RESEARCH ARTICLE OPEN ACCESS

Fabrication and Performance Analysis of Prototype PEM Fuel Cell Hybrid Vehicle

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Abstract:

Most issues are associated with the conventional engines, ICEs (internal-combustion engines), which primarily depend on hydrocarbon fuels. In this contest, different low-polluting vehicles and fuels have been proposed to improve environmental situation. Some vehicle technologies include advanced internal combustion engine (ICE), spark-ignition (SI) or compression ignition (CI) engines, hybrid electric vehicles (ICE/HEVs), battery powered electric vehicles and fuel cell vehicles (FCVs). Fuel cell vehicles, using hydrogen, can potentially offer lower emissions than other alternative and possibility to use different primary fuel option.

Keywords — **Advanced internal combustion engine (ICE), Hybrid electric vehicles (ICE/HEVs), battery powered electric vehicles and fuel cell vehicles (FCVs). Fuel cell vehicles, using hydrogen.**

I. INTRODUCTION

A fuel cell is like a battery in that it generates electricity from an electrochemical reaction. Both batteries and fuel cells convert chemical potential energy into electrical energy and, as a by-product of this process, into heat energy. However, a battery holds a closed store of energy within it and once this is depleted the battery must be discarded, recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction. A fuel cell, on the other hand, uses an external supply of chemical energy and can run indefinitely, if it is supplied with a source of hydrogen and a source of oxygen (usually air).

Fuel cell vehicles (FCVs) powered by pure hydrogen emit no GHGs from their tailpipe, only heat and water. Producing the hydrogen to power FCV can generate GHGs, depending on the production method, but much less than that emitted by conventional gasoline and diesel vehicles. Gasoline and diesel-powered vehicles emit greenhouse gases (GHGs), mostly carbon dioxide (CO2), that contribute to global climate change.

II. Types of Fuel Cells

Direct Methanol Fuel Cell (DMFC)

Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is usually mixed with water and fed directly to the fuel cell anode.

Alkaline Fuel Cell (AFC)

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. In recent years, novel AFCs that use a polymer membrane as the electrolyte have been developed. These fuel cells are closely related to conventional PEM fuel cells, except that they use an alkaline membrane instead of an acid membrane. The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications.

Phosphoric Acid Fuel Cell (PAFC)

Phosphoric acid fuel cells (PAFCs) use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The electro-chemical reactions that take place in the cell are shown in the diagram to the right.

The PAFC is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

Molten-Carbonate Fuel Cell (MCFC)

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. Because they operate at high temperatures of 650°C (roughly 1,200°F), non-precious metals can be used as catalysts at the anode and cathode, reducing costs.

Solid-Oxide Fuel Cell (SOFC)

Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte. SOFCs are around 60% efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 85%.

Reversible Fuel Cells (RFC)

Reversible fuel cells produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells. However, reversible fuel cell systems can also use electricity from solar power, wind power, or other sources to split water into oxygen and hydrogen fuel through a process called electrolysis.

Reversible fuel cells can provide power when needed, but during times of high power production from other technologies (such as when high winds lead to an excess of available wind power), reversible fuel cells can store the excess energy in the form of hydrogen. This energy storage capability could be a key enabler for intermittent renewable energy technologies

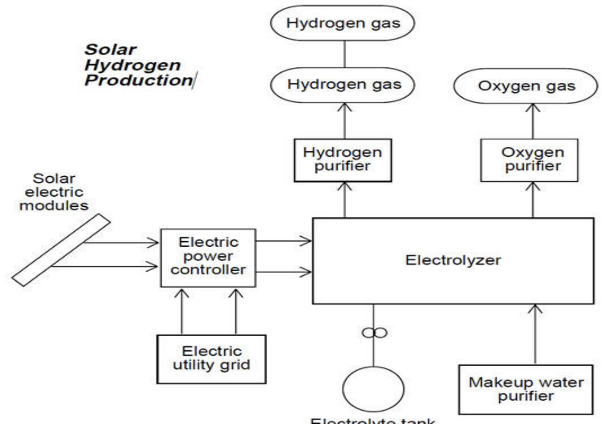

Fig: Reversible Fuel Cell

Working Principle of Fuel Cell

The fuel cell stack is responsible for generating power. This reaction differs depending on the type of fuel used by the system. Inside the stack, there are several modules, each made up of a number of cells.

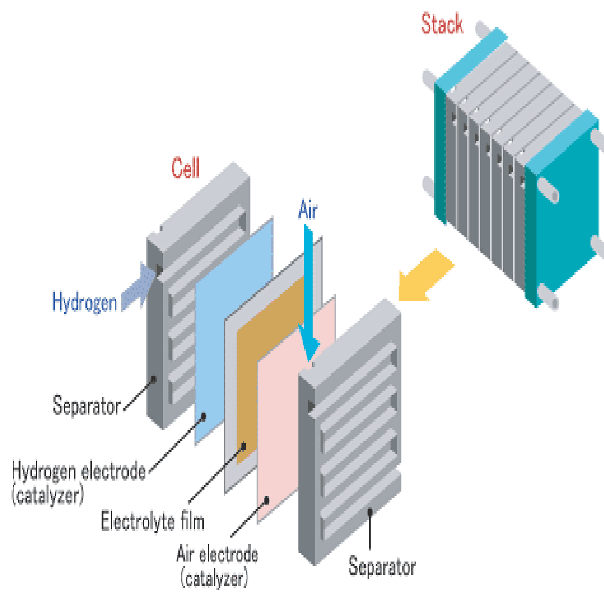

Fig (a)

Each cell is part of what is called a MEA (membrane electrode assembly). MEA's have a negative side (anode) and a positive side (cathode), and squeezed between the two is a membrane coated with a special catalyst. This catalyst separates each element from the methanol and water, breaking the hydrogen into positive and negative ions.

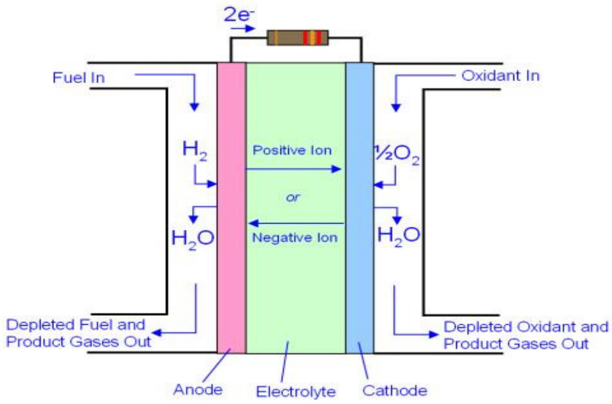

Fig. (b)

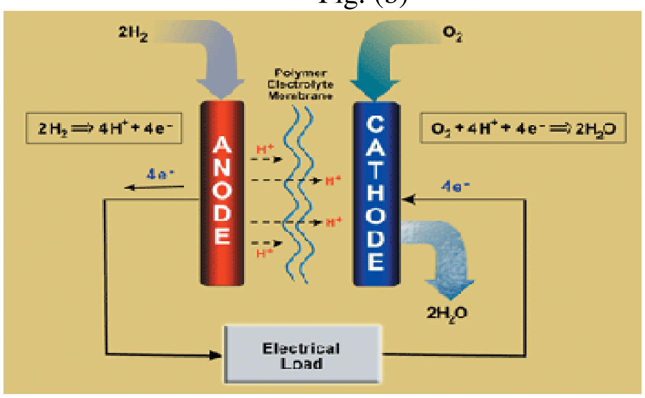

Fig (c)

Once separated, positively charged hydrogen ions (protons) pass through the fine meshed membrane from the anode side to the cathode side. The negatively charged hydrogen ions (electrons) are unable able to pass through this membrane and are routed around the membrane to the cathode side via an external circuit.

As they travel through this external circuit, they generate electricity. Once on the cathode side the electrons are reunited with their partner protons to once again form hydrogen. At the same time air is passed through the cathode side which mixes with the hydrogen atoms to form water, which completes the fuel cell process.

Reaction analysis

Hydrogen (H2) and oxygen (O2) react in a so called 'cold combustion' to water (H20) by providing energy. The overall efficiency is 50%, while combustion engines operate at app. 35% (Carnot diagram). The energy that a fuel cell generates is available as electrical power and heat.

Dependant of the actual load conditions of the split of electrical power and heat changes. The high efficiency, the direct generation of electrical power and the low to zero emissions make the fuel cell a superior technology.

The fuel cell principle is the reversal of the water electrolysis, where water is split into hydrogen and oxygen by applying electrical power. The following reactions occur at the anode and cathode of a PEM fuel cell.

Anode (hydrogen side) :In a first step, molecular hydrogen H2 is split in 2 hydrogen ions H+ and 2 electrons e– under catalytic influence (e.g. Platinum).

Reaction equation anode:

$2\ H_2 \rightarrow 4\ H+ + 4\ e–$Electrolyte (membrane)

In a PEM fuel cell the electrolyte is conductive only for protons, therefore the positively charged H+ ions pass thru the membrane from the anode to the cathode. The negatively charged electrons e– have to travel thru the external load by providing electrical power.

Cathode (oxygen side): The reaction on the cathode is much more complex. In principle a oxygen molecule O_2 from the surrounding air reacts with 2 H+ ions to $H_2\ O_2$ by consuming 2 electrons e–. In a second step H2, O2reacts to 2 H20 (water) molecules by consuming another

2 H+ ions and 2 electrons e–.

Simplified cathode reaction equation:

O2 + 4 H+ + 4 e– → 2 H2O

At the cathode is a lack of electrons while on the anode we have a surplus on electrons. If anode and cathode are electrically connected, electrons pass from the anode to the cathode to balance this difference in electrical charge. This current flows as long as the reaction is taking place or in other words as long as hydrogen and oxygen is available to the anode/cathode of the fuel cell. An electrical load connected to this circuit makes it possible to utilize the so generated electrical power.

Reactions of fuel cell

A proton exchange membrane fuel cell transforms the chemical energy liberated during the electrochemical reaction of hydrogen and oxygen to electrical energy, as opposed to the direct combustion of hydrogen and oxygen gases to produce thermal energy.

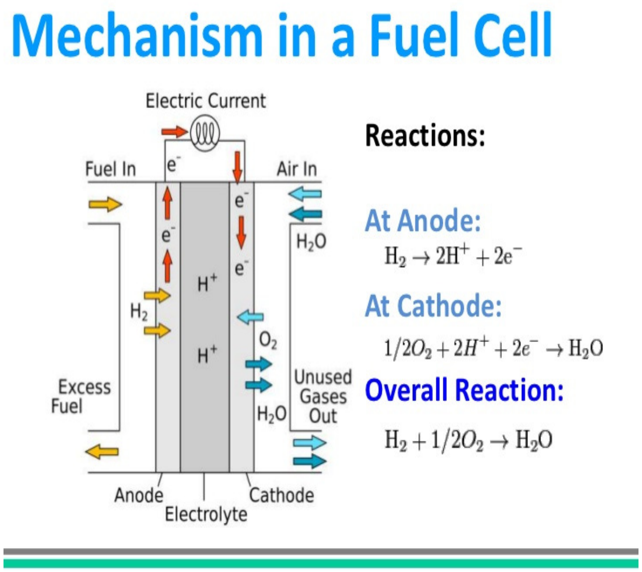

Fig. Mechanism in a Fuel Cell

A stream of hydrogen is delivered to the anode side of the membrane electrode assembly (MEA). At the anode side it is catalytically split into protons and electrons. Thisoxidation half-cell reaction or hydrogen oxidation reaction (HOR) is represented by:

At the anode2 $H_2 \rightarrow 4$ H+ + 4 e–

The newly formed protons permeate through the polymer electrolyte membrane to the cathode side. The electrons travel along an external load circuit to the cathode side of the MEA, thus creating the current output of the fuel cell. Meanwhile, a stream of oxygen is delivered to the cathode side of the MEA. At the cathode side oxygen molecules react with the protons permeating through the polymer electrolyte membrane and the electrons arriving through the external circuit to form water molecules. This reduction half-cell reaction or oxygen reduction reaction (ORR) is represented by :

At the Cathode:O_2 + 4 H+ + 4 e– → 2 H2O

COMPONENTS OF FUEL CELL

Polymer electrolyte membrane (PEM) fuel cells are the current focus of research for fuel cell vehicle applications. PEM fuel cells are made from several layers of different materials. The main parts of a PEM fuel cell are described below.

IC ENGINE DEFINITION

An internal combustion engine (ICE) is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. ... Firearms are also a form of internal combustion engine.

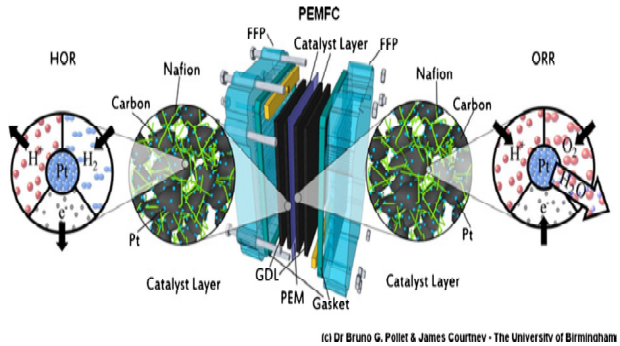

Fig component of fuel cell

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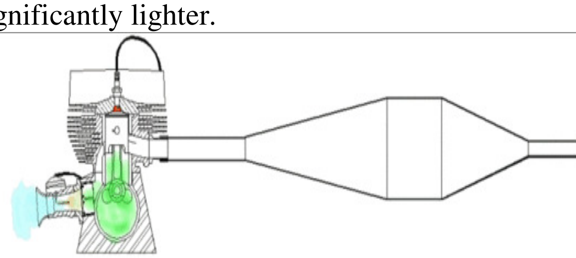
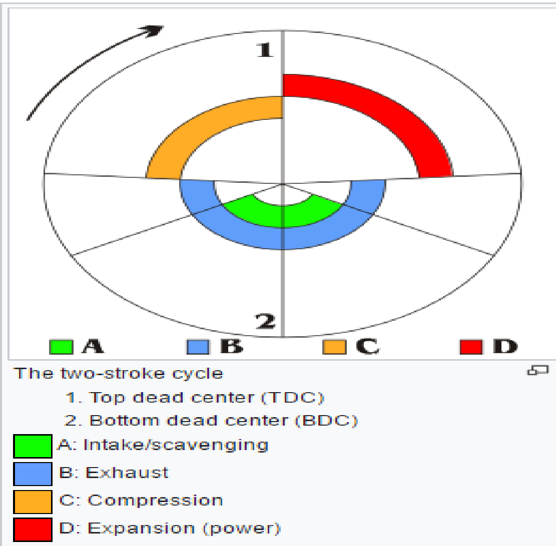
IC Engine Working

A two-stroke, or two-cycle, engine is a type of internal combustion engine which completes a power cycle with two strokes (up and down movements) of the piston during only one crankshaft revolution. This is in contrast to a "four-stroke engine", which requires four strokes of the piston to complete a power cycle. In a two-stroke engine, the end of the combustion stroke and the beginning of the compression stroke happen simultaneously, with the intake and exhaust (or scavenging) functions occurring at the same time.

Two-stroke engines often have a high power-to-weight ratio, power being available in a narrow range of rotational speeds called the "power band". Compared to four-stroke engines, two-stroke engines have a greatly reduced number of moving parts, and so can be more compact and significantly lighter.



Figworking of 2stroke ic engine



Figvalve timing diagram

The cycle of the four-stroke of the piston (the suction, compression, power and exhaust strokes) is completed only in two strokes in the case of a two-stroke engine. The air is drawn into the crankcase due to the suction created by the upward stroke of the piston. On the down stroke of the piston it is compressed in the crankcase, The compression pressure is usually very low, being just sufficient to enable the air to flow into the cylinder through the transfer port when the piston reaches near the bottom of its down stroke. The air thus flows into the cylinder, where the piston compresses it as it ascends, till the piston is nearly at the top of its stroke. The compression pressure is increased sufficientlyhigh to raise the temperature of the air above the self-ignition point of the fuel used. The fuel is injected into the cylinder head just before the completion of the compression stroke and only for a short period. The burnt gases expand during the next downward stroke of the piston. These gases escape into the exhaust pipe to the atmosphere through the piston uncovering the exhaust port.

SOLAR PANEL DEFINITION

A solar panel works by allowing photons, or particles of light, to knock electrons free from atoms, generating a flow of electricity. Solar panelsactually comprise many, smaller units called photovoltaic cells. (Photovoltaic simply means they convert sunlight into electricity.

Solar Panel Working

Under the sun, a photovoltaic cell acts as a photosensitive diode that instantaneously converts light – but not heat – into electricity.

Cell Layers

A top, phosphorus-diffused silicon layer carries free electrons – un-anchored particles with negative charges. A thicker, boron doped bottom layer contains holes, or absences of electrons, that also can move freely. In effect, precise manufacturing has instilled an electronic imbalance between the two layers.

Sun Activation

a) Photons bombard and penetrate the cell.
b) They activate electrons, knocking them loose in both silicon layers.
c) Some electrons in the bottom layer sling-shot to the top of the cell.
d) These electrons flow into metal contacts as electricity, moving into a circuit throughout a 60-cell module.
e) Electrons flow back into the cell via a solid contact layer at the bottom, creating a closed loop or circuit.

Powering Homes and Businesses with Solar

Current leaving a module, or array of modules, passes through a wire conduit leading to an inverter. This device, about the shape of a waffle iron, inverts direct current, which flows with a fixed current and voltage, into alternating current, which flows with oscillating current and voltage. Appliances worldwide operate on AC. From the inverter, the solar-generated power feeds into circuitry of a household, business or power plant and onto the region's electrical grid. A remote, or independent, power system also can form a self-contained circuit without connecting to the grid. The off-grid system, however, requires batteries to store power for times, such as night, when modules do not capture enough light energy from the sun.

HYBRID ELECTRIC VEHICLE

A hybrid electric vehicle (HEV) augments an electric vehicle (EV) with a second source of power referred to as the alter-native power unit (APU). Pure electric vehicles currently do not have adequate range when powered by batteries alone, and since recharging re-quires several hours, the vehicles are viewed as impractical for driving extended distances. If air conditioning or heating is used, the vehicle's range is further reduced. Accordingly, the hybrid concept, where the alternative power unit is used as a second source of energy, is gaining acceptance and is overcoming some of the problems of pure electric vehicles.

III. ASSEMBLING OF COMPONENTS

COMPONENTS

I.) ALUMINIUM FRAME II.) 2 STROKE IC ENGINE

(A) ALUMINIUM FRAME (B) IC ENGINE

Aluminium frame of Dimensions 50cm x 31.5 cm

2 stroke ic engine
Fuel type : petrol
CUBIC CAPACITY: 26CC

III.) FUEL CELL IV.) SOLAR PANEL

(C) Fuel cell(d) Solar Panel
PEM Fuel cellSolar panel
Input voltage: 1.8V ~ 3V power rating 10W, 12V

v.) Battery vi.) Dc motor

Fig (e) Battery Fig (f) Dc Motor
Lead acid battery Dc motor

vii.) Plastic wheels.

Fig (g) Wheels

ASSEMBLY OF PROTOTYPE

Coming to assembly of components it starts withfastening of aluminium frame with threaded bolt and nuts.Next arrangement of solar panel on aluminium frame. 2 stroke ic engine is mounted on frame by means of dollars, bearings and bolts. Connections with are made in a way such that to make a parallel hybrid vehicle.

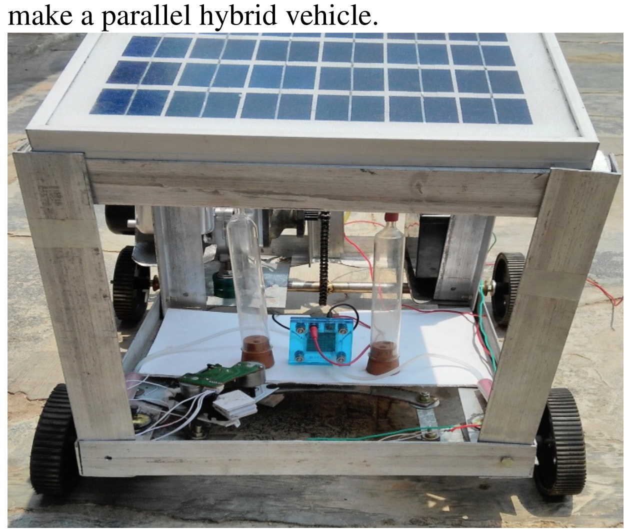


Fig Assembled front view of prototype

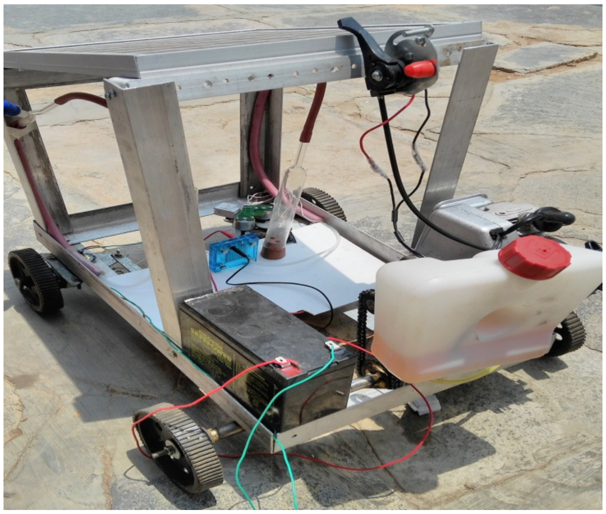


Fig (b) Assembled side view of prototype

IV. CALCULATIONS

Calculations of fuel consumption

$H_2 \rightarrow 2H^+ + 2e^-$

$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$

One ampere of current is defined as 1 C/sec.

Mass of Hydrogen Consumed

Moles of electrons per sec.:

Me = (1 [C/s])/ (F [C/mol]) = $1.0364*10^{-5}$mol/sMoles of hydrogen per sec

M H_2 = me/2 = $0.5182*10^{-5}$mol/s

Moles of hydrogen per hour:

M H_2 /h = 0.01865mol/h

Since molar mass of H_2 = 2.0158 g/mol

Mass of hydrogen per hour:

M H_2/h = $3.759*10^{-5}$ kg/h

Power (P) is the product of voltage (V) and current (I): P = I*V

I = P/V = 30 Amps

Mass of H_2 consumed (kg/h)

Mc = (I)*(mass of H_2/h) = 30 * $3.759*10^{-5}$ kg/h

= 1.1277 * 10^{-3} kg/hUtilization Factor (U_f)

= 0.8

Fuel flow rate:

H_2, in = Mc/U_f = 1.1277 * 10^{-3} / 0.8 Kg/h

= 1.4096 * 10^{-3} Kg/h

Mass of Oxygen Consumed

Moles of electrons per sec.:

Me = (1 [C/s])/(F [C/mol]) = $1.0364*10^{-5}$mol/s

Moles of Oxygen per sec = 1.036 * 10^{-5} / 16

= 6.477 * 10^{-7}mol/sec

Moles of oxygen per hour

M O_2 /hr= 6.477 * 10^{-7} * 3600 mol/hr

= 2.331 * 10^{-3}mol/hr

Since molar mass of O_2 = 32 g/mol

Mass of Oxygen per hour:

M O_2/h = 2.331 * 10^{-3} * 32/1000 g/hr

= 7.46 * 10^{-5} kg/hr

Power (P) is the product of voltage (V) and current(I): P = I*V

I = P/V = 30 Amps

Mass of O_2 consumed (kg/hr)

Mc = (I)*(mass of O_2/h)

= 30 * 7.46 * 10^{-5} kg/hr

Mc= 2.238 * 10^{-3} kg/hr

Mass O_2 consumed (Kg/hr)

Mo2 = (2.238* 10^{-3} *1000)/(2* 2.0158)

= 0.555 kg/h

Utilization factor = 0.8

O2 flow rate: O2, in

= M O_2 /Uox = 0.693 * 10^{-3} kg/hr

V. EFFICIENCY OF FUEL CELL

Introduction

A logical first step in understanding the operation of a fuel cell is to define its ideal performance. Once the ideal performance is determined, losses arising from non-ideal behavior can be calculated and then deducted from the ideal performance to describe the actual operation.

The Role of Gibbs free energy

The maximum electrical work (W) obtainable in a fuel cell operating at constant temperature and pressure is given by the change in Gibbs free energy (ΔG) of the electrochemical reaction:

$$W = \Delta G = -- nFE$$

Where n is the number of electrons participating in the reaction,F is Faraday's constant (96,487 coulombs/g-mole electron), and E is the ideal potential of the cell.The Gibbs free energy change is also given by the following state function:

$$\Delta G = \Delta H - T\Delta S$$

Where ΔH is the enthalpy change and ΔS is the entropy change. The total thermal energy available is ΔH. The available free energy is equal to the enthalpy change less the quantity TΔS which represents the unavailable energy resulting from the entropy change within the system.The amount of heat that is produced by a fuel cell operating reversibly is TΔS. Reactions in fuel cells that have negative entropy change generate heat (such as hydrogen oxidation), while those with positive entropy change (such as direct solid carbon oxidation) may extract heat from their surroundings if the irreversible generation of heat is smaller than the reversible absorption of heat.The maximal theoretical efficiency applying the Gibbs free energy equation ΔG=-237.13 kJ/mol and using the heating value of Hydrogen (ΔH=-285.84 kJ/mol) is 83% at 298 K.

VI. RESULTSAND DISCUSSIONS

The following results are obtained by testing theperformance of fuel cell is

- The efficiency of fuel cell is of about 80% - 90% at the temperature of 25^0 C.
- Mass of hydrogen consumed is twice the mass of oxygen consumed.
- The efficiency of fuel cell can be increased by the increase of flow rate of hydrogen at the same temperatures.

i.) Voltage, Current and Power Readings

TYPE OF CELL :REVERSIBLE PEM FUEL CELL

TEST DATE : MARCH 15 2017

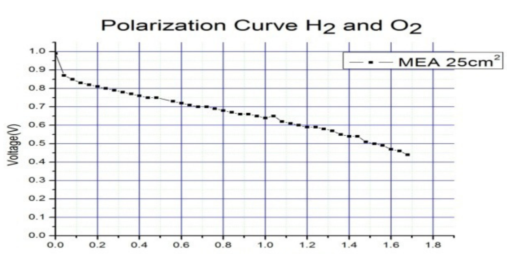
NO. OF CELL : 1

Table.7.1 . Experimental Results

sample	Time min	Cell Voltage V	Cell Current mA	Cell Power mW	H_2 Line pr.	O_2 Line Pr.
1	5	0.58	360	208.8	1.6	1.6
2	5	0.57	355	202.35	1.6	1.6
3	5	0.59	361	212.99	1.6	1.6
4	5	0.58	354	205.32	1.6	1.6
5	5	0.57	358	204.06	1.6	1.6

ii.) Graphs plotted:

a. Polarization curve for H_2 and O_2



iii.) Tables

observations	On inclination less than 15 degree in kmph	On inclination more than 15 degree in kmph
1	2	1.5
2	4	3
3	6	5
4	8	7
5	10	8

Table Speed of prototype in gradually increasing power on Electric & FC drive

observations	On inclination less than 15 degree in kmph	On inclination more than 15 degree in kmph
1	3	2
2	5	4
3	8	7
4	10	8
5	12	10

Table Speed of prototype in gradually increasing power on gasoline drive

observations	On inclination less than 15 degree in kmph	On inclination more than 15 degree in kmph
1	4	3
2	6	5
3	8	7
4	11	10
5	14	12

Table Speed of prototype in gradually increasing power in Hybrid Mode

Power supply	IC engine	Battery and fuel cell	ICE, Battery & FC
Fuel	Petrol	Electricity and H_2	Petrol, H_2 & electricity
Top speed	12kmph	10	15
Price	2,600INR	7,000INR	10,000INR
Emissions	N.A	0	N.A

Table Comparison between different drives

VII. CONCLUSIONS

a. A fuel cell is one of the recently identified electrical energy resources which undergoes certain chemical reactions to produce electrical power using hydrogen as fuel and oxygen as an oxidizing agent. The classification of fuel cells based on the types of fuel used is explained. This research mainly focuses on comparative performance analysis of emulating behaviour of well-known fuel cells systems such as Proton Exchange Membrane Fuel Cell and Solid Oxide Fuel Cell for grid applications and standalone systems.

b. The voltage attained from a single fuel cell is very small and in order to attain the desired value of voltage depending on the applications, a number of fuel cells are connected in series known as stack. The DC stack voltage is boosted using a boost converter with 50 % duty ratio and is converted into three phase AC voltage using an voltage source inverter.

c. Hydrogen Fuel cell vehicles are currently being researched for their feasibility of widespread usage in automobiles and other forms of transportation.

d. By using Fuel cell Hybrid vehicles at a time efficiency of vehicle is increasing as wellas emissions also decreasing but there is a trade off with price of fuel cell.

e. Hydrogen fuel cells are a promising alternative to current automobile fuels. They essentially combine the energy density and the convenience of liquid fuels with the clean and efficient operation of electric vehicles. Although certain aspects of the technology such as efficient on-board storage still require some improvement, there are no reasons why hydrogen couldn’t become an equally convenient and attractive transportation fuel as diesel or gasoline are today.

f. The drawbacks of hydrogen use are low energy content per unit volume, high tankage weights, very high storage vessel pressures, the storage, transportation and filling of gaseous or liquid hydrogen in vehicles, the large investment in infrastructure thatwould be required to fuel vehicles, and the inefficiency of preproduction processes.

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