Numerical Studies on Cooling Characteristics of Electronics Module Using Water-Aluminum Oxide Nanofluid

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ABSTRACT *The standard air cooling exercise is unsuitable for high heat flux electronics gadgets. For that, the thermal management of electronics module is very much crucial to its smooth performance. The currentstudies involve an electronics module kept horizontally at the base, inside a square shaped chamber filled with Water-Al_2O_3nanofluid as coolant. The numerical investigations are performed to get the heat transfer performance of electronics module forkeeping 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 performance. The simulations are conducted to predict the temperature fields and temperature contours. The trends of results are along the expected lines. The important model parameter taken is heat flux of 70 W/cm^{2}related to the electronics module. The Water-Al_2O_3 is witnessed as the nanofluid having superior cooling performance to electronics module without any kind of thermal challenges.*

Keywords: *Electronic Device;Chip;Electronics Module; Simulation; Nanofluid; Water-Al_2O_3.*

I. Introduction

Taking into consideration the present trend of perpetualintensification in both packaging and power densities in modern day's electronics devices, the search for the suitable cooling techniques, motivated the researchers around the world. Webb and Ma [1] studied about single phase liquid jet impingement heat transfer. Xuan and Roetzel [2] discussed about the conceptions of heat transfer correlation of nanofluids. Basak et al. [3] reported on effects of thermal boundary conditions on natural convection flows within a square cavity. He et al. [4] described about heat transfer and flow behaviour of aqueous suspensions of TiO2 nanofluids flowing upward through a vertical pipe. Anandan and Ramalingam [5] reviewed on thermal management of electronics. Kurnia et al. [6] analyzed numerically on laminar heat transfer performance of various cooling channel designs. Yang and Wang [7] simulated a 3D transient cooling portable electronic device using phase change material. Zhu et al. [8] optimized the heat exchanger size of a thermoelectric cooler used for electronic cooling applications. Gong et al. [9] presented numerically on layout of micro-channel heat sink useful for thermal management of electronic devices. Naphon et al. [10] described about different thermal cooling enhancement methodsaimed at electronic apparatuses.

II. Objectives of Present Research Work

From the aforesaidworks, to the best of author' understanding, it is pretty clear that there is not a single comprehensive numerical study relating to the effects of Water-Al_2O_3 nanofluid on heat transfer performance of electronics modules. With this standpoint, the present paper demonstrates numerical investigations with the stated nanofluid 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 nanofluid (as it 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 relating to the said nanofluid are also along the expected lines.

III. Description of Physical Problem

The immaculatedemonstration of a typical 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 coolant considered in the present investigations is Water-Al_2O_3nanofluid. 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.

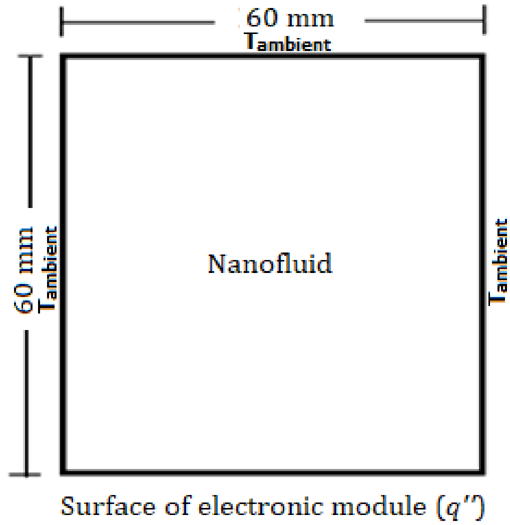

Fig 1. Schematic of electronics module computational domain.

Table 1. Thermophysical properties and model data

Nanoparticle Properties	**Al_2O_3**
Density, ρ (Kg/m^3)	3970
Specific heat, C_P (J/kg-K)	765
Thermal conductivity, k (W/m-K)	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

IV. Mathematical Formulation and Numerical Procedures

The 2D continuity, momentum and energy equations are described as follows.

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

As an outcome of the grid-independence test, 60 × 60 uniform grids have been used for the final simulation. Corresponding time step taken in the simulation is 0.0001 seconds.

V. Results and Discussions

Numerical simulations are carried out to study the effects of Water-Al_2O_3nanofluid 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.

Water-Al_2O_3 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 2 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 3. Here also, the trends of results are along the expected lines.

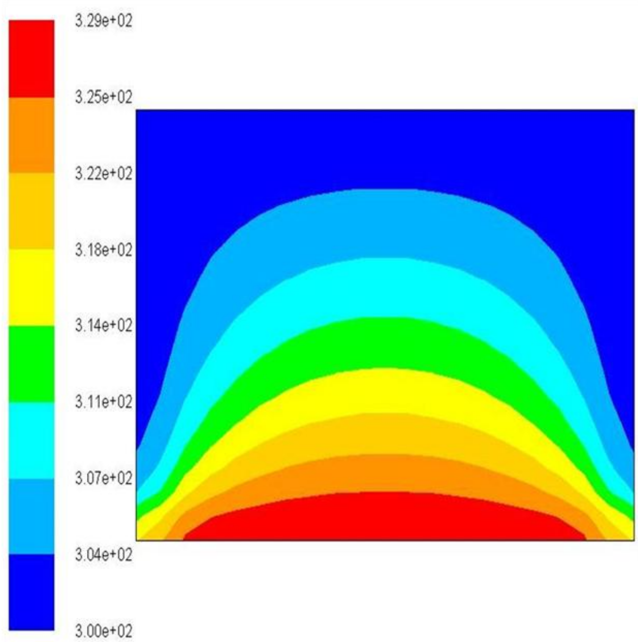

Fig 2. Temperature field with Water-Al_2O_3nanofluid as coolant.

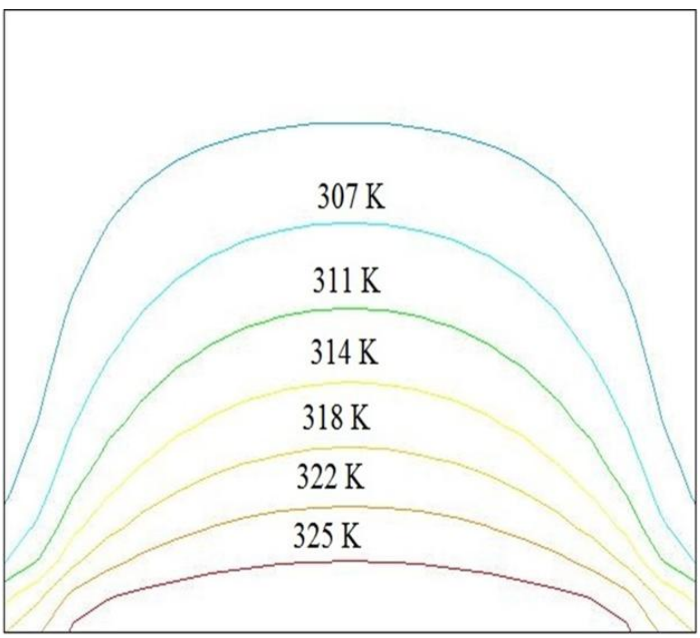

Fig 3. Temperature contour with Water-Al_2O_3 nanofluid as coolant.

VI. Conclusion

A computational model pertaining to the electronics module is developed to predict the thermal behavior with Water-Al_2O_3nanofluid as coolant. The model encompasses 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 nanofluid (as it 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 stated nanofluid 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 stated model conditions, it is witnessed that the Water-Al_2O_3nanofluid deliversappropriately effective cooling performancewithout any such thermal challenges and is the superior one as the electronics module temperature is quite below the safe limit. Hence, the stated model alongside the nanofluid can be used right away in production houses to supplement heat transfer for cooling of electronicgadgets.

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