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Simultaneous energy integration and intensification of the hydrotreating process to produce biojet fuel from jatropha curcas

Dr. Claudia Gutiérrez-Antonio[a,*], Araceli Guadalupe Romero-Izquierdo[b], Fernando Israel Gómez-Castro[b], Salvador Hernández[b], A. Briones-Ramírez[c]

[a] Universidad Autónoma de Querétaro, Facultad de Química, Cerro de las Campanas s/n Col. Las Campanas, Querétaro, Querétaro, 76010, Mexico
[b] Universidad de Guanajuato, Campus Guanajuato, División de Ciencias Naturales y Exactas, Departamento de Ingeniería Química, Noria Alta s/n, Guanajuato, Guanajuato, 38010, Mexico
[c] Exxerpro Solutions, Av. Del Sol 1 B Local 4B, Plaza Comercial El Sol, Col. El Sol, Querétaro, Querétaro, 76113, Mexico

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ABSTRACT

The sustainable development of aviation sector relies on four strategies, being the use of biojet fuel as the most promising. There are different processes to produce biojet fuel; however, the hydrotreating process is certified by ASTM for its use in commercial and passenger flights. This process has several opportunity areas to decrease energy consumption and environmental impact. In this work, we propose the simultaneous energy integration and intensification of the hydrotreating process to produce biojet fuel from jatropha curcas oil. The released energy by the hydrodeoxygenation reactor is used to perform the energy integration of the process. Moreover, the separation zone of the process is intensified through thermally coupled distillation sequences, which are optimized with a multiobjective stochastic strategy. Results show that it is possible to reduce significantly the energy requirements of the process when energy integration is performed; however, the decreasing in the service costs is accompanied by an increasing in the equipment costs. On the other hand, the intensification of the separation zone does not lead to a decreasing in energy consumption. Therefore, net effect of both strategies on the total annual cost and biojet fuel prices is small, but significant decreasing in CO_2 emissions is achieved.

1. Introduction

In most parts of the world, economic activity remains the principal driver of demand for energy and is therefore strongly correlated with carbon emissions [1]. Thus, the growing of the economic sectors faces two main issues. The first one is the climate change, which has driven the reduction in greenhouse gas emissions through cleaner and more efficient production process. The second one is the depletion in the oil reserves that is particularly important, since the actual energy matrix still depends strongly on non-renewable energy sources [2]. These issues have encouraged the research and development of alternative energy sources as well as the reduction of the carbon footprint of the production processes. In an ideal scenario, the development of economic activities must guarantee access to energy, which comes from sustainable production processes; also, minimizing the environmental impact and maximizing the social benefits. The aviation sector is also affected by these issues.

The growing of aviation sector is forecasted at a rate of 4.8% per year until 2036 [3], with the corresponding increasing in greenhouse gas emissions. The International Civil Aviation Organization (ICAO) states that passenger transport accounts for the 2% of the global CO_2 emissions [4], whilst goods transport contribute with 3%, according to the International Maritime Organization (IMO) [5]. However, the forecast indicates that by 2050, the aviation sector (domestic, international and shipping) will contribute with 10%–32% of the total CO_2 emissions [5]. In response to the actual challenges, aviation sector has established ambitious objectives that guarantee its sustainable growth. The objectives include a reduction of 50% in CO_2 emissions by 2050, relative to 2005 emissions levels, and neutral growth in CO_2 emissions from 2020 [5]. In order to reach the proposed objectives a four pillar strategy [6] has been proposed, which consider technological improvements in engines and aircraft structures, operational improvements by on line optimization of flight paths, market-based measures, and development of alternative fuels. According to the International Air Transport Association (IATA) and

* Corresponding author.
E-mail addresses: claugtez@gmail.com, claudia.gutierrez@uaq.mx (C. Gutiérrez-Antonio).

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the ICAO the renewable aviation fuel is the alternative that helps further to the sustainable development of the aviation sector.

Aviation sector employs as main fuel for the airplanes fossil jet fuel, which contains paraffins, naphtenes and aromatic compounds in the range of C8–C16. Meanwhile, the renewable aviation fuel, or biojet fuel, consists only of paraffins and napthenes in the range of C8–C16. The absence of aromatic compounds does not affect the main properties as freezing temperature, viscosity or energy content; however, it could cause leaks in the fuel distribution circuit, since aromatic compounds expand the elastomers. Therefore, the use of biojet fuel is approved in mixtures up to 50% with fossil jet fuel, according to the standard ASTM D7566-16 [7]. Biojet fuel can be produced from lignocellulosic biomass, sugar and starchy, vegetable oils and animal fats. Depending on the renewable raw material, there are five pathways identified: hydroprocessing of lipids, alcohol to jet, biomass pyrolysis to jet, biomass gasification followed by Fischer-Tropsch process, and hydrothermal upgrading of biomass. From these processes, the hydroprocessing of lipids and the biomass gasification followed by Fischer-Tropsch are certified technologies by ASTM to produce biojet fuel for commercial and passenger transportation. Nevertheless, the hydroprocessing technology is one of the most advanced for two reasons. The first one is its similarity to the hydrotreating process of the petro-refineries, being feasible the revamping of those to biorefineries. Also, some of the ongoing construction projects of biorefineries to produce biojet fuel consider the hydroprocessing technology [8,9].

In the hydrotreating process, the transformation of vegetable oil or animal fats through hydrodeoxygenation, hydrocracking and hydroisomerizing occurs; as result, a renewable hydrocarbon stream is generated which has to be purified by means of distillation [10]. Fig. 1 shows a block diagram of the hydroprocessing technology, where the reactive and purification zones are clearly identified. According to UOP Honeywell patent [10], this technology allows obtaining a global conversion to hydrocarbons of 70%, being 36% the maximum conversion to biojet fuel. The hydroprocessing technology has been employed to produce biojet fuel, which has been used in several testing flights. However, this process has opportunity areas, one of which is the reduction of energy consumption. With this objective, some works have been reported in the literature.

In 2013, the modelling of the hydrotreatment of castor oil to produce biojet fuel was presented [11]. In that work the kinetic model was estimated, and conventional distillation schemes were analyzed for the separation of the hydrocarbons stream. Also, the conventional distillation trains were optimized by a multiobjective genetic algorithm coupled to a commercial processes simulator. Results show that the total conversion to hydrocarbons was 82%, while the conversion to biojet fuel was 22%. Moreover, the optimization results show that the direct distillation sequence is the best option to purify biojet fuel. Later, with base on these results [11] the intensification of the separation zone of the hydrotreating process was proposed [12]. For that, four thermally coupled schemes were analyzed: direct and indirect thermally coupled distillation sequences, Petlyuk sequence, and Dividing Wall Column. These schemes were optimized with a multi-objective stochastic technique, and the results showed that the use of intensified sequences allows decreasing in 21% the energy consumption of the separation train.

Recently, the energy integration of the hydrotreating process was presented [13], considering jatropha curcas oil as renewable raw material. In that work, two conventional hydrotreating processes were defined, being the difference between them the use of the direct and the direct-indirect conventional distillation schemes. With base on the conventional hydrotreating processes, energy integration was implemented for both of them. The results showed that the decreasing in heating-cooling services is almost completely compensated with the increased in equipment cost when energy integration is implemented. However, a decreasing of 86% in the total emissions of CO_2 was found when energy integration is used.

From these works it is clear that the decreasing in energy consumption and environmental impact is possible through intensification and energy integration, respectively. Thus, an interesting approach is the simultaneous performing of energy integration and intensification of the hydrotreating process; to the authors knowledge this has not been reported in the literature. Therefore, in this work we propose the simultaneous energy integration and intensification of the hydrotreating process to produce biojet fuel, considering jatropha curcas oil as renewable raw material. For this, we used the model reported for the reactive zone of the hydrotreating process [13], at the operating conditions that allows achieving maximum conversion. Considering the composition of the reaction effluent, conventional distillation sequences are designed for the separation zone. With base on conventional distillation sequences we designed the intensified distillation sequences, using the methodology proposed by Rong and Errico [14]. Optimal designs of both conventional and intensified sequences are a challenge task, since energy consumption and number of stages are objectives in conflict with each other. It is well known that a decreasing in energy consumption implies a higher number of stages, and vice versa. This fact conducts to the

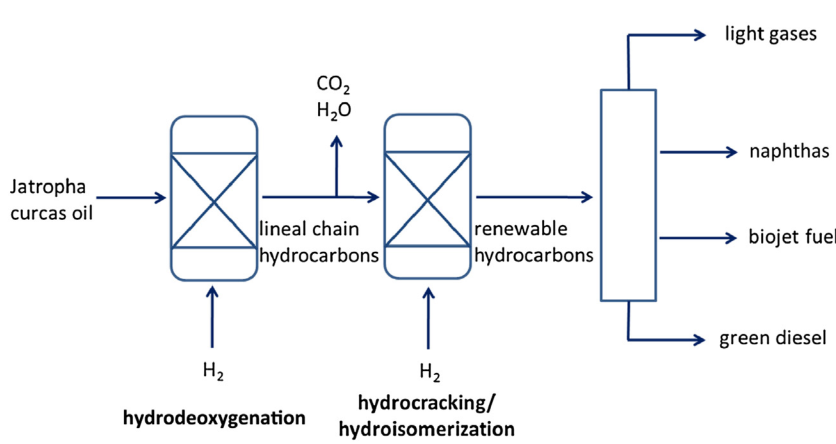

Fig. 1. Block diagram of the hydrotreating process for biojet fuel production.