Numerical Simulation for Cooling of Fuel Cell through Water-Titanium Dioxide Nanofluid

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Abstract

Thermal management of fuel cell is very much essential for its efficient and effective functioning. The present study involves a fuel cell which is encapsulated in a horizontal duct open at both the ends. The TiO_2-Water 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. The model parameters considered are fuel cell heat flux of 10 W/cm^2 and nanofluid velocity of 9 m/s at duct inlet. The TiO_2-Water nanofluid witnessed to provide the optimal fuel cell performance without any such thermal issues.

Keywords: Fuel Cell, Cooling, Numerical, Simulation, TiO_2-Water, Nanofluid.

1. Introduction

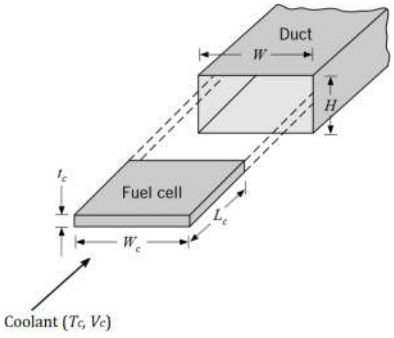
Considering their high energy conversion efficiency, zero emission potential, low noise and potential use of renewable fuels, the fuel cells are considered as future devices for mobiles, stationary and portable power applications. Xuan and Roetzel [1] developed concepts of heat transfer correlations relating to 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] investigated about the performance characteristics of air-cooled proton exchange membrane fuel cell stacks at normal atmospheric conditions.

From the aforesaid literature, to the best of author' knowledge, it is quite obvious that there is not a single comprehensive numerical investigation pertaining to the influences of TiO_2-Water nanofluid on heat transfer behavior of fuel cells. With this perspective, the present paper demonstrates numerical investigations with the stated nanofluids 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 by taking fuel cell heat flux and duct inlet nanofluid velocity as the important model parameters. Lastly, the predictions of the model pertaining to the nanofluid are also along the expected lines.

2. Description of Physical Problem

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 coolant considered in the present investigations is TiO_2-Water nanofluid. 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.



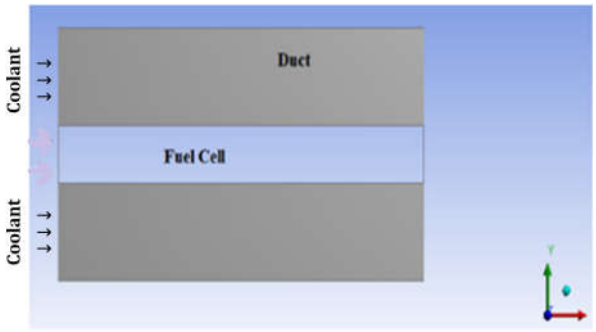


Fig 1. Fuel cell & rectangular duct. **Fig 2. 2D computational domain.**

Table 1. Thermophysical properties of nanoparticles and model data

Nanoparticle Properties	**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 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

3. Mathematical Formulation and Numerical Procedures

A. Generalized governing transport equations

The present 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.

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

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

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

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

B. Numerical techniques

The transformed governing transport equations are discretized with the second order upwind scheme using a pressure based finite volume method with the SIMPLER algorithm. Figure 3 shows the grid of the computational domain. A comprehensive and complete grid-independence test is carried out to establish a suitable spatial discretization, and the levels of iteration convergence criteria to be used. As an outcome of this test, we have used 50 × 20 uniform grids for the final simulation. Corresponding time step taken in the simulation is 0.0001 seconds.

4. Results and Discussions

Numerical simulations are performed to investigate the influences of TiO_2-Water nanofluid on cooling characteristics 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. In addition, the heat flux associated with the fuel cell is taken to be 10 W/cm^2 and the velocity of nanofluid at the duct inlet is chosen to be 9 m/s.

Titanium Dioxide-Water nanofluid as coolant

With the stated model conditions, in order to investigate the influence of TiO_2-Water nanofluid on the thermal behavior of the fuel cell, the numerical simulations are performed, by taking into account the thermophysical properties of the stated nanofluid.

Figure 3 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 TiO_2-Water nanofluid as coolant. The surface temperature of fuel cell is found to be 353 K (which is very close to the safe limit of 356 K temperature as desired in order to avoid the thermal failure of the fuel cell). As expected, the temperature of the TiO_2-Water nanofluid is maximum near the vicinity of fuel cell. And also, the temperature of the Water-TiO_2 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 corresponding temperature contour is also demonstrated in figure 4. Here also, the trends of results are along the expected lines.

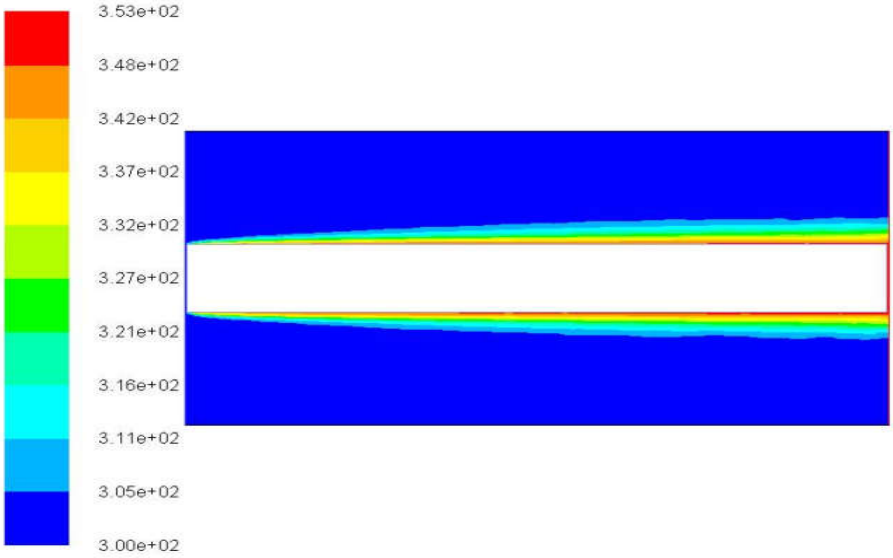


Fig 3. Temperature field with TiO_2-Water nanofluid as coolant.

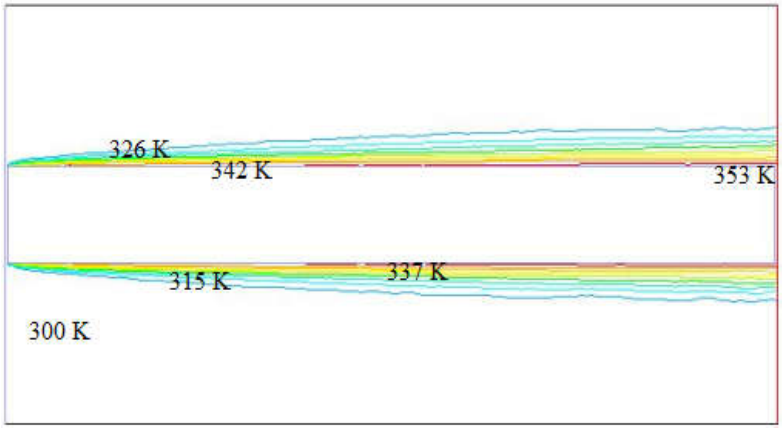


Fig 4. Temperature contour with TiO_2-Water nanofluid as coolant.

5. Conclusion

A numerical model relating to the fuel cell is developed to predict the thermal behavior with the TiO_2-Water nanofluids 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 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 pertaining to the 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. With the said model conditions, it is observed that the TiO_2-Water nanofluid renders appropriately

effective cooling behavior as the fuel cell temperature is very far below the safe limit. Therefore, the stated model together with the nanofluid can be employed directly in industries to augment heat transfer in fuel cell cooling.

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