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FUEL CELLS VERSUS MARITIME TRANSPORT OF THE FUTURE

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Abstract: *A fuel cell is an energy conversion device that produces electricity by electrochemical combination of a fuel with an oxidant, and consists of two electrodes (the anode and cathode) separated by an electrolyte. A fuel cell is similar to a battery in that very efficiently generates Direct Current (DC) electricity from hydrogen rich fuels through an electrochemical and chemical reaction. Fuel cells can continuously generate electricity so long as they have a supply of fuel and air.*

Keywords: *fuel cell, energy, cathode, anode, materials.*

1. What is fuel cell?

A fuel cell is an electrochemical conversion device. It produces electricity from fuel (on the anode side) and an oxidant (on the cathode side), which react in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate virtually continuously as long as the necessary flows are maintained. The correct terminology for describing an operational fuel cell is actually a fuel cell system, as a fuel cell requires a range of other sophisticated operating systems – often called 'balance of plant'– to function properly. Unlike other electricity generators such as internal combustion engines or coal/gas powered turbines, fuel cells do not burn fuel. This means there are no noisy high-pressure rotors or loud exhaust noise and no vibration. Fuel cells produce electricity though a silent electrochemical reaction. Another feature of fuel cells is that they convert the chemical energy in the fuel directly into electricity, heat and water. The term electrical efficiency describes how much input fuel energy is converted into output electrical energy. Naturally, system efficiencies vary from manufacturer to manufacturer and with the size of the installation.

Because fuel cells are very efficient and in the process do not burn the fuel through combustion, fuel cells do not produce large quantities of greenhouse gases such as Carbon Dioxide (CO_2), Methane (CH_4) and Nitrogen Oxide (NO_x). The only emissions from fuel cells are water in the form of steam and low levels of Carbon Dioxide (none if the fuel cell uses pure hydrogen as a fuel). If pure hydrogen is used as a fuel, fuel cells emit only heat and water, eliminating concerns about air pollutants or greenhouse gases. In simplest terms, a fuel cell is an electrochemical conversion

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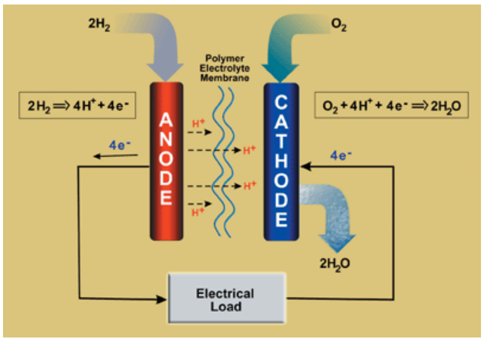
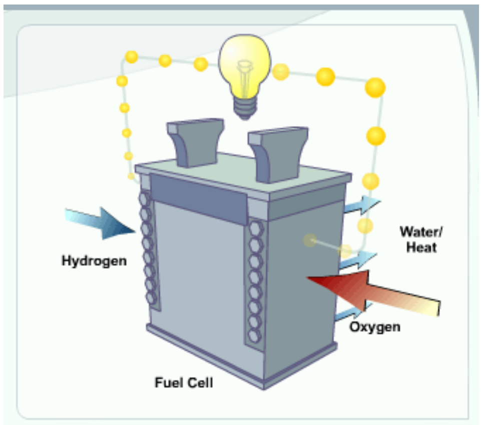
device that combines hydrogen and oxygen to produce water, electricity, and heat.

2. How a fuel cell work?

A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity. Fuel cells are more energy-efficient than combustion engines.



A fuel cell works similar to a battery. In a battery there are two electrodes which are separated by an electrolyte. At least one of the electrodes is generally made of a solid metal. This metal is converted to another chemical compound during the production of electricity in the battery. The energy that the battery can produce in one cycle is limited by the amount of this solid metal that can be converted. In the fuel cell the solid metal is replaced by an electrode that is not consumed and a fuel that continuously replenishes the fuel cell. This fuel reacts with an oxidant such as oxygen from the other electrode. A fuel cell can produce electricity as long as more fuel and oxidant is pumped through it. Fuel cells are often described as being continuously operating batteries, but this is an incomplete idea. Like batteries, fuel cells produce power without combustion or rotating machinery. They produce electricity by utilizing an electrochemical reaction to combine hydrogen ions with oxygen atoms. Hydrogen ions are obtained from hydrogen-containing fuels. Fuel cells, unlike batteries, use an external and continuous source of fuel and produce power continuously, as long as the fuel supply is maintained. Two electrodes, an anode, and a cathode form an individual cell. They are sandwiched around an electrolyte in the presence of a catalyst to accelerate and improve the electrochemical reaction. A proton – conducting polymer membrane (the electrolyte), separates the anode and cathode sides. On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating.



On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water. In this example, the only waste product is water vapor and/or liquid water. In addition to pure hydrogen, there are hydrocarbons fuels for fuel cells, including diesel, methanol and chemical hydrides. The waste products with types of fuel are carbon dioxide and water.

3. The Cell

A typical proton exchange membrane (PEM), fuel cell produces a voltage from 0.6 to 1.0 volt at full rated load. The current produced by an individual fuel cell is approximately a linear function of cell surface area. For commercial cells, the cell area is a trade-off between acceptable current (amperage) levels and manufacturing and transportation constraints. The most common dimensions are two by four feet area. To deliver the desired amount of energy, the fuel cells can be combined in series and parallel circuits, where series yield higher voltage, and parallel allows a stronger current to be drawn, this design is referred to as a fuel cell stack. Two electrodes, an anode, and a cathode form an individual cell. They are sandwiched around an electrolyte in the presence of a catalyst to accelerate and improve the electrochemical reaction. The anode is bathed with fuel, the cathode with oxidant (air and carbon dioxide). These electrodes consist mainly of porous, sintered nickel (anode) or nickel oxide (cathode). Layered between the electrodes is the carbonate electrolyte contained in a porous (ceramic) matrix.

4. Fuel Cell Efficiency

The efficiency of a fuel is dependent on the amount of power drawn from it. Drawing more power means drawing more current, which increases the losses in the fuel cell. As a general rule, the more power (current) drawn, the lower the efficiency. Most losses manifest themselves as a voltage drop in the cell, so the efficiency of a cell is almost proportional to its voltage. For this reason, it is common to show graphs of voltage versus current (so-called polarization curves) for fuel cells.

A typical cell running at 0.7 volts has an efficiency of about 50 % meaning that 50 % of the energy content of the hydrogen is converted into electrical energy; the remaining 50 % will be converted into heat (depending on the fuel cell system design; some fuel might leave the system unreacted, constituting an additional loss). Fuel cells are not constrained by the maximum Carnot cycle efficiency as combustion engines are, because they do not operate with a thermal cycle. At times, this is misrepresented when fuel cells are stated to be exempt from the laws of thermodynamics. Instead, it can be described that the "limitations imposed by the second law of thermodynamics on the operation of fuel cells are much less severe than the limitations imposed on conventional energy conversion systems." Consequently, they can have very efficiencies in converting chemical energy to electrical energy, especially when they are operated at low power density, and using pure hydrogen and oxygen as reactants.

5. Fuel Cell Versus Gasoline & Battery Power Efficiency

Let's study an example with the fuel-cell car. (All of these efficiencies are approximations, but they should be close enough to make a rough comparison). If the fuel cell is powered with pure hydrogen, it has the potential to be up to 80-percent efficient. That is, it converts 80 percent of the energy content of the hydrogen into electrical energy. However, we still need to convert the electrical energy into mechanical work.

This is accomplished by the electric motor and inverter. A reasonable number for the efficiency of the motor/inverter is about 80 percent. So we have 80-percent efficiency in generating electricity, and 80-percent efficiency converting it to mechanical power. That gives an overall efficiency of about 64 percent. The efficiency of a gasoline-powered car is surprisingly low.

All of the heat that comes out as exhaust or goes into the radiator is wasted energy. The engine also uses a lot of energy turning the various pumps, fans and generators that keep it going. So the overall efficiency of an automotive gas engine is about 20 percent. That is, only about 20 percent of the thermal-energy content of the gasoline is converted into mechanical work. A battery-powered electric car has a fairly high efficiency. The battery is about 90-percent efficient (most batteries generate some heat, or require heating), and the electric motor/inverter is about 80-percent efficient. This gives an overall efficiency of about 72 percent. But that is not the whole story. The electricity used to power the car had to be generated somewhere. If it was generated at a power plant that used a combustion process (rather than nuclear, hydroelectric, solar or wind), then only about 40 percent of the fuel required by the power plant was converted into electricity. The process of charging the car requires the conversion of alternating current (AC) power to direct current (DC) power. This process has an efficiency of about 90 percent. So, if we look at the whole cycle, the efficiency of an electric car is 72 percent for the car, 40 percent for the power plant and 90 percent for charging the car. That gives an overall efficiency of 26 percent. The overall efficiency varies considerably depending on what sort of power plant is used. If the electricity for the car is generated by a hydroelectric plant for instance, then it is basically free (we didn't burn any fuel to generate it), and the efficiency of the electric car is about 65 percent.

6. Advantages Of Fuel Cell Technology

Pollution reduction is one of the primary goals of the fuel cell.

Environmental Acceptability - While natural gas is the primary fuel, with appropriate cleanup, any hydrogen-rich gas — including gas from landfills, digesters, coalmines, or liquid fuels — can be used in the fuel cell. Note that electricity, heat, water vapor, and carbon dioxide are the products of these basic reactions. Carbon dioxide is a greenhouse gas, but less toxic than CO and others. Emissions of SO_x and NO_x are 0.003 and 0.0004 pounds/megawatt-hour respectively. Waste heat and steam can be used for heating and auxiliary services. Due to higher efficiencies and lower fuel oxidation temperatures, fuel cells emit less carbon dioxide and nitrogen oxides per kilowatt of power generated. And since fuel cells have no moving parts (except for the pumps, blowers, and transformers that are a necessary part of any power producing system), noise and vibration are practically nonexistent. Noise from fuel cell power plants is as low as 55 dB at 90 feet. This makes them easier to site in urban or suburban locations. The lack of moving parts also makes for high reliability (as demonstrated repeatedly by the U.S. Space Program and the Department of Defense Fuel Cell Program) and low maintenance.

Another advantage of fuel cells is that their efficiency increases at part-load conditions, unlike gas and steam turbines, fans, and compressors. Finally, fuel cells can use many different types of fuel such as natural gas, propane, landfill gas, anaerobic digester gas, JP-8 jet fuel, diesel, naphtha, methanol, and hydrogen. This versatility ensures that fuel cells will not become obsolete due to the unavailability of certain fuels.

Costs - In 2002, typical cells had a catalyst content of US$1000 per kilowatt of electric power output. The goal is to reduce the cost in order to compete with current market technologies including gasoline internal combustion engines.

Flow control - Just as in a combustion engine, a steady ratio between the reactant and oxygen is necessary to keep the fuel cell operating efficiently.

Temperature management - The same temperature must be maintained throughout the cell in order to prevent destruction of the cell through thermal loading. This is particularly challenging as the H2 + O2 -> H20 reaction is highly exothermic, so a large quantity of heat is generated within the fuel cell.

Durability, service life - Stationary applications typically require more than 40,000 hours of reliable operation at a temperature of -35 °C to 40 °C, while automotive fuel cells require a 5,000 hour lifespan (the equivalent of 150,000 miles) under extreme temperatures.

Automotive engines must also be able to start reliably at -30 °C and have a high power to volume ratio (typically 2.5 kW per liter). Fuel cell requires low maintenance.

7. Fuel Cell Problems

Costs - Chief among the problems associated with fuel cells is how expensive they are. Many of the component pieces of a fuel cell are costly. For PEM systems, (proton exchange membranes), precious metal catalysts (usually platinum), gas diffusion layers, and bipolar plates make up 70 percent of a system's cost.

Durability - Researchers must develop PEM membranes that are durable and can operate at temperatures greater than 100 degrees Celsius and still function at sub-zero ambient temperatures. A 100 degrees Celsius temperature target is required in order for a fuel cell to have a higher tolerance to impurities in fuel. Because you start and stop a car relatively frequently, it is important for the membrane to remain stable under cycling conditions. Currently membranes tend to degrade while fuel cells cycle on and off, particularly as operating temperatures rise.

Hydration - Because PEM membranes must by hydrated in order to transfer hydrogen protons, researches must find a way to develop fuel cell systems that can continue to operate in sub-zero temperatures, low humidity environments and high operating temperatures.

At around 80 degrees Celsius, hydration is lost without a high-pressure hydration system.

Delivery - The Department of Energy's Technical Plan for Fuel Cells states that the air compressor technologies currently available are not suitable for vehicle use, which makes designing a hydrogen fuel delivery system problematic.

Storage and Other Considerations - Three hundred miles is a conventional driving range (the distance you can drive in a car with a full tank of gas). In order to create a comparable result with a fuel cell vehicle, researchers must overcome hydrogen storage considerations, vehicle weight and volume, cost, and safety.

8. Conclusions

Current worldwide electric power production is based on a centralized, grid-dependent network structure. This system has several disadvantages such as high emissions, transmission losses, long lead times for plant construction, and large and long term financing requirements. Distributed generation is an alternative that is gathering momentum, and modern technologies, such as fuel cells, are likely to play an increasing role in meeting ever-increasing power demands.

References

1. Novac I., *Maritime Technology Masteral Course UMC 2008*
2. Marica P. E., Novac I., *Fuel Cell, UMC 2009 Constanta*
3. Stanciu G., Novac I., *Fuel Cell*
4. ****Report UMC 2009 Constanta*