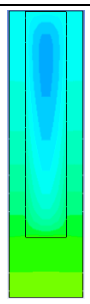
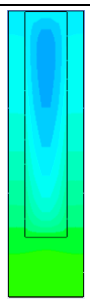
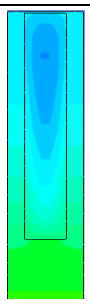
Nanoparticles Concentration percentages.	0%	0.5 %	1%	3%	4%	5%	7%	10%
Al_2O_3-EG								
CuO-EG								

Figure 5. Effects on temperature distribution for different concentration of Al_2O_3 and CuO in ethylene glycol

From Figure 4b it have been observed, for any oxide type of nanoparticle the increment in pumping power was same because in this case study we assumed that fluid was single phase and hence as discussed in literature review of Batchelor et al. [7] the viscosity of nanofluid has been depend only on base fluid and not on type of nanoparticle. Therefore in Figure 4b only CuO and Al_2O_3 cases has been considered. For smaller concentration of nanoparticle the increment in pumping power has been less but as concentration increases above 4 percentage of nanoparticle, the pumping power increases

drastically. Hence above 4 percentage of nanoparticle concentration in Ethylene glycol should not be taken especially in this type of model.

Figure 5 demonstrate ANSYS Fluent results at Z =0.9 cm for varying concentrations of Al_2O_3 and CuO oxide nanoparticles. As nanoparticle concentration increases; minimum temperature of fluid is increases because of increment in fluid conductivity. Furthermore, the plane maximum temperature have been decreases from this we can conclude that heat transfer between nanofluid and heat sink increases which eventually cooled down electronics devices effectively. From all above study we observed that CuO-EG should be the first choice for this case of model and the other choice has been Al_2O_3-EG nanofluid.

4. Conclusions

CFD analysis have been performed using ANSYS FLUENT 13.0 software and following observations were made from above study:

1. 0.005 volume fraction of oxide nanoparticle in Ethylene Glycol decreases local thermal resistance up to 14.56 percentages except for SiO_2.
2. Drop in thermal resistance has been more for lower concentration of nanoparticle but as concentration of nanoparticle increase further the drop eventually goes decreasing.
3. In case of SiO_2-EG nanofluid the thermal resistance goes on increases because of small heat capacity and conductivity of SiO_2 nanoparticle.
4. Because of single phase approach method here viscosity and eventually pump power does not depend on type of oxide nanoparticle.
5. Above 4 percentage of nanoparticle concentration of nanoparticle should not be taken as it increases pumping power drastically and at the same time thermal resistance does not reduces as required.
6. From this simulation study, after comparing above five oxide nanoparticles, a concrete observation can be made that, CuO-EG nanofluid is more effective for cooling of electronics devices in this case.

Nomenclature

ρ_b	density of base fluid	ρ_s	density of heat sink
ρ_p	density of nanoparticles	k_s	thermal conductivity of heat sink
ρ_{eff}	effective density of nanofluid	a	cross sectional of flow area
V_p	volume of nanoparticles	p	wetted perimeter
V_b	volume of base fluid	$\emptyset_b$	volume fraction of nanoparticles
C_b	specific heat of base fluid	w	velocity
C_p	specific heat of nanoparticles	w_{avg}	average fluid velocity
C_{eff}	specific heat of nanofluid	x, y, z	coordinate axis
μ_{eff}	dynamic viscosity of nanofluid	**Abbreviations**	
μ_f	dynamic viscosity of base fluid	Al_2O_3	Aluminium Oxide
k_{eff}	thermal conductivity of nanofluid	TiO_2	Titanium Dioxide
k_f	thermal conductivity of base fluid	CuO	Copper Oxide
k_p	Thermal conductivity of nano-particles	SiO_2	Silicon Dioxide
C_s	specific heat of heat sink	ZnO	Zinc Oxide

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