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Residual heat use generated by a 12 kW fuel cell in an electric vehicle heating system

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ABSTRACT

A diesel or gasoline vehicle heating is produced by the heat of the engine coolant liquid. Nevertheless, electric vehicles, due to the fact that electric motor transform directly electricity into mechanical energy through electromagnetic interactions, do not generate this heat so other method of providing it has to be developed.

This study introduces the system developed in a fuel cell electric vehicle (lithium-ion battery – fuel cell) with residual heat use.

The fuel cell electric vehicle is driven by a 12 kW PEM (proton exchange membrane) fuel cell. This fuel cell has an operating temperature around 50 °C. The residual heat generated was originally wasted by interaction with the environment.

The new developed heating system designed integrates the heat generated by the fuel cell into the heating system of the vehicle, reducing the global energy consumption and improving the global efficiency as well.

1. Introduction

The current energy model based on fossil fuels is unsustainable [1]; high dependence on these fuels located in exclusive regions, high pollution and rising prices are clear examples [2]. There is a real need of change, where mobility represents a significant portion because it is the major consumer of these fuels.

Nowadays, a new fleet of low or zero emission vehicles has been developed: hybrid and electric vehicles, either pure batteries or fuel cell powered [3].

The governments of various countries are encouraging the purchase of these vehicles; they are introducing them to public transport companies [4]. In the EU, several mobility demonstration projects are promoting and testing the use of these vehicles. Within these projects are CUTE, CHIC, HyTransit, HyTech, High V.LO City, H2Moves Scandinavia. This shows the commitment that exists to reduce dependence on fossil fuels and the emission of CO_2 to the atmosphere, in favor of sustainable transport fleet [5].

The heating system of internal combustion engine vehicles is based on the heat exchanging between the coolant and the engine. This liquid, at the outlet, has an approximate temperature of 90 °C, which is used to warm the air in the radiator, and then heating the vehicle cabin [6]. In this case, the use of the heating system do not need additional energy input.

In electric and hybrid vehicles the use of the heating system needs extra energy to work; which may reduce the overall performance of the drive system and the autonomy of the vehicle [7]. This problem also exists in fuel cell electric vehicles because its propulsion is finally made by electric motors.

Since a large amount of energy is lost as heat in the internal combustion engine vehicles [8], they do not need additional energy for heating because they use that heat [9]. However, due to high efficiency of the electric motors, about 90%, electric vehicles do not have that energy lost as heat, which has a serious impact on autonomy, and consequently on the efficiency of the vehicle as sometimes an electric car might need as much energy to heat as used to move it [10].

The standard solution to the heating system of these vehicles is based on a set of electrical resistors that are used to heat the air and after that, transferring this heat air to the inside of the vehicle.

While heating can be simply provided with an electric resistance heater, higher efficiency and integral cooling can be obtained with a reversible heat pump (this is currently implemented in the hybrid Toyota Prius). Positive Temperature Coefficient (PTC)

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junction cooling is also attractive for its simplicity. This kind of system is used for example in the Tesla Roadster.

Due to the fact that cabin climate control system does not depend on an internal combustion engine running, to avoid impacting the electric car range some models allow the cabin to be already at the correct temperature at the time the car is next to be used. For example, the Nissan Leaf and the Mistubishi i-MiEV can be pre-heated when the vehicle is plugged in to reduce the impact on range due to cabin heating.

Some electric cars, for example the Citroën Berlingo Electrique, use an auxiliary heating system (for example gasoline-fueled units manufactured by Webasto or Eberspächer) but sacrifice "green" and "Zero emissions" credentials. Cabin cooling can be augmented with solar power, most simply and effectively by inducting outside air to avoid extreme heat buildup when the vehicle is closed and parked in the sunlight (such cooling mechanisms are available as aftermarket kits for conventional vehicles). Two models of the 2010 Toyota Prius include this feature as an option [11].

Other studies focus on the use of infrared lamps to heat the occupants directly removing cycle transmitting medium (air). These types of lamps are known technology, low cost and high efficiency, but are still in the research phase for this application and are not implemented in any vehicle in the market [12]. Another option is to incorporate a small bioethanol engine responsible for supplying the necessary energy to the heating system [13].

Researchers at MIT (Massachusetts Institute of Technology) have earned a $2.7 million grant to attempt to adapt a completely different type of heating and cooling system that could help reduce the strain on electric vehicle batteries. The system uses two different aspects of the same process based on whether drivers want heat or cool. It features a large reservoir of coolant, often water, which is pumped into a low-pressure chamber and forced to evaporate. The evaporating liquid draws heat from its surrounding, cooling the system down and the interior of the car if desired [14].

Meanwhile, the vapor is absorbed through a specially designed material that can hold a large amount of liquid, keeping the pressure in the chamber low. The absorbent also releases heat as it takes on more water, which can either be vented outside the car or used to heat the inside.

This approach has some limitations, since it is ultimately restricted by the capacity of the absorbent to take on more water vapor and the capacity of the water reservoir itself. However, the system can be recharged over a few hours by heating the absorbent to around 200 °C, a process that could be accomplished during recharging. Heating and cooling using this technique could significantly enhance electric vehicle range, since it only requires enough power to operate a small pump and the fans needed to blow air throughout the car.

It is important to highlight that a lot of efforts has been doing within the heating system of electric vehicles in order to increase the range of the vehicles.

None of the solutions is able to work without extra heat supplying. However, with the introduction of fuel cell electric vehicles, it would be possible to open further studies to improve the heating of such vehicles.

From the solutions that are being implemented in different applications with the use of residual heat as energy (water warm up, power generation, etc.), the study of a heating system is proposed by integrating the residual heat from a fuel cell [15].

Some studies in industrial areas have been carried out to analyze the efficiency that would be obtained by reusing the heat generated by them [16].

Regarding heating systems in vehicles, various assessments have been implemented to recover the waste heat from internal combustion engines [17]. For example, results that show a 12% output power increase in a diesel engine have been reached [18].

A general study helps to have an overview of the use of waste heat in two different cases (at 60 °C and 120 °C), in order to observe the variations and behavior in different applications (vehicles, industries, process plants, etc.) [19].

In this paper, it is presented the use of waste heat generated by the fuel cell to the heating system by removing the electrical resistance, to improve the overall efficiency of the system, and consequently the range of the vehicle.

The purpose of this study is to fulfill part of the objectives of a project which aims to convert an electric vehicle into a fuel cell electric vehicle (lithium-ion batteries and fuel cell) [20] funded by the LIFE+ ZeroHyTechPark [21].

The LIFE+ [22], is an instrument of the European Union to fund environmental projects. The main objective of the LIFE + Zero - HyTechPark is to implement the total capacity of sustainability in technology parks through an optimal power management based on hydrogen technologies and renewable energies. This project is coordinated by the Foundation for the Development of New Hydrogen Technologies in Aragon and the following partners are involved: Zamudio Technology Park (Vizcaya), Andalucía (Málaga) and Walqa (Huesca).

The main actions that are taking place throughout the four years of the project are to design, simulate and implement energy solutions based on hydrogen technologies and renewable energy in the building of Aragon Hydrogen Foundation, located in Walqa Technology Park, and extrapolate these results to other buildings and parks. The results of the project are getting pass by having a building with virtually zero CO_2 emissions, promoting sustainable mobility through the development, implementation and operation of hydrogen-powered vehicles fleet and disseminating as widely as possible the technologies to the general public and scientific-industrial sectors in particular.

The vehicle power train is based on a fuel cell. A fuel cell (Fig. 1) is an electrochemical device that converts chemical energy [23] of a fuel directly into electricity through a chemical reaction with oxygen or another oxidizing agent [24].

Hydrogen is the most common fuel, but hydrocarbons can also be used such as natural gas and alcohols for example methanol. Fuel cells differ from batteries because they provide a continuous supply of electricity until the cessation of the fuel input [25].

A fuel cell consists of a stack of cells. Regardless of the type of fuel cell, each cell consists of three basic components: two porous electrodes (positive or cathode and negative or anode), separated by an electrolyte, which is a dielectric medium, which is a poor conductor of electricity but allows the passage of certain ions.

PEM stacks have a construction based in bipolar plates and membranes [26]. Each cell provides about 0.7 V in open circuit, that is, when the fuel cell is not subjected to any load, it is necessary to stack cells in series in order to achieve greater potential able to feed the connected devices.

Bipolar plates interconnect the anode of one cell with the cathode of the next one. Moreover, they have the function of distributing uniformly the reactant gas at the anode and oxygen/air at the cathode, thereby serving as gas-separator element [27].

The electrodes must be porous to allow the passage of gas through the electrolyte. These porous electrodes PTFE (polytetrafluoroethylene) is hydrophobic (prevents wet) and serve as a gas permeable phase, and carbon is an electron conductor which provides a large surface area of the electrocatalyst support. Carbon also has a certain degree of hydrophobicity, depending on the surface properties of the material.