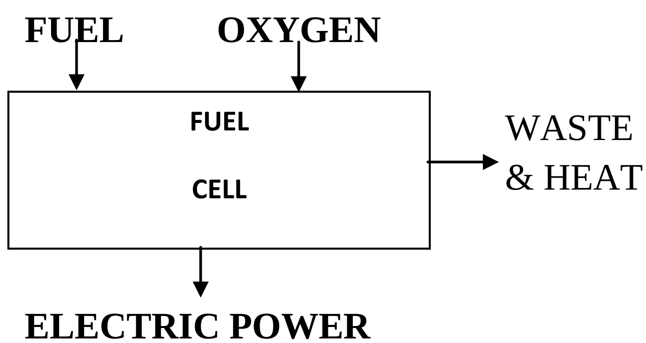
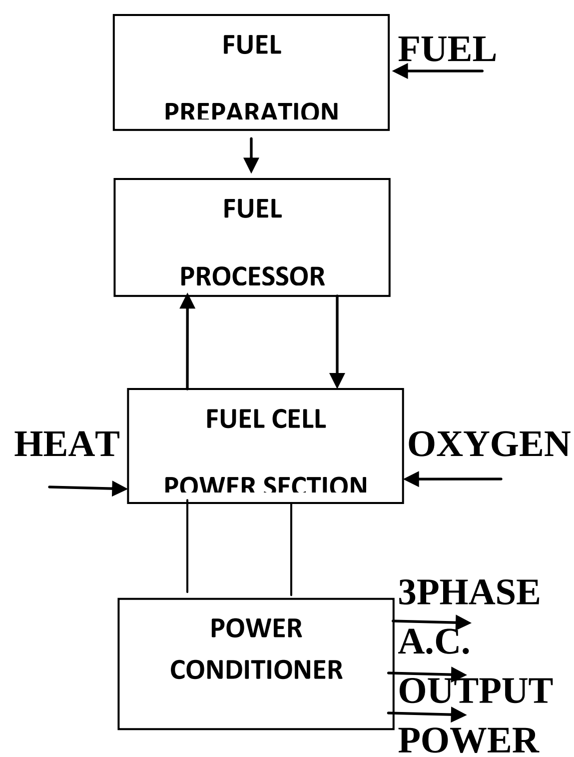
INTRODUCTION:

A fuel cell is controlled chemical – electro – energy conversion device that continuously converts chemical energy to electrical energy. Fuel cell is a device that converts chemical potential energy (energy stored in molecular bonds) into electrical energy. Proton Exchange Membrane (PEM) cell uses hydrogen gas (H2) and oxygen gas (O2) as fuel. The products of the reaction in the cell are water, electricity, and heat. The essential difference between primary/secondary cell and fuel cell is of continues energy input and output of fuel cell. A fuel cell system requires continuous supply of a fuel and an oxidant and generates DC electric power continuously. Battery stores electrical charges.

Battery stores chemical – electro – energy within container. After discharge, it needs recharging or replacement. Fuel cells do not need such recharging replacement. Fuel cells convert chemical energy directly to electrical energy, without intermediate less efficient thermal/turbine stage. Fuel cells have almost 90% efficiency. It does not have moving parts. They are simple and safe. During 1960 – 1980s, practical fuel cells have been developed and used successfully. The fuel cell technology has been ignores due to internal combustion engines and storage batteries. Fuel cells are costly and are not competitive economically.



Schematic of a fuel cell



Schematic of a fuel cell power plant

- The fuel cell has very high conversion efficiency, a direct conversion of energy with a least pollution and modular configuration.

Applications of Fuel cell

- Used as a substitute for storage batteries and primary cells for higher KW and Ah ratings.
- Replacement for internal combustion engines in tractors, automobiles etc. The fuel cells will deliver electric power to drive the electric motor. The IC engine can be substituted by fuel cell – generator and high torque DC motor.
- Source of electrical power for remote installations, space ships, ocean ships, mega – buildings, auxiliary and emergency supplies, passenger boats, submarines, electrical vehicles and possibly for utility power plants.

Individual fuel cell is low voltage (0.6v to 1.23v DC) and low current (100 to 400mA/square cm of electrode surface). Fuel cell power module has several fuel cells connected in series and parallel to obtain required power rating. Power rating of individual fuel cell module is quite low (500W to 5kW).

The H_2O_2 fuel cell module size is 15cm X 15cm X 45cm, weight is 24 kg, number of cells are 35, temperature is 60^0C and power rating is 600 W at 1 atmosphere and 1W at 5 atmosphere. Several modules are connected in series, parallel to obtain desired rating of the fuel cell module. A fuel cell plant rating has several modules connected in series/parallel.

ADVANTAGES OF FUEL CELL POWER SOURCES:

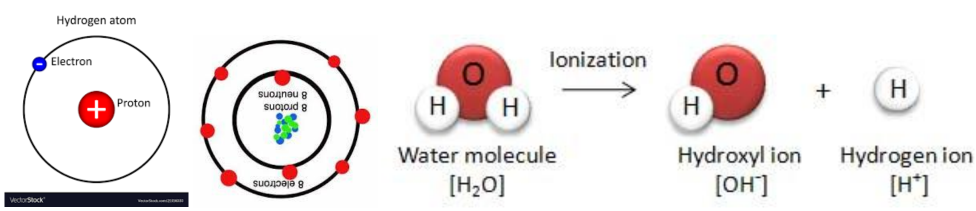
1. It is a simple and efficient energy converter. It takes chemical input and delivers electrical output.
2. Fuel cell power sources are compact, simple, noiseless, do not have rotating or moving parts, and have highest conversion efficiencies around 88% to 97%.
3. Fuel cell plants are modular and available in wide range of size from 5kW to 10 kW.
4. Versatile source of power for domestic, commercial, transport, agricultural, industrial, military, remote applications, Novel power sources with flexibility applications.
5. Pollution free, emission of combination products is negligibly small and is no emission of CO_2, NO_x, So_x, particulates etc.
6. Choice of fuels. Depending upon the type of fuel cell, the fuel cell plants can use natural gas and gasified coal, menthol, hydrogen and several other fuels.
7. Do not need electrical power supply for charging.

8. Simple, static devices without rotating or moving parts.
9. Low, medium or high temperature options available.
10. Power supplies from the fuel cell plants have high operational flexibility. Rate of change of power is very fast. Fuel cell plant can operate efficiently at 50% rated power to 100% rated power. Power flow can be change rapidly.
11. Suited for remote power plants.

THEORY OF ELECTRO – CHEMISTRY APPLIED TO FUEL CELL:

With references of Hydrogen – Oxygen fuel cell the principle of fuel cell can be explained.

A hydrogen atom has one nucleus positively and one electron. Oxygen atom has one nucleus and eight electrons. Two hydrogen atoms combine with one oxygen atom to form one molecule of H_2O. Electromechanical reactions in the fuel cells involve the process of ionization, in which an atoms or molecule losses or gain one or more electron as shown in figure.



Molecule also behaves in similar manner. Water can be ionized into two separate parts: Hydroxyl ion OH^- and Hydrogen ion H^+. The OH ion has additional electron and is therefore one negative charge. The H ion has lost an electron and is therefore has one positive charge.

When a metal electrode is placed in solution containing ions, the situation depends on whether the metal is active or inactive. The active metals such as Na, Z, Ca, Ni dissolves and ionized rapidly. The inactive metals such as Platinum ionize very slowly even at a very high temperature. The charges get collected on the metal surfaces.

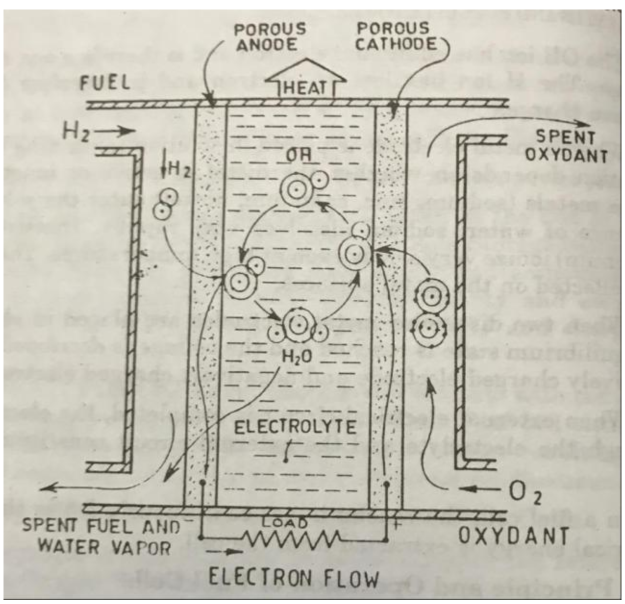
When two dissimilar metal electrodes are placed in electrolyte, an equilibrium state is reached and voltage is developed between positively charged electrode and negatively charged electrode. When external electrical circuit is completed, the electrons flow through the electrolyte and external circuit constituting power flow. In a fuel cell, the reactants are continuously fed to the cell and electrical energy is extracted from the cell.

PRINCIPLE AND OPERATION OF THE FUEL CELLS:

Fuel cell is like a storage battery, but with regular supply of fuel and oxidant. There is no charging – discharging cycle with the fuel cell. Fuel cell has an anode fuel electrode, a cathode oxygen electrode, electrolyte, other components for containers, sealing separators, fuel supply, oxidant supply etc. The fuel cell system consists of power section, fuel processor section, power conditioning section etc.

H_2–O_2 ACIDIC FUEL CELL:

The two porous nickel electrodes are separated by a porous gas barrier. The porous anode (negative poles, fuel electrode) is immersed in oxygen at certain pressure. The hydrogen as a fuel bubbles across the anode. The porous cathode (positive poles, oxidant electrode) is immersed in oxygen at certain pressure. The oxygen as an oxidant bubbles across the porous cathode. The chemical reactions on the electrolyte produces- electrical energy, water, spent fuel and spent oxidants.



Continuous operation requires the supply of fuel, oxidant and removal of heat, water vapor, spent fuel, spent oxidant and inert residues. The porous electrodes provide space for electro–chemical reactions between the fuel oxidant. The electrodes provide conducting path to the electrons flowing through the external circuit. Electrolyte provides path for migration of hydroxyl ions from cathode to anode.

ALKLINE H_2–O_2 FUEL CELL:

The electrolyte is alkaline (KOH). The major electrochemical difference between acidic and alkaline electrolytes is - in acidic electrolyte, the major migration is by hydrogen ions while in alkaline electrolyte the major migration is by hydroxyl ion (OH).

The reactions occurs in KOH electrolyte fuel cell is

Anode Reaction : $H_2 + 2OH^- \rightarrow 2H_2O + 2e$

Cathode Reaction : $\frac{1}{2}O_2 + 2e + H_2O \rightarrow 2OH$

Overall Reaction $H_2 + \frac{1}{2}O_2 \rightarrow H_2O + (\Delta H)$

The net reaction in the fuel cell is hydrogen and oxygen supplied to the fuel cell produce electrical energy, water, heat ΔH.

With acidic electrolyte (H_2SO_4) the chemical reactions is

- Hydrogen dissociates on the anode surfaces and forms hydrogen ions and electrons.

Anode reactions : $H_2 \rightarrow 2H^+ + 2e$

- Hydrogen ions migrate internally from the anode region to the catalytic surface of the cathode through the electrolyte and the porous barrier.
- Electrons move from anode, through external circuit to the catalytic surface.
- Oxygen, hydrogen and electrons combine on the catalytic surface of cathode of warm water

Cathode reactions: $\frac{1}{2}\ O_2 + 2H^+ + 2e \rightarrow H_2O$

Over all chemical reaction $H_2 + \frac{1}{2}\ O_2 \rightarrow H_2O$

The next reaction in the fuel cell is hydrogen and oxygen supplied to the fuel cell produces electrical energy, water and heat. At ambient temperature, the H–O fuel cell has DC potential of about 0.6V, current density of about 100 to 200 ma/cm.

Anode reaction : $H_2 \rightarrow 2H^+ + 2e$

Cathode reaction : $\frac{1}{2}O_2 + 2e + 2H \rightarrow H_2O$

Overall reaction : $\frac{1}{2}O_2 + H_2 \rightarrow H_2O$

CLASIFICATION AND TYPES OF FUEL CELLS:

Classifications of various types of the fuel cells are a) Fuel and Oxidant, b) Basic or Acidic Electrolyte, c) High temperature or ambient temperature.

APPLICATIOS	FUEL	OXIDANT	ELECTROLYTE	TEMPERATURE
VEHICLES	Hydrogen Hydride Methanol hydrocarbon	Air	Phosphoric acid	Intermediate 150^0 to 200^0
REMOTE SITES **SPACE**	Hydrogen – direct	Oxygen – liquid	Aqueous Alkaline Solid polymer	Low, interim
SUBMARINE	Hydrogen – direct	Oxygen – liquid	Aqueous Alkaline	Low
	Hydrogen – direct	Hydrogen peroxide	Aqueous Alkaline	Low
DEFENCE **> 500W** **< 100 W**	Methanol – indirect	Air	Phosphoric acid	Intermediate
	Hydride – indirect	Air	Phosphoric acid	Intermediate
PORTABLE FUEL CELL< 200W	Hydride – indirect	Air	Phosphoric acid	Low
STAND ALONE POWER PLANTS AND COMMERCIAL POWER PALNTS	Hydrocarbon – indirect Hydrocarbon – direct	Air	Phosphoric Acid molten carbonate	Intermediate High > 250^0
	Methanol - indirect Ethanol - direct	Air	Phosphoric Acid molten carbonate	Intermediate High
CENTRAL BASE LOAD POWER PLANTS	Coal – Indirect Coal gas – direct	Air	Phosphoric Acid molten carbonate solid oxide	Intermediate High Very High 600^0 to 750^0

FUELS FOR FUEL CELLS:

In direct type fuel cells the fuel is directly introduced into the fuel cell without requiring conversion at input stage. In indirect type fuel cell the input fuel is first converted into intermediate form and then is supplied to the fuel cell.

Fuel	Cell Reaction	Voltage at 25^0C in V
Ammonia NH_3	$4NH_3 + 3O_2 \rightarrow 6CO_2 + 6H_2O$	1.17
Carbon C	$C + O_2 \rightarrow CO_2 + 4H_2O$	0.746 1.02
Carbon monoxide CO	$2CO + O_2 \rightarrow 2CO_2$	1.229
Ethylene C_2H_4	$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$	1.115
Ethane C_3H_6	$C_3H_6 + 3\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$	1.06
Glycol $C_2H_6O_3$	$C_2H_6O_3 + 2\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$	1.22
Glucose $C_6H_{12}O_6$	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$	1.22
Hydrogen H_2	$2H_2 + O_2 \rightarrow 2H_2O$	1.23
Hydrazine N_2H_4	$N_2H_4 + O_2 \rightarrow N_2 + 2H_2O$	1.61
Methanol CH_3OH	$2CH_3OH + 3O_2 \rightarrow 2CO_2 + H_2O$	1.21
n- butane		1.08
Propane (LPG)	$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	1.09
Sodium	$4Na + 2H_2O + O_2 \rightarrow 4NaOH$	3.126
Zinc	$2Zn + O_2 \rightarrow 2ZnO$	1.65

Hydrogen and other fuels have been considered as fuel for future use. The important criteria of suitability of fuels for the fuel cells are

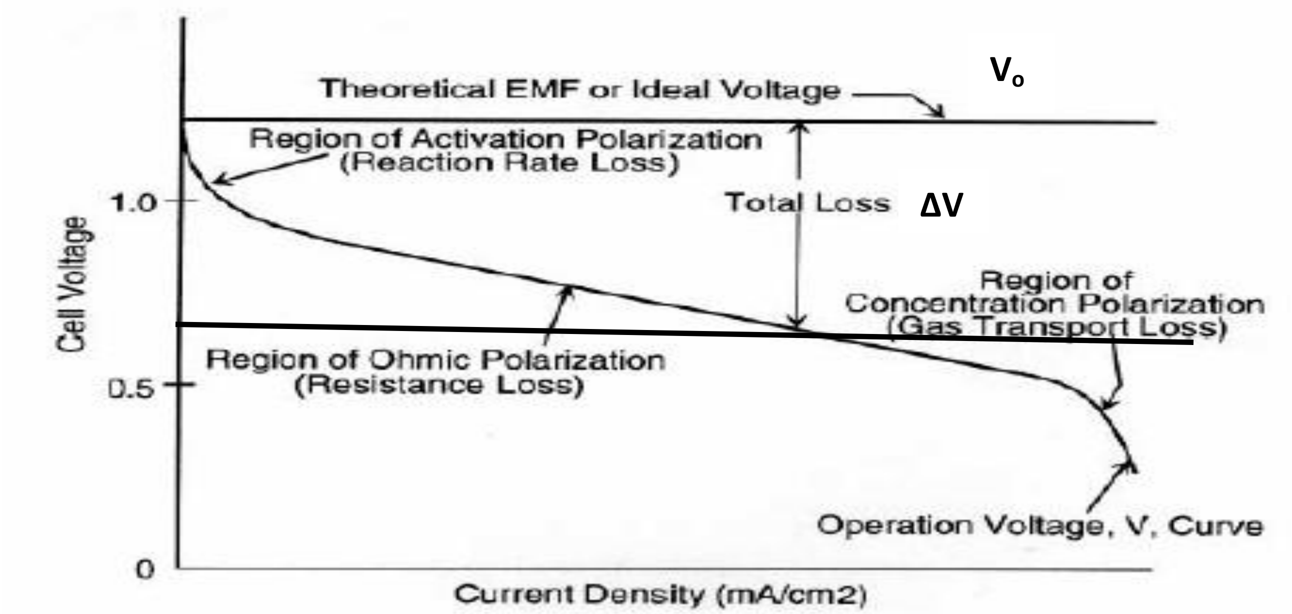
i) Energy density
ii) Free energy of reaction
iii) Market cost, cost per KWh of energy
iv) Chemical activity for reacting with oxidant
v) Physical properties, transportation and storage.

PERFORMANCE CHARACTRISITICS OF FUEL CELLS:

The performance evaluation of fuel cells is represented in terms of current density at electrode surface at specified temperature and reactant partial pressure and voltage. Increase in operating temperature and partial pressure, improves the fuel cell performance i.e. increases cell voltage V_c and current density I_d.

VOLTAGE V_C–CURRENT DENTSITY I_d CHARACTERISTIC (POLARISATION CURVE):

The performance of a fuel cell is evaluated by the cell voltage V_c vs. electrode current density I_d curve. Cell voltage drops with increase in current density due to polarization within the cell. Hence the curve is also called the polarization curve of the fuel cell.



Voltage current density characteristics Polarization curve

Polarization is internal chemical, electrical, thermal effect within the fuel cell resulting in inefficiencies. Polarization the cause of internal energy loss and is measured in terms of polarization voltage V_p.

$$\Delta V_p = V_o - V_c$$

Here ΔV_p is the polarization voltage of the cell = voltage drop

ΔV_p = no load voltage V_o – on load voltage V_c

As the load on the cell increases, the internal electrochemical reactions trying to oppose the cause also increase. The internal losses increases and the terminal voltage V_c drops. These internal losses and inefficiencies increasing with current are called polarization. The drop in voltage ΔV_p is called polarization voltage.

POWER PER CELL P_c:

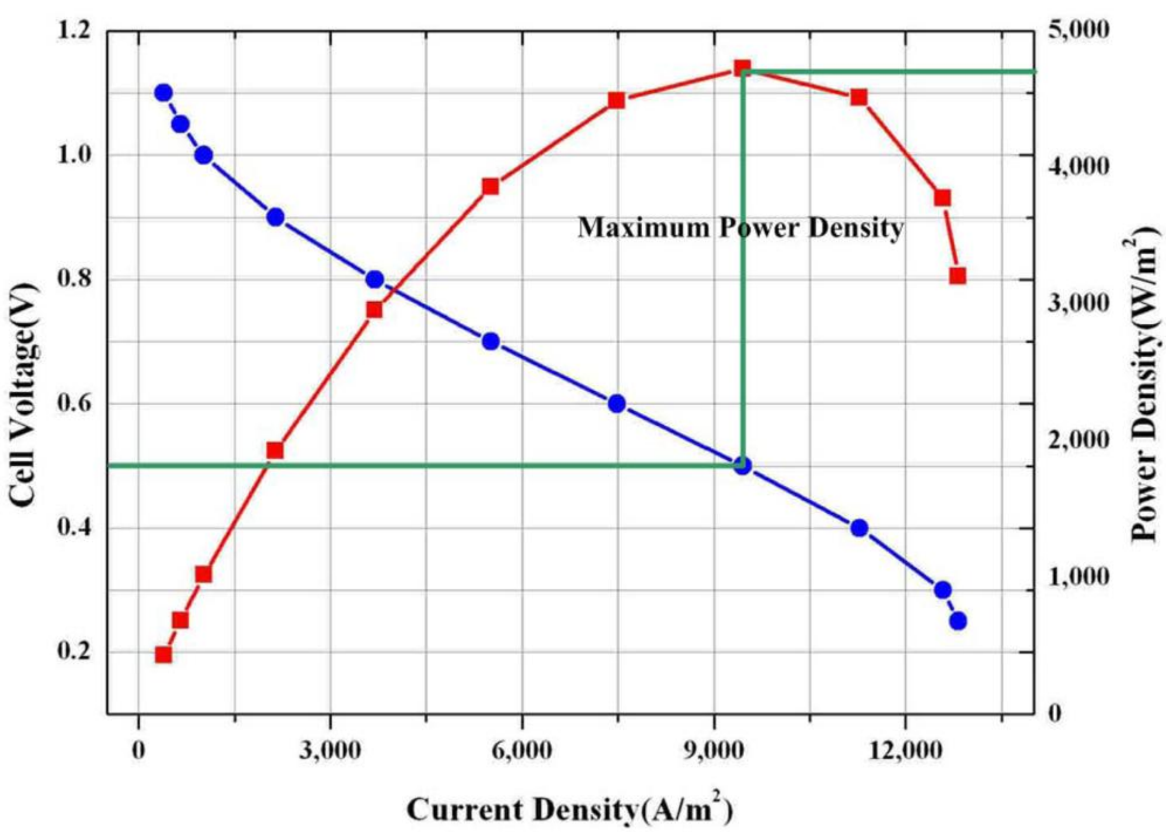
Power of the cell $P_c = V_c \times I_c$

Power of the cell increases with the increase in current density and reaches a saturation point due to polarization.

Input power – Polarization losses = Output power of the cell

The ratio of output power and input power gives efficiency η of the fuel cell.

$$\eta = \frac{Output\ power}{Input\ power}$$

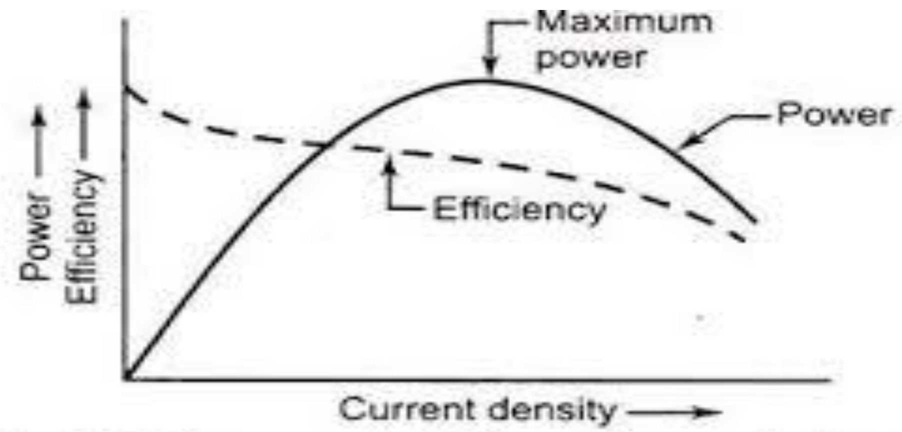


CELL EFFICIENCY;

$$\eta = \frac{Cell\ voltage\ on\ load}{No\ load\ volatge\ of\ the\ cell} = \frac{V_c}{V_o}$$

$$\eta = \frac{No\ load\ volatge - Polarization\ Voltage}{No\ load\ volatge\ of\ the\ cell}$$

The efficiency of the fuel cell varies with the current density at electrode surface due to the polarization effect.



Power and efficiency characteristics of a fuel cell.

The power loss is converted to west heat and released to atmosphere. After reaching saturation the power per cell starts decreasing. The losses increase and are converted to waste heat.

Example: A fuel cell has open circuit voltage of 1.2v, with the loading of 200mA/cm^2, the terminal voltage was 0.108v. Calculate the fuel cell efficiency at the load. (**Ans = 0.9)**