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Exergy Analysis of 1.2 kW Nexa™ Fuel Cell Module

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1. Introduction

There are two key problems with continued use of fossil fuels, which provide about 80% of the world energy demand today. The first problem is that they are limited in amount and sooner or later depleted. The second problem is that fossil fuels are causing serious environmental problems, such as global warming climate changes.

The fuel cell technology is friendly energy conversion with a high potential for environmental-ly. Fuel cells are ideally suited for applications that require electrical energy as the end. Fuel cell systems operate at higher thermodynamic efficiency than heat engines and turbines.

The fuel cell converts chemical energy directly into electricity by combining oxygen from the air with hydrogen gas without combustion. If pure hydrogen is used, the only material output is water and almost no pollutants are produced. Very low levels of nitrogen oxides are emitted, but usually in the undetectable range. The hydrogen can be produced from water using renewable energy forms like solar, wind, hydro or geothermal energy. Hydrogen also can be extracted from hydrocarbons, including gasoline, natural gas, biomass, landfill gas, methanol, ethanol, methane and coal-based gas.

Today, practical fuel cell systems are becoming available and are expected to attract a growing share of the markets for automotive power and generation equipment as costs decrease to competitive levels. Depending on the type of fuel cells, stationary applications include small residential, medium-sized cogeneration or large power plant applications. In the mobile sector particularly low-temperature fuel cells, can be used for passenger vehicles, trains, boats, and air planes [1-2].

Proton Exchange Membrane (PEM) fuel cell: Proton Exchange Membrane (PEM) fuel cells are currently the most promising type of fuel cell for automotive use and have been used in the

majority of prototypes built to date. PEM fuel cells (membrane or solid polymer) typically operated at relatively low temperatures (~50-100°C), have high power densities, can vary their output quickly to meet shifts in power demand, and are suited for many applications.

PEM fuel cells used an electrolyte such as conducted hydrogen ions from the anode to cathode. The electrolyte is composed of a solid polymer film that consists of a form acidified Nafion membrane. The membrane is coated on both sides with highly dispersed metal alloy particles (mostly platinum or platinum alloys) that are active catalysts. Hydrogen is fed to the anode side of the fuel cell where, due to the effect of the catalyst, hydrogen atoms release electrons and become hydrogen ions (protons). The electrons travel in the form of an electric current that can be utilized before it returns to the cathode side of the fuel cell where oxygen is fed. The protons diffuse through the membrane to the cathode, where the hydrogen atom is recombined and reacted with oxygen to produce water, thus completing the overall process [3].

In this work, we will focus on the efficiency of a PEM fuel cell system at variable operating conditions such as working temperature, pressure and air stoichiometry. Determination of an effective utilization of a PEM fuel cell and measuring its true performance based on thermodynamic laws are considered to be extremely essential. Thus, it would be very desirable to have a property to enable us to determine the work potential of a given amount of energy at power plant. This property is exergy, which is also called the availability or available energy.

In an energy analysis, based on the first law of thermodynamics, all forms of energy are considered to be equivalent. The loss of quality of energy is not taken into account.

An exergy analysis, based on the first and second law of thermodynamics, shows the thermodynamic imperfection of a process, including all quality losses of materials and energy, including the one just described. An energy balance is always closed as stated in the first law of thermodynamics. There can never be an energy loss, only energy transfer to the environment in which case it is useless. From the second law of thermodynamics, the exergy analysis of the irreversibility of a process due to increase in entropy. Exergy is always destroyed when a process involves a temperature change. This destruction is proportional to the entropy increase of the system together with its surroundings. Therefore, exergy is a property of the system–environment combination and not of the system alone.

Theoretically, the efficiency of a PEM fuel cell based on the first law of thermodynamics makes no reference to the best possible performance of the fuel cell, and thus, it could be misleading. On the other hand, the second law efficiency or exergetic efficiency of a PEM fuel cell, which is the ratio of the electrical output over the maximum possible work output, could give a true measure of the PEM fuel cell performance. Energy analysis performed on a system based on the second law of thermodynamics is known as exergy analysis [4-8].

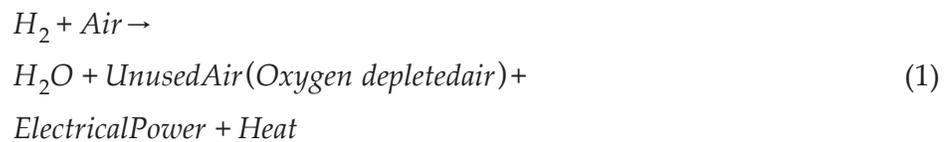
2. Exergy analysis of 1.2kW Nexa™ PEM fuel cell

Exergy analysis is a thermodynamic analysis technique based on the second law of thermodynamics, considering of all components and parametric in the system.

In particular, exergy analysis yields efficiencies which provide a true measure of how nearly actual performance approaches the ideal, and identifies more clearly than energy analysis the causes and locations of thermodynamic losses. Consequently, exergy analysis can assist in improving and optimizing designs. A main aim of exergy analysis is to identify exergy efficiencies and the causes of exergy losses. The exergy of a system is defined as the maximum shaft work that can be done by the composite of the system and a specified reference environment. Typically, the environment is specified by stating its temperature, pressure and chemical composition.

Exergy efficiency: Exergetic efficiency, which is defined as the second law efficiency, gives the true value of the performance of an energy system from the thermodynamic viewpoint. The exergy efficiency of a fuel cell system is the ratio of the electrical output power and actual exergy.

Actual exergy defined as difference between the exergy of the reactants (hydrogen + air) and the exergy of the products (air + hydrogen). In the PEMFC module, a basic reaction occurs as below.



The exergy efficiency of a fuel cell system is the ratio of the power output, over the exergy of the reactants (hydrogen + air), which can be determined [9-11] by following formula:

$$\begin{aligned}
 \eta_{exergy\ system} &= \frac{Electrical\ output\ power}{Actual\ exergy} \\
 \eta_{exergy\ system} &= \frac{Electrical\ output\ power}{(Exergy)_R - (Exergy)_P} = \\
 &\frac{\dot{W}_{elect}}{(\dot{E}_{air,R} + \dot{E}_{H_2,R}) - (\dot{E}_{air,P} + \dot{E}_{H_2O,P})}
 \end{aligned}
 \tag{2}$$

where: \dot{W}_{elect} – electrical output power [kW]; $\dot{E}_{air,R}$, $\dot{E}_{H_2,R}$, $\dot{E}_{air,P}$, $\dot{E}_{H_2O,P}$ – total exergies of the reactants [kW]; air and hydrogen, and the products air and water, respectively.

Electrical output power: The electrical power (gross power) production is the sum of the parasitic load (i.e. the NEXA™ blower, compressor, and control system load) and the external load (e.g. residential load).

$$\dot{W}_{elect} = \dot{W}_{para} + \dot{W}_{net}
 \tag{3}$$

The external load (\dot{W}_{net} -net power) is calculated directly from the voltage and current measured at the load.

$$\dot{W}_{net} = I_{net} \cdot V_{net} \quad (4)$$

where: I_{net} -current measured at the external load (A) , V_{net} -voltage measured at the external load (V) .

Assuming all hydrogen is reacted, for every mole of hydrogen consumed, two moles of electrons become available. Using Faraday's constant (F), the mass flow rate of hydrogen \dot{m}_{H_2} and the number of cells in the stack, a theoretical current for the NEXA™ power module can be found using following equation:

$$I_{Nexa} = \frac{2 \cdot F \cdot \dot{m}_{H_2}}{47} \quad (5)$$

The total theoretical electrical power output of the Nexa can be computed using the voltage of the stack (V_{Nexa}).

$$\dot{W}_{elect} = I_{Nexa} \cdot V_{Nexa} \quad (6)$$

Parasitic loads are estimated as the difference between the primary load and the theoretical electrical power calculated from fuel consumption because power consumption by the individual NEXA™ Sub systems was not measured.

Actual exergy: We already know it before, that the actual exergy is a difference between the exergy of the reactants and the exergy of the products. So intend to calculate the actual exergy we must to know the sub exergies (total exergy). The total exergy of the reactants and the products can be determined through the following equations:

$$\dot{E}_{air,R} = \dot{m}_{air,R} (ex_{ch} + ex_{ph})_{air,R} \quad (7)$$

$$\dot{E}_{H_2,R} = \dot{m}_{H_2,R} (ex_{ch} + ex_{ph})_{H_2,R} \quad (8)$$

$$\dot{E}_{air,P} = \dot{m}_{air,P} (ex_{ch} + ex_{ph})_{air,P} \quad (9)$$

$$\dot{E}_{H_2O,P} = \dot{m}_{H_2O,P} (ex_{ch} + ex_{ph})_{H_2O,P} \quad (10)$$

where: ex_{ph} - physical exergy [kJ / kg] ; ex_{ch} - chemical exergy [kJ / kg] ; \dot{m} – mass flow rates of the reactants and products [kg / s] .

Physical exergy: Physical exergy, known also as thermo mechanical exergy, is the work obtainable by taking the substance through reversible process from its initial state (T, P) to the state of the environment (T_o, P_o). The general expression of the physical exergy can be described as:

$$ex_{ph} = (H - H_o) - T_o(S - S_o) \quad (11)$$

where: H -enthalpy[kJ / kg]; H_o -specific enthalpy at standard condition[kJ / kg]; S - entropy [kJ / kgK]; S_o - specific entropy at standard condition[kJ / kgK]; T_o - ambient standard temperature [K];

The physical exergy of an ideal gas with constant specific heat c_p and specific heat ratio k can be written as:

$$ex_{ph} = c_p T_o \left[\frac{T}{T_o} - 1 - \ln \left(\frac{T}{T_o} \right) + \ln \left(\frac{P}{P_o} \right)^{\frac{k-1}{k}} \right] \quad (12)$$

where: P -pressure (atm), P_o – standard pressure (atm).

Chemical exergy: The chemical exergy is associated with the released of chemical composition of a system from that of the environment. Chemical exergy is equal to the maximum amount of work obtainable when the substance under consideration is brought from the environmental state (T_o, P_o) to the dead state (T_o, P_o, C_o) by processes involving heat transfer and exchange of substances only with the environment. The specific chemical exergy at P_o can be calculated by bringing the pure component in chemical equilibrium with the environment.

The chemical exergy can be calculated from [11, 12] as:

$$ex_{ch} = \sum x_n e_{ch}^n + RT_o \sum x_n \ln x_n \quad (13)$$

where: x_n - molar fraction of component n , e_{ch}^n – standard chemical exergy [kJ / kg]; R - universal gas constant [kJ / kmolK].

The chemical exergies of gaseous fuels are computed from the stoichiometric combustion chemical reactions. The standard chemical exergies of various fuels can found in the literature.

Mass flow rates of the products and the reactants: Depending on the power output (\dot{m}_{elect}), and a fuel cell voltage (V_{cell}), and the stoichiometry of air(), the mass flow rates of the reactants and the products in the fuel cell can be easily evaluated from the equations used by Larminie and Dicks.

To calculate the mass flow rate of reactant air, we must to know the oxygen usage firstly. From the basic operation of the fuel cell, we know that four electrons are transferred for each mole of oxygen. So oxygen usage can be evaluated through the following equation:

$$\begin{aligned} \text{Oxygen usage} &= \dot{m}_{O_2} \rightarrow \\ \dot{m}_{O_2} &= \frac{32 \cdot 10^{-3} \cdot \dot{W}_{elect}}{4 \cdot F \cdot V_{cell}} = 8.29 \times 10^{-8} \left(\frac{\dot{W}_{elect}}{V_{cell}} \right) \end{aligned} \quad (14)$$

At standard atmospheric conditions, the air molar analysis (%) would be: 77.48 N₂, 20.59 O₂, 0.03 CO₂ and 1.9 H₂O. Therefore molar proportion of air that is oxygen is approximately 0.21, and the molar mass of air is 28.97 · 10⁻³ kg mol⁻¹. So the air inlet flow rate or mass flow rate of reactant air can be evaluated through the following equation:

$$\begin{aligned} \text{Air inlet flow rate} &= \dot{m}_{air,R} \rightarrow \\ \dot{m}_{air,R} &= \frac{28.97 \cdot 10^{-3} \cdot \lambda \cdot \dot{W}_{elect}}{0.21 \cdot 4 \cdot F \cdot V_{cell}} = 3.57 \times 10^{-7} \left(\frac{\lambda \dot{W}_{elect}}{V} \right) \end{aligned} \quad (15)$$

The exit air flow rate or mass flow rate of the product air can be defined as the difference between the amount of air inlet flow rate and amount of oxygen usage:

Using equations (14), (15) this becomes:

$$\begin{aligned} \text{Exit air flow rate} &= \dot{m}_{air,P} \rightarrow \\ \dot{m}_{air,P} &= 3.57 \times 10^{-7} \left(\frac{\lambda \dot{W}_{elect}}{V} \right) - 8.29 \times 10^{-8} \left(\frac{\dot{W}_{elect}}{V} \right) \end{aligned} \quad (16)$$

The hydrogen usage or mass flow rate of reactant hydrogen is derived in a way similar to oxygen, except that there are two electrons from each mole of hydrogen. So hydrogen usage can be evaluated through the following equation:

$$\begin{aligned} \text{Hydrogen usage} &= \dot{m}_{H_2,R} \rightarrow \\ \dot{m}_{H_2,R} &= \frac{2.02 \cdot 10^{-3} \cdot \dot{W}_{elect}}{2 \cdot F \cdot V_{cell}} = 1.05 \cdot 10^{-8} \cdot \left(\frac{\dot{W}_{elect}}{V} \right) \end{aligned} \quad (17)$$

In a hydrogen-fed fuel cell, water is produced at the rate of one mole for every two electrons. The molecular mass of water is 18.02 · 10⁻³ kg mole⁻¹. The amount of water produced by the fuel cell can be calculated by the following equation:

$$\begin{aligned} \text{Water production} &= \dot{m}_{H_2O,P} \rightarrow \\ \dot{m}_{H_2O,P} &= \frac{18.02 \cdot 10^{-3} \cdot \dot{W}_{elect}}{2 \cdot F \cdot V_{cell}} = 9.34 \cdot 10^{-8} \cdot \left(\frac{\dot{W}_{elect}}{V} \right) \end{aligned} \quad (18)$$

Negligible to potential and kinetic energy effects on the fuel cell electrochemical process, the total exergy transfer per unit mass of each reactant and product consists of the combination of both physical and chemical exergies:

$$ex = ex_{ph} + ex_{ch} \quad (19)$$

3. Discussion and results

The exergy analysis of a PEM fuel cell system is defined on the 1.2kW Nexa™ PEM power module taken from Ballard Power Systems Inc, the Nexa™ module installed at Fuel Cell Laboratory, Institute of Physics and Technology, Mongolian Academy of Sciences in 2010.

Nexa™ power module description: This module is capable of providing 1.2kW of unregulated DC output. The output module voltage level can vary from 43V at no load to about 26V at the full load. By the way an increasing of load, we were taken the increasing data of the current density at real time. The designed operating temperature in the stack is around 65°C at the full load. There are totally 47 cells connected in series in the stack. A individual fuel cell element consists of two electrodes, the anode and the cathode, separated by a polymer membrane electrolyte. Each of the electrodes is coated on one side with a thin platinum catalyst layer. The electrodes, catalyst and membrane together form the membrane electrode assembly.

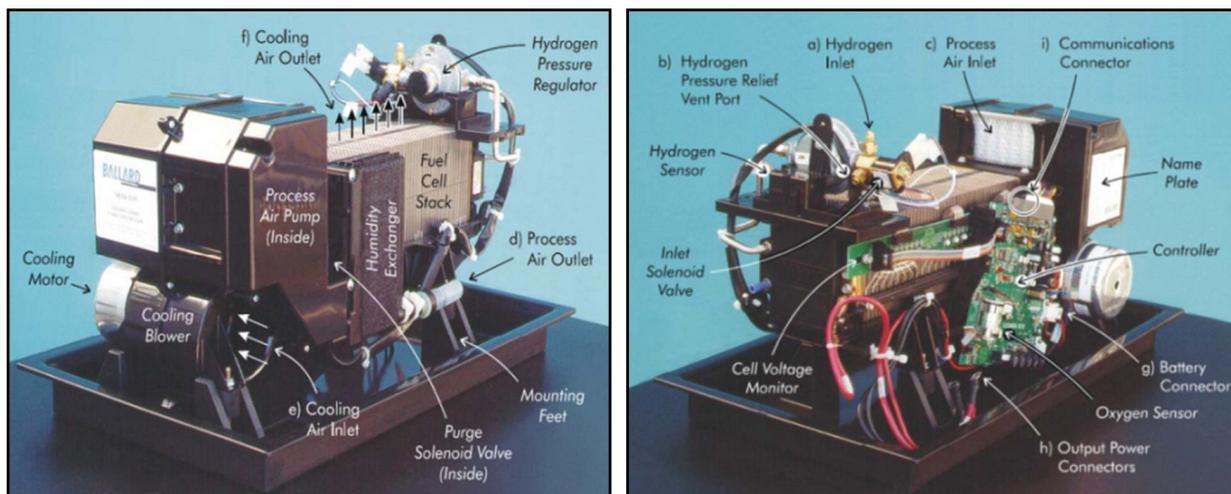


Figure 1. Main components and principle for operation of the Nexa™ PEM power module (Adapted from Ballard, Power systems inc., 2004).

A single fuel cell element produces about 1V at open-circuit and about 0.6V at full current output. The geometric area of the cells is 120 cm². The fuel is 99.99% hydrogen with no humidification, and the hydrogen pressure to the stack is normally maintained at 0.3 bar. Oxygen comes from the ambient air. The pressure of the oxidant air is 0.1 bar, and the air is humidified through a built in humidity exchanger to maintain membrane saturation and prolong the life of the membrane. Any drying of the PEM will greatly reduce the life of the fuel cell system. A humidity exchanger transfers both fuel cell product water and heat from the wet cathode outlet to the dry incoming air. The excess product water is discharged from

formance of certain key fuel cells, which are termed “purge cells”. In response to the purge cell voltage, a hydrogen purge valve at the stack outlet is periodically opened to flush out inert constituents in the anode and restore performance. Only a small amount of hydrogen purges from the system, less than one percent of the overall fuel consumption rate. Purged hydrogen is discharged into the cooling air stream before it leaves the Nexa™ system, as shown in Figure 2. Hydrogen quickly diffuses into the cooling air stream and is diluted to levels many times less than the lower flammability limit. The hydrogen leak detector, situated in the cooling air exhaust, ensures that flammable limits are not reached.

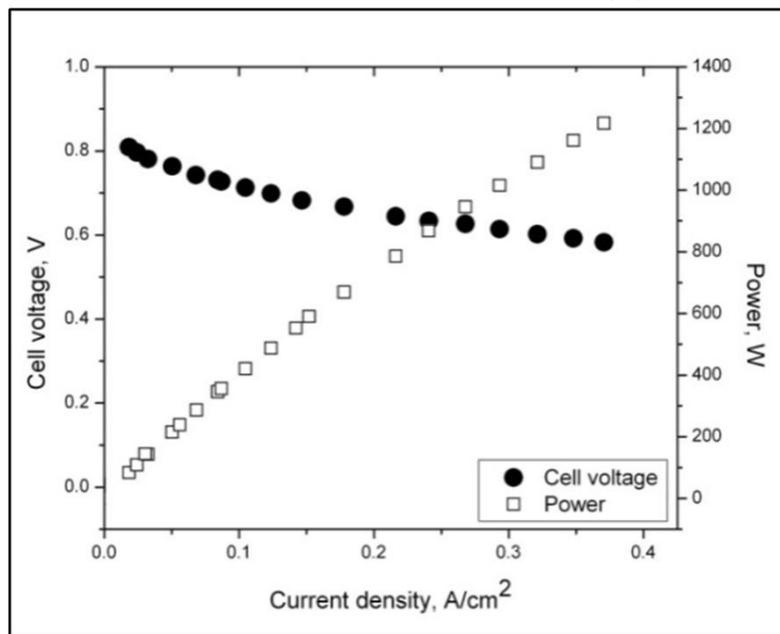


Figure 3. Polarization, power density curves at different temperatures and with different gas flows.

At high current levels, more heat is generated. It is important to keep the fuel cell stack temperature at a constant operating temperature; therefore, the fuel cell stack temperature has to be controlled. Fuel cell systems are either liquid-cooled or air-cooled. The Nexa™ fuel cell stack is air-cooled. A cooling fan located at the base of the unit blows air through vertical cooling channels in the fuel cell stack. The fuel cell operating temperature is maintained at 65°C by varying the speed of the cooling fan. The fuel cell stack temperature is measured at the cathode air exhaust, as shown in Figure 2. Hot air from the cooling system may be used for thermal integration purposes. Heat rejected in the air can be used for integration with metal hydrides, for evolving hydrogen. Hot air may also be used for space heating in some cases. The cooling system is also used to dilute hydrogen that is purposely purged from the Nexa™ module during normal operation.

Nexa™ system operation is automated by an electronic control system. The control board receives various input signals from onboard sensors. Input signals to the control board in-

clude: fuel cell stack temperature, hydrogen pressure, hydrogen leak concentrations, fuel cell stack current, air mass flow, fuel cell stack voltage and purge cell voltage.

Exergy analysis of NEXA™ fuel cell module: The analysis is conducted on cell operating voltages from 0.001 to 0.84 V at air stoichiometries from 13.0 to 2.1 in order to determine their effects on the efficiency of the fuel cell. The calculations of the physical and chemical exergies, mass flow rates and exergetic efficiency are performed at *temperature ratios* (T/T_0) (*Exit air flow rate = Air inlet flow rate - oxygen usage*) and *pressure ratios* (P/P_0) ranging from 0.93 to 1.13 and 7.44 to 4.91, respectively.

In Figure 3 shown calculated load characteristics represent cell voltage depending on current density (I-V curve).

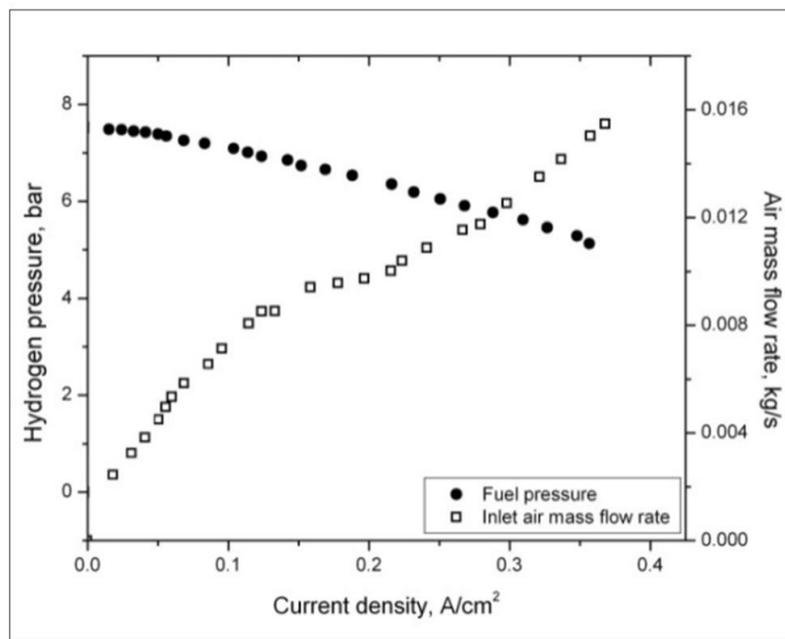


Figure 4. Reactants flow rates and hydrogen pressure of Nexa™ fuel cell module.

From the measured data, we calculated the cell voltage and current density by Eq. (19), Eq. (20).

$$V_{cell} = \frac{V}{47} \quad (20)$$

$$J = \frac{I}{120} \quad (21)$$

where: V – output voltage [V]; 47 – number of stack, J – current density [A/cm²]; I – output current [A]; 120 – geometric area of the cell [cm²].

In Figure 4 illustrated the dependence of hydrogen pressure and mass flow rates of the inlet air. Mass flow rates of the inlet air and hydrogen were calculated from Eq. (15, 17), respec-

tively. Hydrogen pressure data and air stoichiometric ratio values we taken from measured data. With increasing current density the hydrogen pressure decreases and its inlet air mass flow rate increases as shown in Figure 4.

Variation of stoichiometric air ratio (λ) illustrated in Figure 5a. The mass flow rate of the product air, can be defined as the difference between the amount of oxygen in the electrochemical reaction and the amount of oxygen consumed by reacting with hydrogen to produce water. The products, water flow rate and unused air calculated through Eq. (16, 18), respectively.

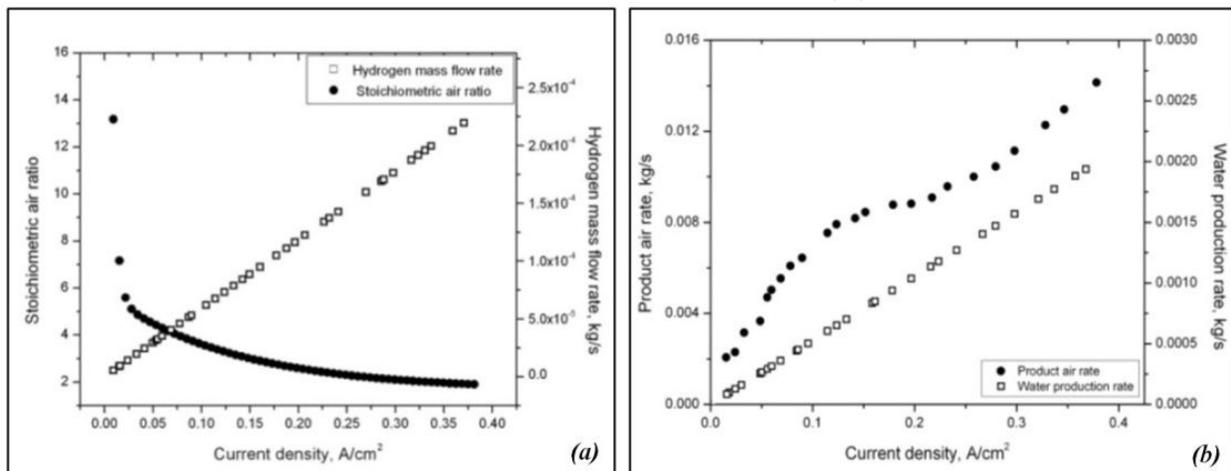


Figure 5. (a) Hydrogen mass flow rate and stoichiometric air ratio (b) Products flow rates of Nexa™ fuel cell module.

In Figure 5b illustrated, water production rate has small amount and production air rate increases depending on current density increase. Values of the chemical exergies for both the reactants and products are taken from published literature [10] and presented in Table 1.

Reactant/Product	Chemical exergy, ex_{ch} (kJ/kg)				
	Reactant Air	Reactant H ₂	Product H ₂ O	Product Air	Reactant O ₂
Nexa™ module	0	159138	2.5	8.58	-
MEA by Pt/MWCNT catalyst	-	159138	2.5	0	246

Table 1. Chemical exergy of the reactants and products of Nexa™ module and MEA by Pt/MWCNT catalyst.

The physical exergies of product water and product air calculated from Eq. (11, 19) was used to determine the physical exergies of inlet air and hydrogen. The values of fuel pressure and operation temperature taken from measured data.

The total exergy of the reactants and the products can be determined Eq. (15-18).

Finally, exergy efficiency was calculated by Eq. (2). The energy efficiency of the system can be calculated from Eq. (17) using the experimental \dot{W}_{net} and $\dot{m}_{H_2,R}$ data [7]:

$$\eta_{energy,system} = \frac{\dot{W}_{elect}}{(HHV_{H_2} \cdot \dot{m}_{H_2})_R} \quad (22)$$

where: HHV – higher heating value [MJ/kg]; $\dot{m}_{H_2,R}$ – reactant hydrogen mass flow rate which calculated by Equation (17).

Figure 6 illustrated the power productions and calculated energy, exergy efficiencies at different current density values. It can be seen that energy and exergy efficiencies decreases while power production increases.

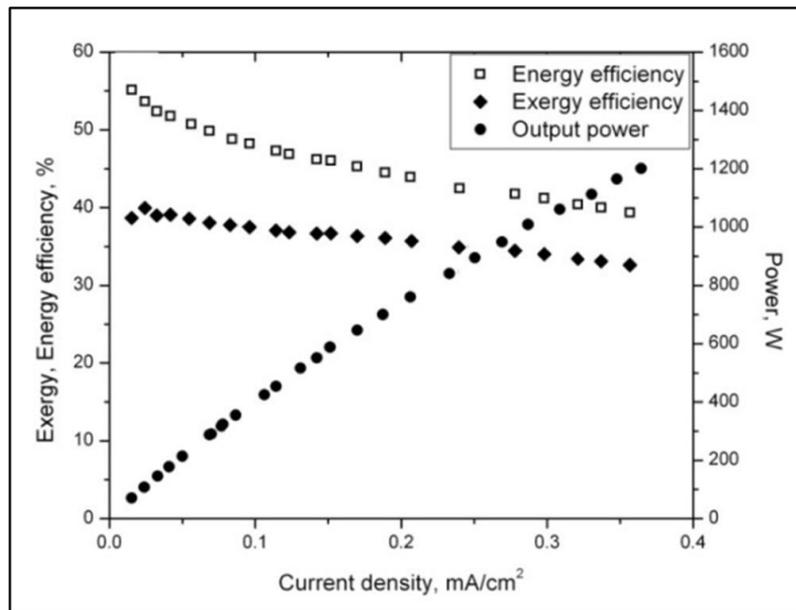


Figure 6. Energy, exergy efficiency and power of Nexa™ fuel cell module depending on current density.

Energy and Exergy efficiency of 1.2 kW Nexa™ power module decreases depending on current density increases. Energy efficiencies vary between 41 – 55%, exergy efficiency from 33% to 42% at the current density of 0.02 - 0.36A/cm² respectively. From the Figure 6, increasing of flow rates and decreasing of hydrogen pressure caused to the decreasing of the energy and exergy efficiencies of the module.

Fabrication of Membrane-electrode assembly by the synthesized Pt/MWCNT catalyst: The preparation of the MEA was carried out using a Nafion® 117 membrane from Dupont. For both electrodes an ink solution was prepared using a method slightly modified from the one reported by Gottesfeld et al., [14]. MEAs with an active electrode area of 25 cm² were fabricated by air-brushing the catalyst ink onto one side of the Nafion membrane, heated to and kept at 120 °C. For the cathode, 100 mg of the catalyst were dispersed in 0.5 ml ultrapure water, isopropanol

and 1 ml Nafion® 5 % solution under sonication. The dispersion was stirred with a high shear mixer at 7000 rpm. For the anode, 200 mg of Pt on carbon (20 wt% Pt, Alfa Aesar HISPEC® 3000) were dispersed in 4 ml of H₂O and 2 ml isopropanol. 1.2 ml of Nafion® 5 % solution was added, and the solution was dispersed by sonication and stirred with a high shear mixer. The inks were filled into an airbrush pistol (Evolution by Harder & Steenbeck) and sprayed successively onto the heated membrane surface, allowing each layer to dry for 10 seconds. Hydrogen and oxygen or air reactants are fed to the anode and cathode compartments, respectively, with or without pre - humidifying. Usually, the cell is conditioned by operating at low loading to activate the MEA. After that, the polarization curve is recorded galvanostatically by stepping the current from zero to the maximum test current density (Figure 7). The polarization curve is effective and intuitional to characterize the performance. However, separation of the electrochemical and ohmic contributions to polarization requires additional experimental techniques. This can be done by measuring the electrochemical impedance spectroscopy. The flow rates of both gases were adjusted to H₂/O₂ 55/25 sccm and 83/38 sccm, respectively, and the cell temperatures varied between 25°C, 50°C, and 65°C. Hydrogen was loaded with water in a humidifier (25 °C) and fed into the anode. The voltage at each current density is allowed to stabilize before measurement. MEAs were conditioned overnight until a steady state current achieved at a potential of 0.6V. The operation of the fuel cell test station was controlled and monitored by LabView programs [15].

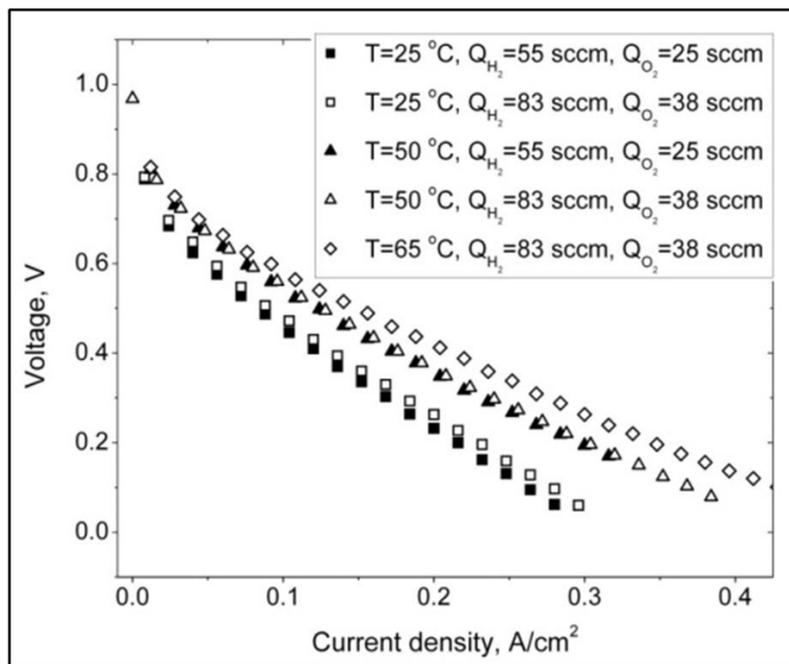


Figure 7. Polarization and power density curves at different temperatures and with different gas flows.

Exergy analysis on the Membrane-electrode assembly by the synthesized Pt/MWCNT catalyst: Based on this exergy analysis of Nexa™ power module, we calculated the exergy efficiency on membrane-electrode assembly by the synthesized Pt/MWCNT catalyst. The MEAs fabri-

cated from the Pt/MWCNT performed well, and the polarization curves and power densities in different operation conditions can be found in Figure 7.

At the current density up to 0.2 A/cm^2 , the exergy efficiency decreases from 72% to 35% as shown in Figure 8. We can explain that the exergy efficiency of 72% at the low current density is caused by the only one MEA and to feed pure oxygen (O_2). Therefore, the activation loss is main effect to the rapid decrease of the exergy efficiency.

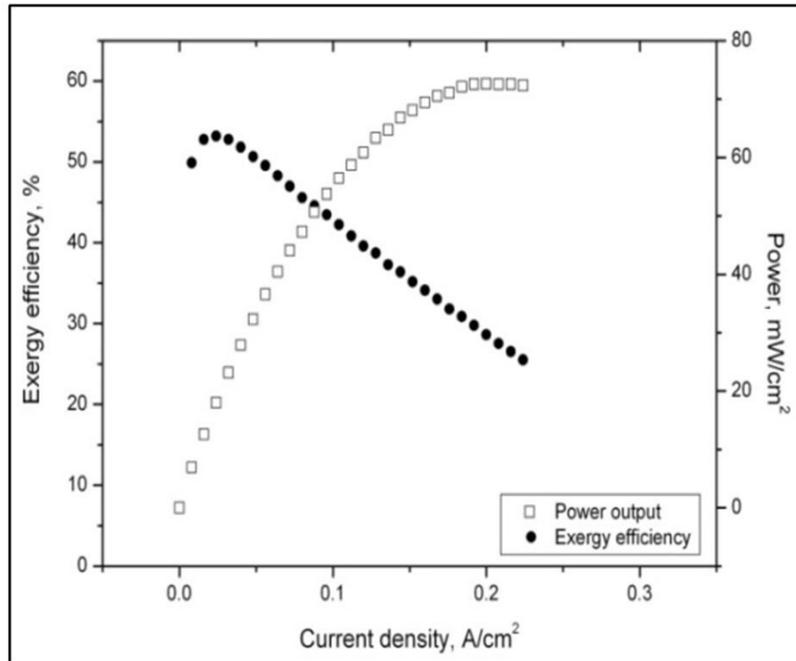


Figure 8. Exergy efficiency and power output of PEM fuel cell.

4. Conclusion

We performed the exergy analysis of 1.2 kW Nexa™ power module at variable operating conditions such as a different temperatures, pressures, cell voltages and stoichiometry.

The total exergy of the reactants and the products consist of both physical and chemical exergies, which are calculated for each element in the electrochemical process. Through the experimental data, we were calculated flow rates, energy efficiency, physical, chemical exergy and exergy efficiency.

The results provided that exergy efficiencies of the PEM fuel cell module less than energy efficiencies. From our calculation, it is recommended that the PEM fuel cell should operate at stoichiometric ratios less than 4 in order to optimize the relative humidity level in the product air and to avoid the membrane drying out at high operating temperatures. Exergy efficiency of the NEXA™ PEM fuel cell can be improved through increasing the fuel cell op-

erating temperature (in our case up to 72°C), and improved by a higher operating pressure. From the result of the exergy efficiency of membrane - electrode assembly of the Pt/MWCNT higher than Nexa™ power module, it might be explained fed pure oxygen (O₂), in other hand a high air stoichiometry could be improve a fuel cell exergetic efficiency.

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