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NUMERICAL STUDIES ON THERMAL BEHAVIORS OF ELECTRONICS MODULE EMPLOYING WATER-TITANIUM DIOXIDE NANOFLUID

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Abstract— The current study involves an electronics module kept horizontally at the base, inside a square shaped chamber filled with nanofluid as coolant. The water based nanofluid, namely Water-TiO_2, is considered as coolant in the present examinations. The numerical studies are carried out 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. The simulations are performed to predict the temperature fields and temperature contours. The trends of results are along the expected lines. The key model parameter considered is heat flux of 70 W/cm^2 associated with the electronics module. The Water-TiO_2 is observed as the nanofluid giving the greater cooling effect to electronics module without any such thermal issues.

Keywords— Numerical, Simulation, Electronics Module, Water-TiO_2, Nanofluid.

I. INTRODUCTION

Wadsworth and Mudawar [1] investigated about the cooling of a multichip electronic module using confined two dimensional jets of dielectric liquid. Webb and Ma [2] studied 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] illustrated about thermal cooling augmentation techniques meant for electronic devices.

From the aforementioned texts, to the best of author' knowledge, it is quite apparent that there is not a single comprehensive numerical investigation pertaining to the influences of water based nanofluid (namely Water-TiO_2) on heat transfer behaviour of electronics modules. With this perspective, 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 affects the cooling characteristics) by taking electronics module heat flux and duct inlet nanofluid velocity as the important model parameters. Finally, the predictions of the model relating to the said nanofluid 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 coolant considered in the present investigations is water based nanofluid named as Water-TiO_2. 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 nanoparticles together with the additional system parameters, are shown in table 1.

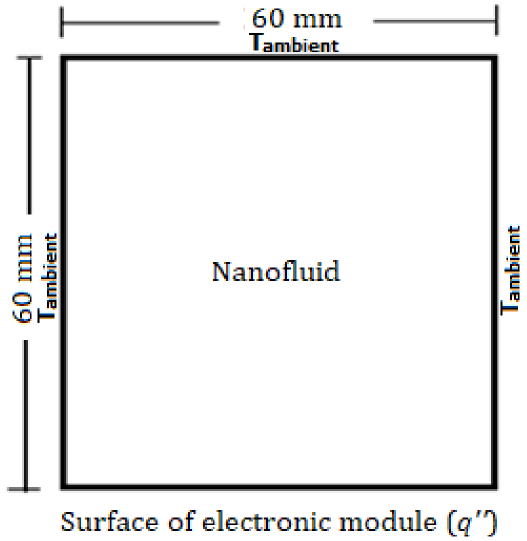

Fig 1. Schematic illustration of electronics module computational domain.

Table 1. Thermophysical properties of nanoparticles and model data

NanoparticleProperties	**TiO_2**
Density, ρ (Kg/m^3)	4175
Specific heat, C_P (J/kg-K)	692
Thermal conductivity, k (W/m-K)	8.4
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 AND NUMERICAL PROCEDURES

The continuity, momentum and energy equations in 2D for a fully developed hydrodynamic and thermal flow situation is described in equations from (1) to (4), respectively. The thermal buoyancy term (represented by $\rho g\beta\Delta T$) is introduced 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: $$\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

At the outset, 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 said equations are solved together owing to interdependency between the related parameters.

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. Convergence in inner iterations is happened while the condition $\left|\frac{\varphi-\varphi_{old}}{\varphi_{max}}\right| \leq 10^{-4}$ is satisfied concurrently 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 present iteration level in the whole domain.

IV. RESULTS AND DISCUSSIONS

Numerical simulations are performed to investigate the influences of the water based nanofluid (namely Water-TiO_2) 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/cm^2.

Water-TiO_2 nanofluid as coolant

With the stated model conditions, in order to investigate the influence of Water-TiO_2 nanofluid on the thermal behaviour 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-TiO_2 nanofluid as coolant. The surface temperature of electronics module is found to be 351 K (which is below 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-TiO_2 nanofluid is maximum near the vicinity of electronics module. And also, the temperature of the Water-TiO_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 expected lines.

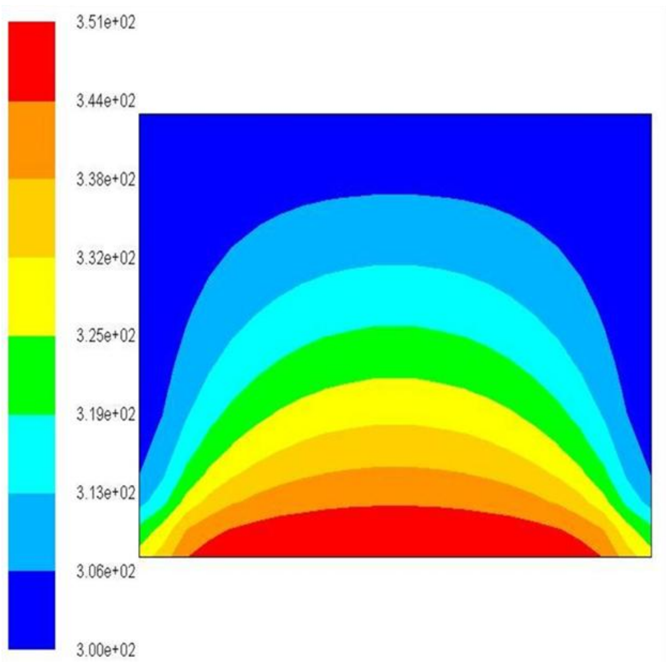

Fig 2. Temperature field with Water-TiO_2 nanofluid as coolant.

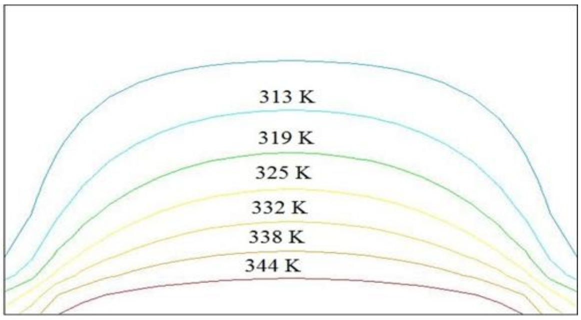

Fig 3. Temperature contour with Water-TiO_2 nanofluid as coolant.

V. CONCLUSIONS

A numerical model concerning the electronics module is developed to predict the thermal behaviour with the water based nanofluid, namely Water-TiO_2, as coolant. 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 nanofluid (as it significantly affects the cooling characteristics) by taking electronics module heat flux of 70 W/cm^2 as the important model parameter. The predictions of the model relating 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 said model conditions, it is observed that the Water-TiO_2 nanofluid offers appropriately effective cooling behaviour without any such thermal issues and is the better one as the electronics module temperature is below the safe limit. Therefore, the stated model along with the nanofluid can be used right away in production houses to augment heat transfer in cooling of electronics devices.

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