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Numerical Studies on Cooling Of Electronics Module Using Nzo, an and Mg Water Based Nanofluids

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Abstract*: The customary air cooling practice is not appropriate for high heat flux electronics devices. 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-ZnO, Water-AlN and Water-MgO, are considered as coolants in the present investigations. The numerical studies are performed to obtain the heat transfer behaviour 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 behaviour. Simulations are conducted 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/cm^2 associated with the electronics module. The Water-AlN is gotten as the nanofluid producing the enhanced cooling characteristics to electronics module without any sort of letdown caused by heat.

Keywords*: Electronics Module, Simulation, Nanofluids, Water-ZnO, Water-AlN, Water-MgO

I. INTRODUCTION

The recent penchant of smallness of electronic devices accompanied by the ever more high circuit densities has caused extremely 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 usual free or forced convection air cooling technique is very poor for the high heat flux applications, the pursuit for different forms of cooling have caught much focus in recent years to resolve the issues of high heat concerning the electronic devices.

II. LITERATURE REVIEW

Wadsworth and Mudawar [1] examined on cooling of a multichip electronic module with 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] exemplified on heat transfer improvement practices on course for electronic implements.From the cited researches, to the best of author' knowledge, it is observed that there is not a single ample numerical study pertaining to the impacts of water based nanofluids (specifically Water-ZnO, Water-AlN and Water-MgO) 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

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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. Ultimately, the model results with reference to the stated nanofluids are along the lines of expectations as well.

III. DESCRIPTION OF PHYSICAL PROBLEM

The immaculate drawing of a normal electronics module demonstrating the base of a square shaped chamber is shown 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-ZnO, Water-AlN and Water-MgO. 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 concerned nanoparticles combined with the additional system data, are summarized in table 1.

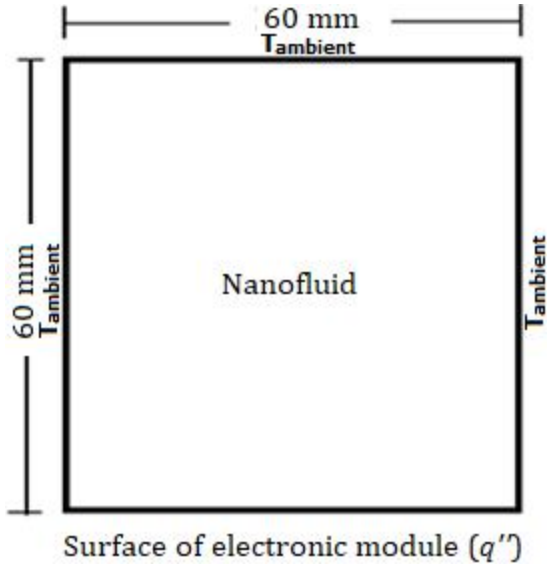

Figure 1. Schematic illustration of electronics module computational domain

Table 1. Thermophysical properties of nanoparticles and model data

Nanoparticle Properties	ZnO	AlN	MgO
Density, ρ (Kg/m^3)	5606	3260	3560
Specific heat, C_P (J/kg-K)	667	740	955
Thermal conductivity, k (W/m-K)	13.0	285	45
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		

IV. MATHEMATICAL FORMULATION

The associated physical problem is converted into a set of governing transport equations which are solved using the related numerical procedures vis-à-vis 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

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compressibility and the viscous heat dissipation effects are neglected in the existing physical situation. On the other hand, the thermal buoyancy term (symbolized by $\rho g \beta \Delta T$) is included 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: $$\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

V. NUMERICAL PROCEDURES

The schematic and detailed representation of a typical fuel cell to be kept in a duct is depicted in the figure 1. The corresponding physical model as illustrated in figure 2, describes about the overall heat transfer from the fuel cell which is encapsulated in a horizontal duct open at both the ends. The coolants considered in the present investigations are three different water based nanofluids named as Water-TiO_2, Water-SiO_2 and Water-ZnO. A 2D model is considered to save computation/simulation time by ignoring end effects in the transverse direction. The model includes the viscosity along with the gravity effect as well. The fluid flow is considered to be laminar and incompressible. The no slip boundary condition is specified at the walls. The velocity inlet boundary condition is set at the entry to the duct from where water based nanofluids are allowed to pass through. A pressure outlet boundary condition is specified at the exit of the duct. The ambient condition is taken at the entry to the duct. For cooling of the fuel cell surface, a convective boundary condition in the form of heat flux is introduced to simulate the overall temperature variation inside the duct due to heat transfer. The thermo-physical properties of various nanoparticles together with the additional system parameters, are shown in table 1.

A. Numerical scheme and solution algorithm

The associated governing transport equations are converted 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 by means of a pressure based finite volume technique with the SIMPLER algorithm, where Γ symbolizes a transport property (k or μ), ϕ signifies any conserved variable and S is a source term.

First of all, both the continuity and momentum equations are solved all together for generating 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 associated equations are solved at a time (but not independently) on account of interdependency between the associated parameters.

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

An exhaustive grid-independence test is done to establish an apposite spatial discretization, and the levels of iteration convergence criteria to be valuable. 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. Besides, the smaller grid pertains to more computational time as to more evenness in results of different contours/fields.

Convergence in inner iterations is guaranteed only when the condition $\left|\frac{\varphi-\varphi_{old}}{\varphi_{max}}\right| \leq 10^{-4}$ is satisfied for all parameters at a time, 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 complete domain.

VI. RESULTS AND DISCUSSION

Numerical simulations are done to investigate the impacts of three different water based nanofluids (for instance Water-ZnO, Water-AlN and Water-MgO) on cooling behaviors of electronics module in terms of temperature distributions (i.e. temperature

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contours/fields) and surface temperatures of electronics modules. To begin with, the size of the square chamber is taken as 60 mm. Besides, the heat flux associated with the electronics module is taken as 70 W/cm^2.

A. Effect of Water-ZnO nanofluid as coolant

With the stated model conditions, so as to study the effect of Water-ZnO nanofluid on the thermal behavior of the electronics module, the numerical simulations are done, by considering the thermophysical properties of the stated nanofluid.

Figure 2 shows the simulated results of the temperature field (in combination with the colored scale bar exhibiting the temperature values in terms of K) as obtaind at the stated model conditions by considering the Water-ZnO nanofluid as coolant. The surface temperature of electronics module is found to be 348 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-ZnO nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-ZnO 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 associated temperature contour is also shown in figure 3. The trends of results are along the lines of expectations as well.

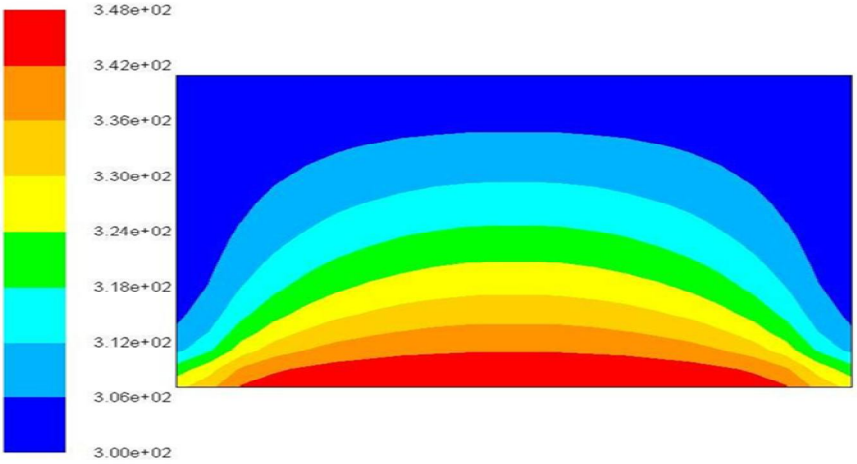

Figure2. Temperature field with Water-ZnO nanofluid as coolant.

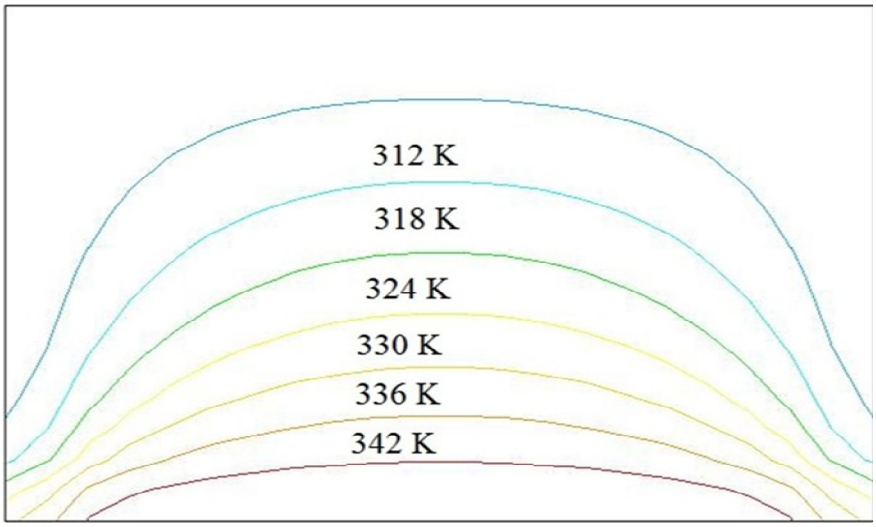

Figure3**.** Temperature contour with Water-ZnO nanofluid as coolant.

B. Effect of Water-AlN nanofluid as coolant

With the stated model conditions, so as to study the influence of Water-AlN nanofluid on the thermal behavior of the electronics module, the numerical simulations are performed, by considering the thermophysical properties of the stated nanofluid.

Figure 4 illuminates 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-AlN nanofluid as coolant. The surface

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temperature of electronics module is found to be 312 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-AlN nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-AlN 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. The trends of results are along the lines of expectations as well.

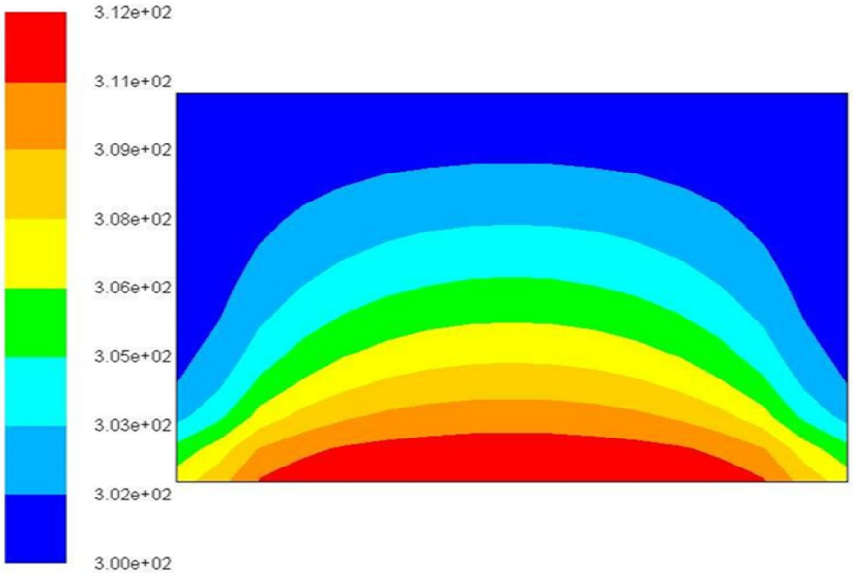

Figure 4. Temperature field with Water-AlN nanofluid as coolant.

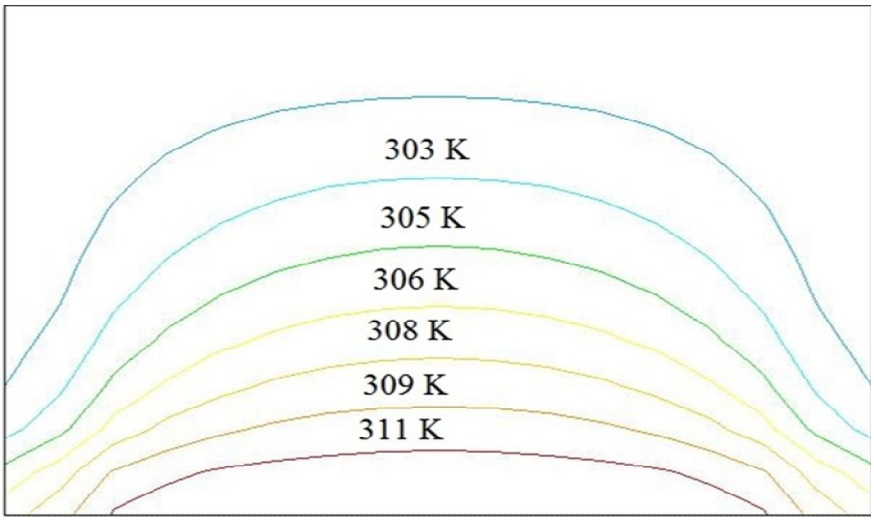

Figure 5. Temperature contour with Water-AlN nanofluid as coolant.

C. Effect of Water-MgO nanofluid as coolant

With the stated model conditions, in order to study the effect of Water-MgO nanofluid on the thermal behavior of the electronics module, the numerical simulations are conducted, by taking into consideration the thermophysical properties of the specified nanofluid.

Figure 6 illustrates the simulated results of the temperature field (together with the colored scale bar exhibiting the temperature values in terms of K) as observed at the stated model conditions by considering Water-MgO nanofluid as coolant. The surface temperature of electronics module is found to be 328 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-MgO nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-MgO nanofluid gradually decreases with the increase in

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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. The trends of results are along the expected lines as well.

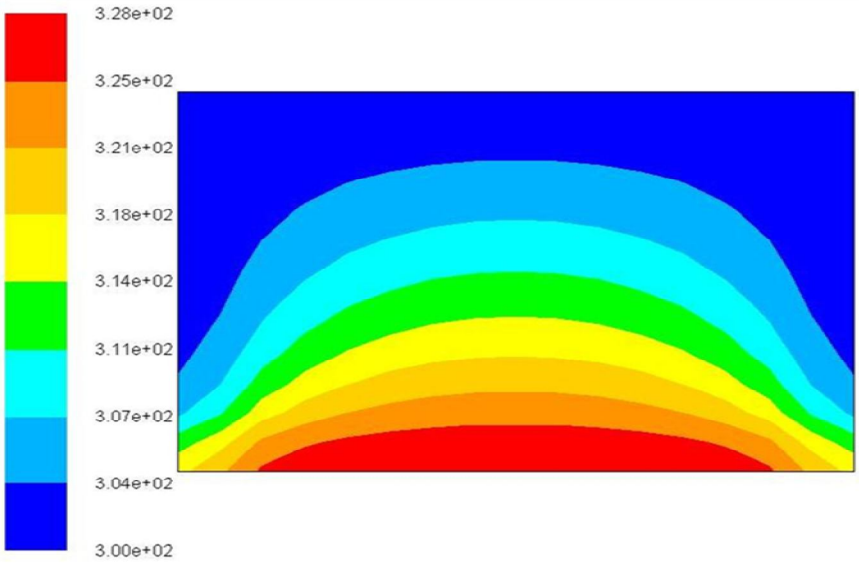

Figure 6. Temperature field with Water-MgO nanofluid as coolant.

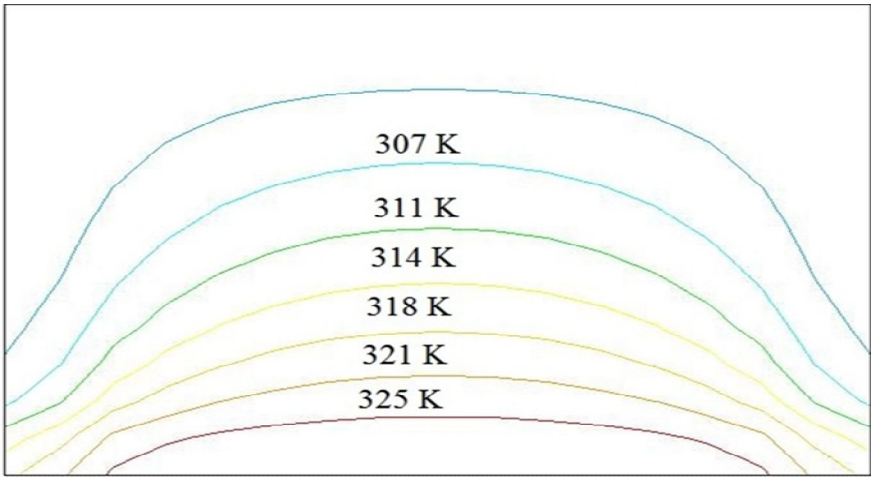

Figure 7. Temperature contour with Water-MgO nanofluid as coolant.

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

Table 2 recapitulates the numerically predicted temperatures of the electronics modules as obtained by using three different water based nanofluids (specifically, Water-ZnO, Water-AlN and Water-MgO) 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 owing to 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-ZnO	348
Water-AlN	312
Water-MgO	328

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Similarly, figure 8 also illustrates the plot representing the variations in the electronics modules temperatures with three different water based specified nanofluids as coolants. It is evident that the trends of the variations in the numerically predicted results are along the lines of expectations.

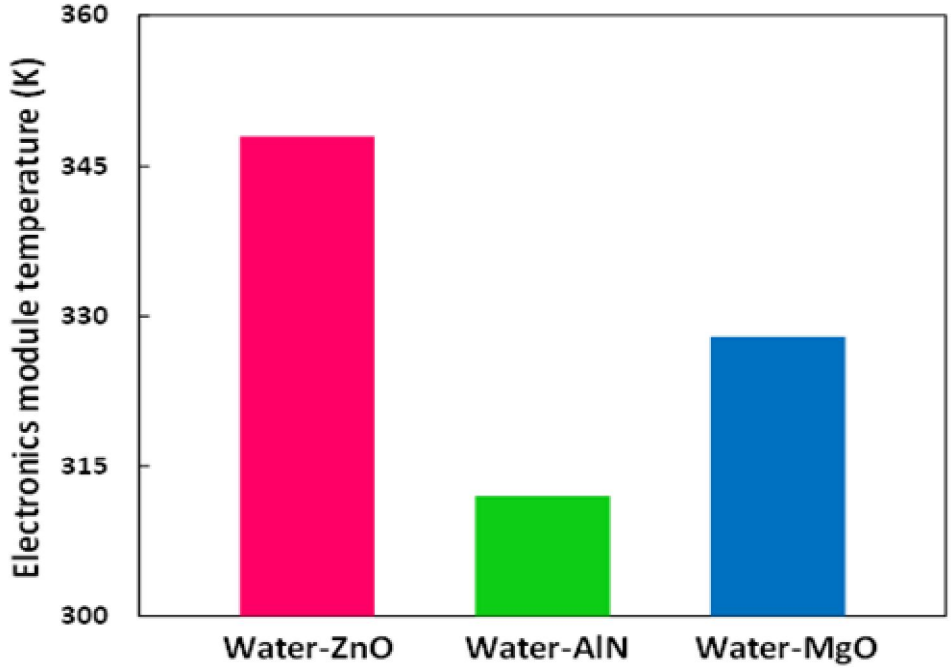

Figure 8. Variations in electronics modules temperatures with different water based nanofluids as coolants.

VII. CONCLUSIONS

A numerical model relating to the electronics module is established to predict the thermal behavior with three different water based nanofluids, specifically Water-ZnO, Water-AlN and Water-MgO 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/cm^2 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 specified model conditions, it is observed that the Water-AlN 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 alongside the nanofluid can be used straightway in manufacturing shops to increase heat transfer and for cooling of electronics modules.

VIII. ACKNOWLEDGMENT

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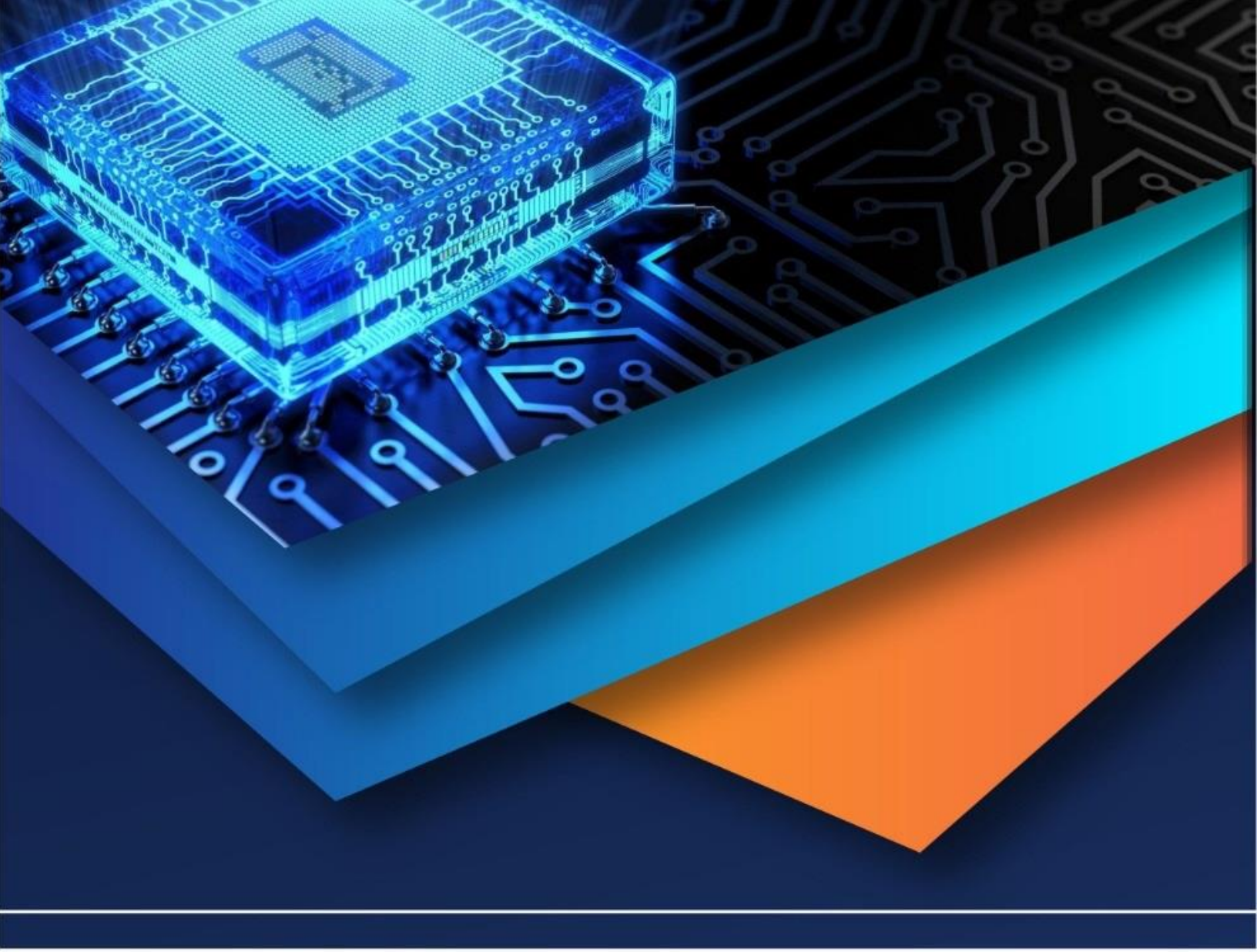

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