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Performance evaluation of a PEM fuel cell stack with variable inlet flows under simulated driving cycle conditions

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HIGHLIGHTS

- Study of fuel cell performance during a driving cycle with variable inlet flows.
- Transient local distributions of key parameters were evaluated.
- Variable inlet flows have marginal effect on the transient performance.
- Thermal, water and gas management are influenced by variable inlet flows.
- Variable flows at cathode, anode and coolant yield the maximum net power.

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ABSTRACT

Alongside battery, polymer electrolyte membrane (PEM) fuel cell stack has been a promising candidate as a power source for hybrid and electric vehicles. On this application, the dynamic performance of the PEM fuel cell is crucial in ensuring smooth operation of the vehicle. The PEM fuel cell stack should be maintained at its optimum performance while being responsive during real road driving condition which is best represented by legislative driving cycle. The present study is conducted to evaluate the performance of a PEM fuel cell stack for vehicle application subjected to New European Driving Cycle (NEDC) by utilizing computational fluid dynamics (CFD) approach. The studied PEM fuel cell stack comprises 320 cells with 1600 cm^2 active catalyst area. The effect of variable inlet following NEDC profile on the PEM fuel cell performance is investigated as well. Several possible scenarios, i.e. steady inlet flows, variable inlet flows at anode, cathode, coolant and combinations of these, are examined and discussed in the light of numerical result. The results reveal that variable inlet flows have considerable effect on the total net power generated, thermal envelope and liquid saturation albeit its marginal effects on the stack performance in term of stack power.

1. Introduction

Driven by the initiative to lessen adverse effect of fossil fuel on the environment and attractive incentives provided by governments worldwide, hybrid and electric vehicles have gained considerable demand globally [1]. Together with batteries, polymer electrolyte membrane (PEM) fuel cell stacks are considered as a promising candidate for propulsion systems of these environmentally friendly vehicles. Over the last decades, PEM fuel cell has been considered as a sustainable energy conversion system to replace the fossil-fuel based counterparts [2]. It offers the possibility to reduce the greenhouse gas emissions in urban areas [3] by having water as its only by-product. It can provide a satisfactory range without the need of an internal combustion engine [4]. Moreover, in contrast to battery vehicle which drawn electric from the grid, fuel cell vehicle can inject power to the grid when it is parked by utilizing the energy stored in the on-board hydrogen tanks [5]. Some other advantages offered by PEM fuel cell in automotive applications include low operating temperature, high power density, quick start-up and response to load changes and high efficiency [6]. As such, in recent years, several leading automakers have turned their attention to fuel cell vehicles, resulting in realization of some commercial fuel cell vehicles and vehicle concepts such as Honda Clarity, Toyota Mirai, Lexus LF-LC, Mercedes-Benz GLC F-CELL, BMW Hydrogen 7, Hyundai Tucson FCEV and Audi h-tron quattro. The development is further supported by the policy adopted by several governments worldwide which encourage the development of hydrogen refuelling network [7].

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Table 1
Investigated cases.

Cases	Description
Case 1	Steady inlet
Case 2	All inlets are varied according to NEDC[a]
Case 3	Inlet of anode is varied according to NEDC[a]
Case 4	Inlets of anode and cathode are varied according to NEDC[a]
Case 5	Inlet of cathode is varied according to NEDC[a]
Case 6	Inlet of coolant is varied according to NEDC[a]

[a] New European Driving Cycle.

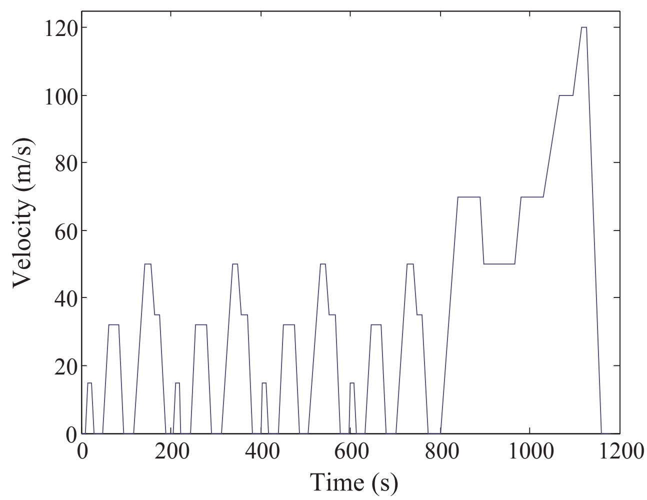

Fig. 1. The new European driving cycle (NEDC).

On its daily operation, a vehicle's powertrain is subjected to rapid changes during typical driving conditions. This implies that, for fuel cell-powered vehicles, the fuel cell dynamic performance is critical in ensuring smooth operation. Past studies indicated that fuel cell performance is more prone to dynamic load cycle than constant load conditions [8]. Load cycle often triggers water management and gas transport problems, resulting in the degradation of fuel cell performance and attenuation of internal parts [9]. As such, maintaining an efficient gas, water and thermal management is critical in the operation of PEM fuel cell [10]. In recent years, several studies on the dynamic performance of PEM fuel cells for automotive applications have been conducted and reported. Hou et al. [11] evaluated the efficiency of PEM fuel cell engine (FCE) according to driving cycles. They highlighted the importance of real road driving condition in analyzing the output power of FCE to get the main operating modes of FCE. The real road driving condition for fuel cell vehicle (FCV) is best represented by driving cycle. Feroldi and Carignano [12] investigated the energy management strategy of fuel cell/supercapacitor hybrid vehicles based on stochastic driving cycles which are generated from standard driving cycles. They indicated that standard driving cycles are extremely important for evaluating the performance of Fuel Cell Hybrid Vehicles (FCHVs). In their optimization study of fuel cell hybrid and plug-in hybrid urban buses, Ribau et al. [13] highlighted the significance of the driving conditions. They found that real driving cycles and Europe Transient Driving Cycle (ETC) have significant impact on the optimization results of efficiency, cost and life cycle of fuel cell hybrid and plug-in hybrid urban buses. Lin et al. [14] analyzed the microstructure of a membrane electrode assembly (MEA) and studied the PEM fuel cell stack performance during a driving cycle. They found that the driving cycle greatly affects the performance of the fuel cell stack with a 39% reduction of electrochemical reactions after 200 cycles. In their follow-up study [15], the performance of PEM fuel cell was found to be severely degraded after 280 h operation. Later, a study by Wang et al. [16] revealed that the fuel cell performance degradation could be recovered by resting the fuel cell overnight at high humidity (more than 50% RH). Gomez et al. [17] investigated the dynamic performance of a dead-end anode PEM fuel cell stack during the segments of the European driving cycle. They evaluated the effect of purging on the transient response of the fuel cell. The results revealed that a short purging duration prevents undesired deceleration at a high current while a long purging period is beneficial to bolster a better performance over time. Kang et al. [18] developed a Fuel Cell Hybrid Vehicle (FCHV) model to

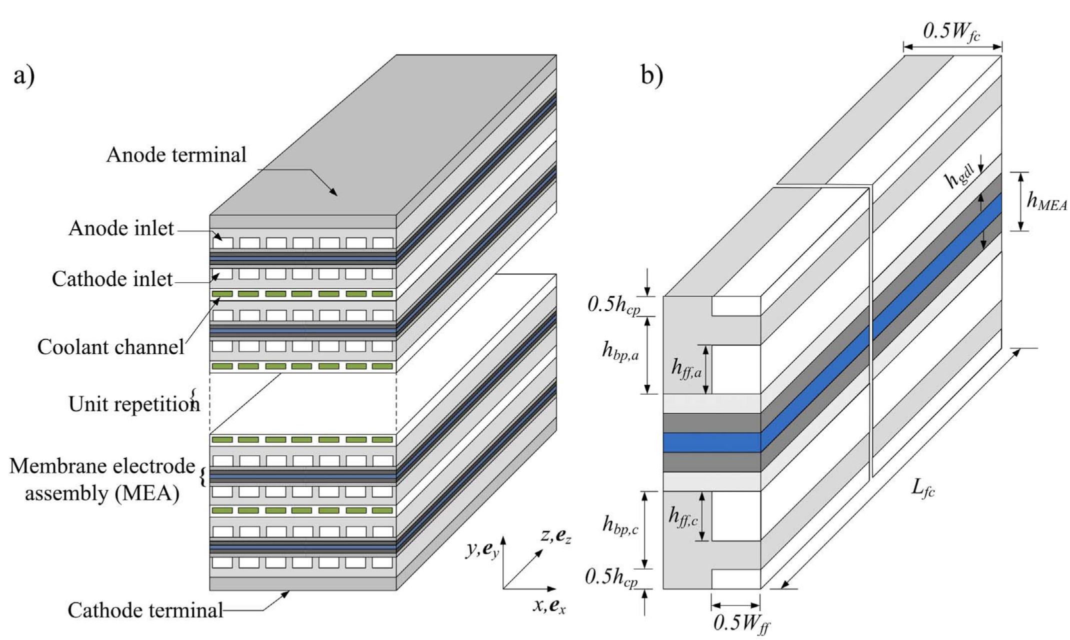

Fig. 2. Schematics representation of (a) a liquid-cooled PEM fuel cell stack and (b) single cell PEM fuel cell.