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Experimental studies and techno-economic analysis of hydro-processed renewable diesel production in Taiwan

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ABSTRACT

For the purpose of promoting hydro-processed renewable diesel as the local replacements of traditional diesel and transestification biodiesel, the experimental investigation and techno-economic analysis were carried out in this study. The experiment was conducted with varying reaction temperature, pressure, weight hourly space velocity (WHSV) and H_2-to-oil ratio over the NiMo/γ-Al_2O_3 catalyst and the conversion, selectivity and yield were determined. The experimental conditions and results were input into process simulation model for determining the mass and energy flows at the scale of 600 tonnes per day. Furthermore, the techno-economic analysis was conducted based on the mass and energy balances obtained from process simulation, and the locally quoted capital and operating costs, yielding to the minimum renewable diesel price (MRDP) of $1.72/L. The effects of hydrogen, plant capacity, catalyst as well as the operating conditions on MRDP were demonstrated and discussed.

1. Introduction

Due to the emissions released from diesel-powered vehicles or machines, alternative diesels such as biodiesel, syndiesel and hydro-processed renewable diesel have been developed. It is reported that the greenhouse gas emissions was reduced by 6.4 million metric tons as the renewable diesel was applied [1]. As one of the renewable diesels, hydro-processed renewable diesel refers to a petrodiesel-like fuel derived from biological sources which are chemically not esters and thus distinct from biodiesel. Table 1 shows the differences of property of renewable diesel, traditional biodiesel, Fischer-Tropsch (FT) syndiesel and ultra-low sulfur diesel (ULSD) [2–4]. Compared to traditional biodiesel, hydro-processed renewable diesel is more favorable according to its heating value, cloud point, cetane number, oxygen content, density, viscosity and stability. High heating value and high cetane number make renewable diesel competitive in engine performance. Hydro-processed renewable diesel also has relatively lower cloud point, which makes it survive in severe climate. Lower viscosity compared to biodiesel and FT diesel helps in atomization process in an engine or a combustor which leads to better ignition performance. Lower sulfur and aromatics contents compared to ULSD and lower oxygen content compared to biodiesel helps reduce the emissions from engine as feeding hydro-processed renewable diesel. Better stability than biodiesel solves its limitation of storage. It was reported that 100% of hydro-processed renewable diesel reduces the exhaust emissions of PM (particulate matter), NO_x, THC (total hydrocarbons) and CO by 28%–46%, 7%–14% and 5%–78%, respectively, compared to regular diesel [4]. Currently, hydro-processed renewable diesel is commercially demonstrated in some oil refineries such as UOP Ecofining™ process [5], Diamond Green Diesel [5] and Neste Oil [6]. In Taiwan, B2 biodiesel (2% biodiesel blended in regular diesel) was suspended in April 2014, due to the quality of the fuel. The problems of storage and engine horse power were the main reasons. In order to reinitiate the use of biofuel in vehicle transportation in Taiwan, hydro-processed renewable diesel would be a good target.

Feedstock play an important role for evaluating the production of biofuel. Plant oils, algal oil and waste cooking oil have been used as feedstocks for producing hydro-processed renewable diesel. For the situation in Taiwan, plant oils such as palm oil and jatropha oil which can be easily imported from Southeast Asia are the best choices. Waste cooking oil is another option but the quality of source is doubtful. Before the quality of waste cooking oil is fully

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Table 1
Comparison of renewable diesel, biodiesel, FT diesel and ultra-low sulfur diesel.

	Renewable Diesel	Biodiesel	FT-diesel	Ultra-low Sulfur diesel
Sulfur (ppm)	<10	<10	0.05	46
LHV (MJ/kg)	44	~38	43.9	42.7
Cloud point (C)	−20	−5	−17	−12
Distillation (C) (10–90%)	265–320	340–355	295–342	264–329
Cetane Number	>80	50	79	53.9
Oxygen (%)	0	11	0	0
Density at 15 C (kg/m3)	780	880	785	840
Viscosity at 40 C (mm2/s)	2.5	4.1	3.5	2.5
Aromatics (wt%)	0	0	0.3	24.4
Stability	Good	Marginal	Good	Good

*Note: Current regulation in Taiwan for sulfur content in diesel fuel is 10 ppm for land vehicle and 5000 ppm for marine vehicle.

controlled, crude palm oil imported from other Asian countries such as Malaysia and Indonesia would be favorable. Based on the fatty acid profile of palm oil, the hydro-processing reaction takes place under the hydrogen environment over a heterogeneous catalyst. As shown in Fig. 1, the glycerides are saturated and converted into free fatty acids through the propane cleave process. High value propane product is yielded from this process. The FFAs are then turned into straight-chain alkanes via the deoxygenation process, which includes the hydro-deoxygenation and decarboxylation/decarbonylation routes. Co-products such as water emitted from hydro-deoxygenation, CO2 emitted from decarboxylation and CO emitted from decarbonylation can be found in the deoxygenation process. Previously, Sotelo-Boyas et al. [7] studied the production of hydro-processed renewable diesel through hydro-processing of rapeseed oil over 3 different catalysts: Pt/H-Y, Pt/H-ZSM-5 and presulfided NiMo/γ-Al_2O_3 in a batch reactor at the temperature ranging from 300 °C to 400 °C and initial hydrogen pressure ranging from 5 to 11 MPa. The results showed that NiMo/γ-Al_2O_3 provides the highest yield of n-paraffins from C_{15} to C_{18}. The highest yield was found at the temperature of 350 °C and initial H_2 pressure of 8–10 MPa. High initial H_2 pressure favors the yield of n-octadecane. As the temperature increased over 375 °C, cracking of the intermediate carbenium ions dominated and this reduced the yield of hydro-treated renewable diesel. Zhou and Lawal [8] conducted the hydro-deoxygenation of microalgae oil over pre-sulfided NiMo/γ-Al_2O_3 in a micro reactor at the reaction temperature and pressure respectively ranging from 300 °C to 360 °C and 2.07 MPa–3.45 MPa and the optimum conditions for this hydro-treatment were found at 3.45 MPa and 360 °C. Approximately 56.2% of C_{13} to C_{20} hydrocarbons was yielded with a 62.7% carbon yield and a nearly complete conversion (98.7%) was achieved. Kiatkittipong et al. [9] carried out the hydro-processing of crude

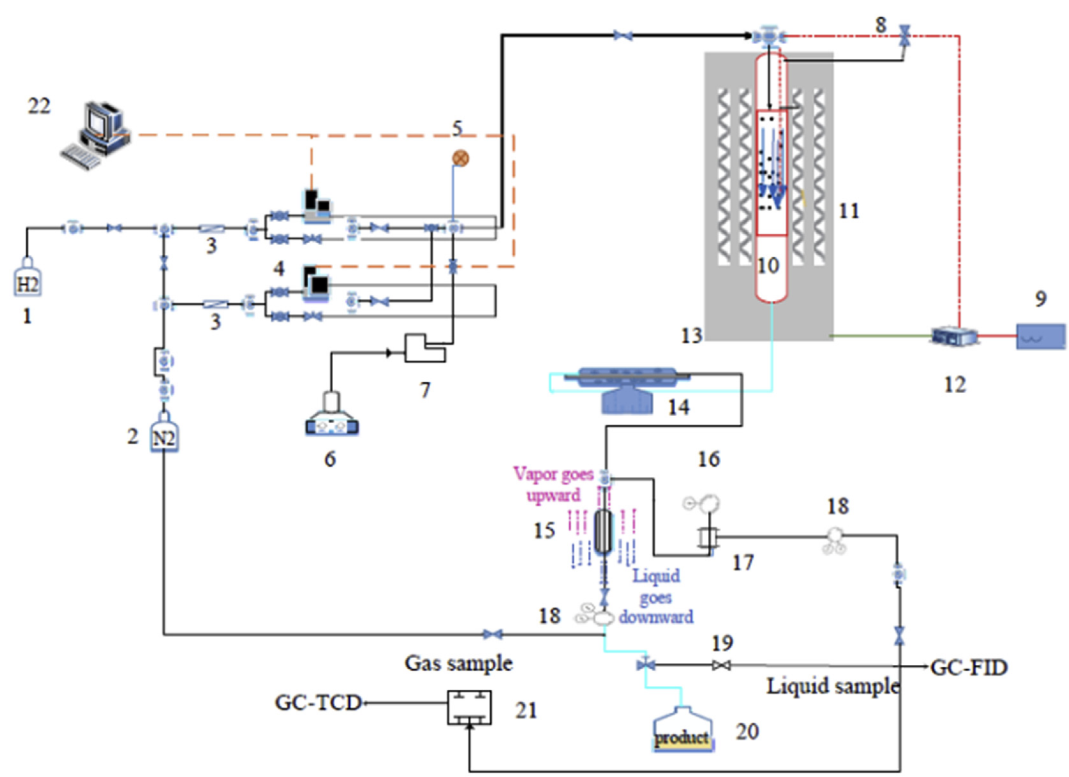

Fig. 1. Experimental setup of hydro-cracking/hydro-isomerization. [(1) H_2 Tank; (2) N_2 Tank; (3) Filter; (4) Mass Flow Controller; (5) Pressure Gauge; (6) Hot Place Stirrer; (7) High Pressure Pump; (8) Pressure Relief Valve; (9) K-Type Thermocouple; (10) Reactor; (11) Heater; (12) Temperature Controller; (13) Condenser; (14) Coolant Tank; (15) Liquid-gas separator; (16) Back Pressure Regulator; (17) Empty Gas Cylinder; (18) Pressure Relief Regulator; (19) Metering; (20) product Container; (21) 5 Port valve; (22) Monitor.].