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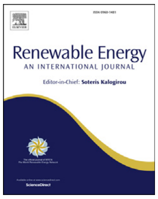

Techno-economic analysis of a bio-refinery process for producing Hydro-processed Renewable Jet fuel from Jatropha

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ABSTRACT

HRJ (Hydro-processed Renewable Jet) conversion technology has been recently used to produce renewable jet fuel for commercial or military flights. In this study, a techno-economic analysis is carried out for evaluating the production of jatropha-derived HRJ fuel through a bio-refinery process. Each component of the chosen feedstock jatropha can be converted into valuable products. The bio-refinery process is split into 6 parts: (1) Fruit Dehulling; (2) Shell Combustion; (3) Oil Extraction; (4) Press Cake Pyrolysis; (5) Oil Upgrading; (6) Product Separation. The minimum jet fuel selling price (MJSP) from this fruit scenario is calculated to be $5.42/gal based on the plant capacity of 2400 metric tonne of feedstock per day. The co-products obtained from the process not only significantly deduct the production cost but make the entire process energy self-sustainable. We also discuss the oil scenario, which oil is the starting material and the process begins from Oil Upgrading section. The oil scenario offers the MJSP of $5.74/gal with lower capital but higher operating costs. The differences of MJSPs for fruit and oil scenarios are due to feedstock cost, refinery capital cost, co-product credits and energy cost. Based on the sensitivity analysis, the feedstock price, oil content, plant capacity, reactor construction and catalyst usage are important parameters that control the price of the produced fuel.

1. Introduction

The worldwide aviation industry consumes approximately 1.5–1.7 billion barrels (47.25–53.55 billion gallons) of conventional jet fuel per year [1,2]. The challenges of crude oil prices, national security, environmental impact, and sustainability make it difficult to have a long term plan and budget for operating expenses. Biomass-derived jet fuels (bio-jet fuels) are a potential alternative to petroleum jet fuel. With proper certification, bio-jet fuel can currently be blended up to 50% and potentially up to 100% with conventional jet fuel [1]. In US, the Air Force has goals to obtain 50 wt% of the Air Force's domestic aviation fuel as an alternative fuel blend by 2016 [3]. The European Union has set a target of two million tonnes per year of aviation biofuels in Europe in 2020, which is approximately 3–4% of total jet fuel use in Europe [4]. It is estimated that by 2050 25%–40% of biofuel will be used in global aviation, and 15%–40% of carbon emissions can be reduced [5].

Many process technologies that convert biomass-based materials into jet fuel substitutes are available. Some are available at commercial or pre-commercial scale, and others are still in the research and development stage. These technologies are varied and depend strongly on the type of feedstock. Oil-based feedstocks are converted into bio-jet fuels through hydro-processing technologies, including hydro-treating, deoxygenation, and isomerization/hydrocracking. A patented process developed by Honeywell UOP named Green Jet Fuel™ converts non-edible, second-generation natural oils and wastes into renewable jet fuel [6]. Solid-based feedstocks are converted into biomass derived intermediate through gasification, into alcohols through biochemical or thermochemical processes, into sugars through biochemical processes, and into bio-oils through pyrolysis processes. Syngas, alcohols, sugars, and bio-oils can be further upgraded to bio-jet fuel via a variety of synthesis, fermentative, or catalytic processes. So far, bio-jet fuels from Fischer-Tropsch (F-T) synthesis and oil hydroprocessing technologies have been approved by ASTM International (ASTM) Method D7566 [7] for blending into jet at levels up to 50%. Among these processes, hydro-processing technologies using vegetable and waste oils represent the only conversion pathways ready for large-scale deployment [8].

HRJ (Hydro-processed Renewable Jet) conversion technology is at a relatively high maturity level, is commercially available, and

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was recently used to produce jet fuel for military flights [9]. HRJ fuel is equivalent to conventional petroleum in properties, but has the advantages of higher cetane number, lower aromatic content, lower sulfur content, and potentially lower GHG emissions [10]. The process flow diagram is shown in Fig. 1. Catalytic hydrogenation could be used to convert liquid-phase unsaturated fatty acids or glycerides derived from renewable fats and oils into saturated ones [11] with the addition of hydrogen. The next step is to cleave the propane and produce three moles of free fatty acids (FFAs) [10]. The glycerol portion of the triglyceride molecule is converted into propane by adding H_2. The fatty acid products are sent to deoxygenation step, either through decarboxylation route or hydrodeoxygenation route, to remove oxygen content in the form of CO_2, CO or H_2O. The normal alkanes associated with the fatty acid carbon chain length are therefore produced. To meet the jet fuel specification, the produced bio-jet fuel has to have not only a high flash point, but also good cold flow properties. Therefore, it is required to hydrocrack and hydro-isomerize the normal paraffins produced from deoxygenation to a synthetic paraffinic kerosene (SPK) product with carbon chains ranging from C_9 to C_{15} [10]. The isomerization process takes the straight-chain hydrocarbons and converts them into the branched structures to reduce the freeze point to meet the jet fuel standard [12]. It is accompanied by a hydrocracking reaction, which results in more or less yield from the isomerized species. The hydrocracking reactions primarily involve cracking and saturation of paraffins. The choice of catalyst will result in variation of cracking at the end of the paraffin molecule and therefore adjust the yield of jet fuel range product [11]. The hydro-isomerization and hydrocracking processes are followed by a fractionation process to separate the mixtures to paraffinic kerosene (HRJ SPK), paraffinic diesel, naphtha, and light gases.

Jatropha curcas has higher oil yields (gallon per acre) than many other oil-yielding crops. In humid regions or under irrigated conditions, the Jatropha plant can be grown year round [13]. Generally 15–20 kg of jatropha fruit can be harvested from one plant and there are approximately 2500 plants per hectare. The land growing jatropha can be harvested four times a year [14]. The jatropha fruits have two or three seeds and each seed contains more than 33% of oil. The seed yield is 7 tonnes per hectare per year and the oil yield is around 2.2–2.7 tonnes per hectare [15]. The future oil yield is expected to be up to 2640 kg oil/ha in the year of 2020 [15]. The utility of jatropha oil as replacement for petroleum fuel has been well demonstrated [16–19]. In 2008, Air New Zealand, Continental Airlines and Japan Airlines used Jatropha derived green jet fuel as part of the aviation fuel which powers their commercial aircrafts. The residue after oil extraction, named seed cake, can be another energy source due to the considerable amount of oil content (9–12 wt%, contributes to 18.2 MJ/kg of energy) or fertilizer after post-treatment [20]. Pyrolysis and anaerobic digestion are the most promising processes to further convert the seed cake into valuable products [20–23]. Additionally, the husk and seed shells can be converted into value-added co-products through the post-treatments [24]. Many techno-economic studies have been done on determining the biofuel production cost based on jatropha feedstock [17–19,25]. Tewfik et al. [18] pointed out that the price of biodiesel from jatropha is in the range of $1.14–2.66 per gallon for various assumed scenarios. Labib et al. [19] suggested the price of $2.53 per gallon of jatropha-derived biodiesel with a gross profit of $37,403,643 per year. Additionally, Chauhan et al. [17] concluded that biodiesel production from jatropha is economically feasible with 13.5% internal rate of return.

An economic analysis of HRJ fuel is described in the literature [26]. The HEFA (Hydro-processed Esters and Fatty Acid) fuel price was found to be $3.85/gal for the plant capacity of 98.28 MM gal/yr and $4.46/gal for the plant capacity of 30.16 MM gal/yr. Additional $0.27/gal –$0.31/gal is required to produce maximum jet fuel because of the increased hydrogen use and decreased yields of jet and diesel fuels. The economic analyses of bio-jet fuels from microalgae and pongamia oils are also studied [27]. The minimum selling prices for jet fuels derived from microalgae and pongamia oils were estimated to be $31.98/gallon and $8.9/gallon, respectively. Based on the sensitivity analysis, the development of technology and market will decrease the prices to be $9.2/gallon and $6.07/gallon, respectively. The techno-economic analysis of

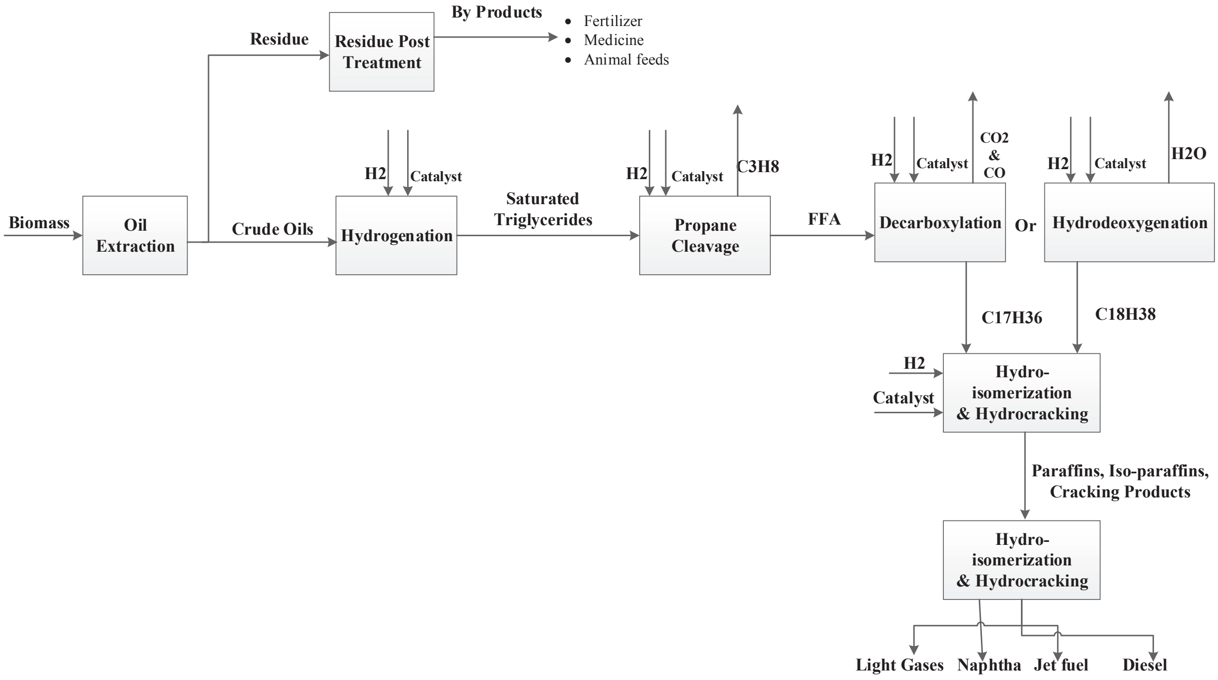

Fig. 1. Hydro-processed renewable jet (HRJ) process.