Hydrogen Fuel Cell Powered Vehicles

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Abstract - *Harnessing the potential of renewable energy worldwide is currently being considered to find alternatives for obtaining energy by using technologies that offer maximum efficiency and minimum pollution. In this context, new energy generation technologies are needed to both generate low carbon emissions, as well as extracting the potential of renewable energy sources. Hydrogen fuel cell technology represents one of the alternative solutions for future clean energy systems. This paper provides a comprehensive study of hydrogen fuel cell powered vehicles. It briefs the principle of fuel cell, how current is produced in fuel cell, components of a fuel cell and its benefits. The paper provides a concise, up-to-date study of fuel cell powered vehicle, their working principle, main parts, how it differs from conventional electric vehicles, advantages and disadvantages. The paper also discusses how hydrogen refueling is done and the main components of a hydrogen fuelling station. As the main challenge in this type of vehicle lies in obtaining pure hydrogen, method for obtaining hydrogen from electrolysis of water is also described. The data from industry and academia have been used with the relation between fuel cell fundamentals and applications.*

Key Words: **Fuel cell, fuel cell powered vehicles, electric vehicles, hydrogen refueling, electrolyzer**

1. INTRODUCTION

The main cause of climate change that our planet Earth is facing now a day is the greenhouse gases like carbon dioxide, methane or nitrous oxide and aerosols that are released into the atmosphere. Of the total carbon dioxide released into the atmosphere, 14% was released by transportation vehicles. As cars make up 72% of the CO2 emissions in this sector (followed by planes, with 10%), the market of electric cars has been growing and seems to be a good solution to fight climate change. Hydrogen fuel cell powered vehicles are also a good choice to substitute the conventional internal combustion engine vehicles. Fuel cell cars and trucks can cut emissions by over 30 percent when compared with their gasoline-powered counterparts.

1.1 Fuel Cell

A device that generates electricity through an electrochemical reaction, not combustion, is a fuel cell. In a fuel cell, electricity, heat, and water are generated by the electro chemical reaction between Hydrogen and Oxygen. Fuel cells are used today in many applications, like providing power to homes and businesses, keeping critical facilities like hospitals, grocery stores, and data centers up and running, and moving a variety of vehicles including cars, buses.[1-3]

1.2 Parts of fuel Cell

Electrochemical reaction is what happens in a fuel cell. It is a chemical reaction, because it involves two chemicals joining together, but it's an electrical reaction too because electricity is produced as the reaction runs its course.

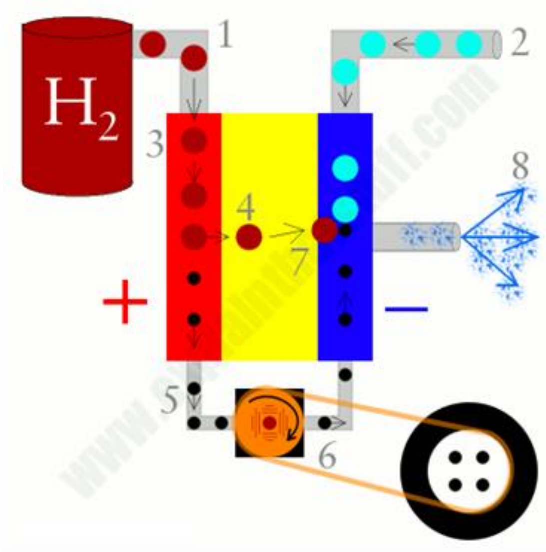

Fig-1: parts and working of a fuel cell

Fig 1 shows the main parts of a fuel cell. They are 1) a positively charged terminal or anode(shown here in red), 2)a negatively charged terminal or cathode(blue), and 3)a separating chemical called an electrolyte in between the two (yellow) keeping them apart.

1.3 How electricity is produced in a fuel cell ?

Anode is made of Platinum, a precious metal catalyst designed to speed up the process that takes place in fuel cell. Hydrogen gas from the tank (the hydrogen storage tank should be extremely strong as hydrogen is flammable and explosive) is fed to the positive terminal or anode and Oxygen from air is fed to the negative terminal or cathode. At the anode site, a catalyst splits the hydrogen molecules into electrons and protons (hydrogen ions).The protons, being positively charged, are attracted to the negative terminal and travel through the electrolyte towards it. The electrolyte is a thin membrane made of a special polymer (plastic) film and only the protons can pass through it. The electrons are forced through a circuit, generating an electric current and excess heat. As they do so, they power the electric motor (orange and black) that drives the car's wheels At the cathode, the protons, electrons, and oxygen combine to produce water molecules. The water is given off from the exhaust pipe as water vapor or steam.[4-6]

This type of fuel cell is called Proton Exchange Membrane.

1.4 Benefits of fuel cell

- Low-to-Zero Emissions: Fuel cells that use pure hydrogen fuel are completely carbon-free, with their only byproducts being electricity, heat, and water
- High Efficiency: Because fuel cells generate electricity through chemistry rather than combustion, they can achieve much higher efficiencies than traditional energy production methods such as steam turbines and internal combustion engines.
- Reliability: It'll keep running for as long as there are supplies of hydrogen and oxygen. Since there is always plenty of oxygen in the air, the only limiting factor is how much hydrogen there is in the tank.
- Fuel Flexibility: Some types of fuel cell systems are capable of using hydrocarbon fuels like natural gas, biogas, methanol, and others.
- Energy Security: a fuel cell can be coupled with a combined heat and power system that uses the cell's waste heat for heating or cooling applications.
- Durability: Fuel cells do not need to be periodically recharged like batteries, but instead continue to produce electricity as long as a fuel source is provided.
- Scalability: This means that individual fuel cells can be joined with one another to form stacks. In turn, these stacks can be combined into larger systems. Fuel cell systems vary greatly in size and power, from combustion engine replacements for electric vehicles to large-scale, multi-megawatt installations providing electricity directly to the utility grid.
- Quiet Operation : As there are no moving parts, fuel cells operate silently.[7,8]

2. Hydrogen fuel cell vehicles

Two ways to power a modern car are:

1. Use an internal-combustion engine which generates heat by burning petroleum-based fuel. The generated heat push pistons up and down to drive the transmission and the wheels.

2. Electric cars rely on batteries that feed electric power to electric motors that drive the wheels directly. Hybrid cars have both internal-combustion engines and electric motors and switch between the two to suit the driving conditions.

A hydrogen fuel cell car has a hydrogen tank that feeds a fuel cell with high pressured hydrogen gas that will mix with oxygen. This starts an electrochemical reaction that produces electricity to power the electric motor. This means hydrogen cars have characteristics of both electric cars (due to the use of electric energy and motor) and conventional petrol cars (because of the tank). They are called FCVs (Fuel Cell Vehicles) or FCEVs (Full Cell Electric Vehicles).

Fuel cells are a combination of internal-combustion engine and battery power. Like an internal-combustion engine, they make power by using fuel from a tank (though the fuel is pressurized hydrogen gas rather than gasoline or diesel). But, unlike an engine, a fuel cell doesn't burn the hydrogen. Instead, it fused chemically with oxygen from the air to make water. In the process, which resembles what happens in a battery, electricity is released and this is used to power an electric motor (or motors) that can drive a vehicle. The only waste product is the water.[9]

Converting hydrogen gas into electricity produces only water and heat as a byproduct, meaning fuel cell vehicles do not create tailpipe pollution when they are driven. Producing the hydrogen itself can lead to pollution, including greenhouse gas emissions, but even when the fuel comes from one of the dirtiest sources of hydrogen, natural gas, fuel cell cars and trucks can cut emissions by over 30 percent when compared with their gasoline-powered counterparts.

2.1 Key Components of a Hydrogen Fuel Cell Electric Car

Battery (auxiliary): In an electric drive vehicle, the auxiliary battery provides electricity to start the car before the traction battery is engaged and also powers vehicle accessories.

Battery pack: This battery stores energy generated from regenerative braking and provides supplemental power to the electric traction motor.
DC/DC converter: This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.
Electric traction motor (FCEV): Using power from the fuel cell and the traction battery pack, this motor drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions.
Fuel cell stack: An assembly of individual membrane electrodes that use hydrogen and oxygen to produce electricity.
Fuel filler: A nozzle from a fuel dispenser attaches to the receptacle on the vehicle to fill the tank.
Fuel tank (hydrogen): Stores hydrogen gas onboard the vehicle until it is needed by the fuel cell.
Power electronics controller (FCEV): This unit manages the flow of electrical energy delivered by the fuel cell and the traction battery, controlling the speed of the electric traction motor and the torque it produces.
Thermal system (cooling) - (FCEV): This system maintains a proper operating temperature range of the fuel cell, electric motor, power electronics, and other components.
Transmission (electric): The transmission transfers mechanical power from the electric traction motor to drive the wheels.

2.2 Differences between fuel cell cars and other Electric Vehicles

Driving range: Hydrogen powered car can travel around 330 miles or 550 km, which is around the same as the electric cars. However, as hydrogen cars densely pack their energy storage, they're usually able to achieve longer distances. While most fully electric vehicles can travel between 100-200 miles on a single charge, hydrogen ones can get to 300 miles.

Refueling time: The amount of time it takes to pump hydrogen into the tank is way more interesting (5 to 10 minutes, just like any petrol car) than the one from electric cars. Electric cars take half an hour to five hours to charge its battery. This is a clear win for the hydrogen car – all because of 1kg of hydrogen storing 236 times more energy than 1 kilogram of lithium-ion batteries.[10]

Power and energy: The power of the vehicle is defined by the size of the electric motor(s) that receive electric power from the appropriately sized fuel cell and battery combination. Although FCEV is designed with plug-in capabilities to charge the battery, most FCEVs use the battery for recapturing braking energy, providing extra power during short acceleration events and to smooth out the power delivered from the fuel cell with the option to idle or turn off the fuel cell during low power needs. The amount of energy stored onboard is determined by the size of the hydrogen fuel tank. This is different from an all-electric vehicle, where the amount of power and energy available are both closely related to the battery's size.

Main component: Fuel cell is the maestro of all the processes happening inside the car so that it has the energy to move. Fuel cells turn the stored hydrogen gas (by mixing it with oxygen) into electricity. This electricity is then used to power an electric motor to propel the vehicle, without any toxic tailpipe emissions. In fact, the only by-product of the whole process is water and heat, as the result of the connection of hydrogen and oxygen atoms that forms H20 molecules.
On the other hand, electric vehicles (EVs), are powered by electric motors that pull current from a rechargeable battery or other portable sources of electricity. Once they are moving, there's no chemical reaction happening either, only an electric one thanks to the power batteries were previously charged with.

3. Hydrogen fueling station

The compression unit is the key component of a hydrogen fueling station. It compresses H_2 stored at low pressure to up to 100 MPa. The ideal compression technology depends on a range of factors, for example the initial state of the hydrogen (gaseous or liquid), the station throughput and the type of vehicle to be fueled.

3.1The ionic compressor

In five steps, the ionic compressor compresses gaseous hydrogen to 100 MPa. Highlights include the eponymous ionic liquid, which does not bond with the gas. It acts as both a lubricant and coolant, and thus significantly reduces wear and tear. Additionally, the ionic compressor has fewer moving parts than a typical piston compressor. The liquid also increases the compressor's energy efficiency due to better cooling and fewer dead spots during the compression process.

By eliminating the need for lubricants, the ionic compressor protects the hydrogen against the risk of contamination. This ensures high levels of purity, making the compressor ideal, for purity-critical fuel-cell applications.

3.2 The cryo pump

The cryo pump operates with liquid hydrogen (LH2) at -253° C. At this temperature, however, hydrogen cannot be simply suctioned in. Hence the pump uses a two-chamber system which is completely immersed in the cryogenic liquid. In the first chamber, LH2 from the storage tank is compressed to 0.6 MPa. The compression to 100 MPa takes place in the second chamber. Subsequently, the temperature of the cryogenic gas is increased up to the fueling temperature of -40° C. During all of these process steps, the high purity level of the hydrogen is maintained.

In addition to its small footprint and high capacity, the cryo pump minimizes the energy required by the fueling station. It only needs 10–20 percent of the energy required by a conventional compressor. The cooling power of cryogenic LH2 also eliminates the need for an external cooling system for the supply line. And the low-maintenance design cuts operating costs further. [11]

Ionic compressor and cryo pump highlights:

- Low energy consumption
- Small footprint
- Energy-efficient compression
- Low maintenance requirements
- Long service life
- High reliability
- Low noise emissions

4. The Real Problem: Getting Hydrogen

Although hydrogen is the most common element in the universe, it doesn't exist in its pure form in the Blue Planet. This means that if we wish to use it as fuel for our cars, we need to produce it out of other compounds like water, natural gas or other fossil fuels, or biomass. And for this, energy needs to be used and environmental and economic costs enter the equation.

In one hand, we can get hydrogen in a clean way by reversing the electrolysis process of water. The problem is that this process of separating H20 molecules to get the hydrogen spends a high amount of energy, making it a very expensive process. However, if this energy is able to come from renewable energy sources like the sun or the wind, the net energy cycle can get very carbon low and the process turns more environmentally-friendly. Yet, another situation is the efficiency of the process, that is only 75% efficient and allows for 25% of electricity loses.

This is why today most hydrogen fuel is obtained is by the process of natural gas reforming, which is less expensive than electrolysis. The downside is that harmful by-products such as carbon dioxide and carbon monoxide, and very rarely methane, are produced in the process, contributing to global warming.

4.1 Hydrogen from water

Fig 2 shows an electrolyzer. In an electrolyzer, a solution is placed in a container and dip two terminals into it. Connect the terminals up to a battery or other power supply and pass electricity through the solution. Chemical reactions take place and the solution splits up into its atoms. If the solution used is pure water (H_2O), it quickly splitting up into hydrogen gas (at the negative electrode) and oxygen gas (at the positive electrode). It's relatively easy to collect and store these gases for use in future.

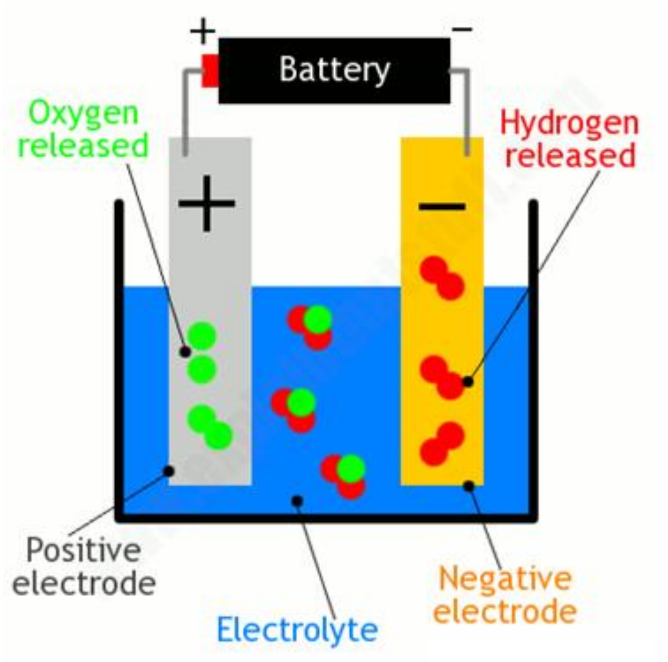

Fig- 2: Working of electrolyzer[12]

Working of electrolyzer to make hydrogen gas from water:

1. A battery connects the positive terminal or anode to the negative terminal or cathode through an electrolyte. In a simple laboratory experiment, the electrolyte could be pure water. In a real electrolyzer, performance is improved considerably by using a solid polymer membrane as the electrolyte, which allows ions to move through it.
2. When the power is switched on, water (H_2O—shown here as two red blobs joined to one green one) splits into positively charged hydrogen ions (hydrogen atoms missing electrons, shown in red) and negatively charged oxygen ions (oxygen atoms with extra electrons, shown in green).
3. The positive hydrogen ions are attracted to the negative terminal and recombine in pairs to form hydrogen gas (H_2).
4. Likewise, the negative oxygen ions are drawn to the positive terminal and recombine in pairs there to form oxygen gas [12]

5. CONCLUSIONS

Hydrogen fuel gas powered vehicles are a good choice to prevent pollution and cut down greenhouse gas emissions as the only byproducts are water and heat. Time taken for refueling the vehicle is less and driving range is high as energy storing capacity is more for hydrogen. The only difficulty is to get hydrogen. The existing methods to get hydrogen have the disadvantages of high energy loss, low efficiency and environmental pollution. However, while new methods of producing hydrogen are being developed, such as the proton exchange membrane, which, according to scientists, might get to an 86% efficiency. Using the extra energy supply for hydrogen production and creating some hybrid version of hydrogen-lithium-ion cars can also be something.

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