

Numerical Modeling on Electronics Module Cooling by Using TiO₂, Al and CuO Water Based Nanofluids

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ABSTRACT

The conventional air cooling technique is no longer adequate for high heat flux electronics components. For that, the thermal management of electronics module is very much important to its smooth operation. The present study involves an electronics module kept horizontally at the base, inside a square shaped chamber filled with nanofluid as coolant. Three different water based nanofluids, namely Water-TiO₂, Water-Al and Water-CuO, are considered as coolants in the present investigations. The numerical studies are carried out to obtain the heat transfer behavior of electronics module for maintaining its temperature within the safe limit. For that, a 2D numerical model is being developed which also includes thermal buoyancy. The continuity, momentum and energy equations are solved to predict the thermal behavior. The simulations are performed to predict the temperature fields and temperature contours. The trends of results are along the expected lines. Simulation results predicted with three different water based nanofluids are analyzed and compared for realizing the relative importance of the stated nanofluids. The key model parameter considered is heat flux of 70 W/cm² associated with the electronics module. The Water-Al is identified as the nanofluid giving the superior cooling effect to electronics module without any such thermal failure.

Keywords: Electronics Module, Simulation, Nanofluids, Water-TiO₂, Water-Al, Water-CuO

I. INTRODUCTION

The present propensity of miniaturization of electronic components alongside the ever more high circuit densities has caused alarmingly high power densities. This tendency towards miniaturization involves high heat flux in various applications and has provided motivation, during the past several years, for significant volume of research related to the design and development of effective cooling schemes. In view of the present trend of continual increase in both packaging and power densities in modern day's electronics components, the search for the suitable cooling techniques, depending on the applications, motivated the investigators all over the world. As the traditional free or forced convection air cooling technique is insufficient for the high heat flux applications, the search for alternative forms of cooling have captured much attention in recent years to circumvent the problems of high thermal resistance associated with the system hardware.

Wadsworth and Mudawar [1] studied about the cooling of a multichip electronic module using confined two dimensional jets of dielectric liquid. Webb and Ma [2] investigated on single phase liquid jet impingement heat transfer. Xuan and Roetzel [3] discussed about the conceptions of heat transfer correlation of nanofluids. Basak et al. [4] reported on effects of thermal boundary conditions on natural convection flows within a square cavity. He et al. [5] described about heat transfer and flow behaviour of aqueous suspensions of TiO₂ nanofluids flowing upward through a vertical pipe. Anandan and Ramalingam [6] reviewed on thermal management of electronics. Kurnia et al. [7] analyzed numerically on laminar heat transfer performance of various cooling channel designs. Yang and Wang [8] simulated a 3D transient cooling portable electronic device using phase change material. Zhu et al. [9] optimized the heat exchanger size of a thermoelectric cooler used for electronic cooling applications. Gong et al. [10] presented numerically on layout of micro-

channel heat sink useful for thermal management of electronic devices. Naphon et al. [11] demonstrated about thermal cooling enhancement techniques meant for electronic components.

From the aforesaid literature, to the best of author's knowledge, it is quite obvious that there is not a single comprehensive numerical investigation pertaining to the influences of water based nanofluids (namely Water-TiO₂, Water-Al and Water-CuO) on heat transfer behavior of electronics modules. With this perspective, the present paper demonstrates numerical investigations with the stated nanofluids on thermal characteristics of electronics modules. And also, the numerical model includes additional key factors like inertia, viscosity and gravity effects apart from the usual issues concerning the present physical problem. However, the stated model ignores both compressibility and viscous heat dissipation effects. The model is very well demonstrated for the detailed numerical investigations on the influences of the already stated nanofluids (as they significantly affect the cooling characteristics) by taking electronics module heat flux and duct inlet nanofluid velocity as the important model parameters. Lastly, the predictions of the model pertaining to the different nanofluids are also along the expected lines.

II. DESCRIPTION OF PHYSICAL PROBLEM

The schematic sketch of a typical electronics module representing the base of a square shaped chamber is depicted in the figure 1. It describes about the overall heat transfer from the electronics module kept horizontally at the base of square shaped chamber. The coolants considered in the present investigations are three different water based nanofluids named as Water-TiO₂, Water-Al and Water-CuO. A 2D model is considered to save computation/simulation time by ignoring end effects in the transverse direction. The model includes thermal buoyancy, viscosity along with the gravity effect as well. The fluid flow is considered to be laminar and incompressible. The ambient together with the no slip boundary condition is specified at the walls. For cooling of the electronics module, a convective boundary condition in the form of heat flux is introduced at the base to simulate the overall temperature variation inside the square chamber due to heat transfer. The thermo-physical properties of various

nanoparticles together with the additional system parameters, are shown in table 1.

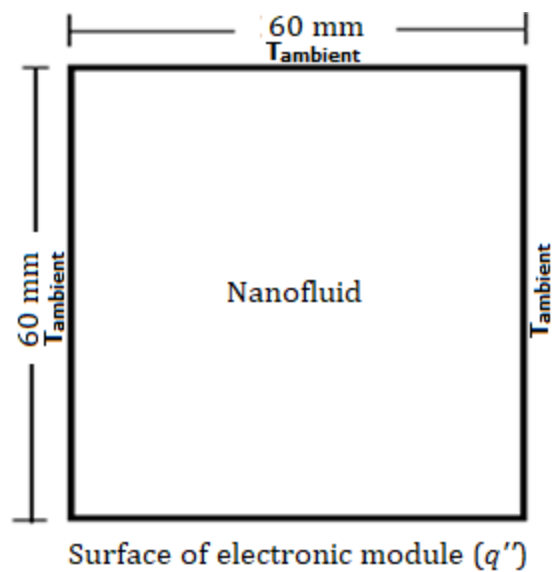


Figure 1. Schematic illustration of electronics module computational domain

Table 1. Thermophysical properties of nanoparticles and model data

Nanoparticle Properties	TiO ₂	Al	CuO
Density, ρ (Kg/m ³)	4175	2700	6315
Specific heat, C_p (J/kg-K)	692	904	532
Thermal conductivity, k (W/m-K)	8.4	237	33
Model Data		Values	
Height/Width of chamber		60 mm	
Electronics module length		60 mm	
Ambient air temperature		300 K	
Electronics module heat flux		70 W/cm ²	

III. MATHEMATICAL FORMULATION

The present physical problem is transformed into a set of governing transport equations which are solved through the present numerical techniques concerning both modeling and simulation. The related continuity, momentum and energy equations in 2D for a fully developed hydrodynamic and thermal flow situations are described in equations from (1) to (4), respectively. The compressibility and the viscous heat dissipation effects are neglected in the existing physical situation. However, the thermal buoyancy term (represented by $\rho g \beta \Delta T$) is introduced in y-momentum equation (3).

$$\text{Continuity equation: } \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

X-momentum equation:

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = -\frac{\partial P}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (2)$$

Y-momentum equation:

$$\rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial P}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + \rho g \beta \Delta T \quad (3)$$

Energy equation:

$$\left(\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (4)$$

IV. NUMERICAL PROCEDURES

A. Numerical scheme and solution algorithm

The aforementioned governing transport equations are transformed into generalized form as follows.

$$\frac{\partial}{\partial t}(\rho \phi) + \nabla \cdot (\rho \mathbf{u} \phi) = \nabla \cdot (\Gamma \nabla \phi) + S \quad (5)$$

The transformed governing transport equations are discretized with the second order upwind scheme using a pressure based finite volume method with the SIMPLER algorithm, where Γ represents a transport property (k or μ), ϕ denotes any conserved variable and S is a source term.

Initially, both the continuity and momentum equations are solved simultaneously to get the pressure and velocity fields. Then, the energy equation is solved using the stated velocity field to get the corresponding temperature field. In other words, all the stated equations are solved together (but not independently) because of interdependency between the associated variables.

B. Choice of grid size, time step and convergence criteria

A comprehensive and complete grid-independence test is carried out to establish a suitable spatial discretization, and the levels of iteration convergence criteria to be used. As an outcome of this test, we have used 60×60 uniform grids for the final simulation. Corresponding time step taken in the simulation is 0.0001 seconds. Though we checked with smaller grids of 90 and 120 in numbers for 60 mm width/height of the computational domain, it is observed that a finer grid system does not alter the results significantly. In other words, the statistical data reveals that the finer

grids have minor effect in the simulation results which is quite obvious from the definition of grid-independence test. And also, the smaller grid pertains to more computational time involving more evenness in results of different contours/fields.

Convergence in inner iterations is declared only when the condition $\left| \frac{\phi - \phi_{old}}{\phi_{max}} \right| \leq 10^{-4}$ is satisfied simultaneously for all variables, where ϕ stands for each variable u , v , and T at a grid point at the current iteration level, ϕ_{old} represents the corresponding value at the previous iteration level, and ϕ_{max} is the maximum value of the variable at the current iteration level in the entire domain.

V. RESULTS AND DISCUSSION

Numerical simulations are performed to investigate the influences of three different water based nanofluids (such as Water-TiO₂, Water-Al and Water-CuO) on cooling characteristics of electronics module in terms of temperature distributions (i.e. temperature contours/fields) and surface temperatures of electronics modules. At the outset, the size of the square chamber is considered to be 60 mm. In addition, the heat flux associated with the electronics module is taken to be 70 W/cm².

A. Influence of Water-TiO₂ nanofluid as coolant

With the stated model conditions, in order to investigate the influence of Water-TiO₂ nanofluid on the thermal behavior of the electronics module, the numerical simulations are performed, by taking into account the thermophysical properties of the stated nanofluid.

Figure 2 illustrates the simulated results of the temperature field (together with the colored scale bar displaying the temperature values in terms of K) as obtained at the stated model conditions by considering Water-TiO₂ nanofluid as coolant. The surface temperature of electronics module is found to be 351 K (which is very close to the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the electronics module). As expected, the temperature of the Water-TiO₂ nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-TiO₂ nanofluid gradually

decreases with the increase in the distance from the electronics module and then it becomes equal to the atmospheric temperature in the far field region. The corresponding temperature contour is also demonstrated in figure 3. Here also, the trends of results are along the expected lines.

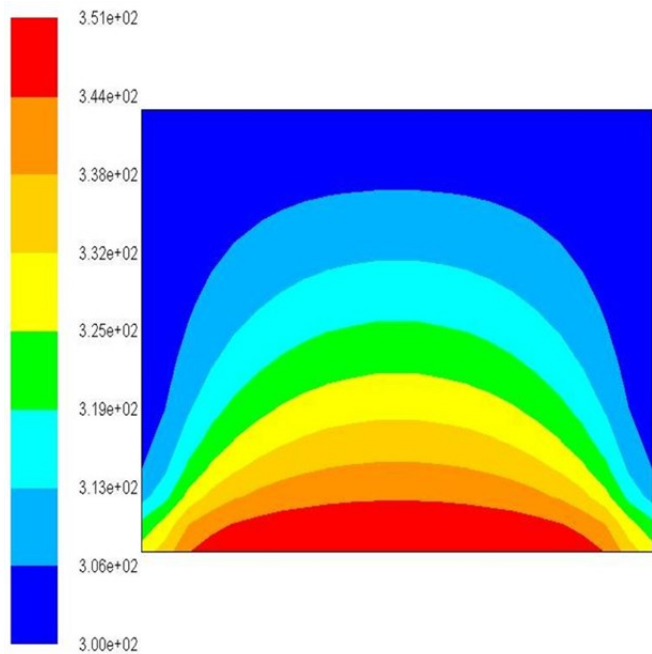


Figure 2. Temperature field with Water-TiO₂ nanofluid as coolant.

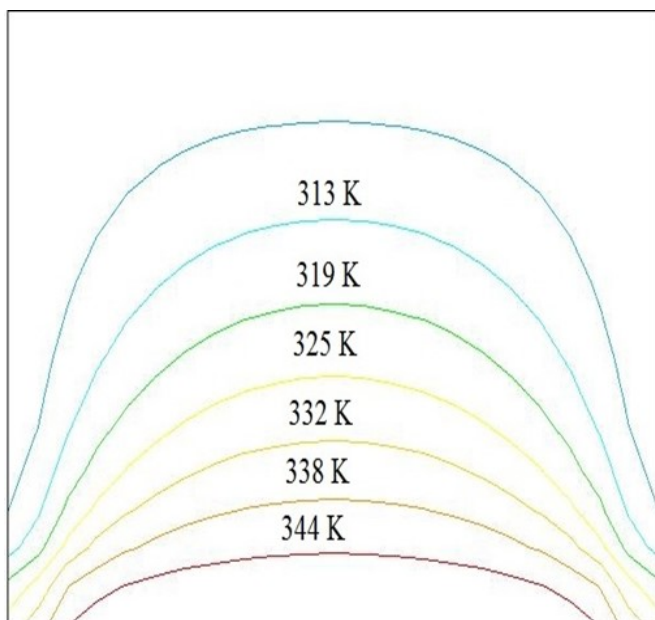


Figure 3. Temperature contour with Water-TiO₂ nanofluid as coolant.

B. Influence of Water-Al nanofluid as coolant

With the stated model conditions, in order to investigate the influence of Water-Al nanofluid on the thermal behavior of the electronics module, the numerical simulations are performed, by taking into account the thermophysical properties of the stated nanofluid.

Figure 4 illustrates the simulated results of the temperature field (together with the colored scale bar displaying the temperature values in terms of K) as obtained at the stated model conditions by considering Water-Al nanofluid as coolant. The surface temperature of electronics module is found to be 313 K (which is also within the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the electronics module). As expected, the temperature of the Water-Al nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-Al nanofluid gradually decreases with the increase in the distance from the electronics module and then it becomes equal to the atmospheric temperature in the far field region. The corresponding temperature contour is also demonstrated in figure 5. Here also, the trends of results are along the expected lines.

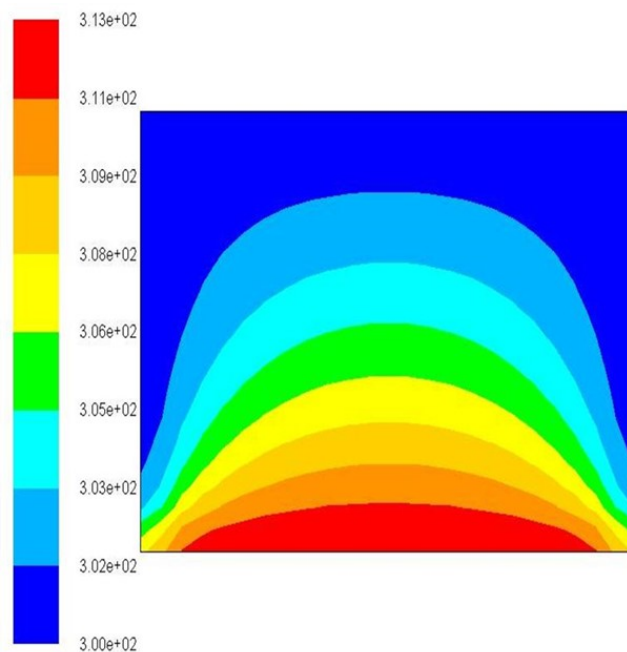


Figure 4. Temperature field with Water-Al nanofluid as coolant.

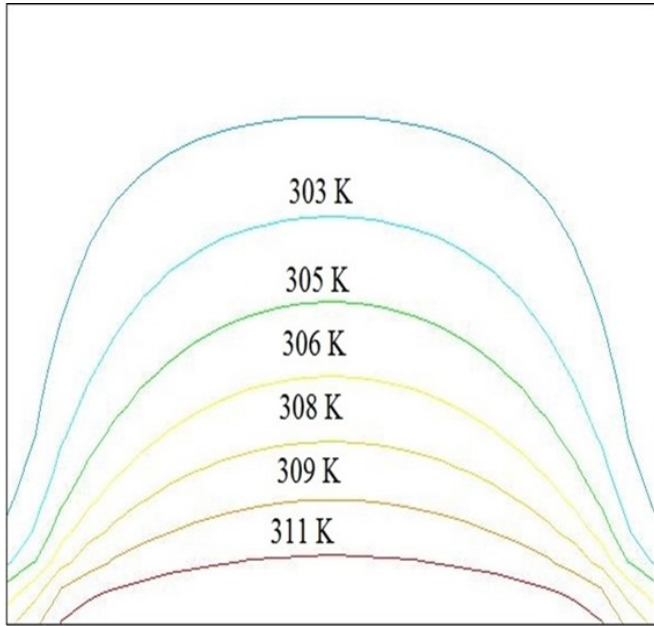


Figure 5. Temperature contour with Water-Al nanofluid as coolant.

C. Influence of Water-CuO nanofluid as coolant

With the stated model conditions, in order to investigate the influence of Water-CuO nanofluid on the thermal behavior of the electronics module, the numerical simulations are performed, by taking into account the thermophysical properties of the stated nanofluid.

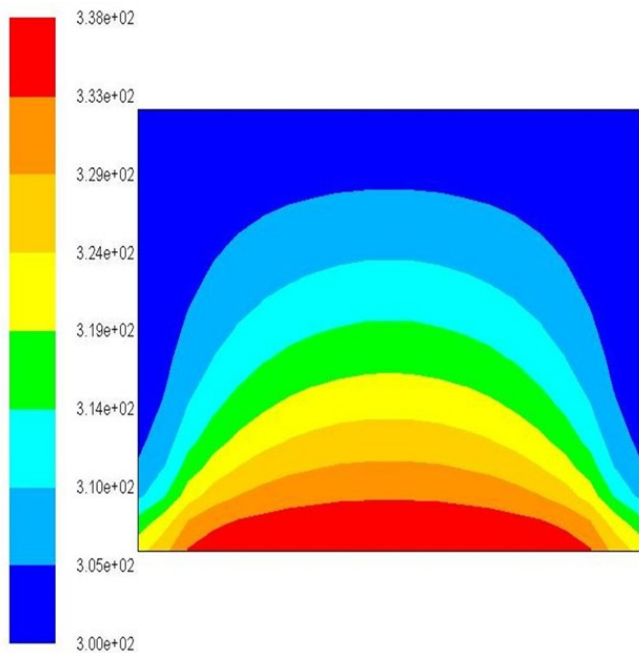


Figure 6. Temperature field with Water-CuO nanofluid as coolant.

Figure 6 illustrates the simulated results of the temperature field (together with the colored scale bar

displaying the temperature values in terms of K) as obtained at the stated model conditions by considering Water-CuO nanofluid as coolant. The surface temperature of electronics module is found to be 338 K (which is also within the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the electronics module). As expected, the temperature of the Water-CuO nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-CuO nanofluid gradually decreases with the increase in the distance from the electronics module and then it becomes equal to the atmospheric temperature in the far field region. The corresponding temperature contour is also demonstrated in figure 7. Here also, the trends of results are along the expected lines.

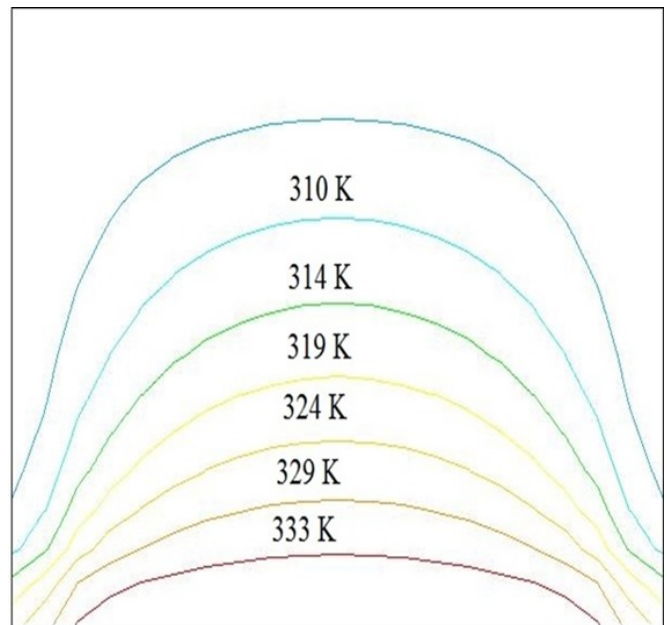


Figure 7. Temperature contour with Water-CuO nanofluid as coolant.

D. Comparison of predicted temperatures of electronics modules obtained with different nanofluids as coolants

Table 2 summarizes the numerically predicted temperatures of the electronics modules as obtained with the use of three different water based nanofluids (namely, Water-TiO₂, Water-Al and Water-CuO) as coolants. It is observed that the numerical predictions/results are comparable with each other. As expected, the variations in the numerically predicted temperatures of the electronics modules are witnessed very clearly with the use of the stated water based nanofluids as coolants. This is because of the variations

in the thermal conductivities of the corresponding nanoparticles as mentioned in table 1.

Table 2. Comparison of numerical predictions of electronics modules temperatures with different nanofluids as coolants.

Name of Nanofluid	Numerically Predicted Temperature of Electronics Module (K)
Water-TiO ₂	351
Water-Al	313
Water-CuO	338

Correspondingly, figure 8 also illustrates the plot representing the variations in the electronics modules temperatures with three different water based stated nanofluids as coolants. It is quite obvious that the trends of the variations in the numerically predicted results are along the expected lines.

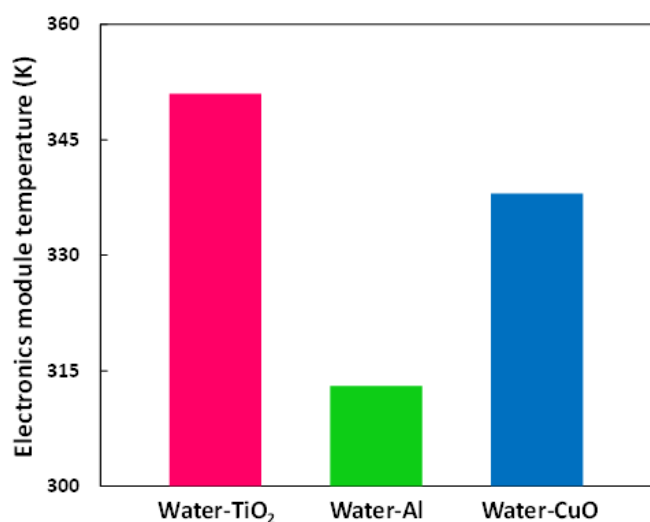


Figure 8. Variations in electronics modules temperatures with different water based nanofluids as coolants.

VI. CONCLUSION

A numerical model relating to the electronics module is developed to predict the thermal behavior with three different water based nanofluids, namely Water-TiO₂, Water-Al and Water-CuO as coolants. The model includes additional key factors like inertia, viscosity, gravity and thermal buoyancy effects apart from the usual issues concerning the present physical problem.

However, the stated model ignores both compressibility and viscous heat dissipation effects. The model is very well demonstrated for the detailed numerical investigations on the influences of the already stated nanofluids (as they significantly affect the cooling characteristics) by taking electronics module heat flux of 70 W/cm² as the important model parameter. The predictions of the model pertaining to the different nanofluids are along the expected lines. Direct comparison with other numerical models of electronics modules is not possible because of the absence of such models in the literature. However, the experimental comparison with an in-house experimental setup is planned for the future. With the said model conditions, it is observed that the Water-Al nanofluid renders appropriately effective cooling behavior without any such thermal failure and is the superior one as the electronics module temperature is far below the safe limit. Hence, the stated model together with the nanofluid can be utilized directly in industries to enhance heat transfer and for cooling of electronics modules.

VII. REFERENCES

- [1] D.C Wadsworth and I.Mudawar, Cooling of a multichip electronic module by means of confined two dimensional jets of dielectric liquid, *Journal of Heat Transfer*, November (1990), Vol. 112/891.
- [2] Webb, B. W., and Ma, C. F., (1995), "Single phase Liquid Jet impingement heat transfer," *Adv. Heat Transfer*, vol. 26, pp.105–217.
- [3] Xuan Y, Roetzel W. Conceptions for heat transfer correlation of nanofluids. *Int J Heat Mass Transfer* 2000; vol 43:3701-7.
- [4] Tanmay Basak, S.Roy and A.R. Balakrishnan, Effects of thermal boundary conditions on natural convection flows within a square cavity, *International Journal of Heat and Mass Transfer* 49 (2006) 4525–4535.
- [5] He Y, Jin Y, Chen H, Ding Y, Cang D, Lu H. Heat transfer and flow behaviour of aqueous suspensions of TiO₂ nanoparticles (nanofluids) flowing upward through a vertical pipe. *Int J Heat Mass Transfer* 2007; vol 50:2272-81.
- [6] Shanmuga Sundaram Anandan and Velraj Ramalingam, Thermal management of electronics: A review of literature, *Thermal Science: Vol. 12* (2008), No. 2, pp. 5-26.
- [7] Jundika C. Kurnia , Agus P. Sasmito , Arun S. Mujumdar, Numerical investigation of laminar heat transfer performance of various cooling channel designs, *Applied Thermal Engineering* 31 (2011), pp. 1293-1304.

- [8] Yue-Tzu Yang, Yi-Hsien Wang, Numerical simulation of three-dimensional transient cooling application on a portable electronic device using phase change material, *International Journal of Thermal Sciences* 51 (2012), pp. 155-162.
- [9] Lin Zhu, Hongbo Tan, Jianlin Yu, Analysis on optimal heat exchanger size of thermoelectric cooler for electronic cooling applications, *Energy Conversion and Management* 76 (2013), pp. 685–690.
- [10] Liang Gong, Jin Zhao, Shanbo Huang, Numerical study on layout of micro-channel heat sink for thermal management of electronic devices, *Applied Thermal Engineering* xxx (2014), pp. 1-11.
- [11] P. Naphon , S. Wiriyasart , S. Wongwises, Thermal cooling enhancement techniques for electronic components, *International Communications in Heat and Mass Transfer* 61 (2015), pp. 140-145.