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Flows consumption assessment study for fuel cell vehicles: Towards a popularization of FCVs technology

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ABSTRACT

Climate change can be caused by a major part from the high fossil fuel usage and consumption in transportation field. It contributes to the increase of pollutant emissions, which lead to serious problems on human health in addition to the environmental degradation phenomena. Hydrogen fuel cell vehicles (FCVs) are expected to have a significant impact in meeting both energy security and environmental concerns globally. Starting for the premise that public acceptance and attitudes studies were generally positive towards hydrogen and fuel cells vehicles, even if the public knows few things about this technology; authors then got the idea to present a simplified scientific work dealing with the description of the energy management and flows calculations on board FCVs. This work aims not only to the popularization of this technology but also to outreach people about its sustainable character. A variable driving profile is adopted with a total distance of 1 km with duration of 60 s. The total hydrogen amount consumed is 1,34 g km^{-1}. Under pressure, only 5 kg of hydrogen give optimal autonomy of 700 km, which is really competitive to the conventional gasoline cars. A nice advantage is yet observed and its concerns the environmental profits.

Introduction

Fossil fuels used in transportation for our daily life are not only going to be depleted, but also they are highly polluting. This pollution has obviously very bad impacts on human health. Against this serious problem, some industrial countries are encouraging electrical vehicles under the slogan of zero emission cars. Unfortunately, these Electrical cars present some technological drawbacks which are summed up on the long charging time and the autonomy.

A comprehensive and sustainable solution of the issues of climate change, urban air pollution and oil dependence, can be found by using hydrogen energy and fuel cells technology

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Nomenclature

C_p	Heat capacity, J kg^{-1} K^{-1}
C_r	Car rolling coefficient
C_x	Air penetration coefficient
d	Difference (dv/dt), m^2 s^{-1}
g	Gravity, m s^{-2}
M_v	Car Weight, kg
N_{cell}	Cell number, cells
P	Power, W
P_0	Atmospheric Pressure, atm
P_{syst}	System Pressure, atm
q	Reactants and products flows, kg s^{-1}
S	Frontal car surface, m^2
t	Time, s
T_e	Temperature of air, K
v	Car Speed, km h^{-1}
Vc	Cell Voltage, V

Greek letters

α	car angle with horizon
η	Efficiency
ρ	Density, kg m^{-3}
ν	Air stoichiometric rate
γ	Air isentropic coefficient

Superscripts and subscripts

aux	auxiliaries
c	compressor, efficiency
comp	compressor
m	mechanical
m	moto compressor, efficiency
net	net, power
t	traction, efficiency

on board cars, which lead to the expression of Fuel Cell Vehicles (FCVs) or even Fuel Cell Electrical Vehicles (FCEVs). In fact, the Polymer Electrolyte Membrane Fuel Cells PEMFCs uses hydrogen to produce power, heat and water. The power is instantly produced while hydrogen feed the PEMFC [1]. Significant advantages are obtained from this relatively expensive technology. The hydrogen feeding the PEMFC can be produced using a renewable energy source; some experimental works at the laboratory scale demonstrated the possibility to produce hydrogen from water electrolysis using Solar Photovoltaic Panels [2]. This step is considered as an environment protection action.

FCVs have the highest potential efficiencies and lowest potential emissions of any vehicular power source. Current researches are dealing with the improvement of FCVs performance, durability and cost of fuel cell technology. Component degradation and durability is anticipated to be a critical issue for the practical use of fuel cells. Component development is also a key issue for the development of FCVs; Dawei et al. [3] proposed in their works an interleaved step – up/step – down converter for fuel cell vehicle applications.

An environmental analysis of the impact of FCVs is a popular topic for research, and has appeared frequently in recent literature. Fletcher et al. [4] have even discussed the energy management strategy to optimize both fuel consumption and PEM fuel cell lifetime in a hybrid vehicle. Mebarki et al. [5] have studied a hybrid power system composed of a PEM fuel cell and a battery storage system to supply an electric vehicle.

Furthermore, vehicular fuel cell stacks are expected to have a nominal lifetime of at least 5000 h, which is equivalent to 150,000 mile at 30 mile per hour [6].

A good review was conducted by Al Amin et al. [7] on the public acceptance and attitudes for hydrogen Fuel cell vehicles. This review was very important to influence the consumer behavior towards environmental benefits.

Henceforth, it is acknowledge that public acceptance and attitudes studies were generally positive towards hydrogen and fuel cells vehicles, even if the public knows few things about this technology [8]. Starting from this premise, authors got the idea to present a simplified scientific work dealing with the technology of Fuel Cell Vehicles FCV's.

This work aims not only to the popularization of this technology but also to outreach people about its sustainable character.

The different flows (reacted, consumed and produced) are illustrated based on a variable and comprehensive driving profile achieving a distance of 1 km in one minute. This work will help young researchers and interested public to get a clear idea about the real challenge of this environment friendly technology.

This work can also be coupled with an environmental and economic analysis to obtain a realistic indication of the viability of an FCV market such as in the work of Veziroglu et al. 2011 [6].

Fuel cell vehicle technology description and state of the art

The PEMFC is known to produce power with an efficiency of 55% for the stack. It is very suitable for vehicles as it can offer efficient energy conversion in a compact and robust package. Its significant features in generating reliable and efficient electrical power at steady state condition, with higher power density and lower operation temperature, are considered as the prime candidate for vehicular applications [9].

The average fuel efficiency of new cars is between 20 and 30 mpg (miles per gallon), which is equivalent to a range starting from 8.5 to 12.75 km l^{-1}, (kilometer per liter).

Current vehicles hold 10 to 16 gallons of gasoline, or 30–45 L of space. Since hydrogen has twice the efficiency of gasoline vehicles, they would store between 5 and 8 kg of hydrogen, which is equivalent to between 200 and 400 L, which is a sizable reduction in the space needed for fuel. Liquid hydrogen tanks are also less bulky and can also be used in the vehicle to feed the PEMFC Stack, but they must be stored at extremely low temperatures [10].

The four major subsystems of any hydrogen fuel cell system are the fuel cell stack, air supply, hydrogen supply, and water and thermal management. A good illustration of this system is presented in Fig. 1.

However, the net power delivered by a PEMFC stack can be limited to 65%, while air circuit need 25%, humidification circuit need 5%, the cooling circuit need 3% and 2% of the total

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