Numerical Simulation on Thermal Performance of Fuel Cell Expending Water-Aluminum Nitride Nanofluid

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ABSTRACT *Really,it is needed to perform thermal studies on fuel cell for its smooth and efficient functioning. The present research involves a fuel cell which is encapsulated in a horizontal duct open at both the ends. In the present investigations,water-AlN nanofluid as coolant is allowed to pass through the annular region between the fuel cell and duct. The numerical studies are carried out to obtain the heat transfer behavior of encapsulated fuel cell for maintaining its temperature within the safe limit. For that, a 2D numerical model is being developed. 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. Model parameters considered are fuel cell heat flux of 10 W/cm^2 and nanofluid velocity of 9 m/s at duct inlet. Water-AlN is observed as the nanofluid delivering the ultimate fuel cell workout without any sort of thermal devastation.*

Keywords:*Fuel Cell; Cooling; Simulation; Nanofluid; Water-AlN.*

I. Introduction

The generation electricity takes place by fuel cells through the electrochemical reactions. Xuan and Roetzel [1] introduced ideas of thermal correlations about various nanofluids.S. Litster and McLean [2] described about the functioning of various proton exchange membrane (PEM) fuel cell electrodes.Min et al. [3] performed the parametric studies of proton exchange membrane fuel cell (PEMFC) numerically. Xuan et al. [4] reviewed about the contaminations in PEM type hydrogen fuel cells. Chaitanya et al. [5] investigated about the effects of anisotropic heat conduction in PEM type fuel cells. Nguyen et al. [6] used Al_2O_3 water nanofluid to enhance heat transfer in an electronic liquid cooling system.Sangseok and Dohoy [7] described about the various approaches for thermal management of proton exchange membrane fuel cell systems. Jong-Woo and Song-Yul [8] investigated about the coolant control in PEM fuel cell systems.Zhang and Kandlikar [9] performed critical reviews of cooling techniques in PEM fuel cell stacks. Houchang et al. [10] examined about the functional behaviors of air-cooled proton exchange membrane fuel cell lots at ambient circumstances.

II.Objectives of Present Research Work

From the already stated research works, to the best of author' understanding, it is very apparent that there is not a single complete computational research concerning to the impacts of water based nanofluid (namely Water-AlN) on thermal performance of fuel cells. With this perspective, the present paper demonstrates numerical investigations with the stated nanofluid on thermal characteristics of fuel cells. 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 this significantly affect the cooling characteristics) by taking fuel cell heat flux and duct inlet nanofluid velocity as the important model parameters. Finally, the model results relating to the stated nanofluid are along the expected lines as well.

III. Description of Physical Problem

The illustrative sketch of a distinctive fuel cell to be inserted in a duct is portrayed in the figure 1. The associated physical model as demonstrated 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. Water-AlN nanofluid as coolantis considered in the present investigations. 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 nanofluid is 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 several nanoparticles accompanied by the concerned system variables, are mentioned in table 1.

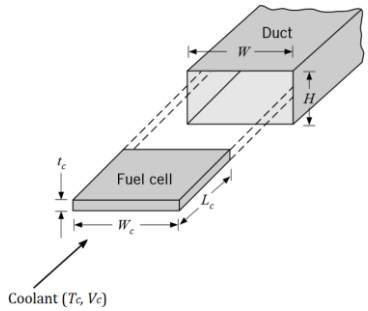

Fig 1. Schematic of fuel cell with duct.

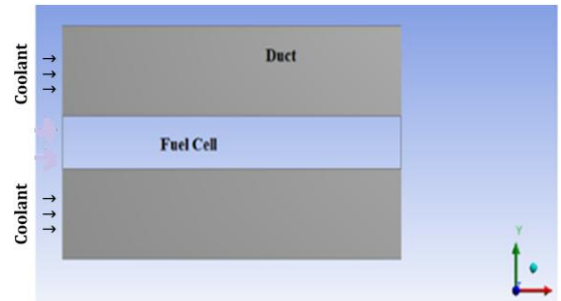

Fig 2. 2D domain with coolant flow in duct.

Table 1 Thermophysical properties of nanoparticles and model data

Nanoparticle Properties	**AlN**
Density, ρ (Kg/m^3)	3260
Specific heat, C_P (J/kg-K)	740
Thermal conductivity, k (W/m-K)	285
Model Data	**Values**
Height of duct (H)	26 mm
Length of fuel cell (L_c)	50 mm
Thickness of fuel cell (t_c)	6 mm
Width of fuel cell (W_c)	50 mm
Width of duct (W)	50 mm
Ambient air temperature	300 K
Fuel cell heat flux	10 W/cm^2
Velocity of coolant at duct inlet	9 m/s

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

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, 50 × 20 uniform grids have been used for the final simulation. Corresponding time step taken in the simulation is 0.0001 seconds.

IV. Results and Discussions

The numerical simulations are done to examine the impacts of Water-AlN nanofluid on cooling behaviors of fuel cell in terms of temperature distributions (i.e. temperature contours/fields) and surface temperatures of fuel cells. At the outset, the height of the duct is considered to be 26 mm, besides, the thickness and the length of the fuel cell as 6 mm and 50 mm respectively. Furthermore, the heat flux related with the fuel cell is considered to be 10 W/cm^2 and the velocity of nanofluid at the duct inlet is taken to be 9 m/s.

Water-AlN Nanofluid as Coolant

With the talked about model conditions, with the aim of examining the impact of Water-AlN nanofluid on the heat transfer characteristics of the fuel cell, the numerical simulations are accomplished, by considering the thermophysical properties of the said nanofluid.

Figure 3 demonstrates the simulated results of the temperature field (alongside the colored scale bar showing the temperature values in terms of K) as observed at the present model conditions by taking Water-AlN nanofluid as coolant. The surface temperature of fuel cell is found to be 320 K, which is far above the ambient and will not trigger thermal failure of the fuel cell. As expected, the temperature of the Water-AlN nanofluid is maximum near the vicinity of fuel cell. And also, the temperature of the Water-AlN nanofluid gradually decreases with the increase in the distance from the fuel cell and then it becomes equal to the atmospheric temperature in the far field region. The associated temperature contour is also illustrated in figure 4. The trends of results are along the expected lines as well.

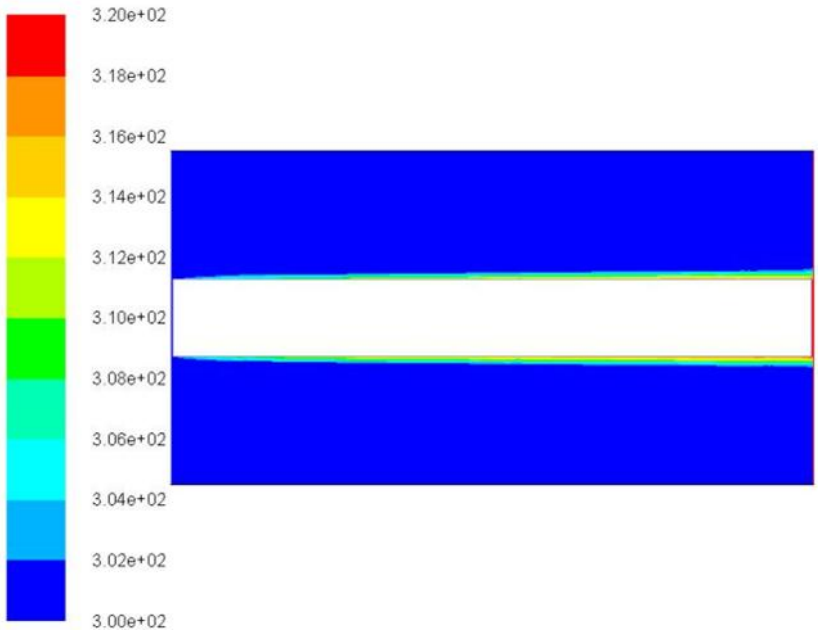

Fig 3. Temperature field with Water-AlN nanofluid as coolant.

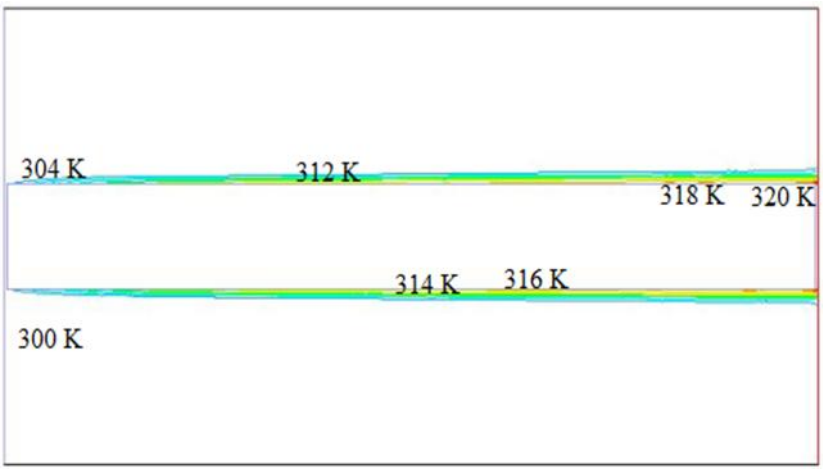

Fig 4. Temperature contour with Water-AlN nanofluid as coolant.

V. Conclusion

A numerical model pertaining to the fuel cell is established to get the heat transfer characteristics with Water-AlN nanofluid as coolant. The 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 this significantly affect the cooling characteristics) by taking fuel cell heat flux of 10 W/cm^2 and duct inlet nanofluid velocity of 9 m/s as the important model parameters. The predictions of the model with regard to the stated nanofluid are along the expected lines. Direct comparison with other numerical models of fuel

cells 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. In addition, it is observed that the Water-AlN nanofluid renders suitablyactive cooling behavior without any such thermal failure and is the better one as the fuel cell temperature is far below the safe limit. Therefore, the present model alongside the nanofluid can be applied right away in manufacturing shops to improve heat transfer characteristics useful for thermal management of fuel cells.

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The superior man acts before he speaks, and afterwards speaks according to his action.

~ Confucius