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Research paper

Techno-economic assessment of a heat-integrated process for hydrogenated renewable diesel production from palm fatty acid distillate

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A B S T R A C T

Hydrogenated renewable diesel (HRD), which is defined as paraffinic hydrocarbon derived from vegetable oil and animal fat, has received consideration worldwide as an alternative diesel fuel. In this work, HRD production from palm fatty acid distillate (PFAD) feedstock was designed and techno-economic evaluation of a heat-integrated HRD production plant was performed. HRD production for a PFAD feed flow rate of 579 g s^{-1} was simulated in Aspen Plus® software as the base-case model; the minimum energy consumption was calculated using pinch point analysis, and a heat exchanger network of heat integration was designed. Subsequently, the modified heat integration HRD production plant was subjected to economic analysis to determine the HRD production attractiveness to investment. It was found that investment in HRD production would be attractive as the fixed capital investment cost of the production plant was 20.735 M$. With a HRD selling price of 950 $ m^{-3} the project gave 39.4% of return on investment and 3.0 years of payback period. If the company has PFAD readily available, a HRD production project was attractive to investment with a NPV of 61.89 M$.

1. Introduction

Hydrogenated renewable diesel (HRD) is a promising alternative fuel due to it having similar properties to diesel derived from petroleum and due to it having a higher cetane number, having a higher heating value and being more environmentally friendly than that derived from petroleum [1–6].

HRD can be produced from catalytic hydroprocessing of vegetable oil or animal fat under suitable conditions [7–20]. At present, HRD production technology, which can be considered an ecofining process, has been developed by several companies, such as UOP, Neste Oil, and ConocoPhillips [21]. There are two types of HRD production: a standalone process and a co-process. A standalone process is built as new plant at a new location, for example, where feedstock can be readily supplied to the process, while a co-process is operated by feeding feedstock together with oil to existing catalytic cracking and hydrotreater units in a petroleum refinery [2,3,22].

Feedstock of HRD process can be one of a variety of vegetable oils. Palm oil is one potential feedstock, particularly in South East Asia, because in this region the production rate of palm oil is higher than that in other regions [5]. Compared to other vegetable oils, palm oil consumes less hydrogen in hydroprocessing reaction because it contains a lower fraction of unsaturated fatty acid [23]. Kiatkittipong [24] demonstrated HRD production from relevant refining palm oil including crude palm oil (CPO), degummed crude palm oil (DPO) and palm fatty acid distillate (PFAD). The effects of

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operating parameters and catalyst types were examined in order to determine suitable operating conditions for each feedstock. It was found that CPO feedstock with supported palladium on carbon (Pd/C) catalyst at a temperature and pressure of 673.15 K and 4 MPa, respectively, provided a 51% mass yield of diesel on the dry PFAD basis, at a reaction time of three hours, while DPO feedstock gave 70% mass yield at a reaction time of one hour under the same operating conditions. In the case of PFAD, at 648.15 K and 4 MPa with the reaction time of 1.8 ks (0.5 h), a diesel yield of 81% could be attained. Additionally, Srifa [25] reported results of refined palm olein catalytic hydrotreating in a continuous-flow fixed-bed reactor to find the optimal hydrotreating conditions. This study recommended that operating conditions of 573.15 K, 3–5 MPa, liquid hourly space velocity (LHSV) 1–2 h^{-1}, and H_2/oil volume ratio between 750 and 1000 (cm^3 cm^{-3}), at standard conditions of pressure and temperature, can provide a HRD product yield of 90% by mole of diesel fraction on a dry PFAD basis, and a product containing more than 95.5% by mole of n-alkane. Reaction pathways in catalytic hydrotreating were affected by operating temperature and pressure and the H_2-to-oil ratio should be higher than 3–5 times of the theoretical requirement. For the pilot plant scale, Guzman [23] reported hydroprocessing of crude palm oil using NiMo/γAl_2O catalyst under a pressure of 4–9 MPa. The products from this process mainly consisted of paraffin in the diesel range, and this study recommended that at lower pressures hydrodeoxygenation reaction cannot be fully reached and intermediates, such as C16–C18 alcohols, C16–C18 acids and esters, occurred.

As regards techno-economic assessment of HRD process from relevant palm oil, there have been a limited number of studies reported in the literature. Miller [21] assessed an economic model of hydrogenation of canola oil and camelina oil for hydrogenation-derived renewable diesel (HDRD) at the capacity of 15–1161 dam^3 y^{-1}. The hydrogenation reaction in the process was operated at a temperature and pressure of 673.15 K and 15.2 MPa, respectively, using supported palladium on carbon (Pd/C) catalyst with a residence time of 6 h. It was found that the minimum costs of HDRD from canola and camelina oil were 1.090 k$ m^{-3} and 850 $ m^{-3}, respectively.

In our previous work, HRD or bio-hydrogenated diesel (BHD) production from crude palm oil (CPO) was studied in a capacity of 345 dam^3 y^{-1}. It was found from the feasibility study that BHD was produced under operating temperatures of 575.15–655.15 K and pressures of 4–8 MPa, and a suitable price of the BHD was 1.160 k$ m^{-3}, which gave 5 years of payback period (PBP) with a return on investment (ROI) of 17.02% [26].

In this work, a new process design with heat integration and the techno-economic assessment of HRD production from relevant palm oil were studied. The main feedstock was palm fatty acid distillate (PFAD), which was a byproduct from a palm oil refining process. The case study was based on potential supply from an existing palm oil refining plant of Suksomboon Palm Oil, Co., Ltd, Thailand. Therefore, this study gives preliminary assessment of HRD production as an additional plant in an existing palm oil refining process. Economic potential was studied and reported with unit prices broken down. The process model was conducted with heat integration to enhance energy utilization. PFAD was used as feedstock for HRD production to produce diesel-like liquid hydrocarbon for transportation use.

2. Process background

2.1. Palm oil refining

Crude palm oil or palm oil is a product which can be extracted from oil fruit (mesocarp) or kernel fruit (Palm kernel oil, PKO) and which is used as raw material of refined palm oil for consumption, biodiesel production and animal food components. The refining process for refined palm oil production can be classified into two types: physical or steam refining and chemical refining [27–29]. Fig. 1 shows the steps in the palm oil refining process. Pretreatment units consist of degumming, neutralization, bleaching and deodorization. Palm fatty acid distillate (PFAD) is a byproduct from palm oil from the pretreatment unit in the deodorization step. PFAD can be used for many industries as raw materials: soap industries, animal food industries and also biodiesel and chemical industries. In this study, PFAD was considered for use as a potential feedstock for HRD production to be used as an alternative energy source for transportation use.

2.2. HRD technology production

The HRD process is mainly comprised of three steps as shown in Fig. 2: catalytic hydroprocessing, separating and product upgrading [3]. The catalytic hydroprocessing step uses hydrogen to remove oxygen from the triglyceride or fatty acid molecules. Oxygen can be removed from oxygenated compounds via three main reaction pathways [25]: hydrodeoxygenation, decarboxylation and decarbonylation. The three reactions can be seen in the following equations:

$$R - CH_2 - COOH + 3H_2 \rightarrow R - CH_2 - CH_3 + 2H_2O \quad (1)$$

$$R - CH_2 - COOH \rightarrow R - CH_2 - CH_3 + CO_2 \quad (2)$$

$$R - CH_2 - COOH + H_2 \rightarrow R - CH_2 - CH_3 + CO + H_2O \quad (3)$$

In the hydroprocessing step, selectivity of each reaction depends on catalyst type [7] and process conditions [19]. Oxygen contained in the feed can be eliminated either as carbonmonoxide, carbon dioxide or water. In addition, product from the reactions consists of mainly paraffinic hydrocarbons.

By-products (H_2O, CO, CO_2) can be separated from the hydrocarbon products in a separator, and then hydrocarbon products are sent to a fractionation section. Finally, cold-flow properties of HRD product must be upgraded to meet a standard of diesel specification in an upgrading step. At the product upgrading step, HRD in the form of normal paraffin from the distillation column is isomerized into iso-paraffin via isomerization reaction to improve cold-flow properties. In the study of Ono [30], the ratio of 50% isomerized HRD by weight was recommended for blending with conventional diesel fuel for up to 20% by volume.

3. Equipment specifications, design and purchased cost estimation

The cost estimation of equipment in the processes was determined using data from the process simulation using Aspen Plus. The capacity of the HRD production plant was specified, process specifications were assigned and, consequently, material and energy data were obtained. The cost estimation for the unit in the process can be calculated as follows.

3.1. Pumps and drivers

The centrifugal pump and motor f.o.b. costs were estimated according to capacity, head and brake horsepower, using the following equation [31]: