BIODIESEL FUELS CONVERSION TO HYDROGEN-RICH GAS AND ELECTRICITY WITH SOLID OXIDE FUEL CELL TECHNOLOGY

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Received: March 16, 2012

Abstract

Direct feeding of hydrocarbon fuels to Solid Oxide Fuel Cells (SOFCs) has attracted much attention in recent years. The aim of this paper is to investigate the viability of anode-supported type cells (Ni-ScSZ/ScSZ/LSM-ScSZ) operating with biodiesel fuels (BDFs) derived from Palm, Jatropha and Soybean oils, for realizing carbon-neutral power generation using fuel cells in the temperature range of 700 - 800^{o}C. The results demonstrated that in principle direct internal reforming (DIR) of BDFs in the SOFC anode is viable, but the content of unsaturated components in BDFs should be as lower as possible to suppress performance degradation. Palm-biodiesel, containing highest amount of saturated fatty acid methyl ester (FAME) among tested BDFs, had led to most stable SOFC operation, and the amount of deposited carbon was considerably small compared to the other fuels with higher degree of unsaturation.

Keywords: Steam Reforming, Biodiesel Fuel, Carbon Deposition, Direct Internal Reforming, Hydrogen Production, Solid Oxide Fuel Cell

Introduction

Nowadays, heat engines are used worldwide for transportation, manufacture, power generation, construction, and farming. However, the engines are a major contributor to environment pollution and climate change. In addition, fossil fuels could be spent only within several decades. Fuel cells are electrochemical devices that convert chemical energy directly into electrical energy without converting it to mechanical energy. Therefore, the fuel cell has potential of attaining higher electrical conversion efficiency than those of conventional technologies such as heat engines limited by Carnot efficiency. Besides, fuel cell systems can be operated with very low environmental emission levels due to their electrochemical conversion. Therefore, fuel cells are regarded as efficient and environmentally-friendly energy conversion system in the next generation. Most of fuel cells require hydrogen as a fuel, however the use of hydrocarbon fuels such as fossil fuels and biofuels is also desirable. Solid oxide fuel cell (SOFC) operated at high temperatures (600 - 900^{o}C) which allows direct oxidation of hydrocarbon fuels without external reformer attracts much attention [1-3]. Direct internal reforming (DIR) of hydrocarbon fuels has been reported including gaseous fuels such as methane [4-5], ethane [4], and butane [4, 6], and liquid fuels such as n-decane [7], gasoline [8], synthetic diesel [7], crude and jet fuel oils [9]. In view of the exhaustion of fossil resources, the utilization of biomass sources as sustainable energy resources should be promoted more in large scale [10]. Biodiesel fuel (BDF) is an oxygenated fuel produced from biomass resources such as animal fat, plants, and waste-cooking oils. Biodiesel fuels have a high flash point, and their non-toxicity and biodegradability make their handling and storage safer compared to petro-diesel fuel. While in the past decade the share of BDF increased as an alternative fuel to petro-diesel fuel for the diesel engine, BDF is also a promising feedstock for electricity generation by solid oxide fuel cell (SOFC) [11]. However, no preceding research which systematically addressed steam reforming of practical biodiesel fuel for electricity generation has been reported. Therefore, feasibility of DIR of BDFs, produced from Palm, Jatropha and Soybean oils, to SOFC is examined in this study. In this study, in order to evaluate the potential of these fuels for SOFC applications, anodic-off gas and cell voltages of DIRSOFC running on BDFs were measured at various SOFC operating temperatures between 700 and 800^{o}C, at S/C = 3.5.

Experimental

Biodiesel Fuels Used in This Study

In this study, Palm-biodiesel fuel (Palm-BDF), Jatropha-biodiesel fuel (Jatropha-BDF) and Soybean-biodiesel fuel (Soybean-BDF) were produced from refined Palm, Jatropha Curcas Linn and Soybean oils, respectively, by the alkali catalysed trans-esterification reaction in a pilot scale reactor at Bandung Institute of Technology, Indonesia [12]. According to their analysis, following the ASTM methods, the fuels had almost the same physical and chemical properties as petroleum diesel fuel as shown in Table 1. The physical properties of these fuels met most of the specifications of ASTM D-6751 standard for biodiesel fuel.

Table 1. Physical Properties of the Tested BDFs

Parameter	Unit	Diesel	Palm-BDF	Jatropha-BDF	Soybean-BDF
Density, 40^{o}C	kg/l	0.825	0.860	0.864	0.864
Kinematic viscosity, 40^{o}C	cSt	3.28	4.50	4.40	4.17
Distillation, T90	^{o}C	330	336	347	349
Pour point	^{o}C	-	9	0	6
Cloud point	^{o}C	-	17	7	0
Sulphur content	ppm	-	1	7	<1
Phosphorus content	ppm	-	< 3	< 3	< 3
Cetane number		55-60	56.8	56.4	55.6
Acid value	mg-KOH/g	-	0.2	0.28	0.29
Ester content	%	-	99.3	94.0	97.5

The chemical compositions and impurities (Sulphur and Phosphorus) in the tested BDFs were analyzed in Shimadzu Inc., Japan. The biodiesel fuel is a complex mixture of various fatty acid methyl esters (FAME) as listed in Table 2. The main chemical compositions of the fuels were palmitic acid methyl ester (C16:0), oleic acid methyl ester (C18:1), and linoleic methyl ester (C18:2). Table 3 shows the concentrations of saturated and unsaturated components in the respective BDFs and their average structures. Palm-BDF consisted mainly of 46.4 % of saturated FAME (main component was 39.9 % of palmitic acid methyl ester) and 40.7 % of mono-unsaturated FAME (main component was 40.4 % of oleic acid methyl ester). Jatropha- and Soybean-BDF contained higher amount of unsaturated FAME compared to Palm-BDF. Jatropha-BDF consisted mainly of 41.4 % of mono-unsaturated FAME (main component was 40.5 % of oleic acid methyl ester) and 31.5 % of di-unsaturated FAME (linoleic acid methyl ester). Soybean-BDF consisted mainly of 22.5 % of mono-unsaturated FAME (main component was 22.4 % of oleic acid methyl ester) and 53.9 % of di-unsaturated FAME (linoleic acid methyl ester). Soybean-BDF not only contained higher amount of di-unsaturated FAME compared to Jatropha-BDF but also contained rather high amount of tri-unsaturated FAME (5.28 % of linolenic fatty acid methyl ester). Amount of unsaturated FAME in BDF increases in order of Palm-BDF < Jatropha-BDF < Soybean-BDF. In this study, using these fuels the influence of the chemical compositions of the biodiesel fuels on hydrogen production properties and the related SOFC performance will be discussed.

Table 2. FAME Composition of the Tested BDFs

Components	Concentration / wt%		
	Palm-BDF	Jatropha-BDF	Soybean-BDF
C8:0	0.05	0.07	0.09
C10:0	-	-	0.05
C12:0	0.41	0.06	0.31
C14:0	1.08	0.07	0.17
C15:0	0.05	-	-
C16:0	39.9	13.7	10.7
C17:0	0.08	0.09	0.09
C18:0	4.35	0.09	3.19
C20:0	0.36	6.65	0.33
C22:0	0.08	0.07	0.41
C23:0	-	-	0.07
C24:0	0.05	-	0.11
C16:1	0.19	0.86	0.09
C18:1	40.4	40.5	22.4
C18:2	12.0	31.5	53.9
C18:3	0.21	0.17	5.28
C20:1	0.15	0.07	0.31

Table 3. Composition of Saturated and Unsaturated Components in the Tested BDFs

	Concentration / wt%		
	Palm-BDF	Jatropha-BDF	Soybean-BDF
Saturated	46.4	20.9	15.5
Mono-unsaturated	40.7	41.4	22.5
Di-unsaturated	12.0	31.5	53.9
Tri-unsaturated	0.21	0.17	5.28
Average structure	$C_{18.0}H_{34.8}O_2$	$C_{18.7}H_{35.0}O_2$	$C_{18.8}H_{34.5}O_2$

Fabrication of Single Cell of Solid Oxide Fuel Cell

Anode-supported half cells with a diameter of 20 mm (purchased from Japan Fine Ceramics, Japan) in which 10 mol% Sc_2O_3-1 mol% CeO_2-89 mol% ZrO_2 (scandia-stabilized zirconia abbreviated by ScSZ) electrolyte with a thickness of 30 μm was sintered on a porous anode support (mixture of NiO and ScSZ (NiO:ScSZ = 5.6:4.4)) with a thickness of 800 μm were used to fabricate single cells. A mixture of NiO (> 99.9 %, Kanto Chemical, Japan) and ScSZ (Daiichi Kigenso Kagaku Kogyo, Japan) powders with a weight ratio of 8:2 was screen-printed and subsequently sintered on the anode support at 1200 ^oC for 3 h as an anode current collector with the area of 8 x 8 mm^2. A mixture of $(La_{0.8}Sr_{0.2})_{0.98}MnO_3$ (> 99.9 %, Praxair,