

Polypropylene Oil as a Fuel for Ni-YSZ | YSZ | LSCF Solid Oxide Fuel Cell

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Abstract. This research aims to convert polypropylene plastic to polypropylene oil through pyrolysis method and use the polypropylene oil as fuel for Solid Oxide Fuel Cell, SOFC, to produce electricity. The material for SOFC single cell are Ni-YSZ, YSZ, and LSCF as anode, electrolyte and cathode, respectively. YSZ is yttria-stabilized-zirconia. Meanwhile, LSCF is a commercial $\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_3$. The Ni-YSZ is a composite of YSZ with nickel powder. LSCF and Ni-YSZ slurry coated both side of YSZ electrolyte pellet through screen printing method. The result shows that, the produced polypropylene oil consist of C_8 to C_{27} hydrocarbon chain. Meanwhile, a single cell performance test at 673 K, 773 K and 873 K with polypropylene oil as fuel, found that the maximum power density is $1.729 \mu\text{W} \cdot \text{cm}^{-2}$ at 673 K with open circuit voltage value of 9.378 mV.

1.Introduction

In the last few decades, plastic production in the world growth rapidly. It allows a serious environmental problems due to plastic waste needs almost 100 years to degrade [1]. Therefore, the pyrolysis waste plastic to produce a liquid fuel will be a good alternative to solve the environmental problems and also to produce an alternative fuel for energy supply [2]. The previous research found that the pyrolysis of polypropylene plastics in a vacuum reactor at 673 K – 773 K produces some long hydrocarbon chains that can be isolated as oil [3]. However, the produced oil quality is still insufficient to be directly used to fuel motor vehicles. Therefore, to increase the utilization of polypropylene oil, SOFC as an electrochemical based-energy conversion might become a promising technique to convert the polypropylene oil into electricity. It is known that SOFC can convert many type of fuels into electricity without any concern of fuel purity.

SOFC has emerged as a new alternative energy resources with a high efficient power generation, clean energy conversion and low noise [4]. The SOFC operating temperatures depends on the functional material in the fuel cell, i.e., anode, cathode and electrolyte. The operating temperature can be defined into the low temperature SOFC (LT-SOFC) at 773 K – 923 K and the high temperature SOFC (HT-SOFC) at 1073 K - 1273 K [5]. In this research the polypropylene oil from polypropylene waste is



directly used as fuel for Ni-YSZ | YSZ | LSCF single cell at 673 K, 773 K and 873 K to investigate the performance of the single cell with polypropylene oil fuel by measure the power density ($\mu\text{W}\cdot\text{cm}^{-2}$) and the open circuit voltage (OCV).

2. Experiment

2.1. Pyrolysis of polypropylene oil

The drinking water bottle waste as polypropylene oil sources was cutted into little pieces and then was placed into the pyrolysis reactor and was heated at 673 K - 773 K [3]. The pyrolysis vapor was condensed by cooling water system and then collected in a container, as the polypropylene oil. The oil was analyzed by viscosity testing and Gas Chromatography Mass Spectroscopy (GCMS) (GC17A MSQP 5000 Shimadzu) to identify the molecular content in the oil.

2.2. Preparation of single cell

The YSZ (Yttria Stabilized-Zirconia) pellet were prepared by pressing with a hydraulic press. This research used a YSZ (Yttria Stabilized-Zirconia) (TOSOH), Nickel (Merck), (S)-(-)- α -Terpineol (Merck), Lanthanum Stronsium Cobalt Ferrite (Aldrich). The green pellets then were sintered at 1523 K for 2 hours. The Ni-YSZ electrode was produced by mix Ni powder and YSZ powder at weight ratio of 0.2:0.8 and then mixed with α - terpineol as solvent, to form a homogeneous slurry. The sintered YSZ pellet was coated at the one sides with the Ni-YSZ slurry by screen printing method and then sinter at 1273 K for 2 hours. The LSCF ($\text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_3$) electrode was produced by mix LSCF powder with α - terpineol as solvent, to form a homogeneous slurry. The YSZ pellet has diameter 10 mm and thickness 1.246 mm. The pellet was coated at the other sides with the LSCF slurry by screen printing method and then sinter at 1073 K for 2 hours, producing a single cell of Ni-YSZ | YSZ | LSCF. Figure 1 described the scheme of single cell Ni-YSZ | YSZ | LSCF.

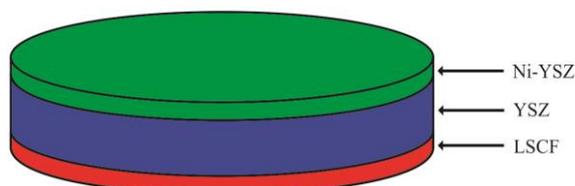


Figure 1. Single cell of Ni-YSZ | YSZ | LSCF

2.3. Testing of single fuel cell with polypropylene oil as fuel

Ag mesh equipped with Ag wire, was attached on both side of single cell with Ag paste as sealer. The Ag wire connected the cell with I-V meter (Microampere-volt Multimeter, Constant 88) and a potentiometer. The fuel cell test was conducted at 673 K, 773 K and 873 K with polypropylene liquid as fuel and oxygen in the air as oxidant. The polypropylene liquid was converted into gas by heating at 418 K. The gas would then flowed into fuel cell compartment to undergo gas reforming under high operational temperature.

3. Result and discussion

The polypropylene oil that was produced from pyrolysis was analyzed by GC-MS. The spectrum is described in Figure 2.

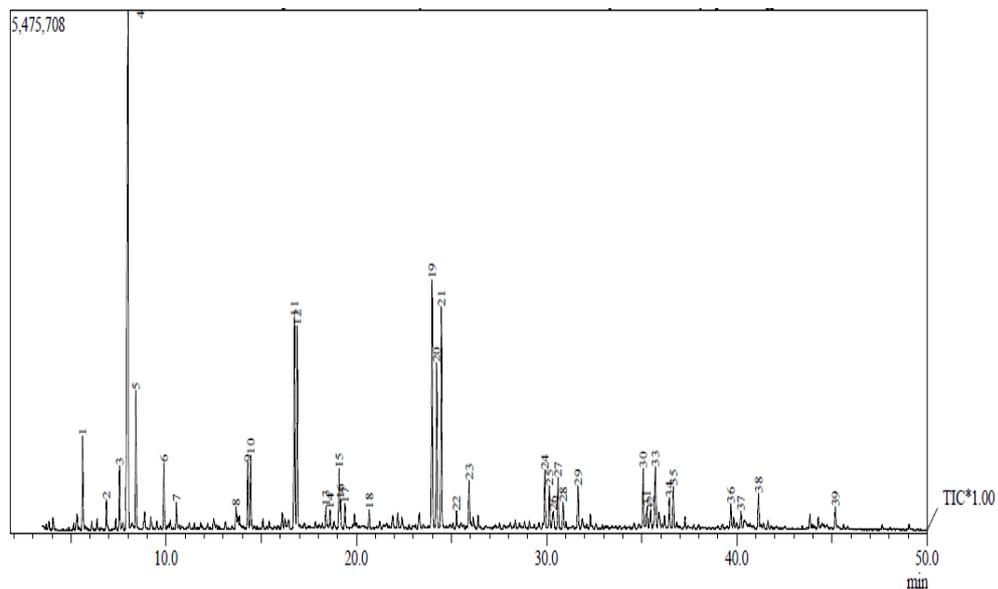


Figure 2. Chromatogram of polypropylene oil

The GC-MS spectrum in Figure 2 shows that the polypropylene oil consist of aliphatic and aromatic hydrocarbon chain compounds with carbon chains of C₈-C₉ dominates at 33.18%. Table 1 shows that the carbon chain ranging from C₈-C₂₇. Large range of chain number might be a problem during gas reforming due to different molecules size especially large molecules would be hard to degrade into smaller hydrocarbon molecules or even into hydrogen gas. Therefore, development on gas reforming process by supplying water steam should be considered. Increasing of gas reforming might increase redox reaction inside fuel cell, in which the oxygen in air reduce into oxygen ions and the hydrocarbon or the reformed product of hydrocarbon undergo oxidation at the anode side. As the reaction proceeds, the electrons flows would be detected as the electricity. The predicted reaction is described in equation (1) and (2) [6].



TABLE 1. The % area of carbon chain peaks as recorded in the polypropylene oil GC-MS

Compound	% Area
C ₈ -C ₉	33.18
C ₁₀ -C ₁₁	11.70
C ₁₂ -C ₁₃	26.09
C ₁₄ -C ₁₅	13.24
≥C ₁₆	16.42

The single fuel cell test produces I-V-P curves as shown in Figure 3, 4, and 5 at 673 K, 773 K, and 873 K. The I-V and I-P curves inform the open circuit voltage, OCV, value (mV) and the power density ($\mu\text{W}\cdot\text{cm}^{-2}$) of fuel cell.

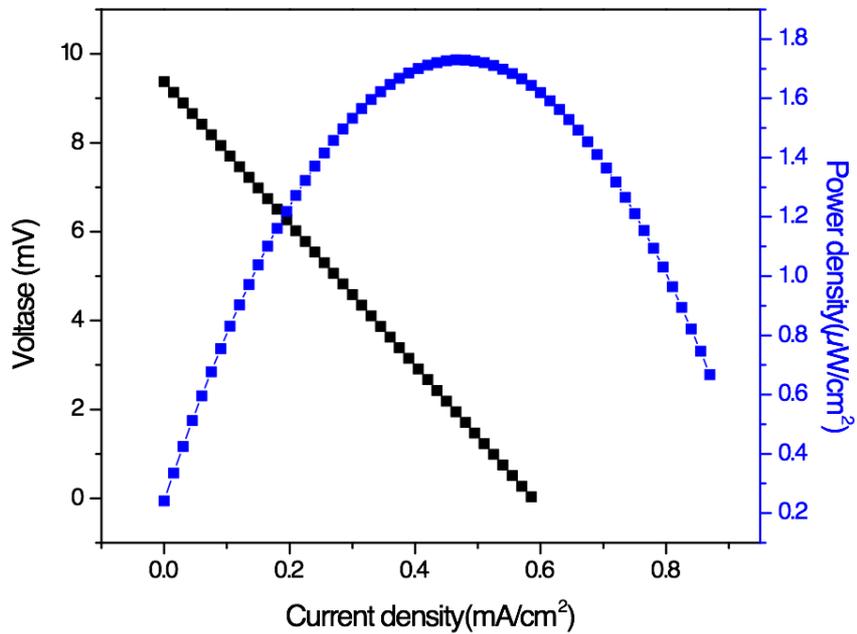


Figure 3. I-V-P curve as resulted from measurement of fuel cell test with polypropylene as fuel at 673 K

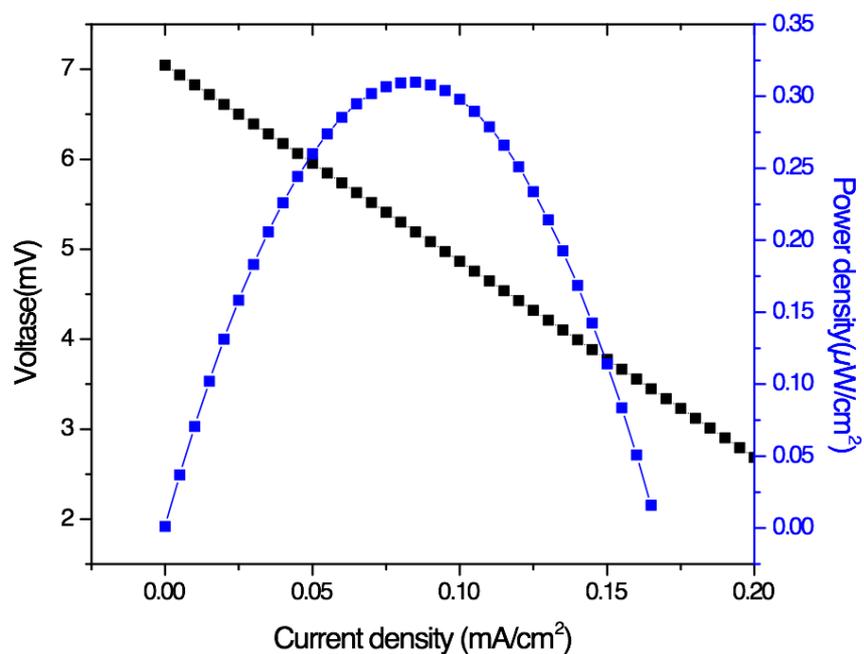


Figure 4. I-V-P curve as resulted from measurement of fuel cell test with polypropylene as fuel at 773 K

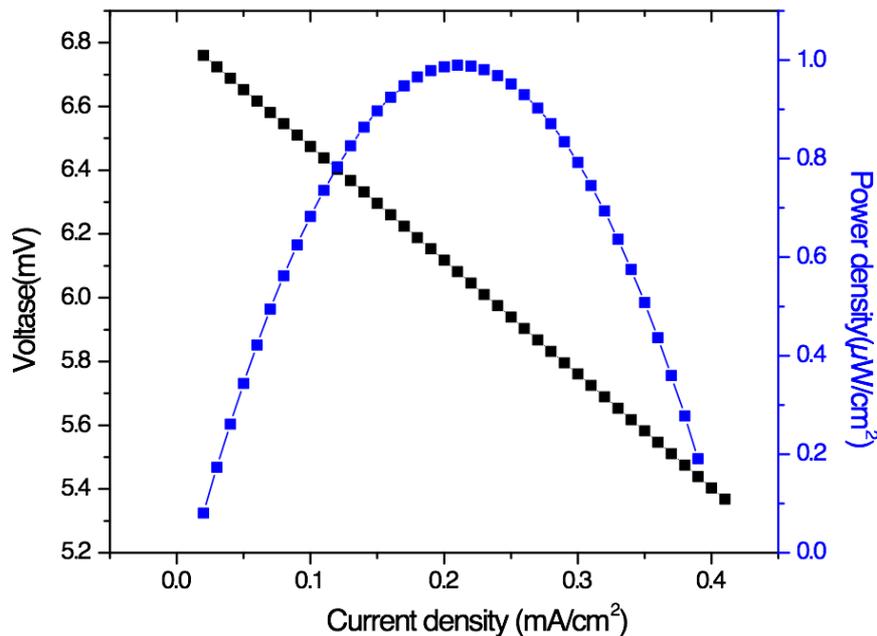


Figure 5. I-V-P curve as resulted from measurement of fuel cell test with polypropylene as fuel at 873 K

The result shows that the optimum power density is $1.729 \mu\text{W}\cdot\text{cm}^{-2}$ at 673 K with OCV of 9.378 mV (Figure 3). When the temperature is increased to 773 K, the power density decreased up to $0.309 \mu\text{W}\cdot\text{cm}^{-2}$. It also happen at the temperature 873 K, the power density decreased up to $0.989 \mu\text{W}\cdot\text{cm}^{-2}$ as shown in Table 2. It indicates that the functional material started to drop their performance when the temperature reach over 673 K. It is because, at a temperature more than 673 K, cracking occurs in the electrolyte material so that instead of ion migration, it occurs ion migration, thus decreasing the conductivity value.

The power density is too small compare to the Samarium Doped-Ceria (SDC)-Carbonate as electrolyte, as it was studied in the previous research using the same polypropylene oil, producing the power density of $0.3736 \text{ mW}\cdot\text{cm}^{-2}$ and OCV of 0.770 V at 773 K [3]. It is because YSZ has lower ionic conductivity than SDC at 673 K. YSZ has ionic conductivity $5 \times 10^{-6} \text{ S}\cdot\text{cm}^{-1}$ [7], SDC has $3.24 \times 10^{-5} \text{ S}\cdot\text{cm}^{-1}$ [8]. The high molecular weight of hydrocarbon consisted in the polypropylene oil i.e., C₈-C₂₇, that was produced by pyrolysis might also became a problem for gas reforming. High molecular fuel also has less diffusion into the functional material producing slow reaction during fuel cell operation. In addition, the number of steam released by 30% part of the polypropylene-water mixture seems does not sufficient for gas reforming. Furthermore, redox reaction inside fuel cell can be increased by supplying water steam.

TABLE 2. The OCV and power density value at various operational temperature

Temperature	Open circuit voltage (mV)	Power density maximum ($\mu\text{W}\cdot\text{cm}^2$)
673 K	9.378	1.729
773 K	7.048	0.309
873 K	6.831	0.989

4. Conclusion

Pyrolysis of polypropylene plastic waste produces liquid with fuel characteristics and has a hydrocarbon chemical compound ranging from C_8 - C_{27} . The result of the test of the resulting power conversion, obtained the maximum value at the operating temperature of 673 K at 1.729 mW/cm².

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