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CLEAN CHEAP AND COMPACT (3C) POWER GENERATION SYSTEM FOR MOBILE AND PORTABLE APPLICATION: PEM FUEL CELL

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ABSTRACT

The main objective of this paper is to develop a PEMFC for mobile and portable application using methanol as the fuel sources. From the economic view of point, this design is very competitive with conventional internal combustion engine, ICE. The advantage of fuel cell usage is able to reduce the environmental pollution as well as the world demand of fossil fuels. The electricity cost was calculated as RM 0.16kWh^{-1} compared to the current existing cost of TNB as RM 0.218kWh^{-1}

INTRODUCTION

One of the most promising power plant technologies for zero emission vehicles is the polymer electrolyte membrane fuel cell (PEMFC). However, the lacks of safe, efficient and cost effective hydrogen storage as well as the difficulty of separation and sequestration of the CO produced during H_2 production, hamper the diffusion of hydrogen as an energy carrier. Methanol is chosen as the fuel source because it is the most promising organic fuel compared to hydrogen: high solubility in aqueous electrolytes, high availability at low cost, easily handled as well as transported and stored and high theoretical density of energy (6 kWh/kg).

SYSTEM DESCRIPTION

Figure 1 shows the schematic diagram of a PEMFC system. The main electric power generator in the system is the fuel cell stack (that contains the anode, cathode, PEM and cooling plates) as shown in the diagram. Fuel gas containing H_2 is fed to the anode side and oxygen (or air) is fed to the cathode side of the stack. The spent fuel gas and the gas leaving the fuel cell stack are referred to as the anode exhaust and cathode exhaust, respectively.

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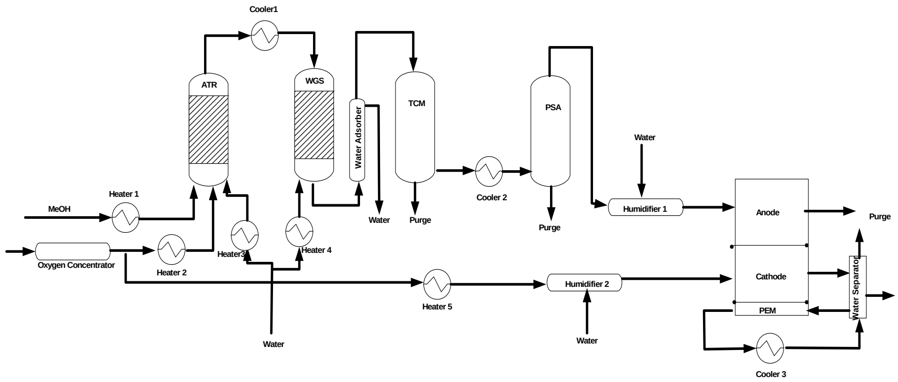

Figure 1: The Proposed Schematic Diagram Of PEMFC System In This Study

The ATR involves in producing H_2 from methanol and steam with co-feeding with oxygen. The conversion of auto-thermal methanol steam to hydrogen combines two reactions namely, the highly endothermic steam reforming,

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2 \qquad (1)$$

And exothermic partial oxidation,

$$CH_3OH + 0.5O_2 \rightarrow CO_2 + 2H_2 + \text{(CO)} \qquad (2)$$

Both reactions produce hydrogen at different selectivity, carbon dioxide and carbon monoxide. Due to that, the selection of the feed ratio is very important in order to produce a high purity of hydrogen with necessary heat supply for the endothermic SR process by an exothermic POX. The other step of fuel processing is a water gas shift reaction (WGS). The WGS is also considered as secondary hydrogen producer and primary CO clean-up system. The carbon monoxide in the presence of steam will be converted to carbon dioxide and hydrogen. The selectivity of H_2 based on the CO in the feed stream to the WGS reactor is given by:

$$CO + H_2O \Leftrightarrow CO_2 + H_2 \qquad (3)$$

Reformate from the fuel processor units consists of hydrogen, carbon dioxide, carbon monoxide and residues of hydrocarbons. Since the anode catalyst of a proton electrolyte membrane fuel cell (PEMFC) is usually based on platinum, which can be easily poisoned by CO, a CO management system is required to lower the CO concentration to acceptable levels. In general, the CO content in the product hydrogen has to be below 20ppm in order to be used as the anode gas for the PEMFC. In this study, two separation units are introduced namely, the membrane unit (TCM) and adsorber (PSA). Both TCM and PSA will be operated in parallel to yield the product purity as 99.9% hydrogen and CO less than 20ppm. In the separation level, the rentantate stream from the TCM will be recycled back to the WGS. The last unit introduced in the system is the PEMFC. Generally the PEMFCs consists of three major components; anode, typically featuring a platinum or platinum-contain catalyst, a thin,

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solid polymeric sheet which acts as electrolyte, and a cathode, also platinum-catalyzed. The reactions in a hydrogen/oxygen fuel cell can be written as:

Anode: $2H_2 \rightarrow 4e^- + 4H^+$ (4)

Cathode: $4e^- + 4H^+ + O_2 \rightarrow 2H_2O$ (5)

Overall: $2H_2 + O_2 \rightarrow 2H_2O$ (6)

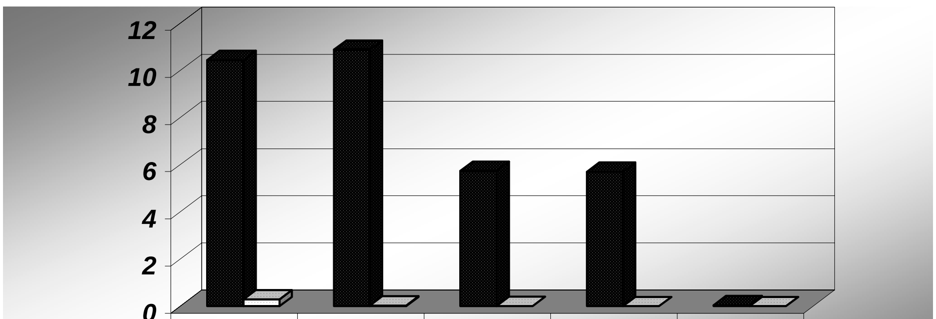
The fuel cell electricity cost, *EC*, is given as follows [1]:

$$EC = \left[\frac{\left(\frac{C_F\, AEP}{\overline{\eta}}\right) + \left\{ C_{fix} + C_{cell}\left(\frac{\dot{W}}{V_C A_C A_{cell}}\right)\right\}\left(\frac{i_r (1+i_r)^{n_y}}{(1+i_r)^{n_y - 1}}\right)}{AEP} \right] \quad (7)$$

with C_F as the fuel cell cost, AEP as the annual fuel cost, $\overline{\eta}$ as the fuel cell effectiveness average, C_{fix} as the fuel stack cost, C_{cell} as the fuel cell cost, A_{cell} as the active surface area of the cell, i_r as the annual interest and n_y as the life span of the fuel cell.

RESULT AND DISCUSSION

Methanol is taken as a primary fuel source to the ATR system, which is fed together with steam and oxygen. The conceptual design indicates that if the mole ratio of O_2/MeOH is 0.20-0.25, then the hydrogen selectivity is around 2.5 – 2.6 for complete methanol conversion. With that the ratio of MeOH: H_20 and MeOH: O_2 are taken as 1:1.3 and 1:0.25, respectively. The conceptual design also proves that WGS reaction plays a very important role in the reduction of the CO produced in the ATR. In the conceptual design, the ATR product contains H_2: 73%, CO: 2%, and CO_2: 25%.



	ATR	WGS	TCM	PSA	STACK
■ H2	10.44	10.88	5.74	5.7	0.04
□ CO	0.2882	0.029	0.00299	0.00006	0.000006

Figure 2: The Output Flow Rate Of CO And H_2

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The CO level is then further reduced to less than 2000ppm in the WGS reactor. Hydrogen-rich reformate, which is produced by reforming primary fuels in the fuel processor system contains significant amount of CO, is further reduced by tubular ceramic membrane (TCM) and a pressure swing adsorber (PSA) in series. From the overall material balance, it is observed that the final concentration of hydrogen is purified to 99.99% with the concentration of CO is reduced to less than 10ppm before entering the fuel cell stack (refer to Figure 2). Finally this paper will calculate the overall heat balance of the system in order to calculate the power plant efficiency. The gross efficiency of the system is calculated as 49.3% while the net efficiency of the system after considering the parasitic load is estimated as 45.5% [2].

For economic point of view, an electricity cost comparison between this study and the previous ones are shown in Table 2 based on the information given in Table 1. The electricity cost in this study is estimated at RM 0.16 kWh^{-1}based on Equation (7). The cost value was found to be almost the same as the values found by other studies but the cost of fuel cell is very much cheaper compared to the local electricity cost, RM 0.218 kWh^{-1}

However, the fuel cell cost per kW has also been compared with the conventional combustion engine as shown in Table 3 and the fuel cell cost is found to be almost the same as the current conventional engine cost, *ICE*. The increased factor in the *ICE* cost from RM 2000 - 4000 to RM 4000 - 6000 was proven by [3] in their study. Therefore, the advantage is on the fuel cell usage rather than *ICE*. Furthermore, fuel cell usage is able to reduce the environmental pollution as well as the world demand of fossil fuels.

Table 1: Data For Electricity Cost Estimation

Parameter	**Value**
Power Output	5 kW
Hydrogen Cost	RM 40/GJ
Capacity Factor Of Fuel	0.9
Life time	5 years
Annual rate	7%

Table 2: Comparison Of Electicity Cost With Other Studies

References	**kWh^{-1} (RM)**
[4]	0.152-0.912
[5]	0.266
[6]	0.152
[7]	0.152
This Study	0.152

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Table 3: Cost Comparison Of PEM Fuel Cell System With ICE

References	System	RM
[8]	ICE	1,900-3,800
[9]	ICE	1,900-3,800
[10]	ICE	5,000-5700
[5]	ICE	3,800-4,560
This Study	PEMFC	3,800-5,700

CONCLUSION

From the economic view of point, this design is very competitive with conventional internal combustion engine, ICE. The advantage of fuel cell usage is able to reduce the environmental pollution as well as the world demand of fossil fuels. The electricity cost was calculated as RM 0.16kW^{j-1} compared to the current existing cost of TNB as RM 0.218kWj^{-1}

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