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Numerical Investigation on Cooling Performances of the Stack Cooling System for a Passenger FCEV

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Abstract- In this study, the cooling performances of the stack cooling system for a passenger fuel cell electric vehicle (FCEV) have been numerically carried out under various psychrometric conditions. In order to analyze the thermal flow characteristics numerically, the UH3D program was applied for theoretical analysis using standard k-e turbulence model for solving the Reynolds averaged Navier-Stokes equations for incompressible flows using three dimensional finite volume with the variation of the operating conditions including the driving loads and air conditioning (A/C) operations. The coolant inlet temperature of the radiator for the stack cooling with the operation of the air conditioning showed 3.0 ^{o}C higher than that without the operation of the air conditioning and the coolant inlet temperature of the stack cooling system at the uphill mode exceeds the desired temperature of 70.0 ^{o}C with the shortage of the air flow rate due to relatively low vehicle speed.

Keywords- Cooling, Electric vehicle, Fuel cell, Radiator, Stack

1. Introduction

With challenging on reducing fossil fuel energy consumption of the internal combustion engines, the electric vehicles including the battery type, fuel cell type, and hybrid type as a power source for driving are better replacement for fossil fuels for considering the world energy crisis and global warming. However these vehicles have some issues to overcome the short driving ranges and high manufacturing costs and these are the main reason for the lack of international popularization [1~3]. Among these electric vehicles, as a powerful alternative to the internal combustion engines, the fuel cell electric vehicle has been considered as a good option to overcome the some issues from the electric vehicles. One of the technical issues for FCEVs is to cool the generated heat from the stack effectively and properly [4]. In this paper, the cooling performances of the stack cooling system for a passenger fuel cell electric vehicle (FCEV) were considered numerically to improve and keep the stable performances using theoretical performance analysis technique using UH3D model with variations of the operating conditions including the driving loads and air conditioning (A/C) operations. In addition, the prediction of the stack cooling performance for FCEV under severe driving conditions was showed.

2. Numerical model

Figure 1 shows the present numerical model with the intensive elements applied at front end module for the vehicle and computational set-up for theoretical analysis using UH3D model. The used commercial program of UH3D is specialized to simulate the cooling systems for driving vehicles. As shown in Fig. 1, Cartesian volume mesh was generated for simulation the cooling performances of the considered vehicle and standard k-e turbulence model was used with solving the Reynolds averaged Navier-Stokes equations for incompressible flows using three dimensional finite volume method under steady state condition. The used UH3D program is based on the structured Cartesian grid and the cell-based porosity approach to represent the geometry. The tested vehicle is located in the room with the width and height of the wind tunnel and put on the bottom face and floor in the room. The number of mesh grids were used approximately 8.0 millions (169.0 X 137.0 X 222.0) in the x-,y-,z- directions where y-axis is a vertical direction and z-axis is lateral direction. The grids are stretched in all three directions, but is very refined near the cooling package. The used UH3D program contains built-in empirical component models for simulating the heat exchanger and cooling fan performances. The wall functions are considered as the boundary conditions as a suggested by the manual [5]. The boundary conditions were selected to reflect the normal highway and severe driving conditions including the uphill, low speed, and high ambient temperature conditions. Table 1 shows the operating and boundary conditions for simulation analysis to reflect the various driving and operating conditions. For two considered models ass shown in Table 1, the ambient temperatures of 35.0 ^{o}C and 35.0 ^{o}C, respectively, for two models were considered with the atmospheric pressure and the driving velocities of 120 km/h with the 0% slope and 50.0 km/h with the 8.0% slope, respectively, were considered. The coolant for the cooling system of the stacks in FCEVs is used as working fluid and the ambient is air.

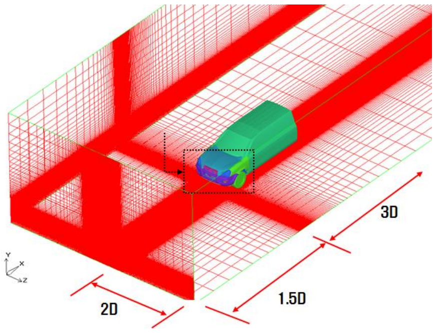

Fig. 1. Numerical model and computational set-up

Table 1. The simulation conditions.

Components	Specifications	
	Model 1	Model 2
Velocity (km/h)	120	50
Ambient temperature (°C)	35	35
Heat transfer capacity (kW)	25	30
Volume flow rate (*l*/min)	60	60
Inclination rate (%)	0	8

3. Results and Discussion

The stack cooling system was simulated as varying various operating conditions including the driving loads (high way and uphill modes) and air conditioning (A/C) operations. Generally, when air conditioning system was operated, the thermal load to remove from radiator increased compared with the normal conditions due to the heat rejection form the condenser. This is because the radiator located in the front end module (FEM) is serially coupled to the condenser for air conditioning for cabin cooling of the vehicle. Accordingly, as the cooling system for vehicles is considered, the additional thermal load from the condenser with the operation of the air conditioning for cabin cooling would be considered. The coolant inlet temperate of the radiator for stack cooling system was analyzed from UH3D with and without the operation of the air conditioning. Figure 2 shows the influence of the stack cooling system with and without the air conditioning at highway driving conditions. The coolant inlet temperature of the radiator for stack cooling with the operation of the air conditioning showed 3.0 °C higher than that without the operation of the air conditioning. However, the coolant inlet temperature does not exceed the temperature of 70.0 °C due to the sufficient entering air flow rate from the ambient at high vehicle speed. Generally, the proper coolant temperature of the stack cooling system was maintained under 70.0 °C [6].

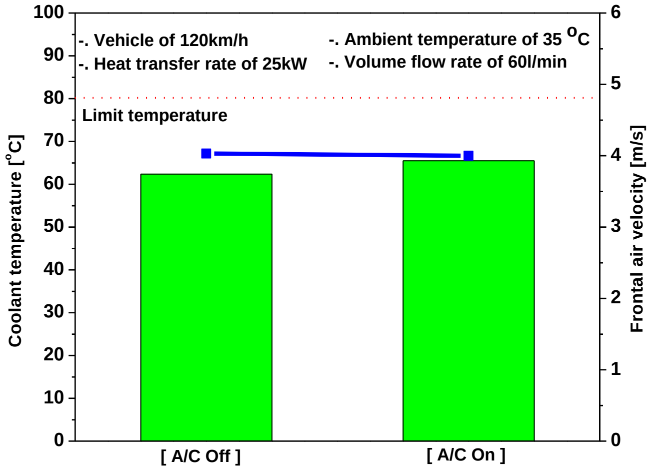

Fig. 2. Influence of stack cooling system for A/C operation

Figure 3 shows the influence of the stack cooling system with the driving modes for analyzing the cooling capacity with variations of the vehicle speed, highway and uphill conditions. In case of the uphill mode, coolant inlet temperature of the stack cooling system would exceed the desired temperature of 70.0 °C with the shortage of the air flow rate due to relatively low vehicle speed in spite of the same thermal load. As a result, we can conclude that the further study for optimized stack cooling system of the FCEV would be required with the modification of layout and the enhancement of the cooling module performance.

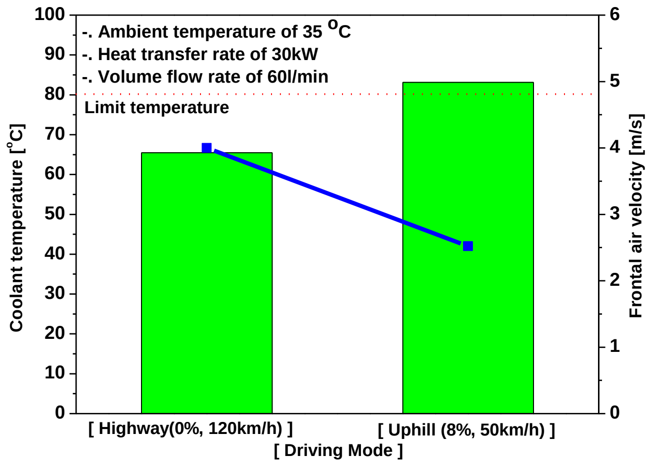

Fig. 3. Influence of stack cooling system for A/C operation

Figure 4 shows the contour plot of the inlet air velocity of the stack radiator for the considered the stack cooling module. At the lower corner of the stack radiator, the air velocity with the red color expression at the bumper hole region shows the comparatively higher than other regions.

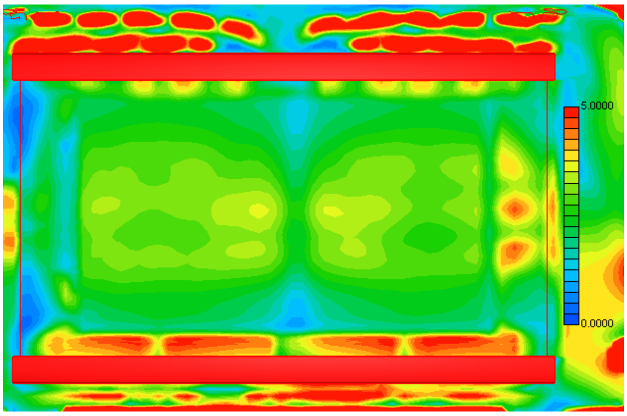

Fig. 4. Radiator air inlet velocity contour plot for uphill mode

4. Conclusions

This paper presented numerical results on the the cooling performances of the stack cooling system for a passenger fuel cell electric vehicle (FCEV) under various operating conditions including the driving loads and air conditioning (A/C) operations. The theoretical model was set-up to evaluate stack cooling performances for the FCEV under highway (0% slope, 120.0 km/h) and up-hill mode (8.0% slope, 50.0 km/h). As results, the coolant inlet temperature of the radiator for stack cooling with the operation of the air conditioning showed 3.0 ^{o}C higher than that without the operation of the air conditioning. However, the coolant inlet temperature does not exceed the temperature of 70.0 ^{o}C due to the sufficient entering air flow rate from the ambient at high vehicle speed. In case of the uphill mode, coolant inlet temperature of the stack cooling system would exceed the desired temperature of 70.0 ^{o}C with the shortage of the air flow rate due to relatively low vehicle speed.

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