The International Journal of Multi-Disciplinary Research
ISSN: 3471-7102

IMPLEMENTATION OF HYDROGEN FUEL CELL ENERGY IN ZAMBIA.

(Conference ID: CFP/293/2017)

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Abstract

In every developing and already developed nations, energy in any form is the engine of an economy. A sustainable source of energy can drive a nation to prosperity as it supports the very core of business and industrialization. It is for this reason that developed nations around the world have gone out of their way exploiting all available forms of energy sources in order to sustain their economies and make the lives of their citizens bearable. Therefore it is recommended that implementing the hydrogen – oxygen fuel cell in the energy sector will save the environment from decaying, and also as alternative means to the conventional system of energy generation in Zambia via a clean, effective and sustainable way. In this paper the study carried out is a test on the ability of hydrogen - oxygen fuel cell to make electrical power. It demonstrates that two pure platinum wire (acting as a catalyst) immersed in water (hydrogen and oxygen source) can cause bubbles of hydrogen to cling to one electrode, and bubbles of oxygen to cling to the other electrode (hydrolysis) when connected to a battery. When the battery is disconnected the platinum acts as a catalyst, allowing the hydrogen and oxygen to recombine to make water again (hydrolysis reaction is reversed), and produce electricity. One advantageous fact is that the end product of the reaction (water) is environmentally friendly, produces no emissions capable of depleting the ozone layer and also can be converted to home use for economical purposes.

Keywords: hydrolysis reaction, electricity, hydrogen-oxygen fuel cell, implementation, energy generation, Zambia.

1.0 INTRODUCTION

Fuel cells generate electricity by an electrochemical reaction in which oxygen and a hydrogen-rich fuel combine to form water. Unlike internal combustion engines, the fuel is not combusted, the energy is being released electrocatalytically. This allows fuel cells to be highly energy efficient, especially if the heat produced by the reaction is also harnessed for space heating, hot water or to drive refrigeration cycles.

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 also, 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, or recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction.

1.1 WHAT IS A FUEL CELL?

A fuel cell by definition is an electrical cell, which unlike storage cells can be continuously fed with a fuel so that the electrical power output is sustained indefinitely (Connihan, 1981). They convert hydrogen, or hydrogen-containing fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. The process is that of electrolysis in reverse. The basic Principle Fuel Cell is shown in figure 1 below.

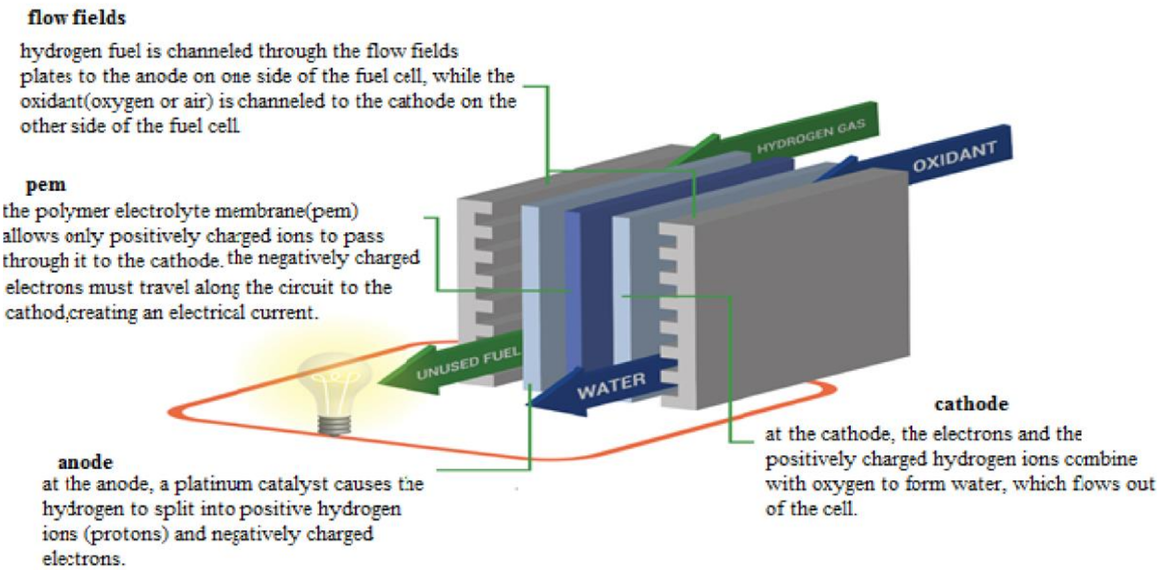

figure 1

Overall reaction: $2\ H_2\ (gas) + O_2\ (gas) \rightarrow 2\ H_2O + energy$ (Equation.1)

Because hydrogen and oxygen gases are electrochemically converted into water, fuel cells have many advantages over heat engines. These include: high efficiency, virtually silent operation and, if hydrogen is the fuel, there are no pollutant emissions. If the hydrogen is produced from renewable energy sources, then the electrical power produced can be truly sustainable.

1.2 BRIEF THEORY AND OPERATION

For the hydrogen/oxygen (air) fuel cell, the overall reaction is: $H_2 + ½ O2 = H_2O$. The product of this reaction is water released at the cathode or anode depending on the type of fuel cell. For PEM fuel cell, hydrogen is oxidized at the anode as given by the reaction, $H_2 = 2 H^+ + 2e^-$. Electrons generated at the anode are flown through external load to the cathode. Protons (H^+) are migrated through the proton exchange membrane to the cathode. The protons and electrons reached at the cathode react with oxygen from air as given by the reaction,

$2H^+ + 2 e^- + ½ O_2 = H_2O$.

1.3 THERMALDYNAMICS OF FUEL CELL.

Combining a mole of hydrogen gas and a half mole of oxygen gas from their normal diatomic forms produces a mole of water. A detailed analysis of the process makes use of the thermodynamic potentials. This process is presumed to be at 298K and one atmosphere pressure, and the relevant values are taken from a table of thermodynamic properties.

Quantity	H_2	0.5 O_2	H_2O	Change
Enthalpy	0	0	-285.83 kJ	ΔH = -285.83 kJ
Entropy	130.68 J/K	0.5 x 205.14 J/K	69.91 J/K	$T\Delta S$ = -48.7 kJ

Energy is provided by the combining of the atoms and from the decrease of the volume of the gases. Both of those are included in the change in enthalpy included in the table above. At temperature 298K and one atmosphere pressure, the system work is

$$W = P\Delta V = (101.3 \times 10^3 \text{ Pa})(1.5 \text{ moles})(-22.4 \times 10^{-3} \text{ m}^3/\text{mol})(298K/273K) = -3715 \text{ J}$$

Since the enthalpy H= U+PV, the change in internal energy U is then

$$\Delta U = \Delta H - P\Delta V = -285.83 \text{ kJ} - 3.72 \text{ kJ} = -282.1 \text{ kJ}$$

The entropy of the gases decreases by 48.7 kJ in the process of combination since the number of water molecules is less than the number of hydrogen and oxygen molecules combining. Since the total entropy will not decrease in the reaction, the excess entropy in the amount

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TΔS must be expelled to the environment as heat at temperature T. The amount of energy per mole of hydrogen which can be provided as electrical energy is the change in the Gibbs free energy:

$$\Delta G = \Delta H - T\Delta S = -285.83 \text{ kJ} + 48.7 \text{ kJ} = -237.1 \text{ kJ}$$

For this ideal case, the fuel energy is converted to electrical energy at an efficiency of 237.1/285.8 x100% = 83%! This is far greater than the ideal efficiency of a generating facility which burned the hydrogen and used the heat to power a generator! Although real fuel cells do not approach that ideal efficiency, they are still much more efficient than any electric power plant which burns a fuel.

The standard free energy change of the fuel cell reaction is indicated by the equation number

$$\Delta G = -nFE \qquad \text{(equation: 3)}$$

Where ΔG is the free energy change, n is the number of moles of electrons involved, E is the reversible potential, and F is Faraday's constant. If the reactants and the products are in their standard states, the equation can be represented as

$$\Delta G^o = -nFE^o \qquad \text{(equation: 4)}$$

The value of ΔG corresponding to (equation: 2) is −229 kJ/mol, $n = 2$,
F = 96500 C/g.mole electron, and hence the calculated value of E is 1.229 V.
The enthalpy change ΔH for a fuel cell reaction indicates the entire heat released by the reaction at constant pressure. The fuel cell potential in accordance with ΔH is defined as the thermo-neutral potential, E_t,

$$\Delta H = -nFE_t \qquad \text{(equation: 5)}$$

Where E_t has a value of 1.48 V for the reaction represented by Equation: 2
The electrochemical reactions taking place in a fuel cell determine the ideal performance of a fuel cell; these are shown in Table 1.3.1 for different kinds of fuels depending on the electrochemical reactions that occur with different fuels, where
CO is carbon monoxide, e^- is an electron, H_2O is water, CO_2 is carbon dioxide, H^+ is a hydrogen ion, O_2 is oxygen, CO_3^{2-} is a carbonate ion, H_2 is hydrogen, and OH^- is a hydroxyl ion.

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

$W = \Delta G = -n\mathrm{F}E$ (equation: 6)

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. If we consider the case of reactants and products being in the standard state, then

$\Delta G^{o} = -n\mathrm{F}E^{o}$ (equation: 7)

The overall reactions given in Table 1.3.2 can be used to produce both electrical energy and heat. The maximum work available from a fuel source is related to the free energy of reaction in the case of a fuel cell, whereas the enthalpy of reaction is the pertinent quantity for a heat engine, *i.e.*,

$\Delta G = \Delta H - T\Delta S$ (equation: 8)

Where the difference between ΔG and ΔH is proportional to the change in entropy ΔS. This entropy change is manifested in changes in the degrees of freedom for the chemical system being considered. The maximum amount of electrical energy available is ΔG as mentioned above, and the total thermal energy available is ΔH.
The amount of heat that is produced by a fuel cell operating reversibly is $T\Delta S$.
Reactions in fuel cells that have negative entropy change generate heat, while those with positive entropy change may extract heat from their surroundings.

Table 1.3.1 Summary of the electrochemical reactions taking place in different fuel cells

Fuel cell type	Anode reaction	Cathode reaction
Acid fuel cell (including PEM)	$H_2 \rightarrow 2H^- + 2e^-$	½ $O_2 + 2H^- + 2e^- \rightarrow H_2O$
Alkaline fuel cell	$H_2 + 2(OH)^- \rightarrow 2 H_2O + 2e^-$	½ $O_2 + H_2O + 2e^- \rightarrow 2(OH)^-$
Oxide fuel cell	$H_2 + O^{2-} \rightarrow H_2O + 2e^{2-}$ $CO + O^{2-} \rightarrow CO_2 + 2e^{2-}$ $C H_4 + 4O^{2-} \rightarrow 2 H_2O + CO_2 + 8e^-$	½ $O_2 + 2e^- \rightarrow O_2^-$
Molten carbonate fuel cell	H2 + CO_3^{2-} $2^- \rightarrow H_2O + CO_2 + 2e^{2-}$ $CO + CO_3^{2-}$ $2^- \rightarrow 2 CO_2 + 2e^{2-}$	½ $O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$

Table 1.3.2 the relationship between fuel cell reaction and the Nernst equation

Fuel cell reaction	Nernst equation
$H2 + ½ O_2 \rightarrow H_2O$	$E = E^o + (RT/2F) \ln [PH2/PH2O] + (RT/2F) \ln [PO2^{1/2}]$
$H_2 + ½ O_2 + CO_2$ (cathode) →	$E = E^o + (RT/2F) \ln [P\ H2/PH2O\ (PCO2anode)] +$
$H_2O + CO_2$ (anode)	$(RT/ 2F) \ln [PO2^{1/2}\ (PCO2cathode)]$
$CO + ½ O_2 \rightarrow CO_2$	$E = E^o + (RT/2F) \ln [\ PCO / PCO2] + (RT/ 2F) \ln [PO2^{1/2}]$
$C H_4 + 2 O_2 \rightarrow 2 H_2O + CO_2$	$E = E^o + (RT/8F) \ln [PCH4 /PH2O\ 2\ PCO2] + (RT/ 8F) \ln [PO2^2]$

2.0 STUDY OF HYDROGEN – OXYGEN FUEL CELL TEST BED.

2.1 MATERIALS

To make the fuel cell, we need the following:

- One foot of platinum coated nickel wire, or pure platinum wire. Since this is not a common household item, we carry platinum coated nickel wire in our catalogue.
- A Popsicle stick or similar small piece of wood or plastic.
- A 9 volt battery clip.
- A 9 volt battery.
- Some transparent sticky tape.
- A glass of water.
- A volt meter.

2.2 METHODE

1. The first step is to cut the platinum coated wire into two six inch long pieces, and wind each piece into a little coiled spring that will be the electrodes in our fuel cell. I wound

mine on the end of the test lead of my volt meter, but a nail, an ice pick, or a coat hanger will do nicely as a coil form.

2. Next, we cut the leads of the battery clip in half and strip the insulation off of the cut ends. Then we twist the bare wires onto the ends of the platinum coated electrodes, as shown in the photo. The battery clip will be attached to the electrodes, and two wires will also be attached to the electrodes, and will later be used to connect to the volt meter.
3. The electrodes are then taped securely to the pop sickle stick. Lastly, the pop sickle stick is taped securely to the glass of water, so that the electrodes dangle in the water for nearly their entire length. The twisted wire connections must stay out of the water, so only the platinum coated electrodes are in the water.
4. Now connect the red wire to the positive terminal of the volt meter, and the black wire to the negative (or "common") terminal of the volt meter. The volt meter should read 0 volts at this point, although a tiny amount of voltage may show up, such as 0.01 volts.

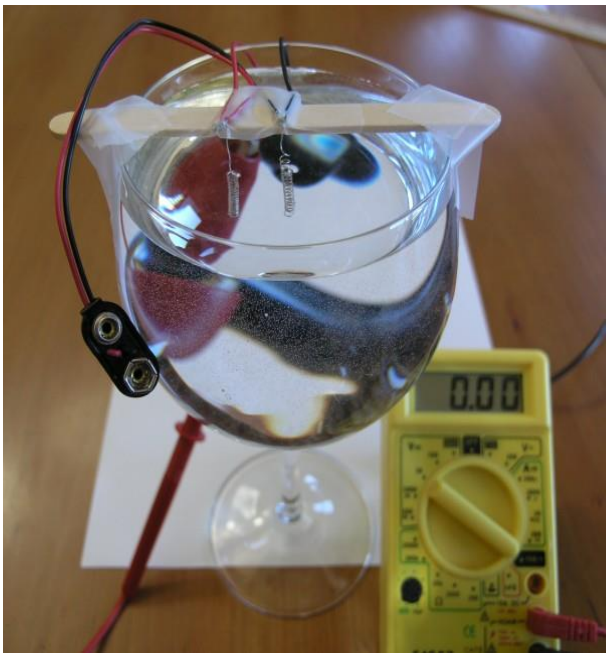

Figure: 2.2.1

5. The fuel cell test bed is now complete.
6. To operate the fuel cell, we need to cause bubbles of hydrogen to cling to one electrode, and bubbles of oxygen to cling to the other. There is a very simple way to do this.
7. We touch the 9 volt battery to the battery clip (we don't need to actually clip it on, since it will only be needed for a second or two).

8. Touching the battery to the clip causes the water at the electrodes to split into hydrogen and oxygen, a process called *electrolysis*. You can see the bubbles form at the electrodes while the battery is attached.

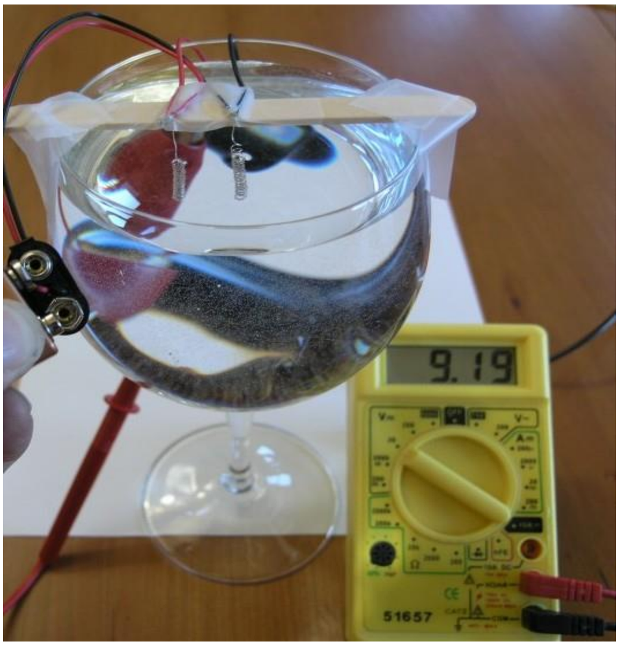

Figure: 2.2.2

9. Now we remove the battery. If we were not using platinum coated wire, we would expect to see the volt meter read zero volts again, since there is no battery connected.
10. The platinum acts as a *catalyst*, allowing the hydrogen and oxygen to recombine.

Figure: 2.2.3

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11. The hydrolysis reaction reverses. Instead of putting electricity into the cell to split the water, hydrogen and oxygen combine to make water again, and produce electricity.

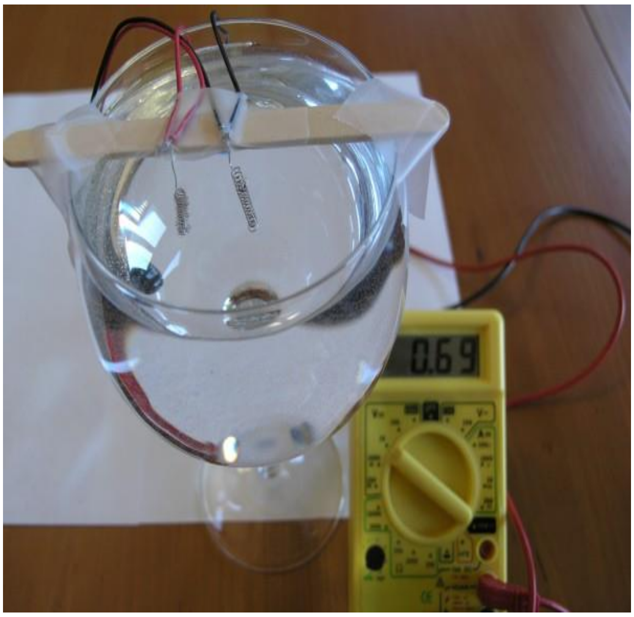

Figure: 2.2.4

We initially get a little over two volts from the fuel cell. As the bubbles pop, dissolve in the water, or get used up by the reaction, the voltage drops, quickly at first, then more slowly.

Notice that we are storing the energy from the 9 volt battery as hydrogen and oxygen bubbles.

We could instead bubble hydrogen and oxygen from some other source over the electrodes, and still get electricity. Or we could produce hydrogen and oxygen during the day from solar power, and store the gasses, then use them in the fuel cell at night. We could also store the gasses in high pressure tanks in an electric car, and generate the electricity the car needs from a fuel cell.

2.3 DESIGNS.

2 DIMENSIONS OF A FUEL CELL.

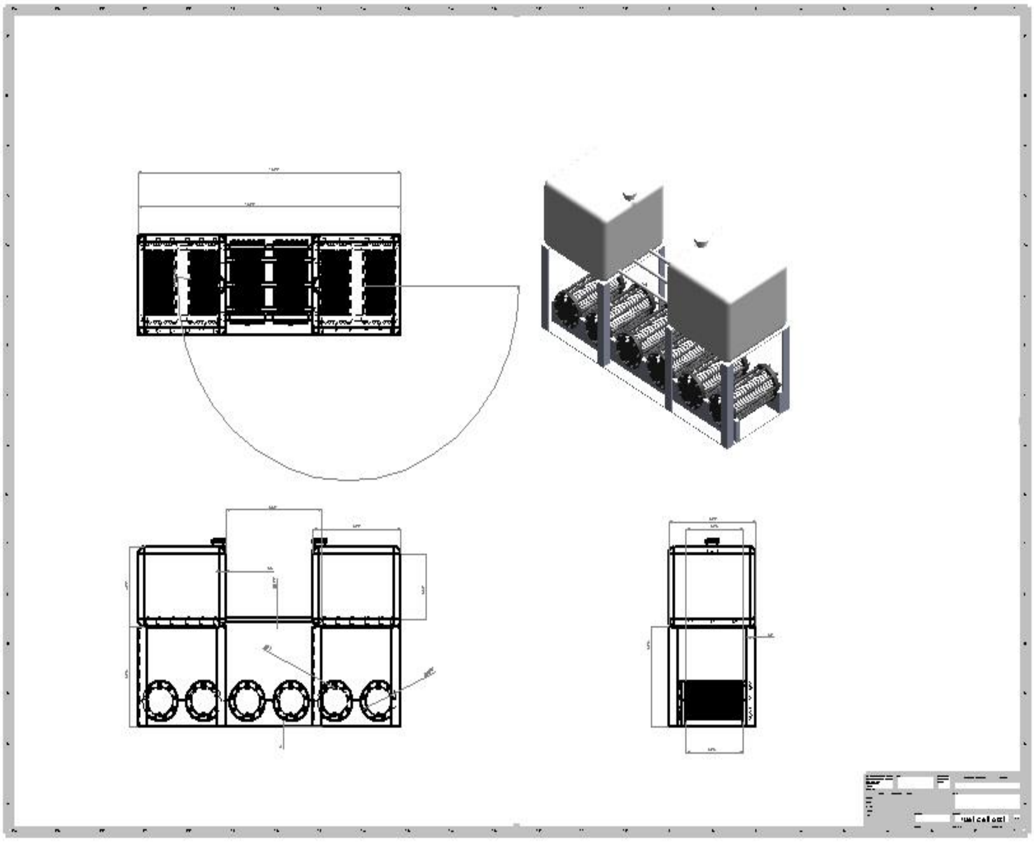

Figure: 2.2.5

3 DIMENSIONS OF A FUEL CELL.

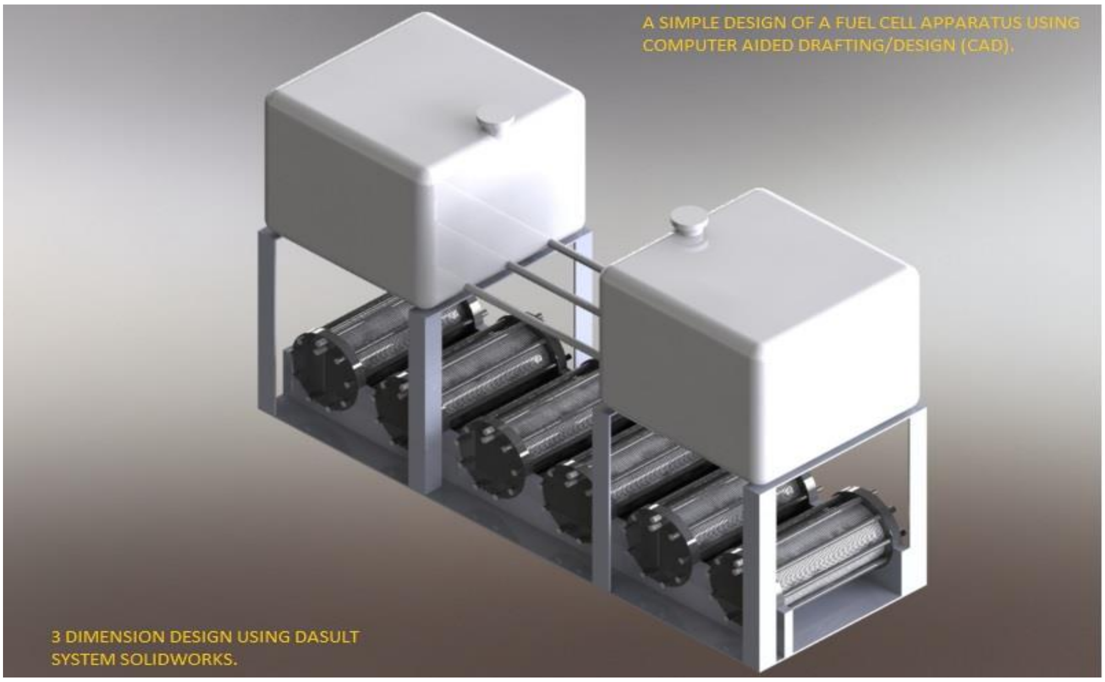

Figure: 2.2.6

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3.0 RESULTS AND DISCUSSION

3.1 EFFICIENCY OF A FUEL CELL.

The fuel cell thermodynamic efficiency is given by the ratio of the Gibbs function change to the Enthalpy change in the overall cell reaction. The Gibbs function change measures the electrical work and the enthalpy change is a measure of the heating value of the fuel.
Efficiency = (dG/dH) (equation: 9)

For the hydrogen -oxygen reaction: dH = - 68,317 cal/g mole of H_2, and dG = - 56,690 cal/g mole of H_2 . The efficiency of the Ideal Fuel Cell is therefore:

Efficiency = (56,690/68,317) = 83%

Another measure of the fuel cell efficiency is known as the "Voltage Efficiency" and is the ratio of the actual voltage under operating conditions to the theoretical cell voltage.

Voltage Efficiency = (Actual Voltage)/(Theoretical Voltage) = (V_A / 1.23)

3.2 FUEL CELL PERFORMANCE VARIABLES.

The performance of fuel cells is affected by operating variables (e.g., temperature, pressure, gas composition, reactant utilizations, current density) and other factors (impurities, cell life) that influence the ideal cell potential and the magnitude of the voltage losses described above. Any number of operating points can be selected for application of a fuel cell in a practical system, as illustrated by Figure: 3.2.1

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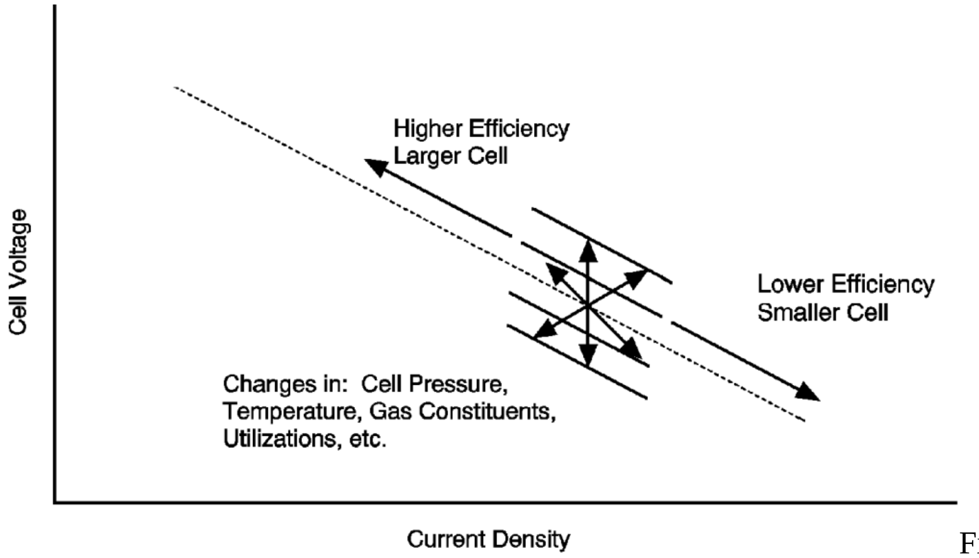

Figure: 3.2.1

Figure 2-4 Flexibility of Operating Points According to Cell Parameters

Temperature and Pressure: The effect of temperature and pressure on the ideal potential (E) of a fuel cell can be analysed on the basis of changes in the Gibbs free energy with temperature and pressure. The derivation of these equations is addressed in Section 3.2.1.

3.4 OPERATION.

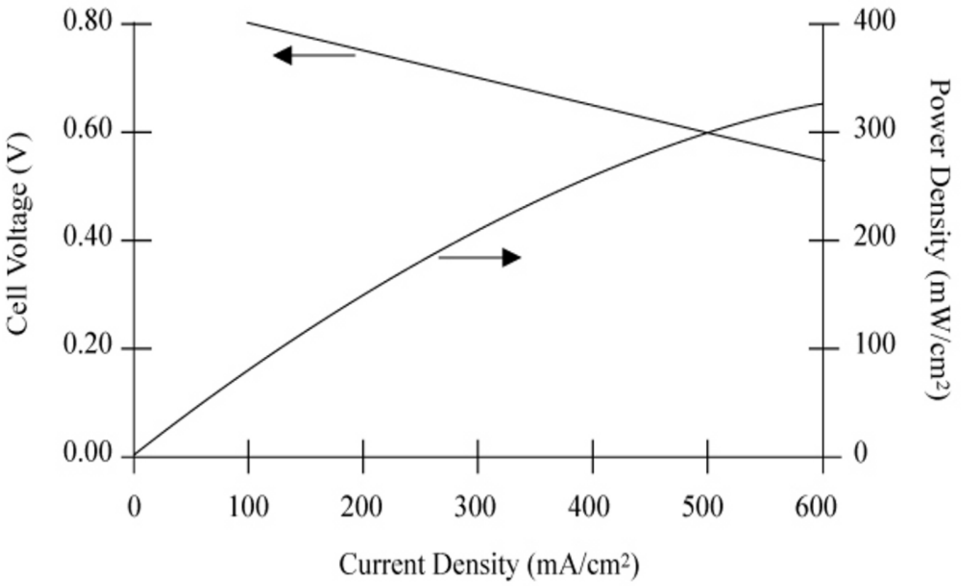

Figure: 3.2.2

The voltage–current density and power density–current density relations for a fuel cell showing the operating conditions for a fuel cell

Figure 3.2.2 presents the same information as Figure 3.2.1, but in a way to highlight another aspect of determining the cell design point. It would seem logical to design the cell to operate at the maximum power density that peaks at a higher current density (off to the right of the figure). However, operation at the higher power densities will mean operation at lower cell voltages or lower cell efficiency. Setting operation at the peak power density can cause instability in control because the system would have a tendency to vacillate between higher and lower current densities around the peak. It is usual practice to operate the cell to the left side of the power density peak and at a point that yields a good compromise of low operating cost (high cell efficiency that occurs at high voltage/low current density) and low capital cost (less cell area that occurs at low voltage/high current density).

3.5 ADVANTAGES OF A FUEL CELL.

1. Available and Renewable
One of the biggest reasons that hydrogen is such a great choice for power is because of the abundance of it. There is no worry about running out of hydrogen anytime soon, unlike fossil fuels and other non-renewable resources.

2. Non Toxic
All of the energy sources that we are currently utilizing are harmful and toxic. Not only for humans and animals, but for our environment as well. Hydrogen fuel cells are completely non-toxic and pose no risk to our climate.

3. Very Powerful
Along with being renewable and nontoxic, hydrogen fuel cells are also incredibly powerful. They are so powerful in fact that they are used as fuel in rockets that go into space!

4. Doesn’t Contribute To Climate Change
there are no greenhouse gas emissions that are associated with hydrogen fuel cells. These gasses, which are released by other types of non-renewable resources, are the cause of global warming and a massive climate change.

5. Cheap Maintenance
While the initial costs may be a bit high, once they are installed, hydrogen fuel cells are very affordable to maintain. This same idea would go if cars began running on hydrogen energy. Costly car repairs would be a thing of the past.

3.6 DISADVANTAGES OF A FUEL CELL.

1. Fossil Fuels Are Still Needed
In order to separate the atoms of the hydrogen and oxygen and actually generate hydrogen fuel, fossil fuels are needed. This completely defeats the purpose of an alternative energy source. If we ran out of fossil fuels we would no longer be able to produce hydrogen energy.

2. Costly to Produce.
One of the biggest pitfalls of hydrogen fuel cells is the simple fact that it is very expensive to produce. As of now, the energy is not efficient enough to produce hydrogen energy in a cost effective way.

3. Flammable!
While it may not be toxic, it sure is flammable. The source of the hazard comes from the hydrogen itself, which is very prone to catching on fire, or even exploding. This would add unnecessarily and new risks into society.

4. Much Work to be done
the use of fuel cells is very new, and quite a bit of advancement and research still needs to be done before it can be used on a wide scale basis. The plausibility of it's use isn't even fully known yet, and many people believe it is just a fairy tale.

5. Cells can't hold much
the actual cells that the hydrogen energy is stored in can store only a small amount of power. This makes the process of maintaining reliable power sources with the use of hydrogen fuel cells very unlikely.

3.7 DISCUSSION QUESTIONS

Is hydrogen a source of energy?
Hydrogen is not a source of energy, while solar, wind, natural gas and oil are. Hydrogen is a way of storing and transporting energy, but not a source of energy itself.

There are already many well-known types of devices that produce electricity, why should we consider another type?
Every device has advantages and disadvantages that influence its suitability for use in a particular application or location. Hydrogen fuel cells have some unique characteristics that make them more suitable for certain uses than other sources of electricity.

Are hydrogen fuel cells safe for people and the environment?

Hydrogen is very combustible, just like gasoline. However, containers suitable for holding hydrogen are put through many rigorous tests to make sure they are safe for the public. Hydrogen is composed of very small, light molecules, and is much less dense than air. This means that a hydrogen leak will tend to disperse very rapidly upwards into the air, unlike a gasoline leak that will pool below a vehicle and remain a hazard until it evaporates. The same precautions that people exercise at gas stations must also be used at hydrogen filling stations, such as not smoking and not using a cell phone.

Are hydrogen fuel cells a new idea?

Sir William Grove demonstrated the concept of the fuel cell in 1839. However, it was not until 1932 that Francis Bacon developed the first successful fuel cell. Limited progress was made over the next quarter century. The pace of development increased around the time that NASA began to research the technology for use in the Gemini, and later the Apollo, programs. Fuel cells are also used on the space shuttle fleet.

Can hydrogen fuel cells be used to power a vehicle?

Hydrogen fuel cells can be used to power any device that uses electricity. So they can be used to power vehicles that run off electricity. In a vehicle that operates from an internal combustion engine the energy flow is as follows:

$$\text{Chemical Energy} \rightarrow \text{Thermal Energy} \rightarrow \text{Mechanical Energy}$$

In a vehicle that operates from a fuel cell the energy flow is:

$$\text{Chemical Energy} \rightarrow \text{Electrical Energy} \rightarrow \text{Mechanical Energy}$$

How does the level of efficiency of a hydrogen fuel cell compare to other devices that produce electricity?

Fuel cells convert chemical energy directly into electrical energy.

$$\text{Chemical Energy} \rightarrow \text{Electrical Energy}$$

Compare this to the energy transformations that occur when a heat engine (such as a gas powered generator) produces electricity:

$$\text{Chemical Energy} \rightarrow \text{Electrical Energy} \rightarrow \text{Mechanical Energy} \rightarrow \text{Electrical Energy}$$

Since each energy transformation involves some amount of energy loss, the fuel cell is more efficient at producing electricity than a heat engine.

Fuel cells operate at an efficiency of about 40 to 50%. Compare this to a fossil fuel fired power plant, which is typically 35% efficient, and the internal combustion engine in most vehicles, which operates at about 15% to 20% efficiency.

Are hydrogen fuel cells in use today?
Hydrogen fuel cells can be found in many different places today. Because the technology is still developing, most fuel cell applications to date have been for demonstration projects.

4.0 CONCLUSION

The more the need to utilize power for electricity propagate, it becomes highly urgent to find new ways of meeting it accountably and harmlessly as well as sustaining. The proposed methodology in this work to implement the fuel cell technology in Zambia functions quite well. Even though there may be some inaccuracies, the trends are clearly seen. This methodology can be used to power up the nation effectively. Following the historical record, the restrictive dynamics of renewable energy have been the storage and transportation of that energy. Therefore, this experiment I carried proves to us through using hydrogen technology and fuel cells, electrical power from renewable energy sources can be attained at any time we need it in a, clean, efficient and sustaining.

ISSN: 3471-7102

5.0 ACKNOWLEDGEMENT

I would like to thank Doctor Silumbe Richard the director of research and development at the Zambia Research and Development Centre as well as program coordinator at the Information and Communications University for the sponsorship throughout my academic period, I would particularly like to single out my supervisor Doctor. Silumbe Oliver of Design and Technology at the Information and Communications University,
I would like to thank my co-researchers and students. You supported me greatly and were always willing to help me. In addition, I thank my parents and family.

Thank you very much, everyone!

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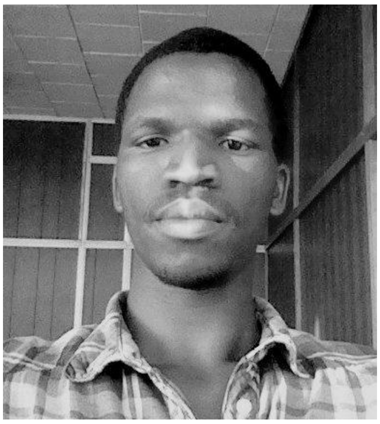

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