Numerical Modeling on Thermal Management of Electronics Module by Using SiO_2, Al and Al_2O_3 Water Based Nanofluids

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Abstract*-The traditional air cooling technique is not suitable for high heat flux electronics gadgets. 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-SiO2, Water-Al and Water-Al2O3, 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 found as the nanofluid having the better cooling performance to electronics module without any kind of thermal letdown.*

Keywords: Electronics Module, Simulation, Nanofluids, Water-SiO2, Water-Al, Water-Al2O3.

I. INTRODUCTION

The current tendency of miniaturization of electronic gadgets together with the ever more high circuit densities has triggered exceedingly 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 gadgets, the search for the suitable cooling techniques, depending on the applications, motivated the investigators all over the world. As the convetional free or forced convection air cooling technique is inadequate for the high heat flux applications, the search for alternative forms of cooling have captured much attention in recent years to resolve the problems of high thermal resistance related to the electronic gadgets.

II. LITERATURE REVIEW

Wadsworth and Mudawar [1] investigated on cooling of a multichip electronic module using confined 2D jets of dielectric liquid. Webb and Ma [2] studied about 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] illustrated on thermal cooling enhancement techniques intended for electronic devices.

III. OBJECTIVES OF PRESENT RESEARCH WORK

From the aforementioned texts, to the best of author' knowledge, it is very clear that there is not a single complete numerical study relating to the effects of water based nanofluids (namely Water-SiO2, Water-Al and Water-Al2O3) on heat transfer performance of electronics modules. With this standpoint, 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. Finally, the model predictions concerning about the various nanofluids are also along the lines of expectations.

IV. DESCRIPTION OF PHYSICAL PROBLEM

The neat illustration of a usual electronics module representing the base of a square shaped chamber is portrayed 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-SiO2, Water-Al and Water-Al2O3. 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 several nanoparticles alongside the additional system variables, are presented in table 1.

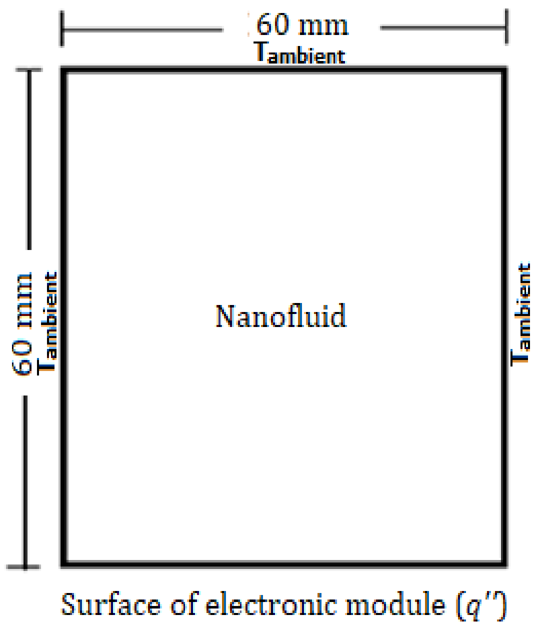

Fig.1. Schematic of electronics module computational domain

Table 1.Thermophysical properties and model data

Nanoparticle Properties	**SiO_2**	**Al**	**Al_2O_3**
Density, ρ (Kg/m^3)	2648	2700	3970
Specific heat, C_P (J/kg-K)	745	904	765
Thermal conductivity, k (W/m-K)	10.4	237	36
Model Data	**Values**		
Height/Width of chamber	60 mm		
Length of electronics module	60 mm		
Ambient air temperature	300 K		
Electronics module heat flux	70 W/cm^2		

V. MATHEMATICAL FORMULATION

The current 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. Nevertheless, the thermal buoyancy term (denoted by $\rho g\beta\Delta T$) is presented in y-momentum equation (3).

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

X-momentum equation:

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

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

VI. NUMERICAL PROCEDURES

A. Numerical scheme and solution algorithm

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

$$\frac{\partial}{\partial t}(\rho\,\varphi)+\nabla.(\rho\,\mathbf{u}\,\varphi)=\nabla.(\Gamma\nabla u)+S \quad (5)$$

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 symbolizes any conserved variable and S is a source term.

Initially, both the continuity and momentum equations are solved all together 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) owing to interdependency between the related parameters.

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

A detailed and thorough grid-independence test is conducted to develop an appropriate 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. In addition, the smaller grid relates to more computational time concerning more evenness in results of various contours/fields.

Convergence in inner iterations is ascertained only when the condition $\left|\frac{\varphi-\varphi_{old}}{\varphi_{max}}\right| \leq 10^{-4}$ is ensured simultaneously for all parameters, where φstands 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 $\varphi_{max}$is the maximum value of the parameter at the present iteration level in the whole domain.

VII. RESULTS AND DISCUSSION

Numerical simulations are carried to study the effects of three different water based nanofluids (such as Water-SiO_2, Water-Al and Water-Al_2O_3) on cooling behaviors of electronics module in terms of temperature distributions (i.e. temperature contours/fields) and surface temperatures of electronics modules. To begin with, the size of the square chamber is taken as 60 mm. Furthermore, the heat flux related to the electronics module is consider as 70 W/cm^2.

A. EFFECT OF WATER-SILICON DIOXIDE NANOFLUID AS COOLANT

With the specified model conditions, to study the influence of Water-SiO_2 nanofluid on the thermal behavior of the electronics module, the numerical simulations are conducted, by considering the thermophysical properties of the specified nanofluid.

Figure 2 demonstrates the simulated results of the temperature field (in conjunction with the colored scale bar displaying the temperature values in terms of K) as observed at the specified model conditions by taking into account the Water-SiO_2 nanofluid as coolant. The surface temperature of electronics module is found to be 349 K (which is very near 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-SiO_2 nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-SiO_2 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 lines of expectations.

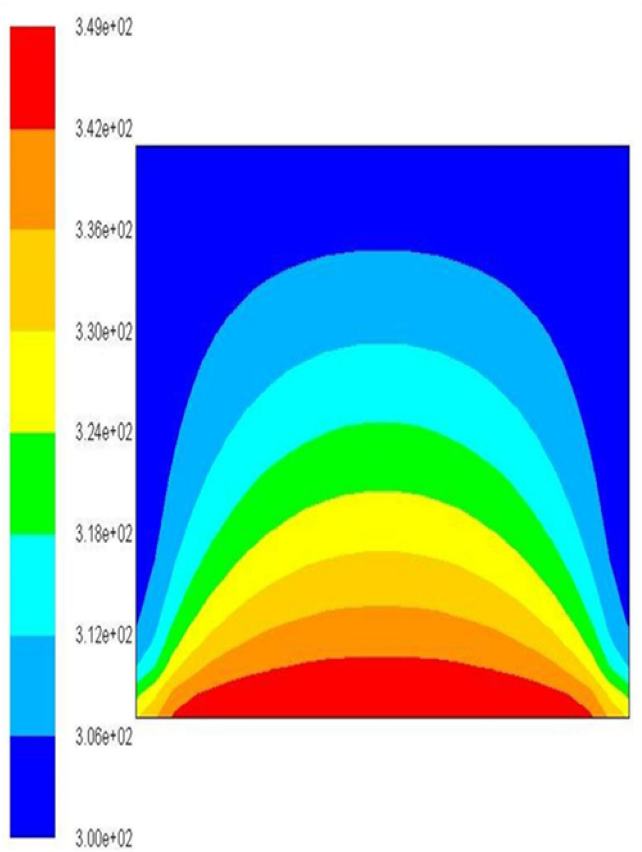

Figure 2 Temperature field with Water-SiO_2 nanofluid as coolant.

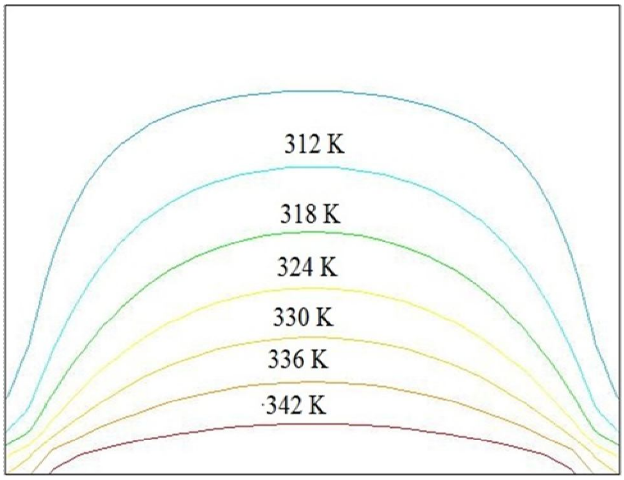

Figure 3. Temperature contour with Water-SiO_2 nanofluid as coolant.

B. EFFECT OF WATER-ALUMINUM NANOFLUID AS COOLANT

With the specified model conditions, so as to study the effect 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.

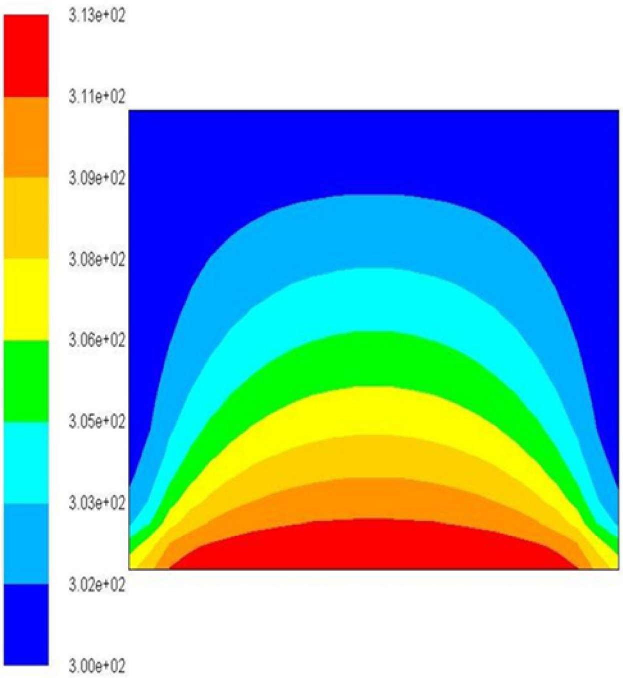

Figure 4. Temperature field with Water-Al nanofluid as coolant.

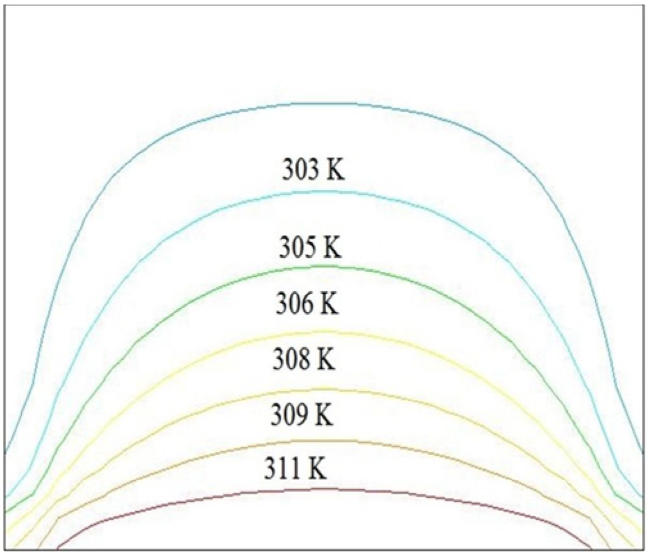

Figure 5. Temperature contour with Water-Al nanofluid as coolant.

Figure 4 elucidates 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 lines of expectations.

C. EFFECT OF WATER-ALUMINUM OXIDE NANOFLUID AS COOLANT

With the specified model conditions, in order to examine the influence of Water-Al_2O_3 nanofluid on the thermal behavior of the electronics module, the numerical simulations are conducted, by taking into consideration the thermophysical properties of the selected nanofluid.

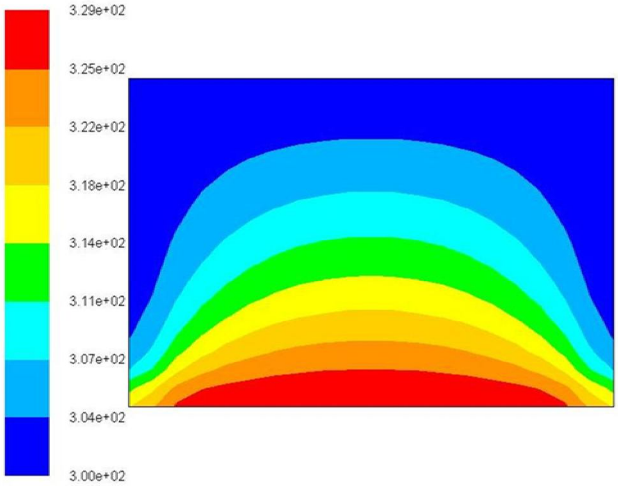

Figure 6. Temperature field with Water-Al_2O_3 nanofluid as coolant.

Figure 6 illuminates the simulated results of the temperature field (accompanied by the colored scale bar displaying the temperature values in terms of K) as observed at the specified model conditions by considering Water-Al_2O_3 nanofluid as coolant. The surface temperature of electronics module is found to be 329 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_2O_3 nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-Al_2O_3 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 illustrated in figure 7. Here also, the trends of results are along the expected lines.

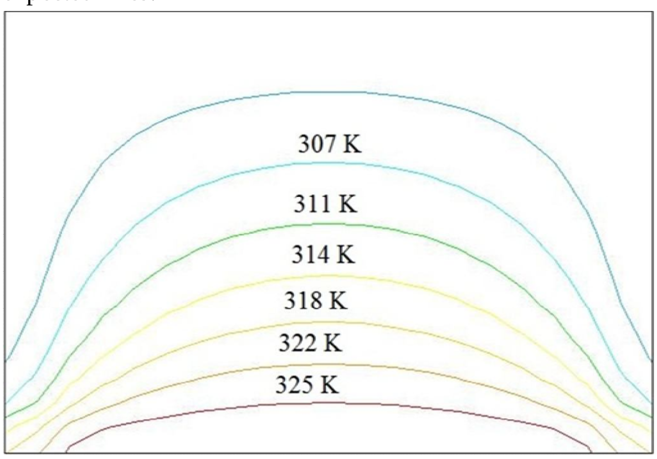

Figure 7. Temperature contour with Water-Al_2O_3 nanofluid as coolant.

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 observed by using three different water based nanofluids (namely, Water-SiO_2, Water-Al and Water-Al_2O_3) 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 on account of the variations in the thermal conductivities of the corresponding nanoparticles as described 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-SiO_2	349
Water-Al	313
Water-Al_2O_3	329

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

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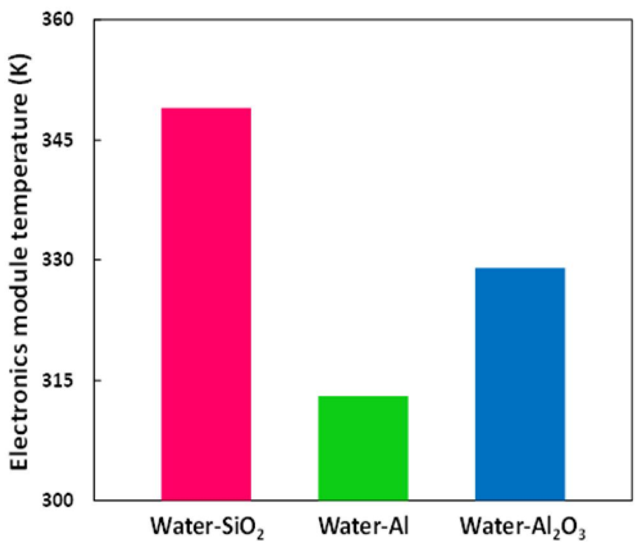

Figure 8. Variations in electronics modules temperatures with various water based nanofluids as coolants.

VIII. CONCLUSION

A numerical model concerning about the electronics module is developed to predict the thermal behavior with three different water based nanofluids, namely Water-SiO2, Water-Al and Water-Al2O3 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 specified 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 specified model together with the nanofluid can be used directly in industries to enhance heat transfer and for electronics modules cooling.

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