A review on process system engineering for biodiesel refineries

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Abstract
Recently, biofuels have been focused because of environmental and society crisis including air pollution and limitation of crude oil resources. Biodiesel is known as fatty acid methyl ester which has been chosen as promising fuel because of its renewable nature and environmental benefits. The approaches for the continued growth of biodiesel process plant for development of new policies, reduction of biodiesel cost, external funding for increasing fuel cost and support for research and development of possible biodiesel feedstocks. The main purpose of this study is designing biodiesel refineries for getting maximum conversion of esters at the lowest capital cost of the refineries. Process systems engineering (PSE) approaches are ideally suited to modelling, design, optimization, and operations challenges and opportunities in the development of biodiesel plant. This review also focused on the renewability and sustainability of biodiesel production.

Keywords
Biodiesel, Refineries, Transesterification, PSE, Aspen plus.

1. Introduction
Fossil fuels such as coal, oil and natural gas, are currently the world's primary energy source formed from organic material. Recent production of fossil fuel has reached up to 79% compared to other energy sources as shown in Figure 1[1]. Yet fossil fuels are responsible source for the harm the environment. According to the Environmental Protection Agency (EPA), the burning of fossil fuels was responsible for 79% of U.S. greenhouse gas emissions in 2010[2-4]. Greenhouse gas emissions generated by fossil fuels can reduce with the help of Carbon Capture and Storage (CCS) technology [5]. But other, more sustainable solutions exist: energy efficiency and renewable energy which save the environment on fossil fuels as natural power source[6-9]. With the rise of global warming issues with the increase of the greenhouse gas emission and more generally with growing importance granted to renewable and sustainable development. In this regard, process system engineering (PSE) has turned to think more and more environmentally. Process systems engineering (PSE) deals with the overall system behaviour and also define that how the individual units should be combined to achieve optimal overall performance. It is a method to design and operate sustainable chemical process plant.

Figure 1 World primary energy (a) production and (b) consumption in January 2016, per source
2. Biodiesel production process
To produce energy from low carbon sources and introduction of eco-friendly green Technology are the main aim of human society. Biodiesel, the alternative renewable liquid fuel, derived from vegetable oils holds promise to compensate the increase demand of petroleum diesel[10]. Biodiesel is prepared via transesterification reaction in which triglycerides reacts with alcohol in presence of catalyst as shown in Figure 2[11]. Glycerol is the by-product of the reaction. This is the most common method for producing biodiesel. The main purpose of transesterifying the vegetable oil is to lower its viscosity. Different types of feedstock like edible oils such as soybean oil, castor oil, sunflower oil, palm oil, linseed oil [12-16] and non-edible oil resources like Jatropha oil, karanja oil and thumb oil[17-19] are present in the market for biodiesel production. Transesterification reaction can be catalyzed by homogeneous and heterogeneous catalyst. Commonly homogeneous catalyst such as NaOH, KOH have high catalytic activity but it is also difficult to separate purify and reuse them after the reaction [20-21].

These drawbacks increase the economics and environmental cost in biodiesel production. So to overcome these drawbacks, heterogeneous solid catalyst such as alkali metal oxides and derivatives [22-26], alkaline earth metal oxides and derivatives, transition metal oxides and derivatives, mixed metal oxides and derivatives [27] ion exchange resins type acid heterogeneous catalyst [11], sulfated oxides as a acid heterogeneous catalyst, carbon based heterogeneous catalysts[28-30], boron group base heterogeneous catalyst waste material based heterogeneous catalysts[31-35]have been explored. Heterogeneous catalyst have many advantages as they are cheap, noncorrosive, recyclable, fast reaction rate and no need of any water purification step[36].

Figure 2 Transesterification of triglycerides with alcohol

3. Process modelling and simulation
Two possible strategies involved for the design of biodiesel are processed plant and integration. The first design tactics are selecting a reactor and moving outward by adding a separation and recycle system. This strategy is based on rules of thumb developed from the experience of the designer. Another strategy for designing biodiesel process plant is by using a process superstructure. It starts by installing all possible process options and possible interconnections as candidates for an optimal design structure. Excessive features are included to ensure that all elements that could be part of optimal solutions are incorporated.

The full design of biodiesel plant from waste cooking oil by using alkali and acid catalysts [37]. In the biodiesel production process, esterification, transesterification, methanol recovery, water washing and FAME purification were also included. Taptasvi et al. [37] performed similar research, but discrimination is the mass and energy balances in the process model. The model developed could be further applied in performing economic feasibility studies of biodiesel production. Further research on phase equilibrium systems for biodiesel production was reported in [38] to determine the liquid-liquid equilibrium of multicomponent mixtures containing fatty acid esters, alcohols and glycerol in the production and purification process. Peng–Robinson equation of state was studied in [39] to determine the methanol–triolein binary system at various temperatures and pressures.

In opposition to the studies mentioned above, Zong et al. [40] reported the use of triglycerides pure component properties for modeling the biodiesel production methods. The used method was the fragment-based strategy which comprised of constituent fragment-based modeling approach, identification of fragment-specific parameters, correlation of the parameters and estimation of double-bond effects. Subsequently Design and operation of chemical refineries by incorporating sustainability elements are currently acceptable as it promoted minimum energy usage and wastes.

For sustainable biodiesel refineries, Myint and El-Halwagi[41] had explored opportunities for cost minimization and process integration; and performed the simulation with various mass and integration processes with capital cost calculation, profitability, and sensitivity analyses. Similarly, Elms and El-Halwagi[42] also performed process design and optimization on biodiesel production process and performed capital and operating cost estimation. In short, the systematic approach to the design of
biodiesel production processes per the GHG policies did contribute a powerful decision-making tool for policy makers and producers. Various works have been carried out on process simulation of biodiesel conversion technologies to see the effect of operating conditions towards value added products. Process simulations usually based on the evaluation of the chemical components, and selection of proper thermodynamic model.

Subsequently, unit operations, operating conditions, input conditions and plant capacity must be specified. Most of the property data of components are available in the software library. However, if the certain component property is unavailable in the simulator library, registration of the component can be made by introducing the component as a new chemical component. Garcia et al. [43] reported a simulation study to analyzed biodiesel properties using different feedstock and compared the results obtained with previous experimental data and found that the predictive model was mostly well-suited to experimental data. Zhang et al. [37] reported simulation of biodiesel plant from waste cooking oil by using alkali and acid catalysed transesterification of biodiesel.

The simulation study concluded the right amount of water could lead to near-complete separation between the FAME and glycerol phase by using pure oil in alkali transesterification process. Acid catalysed transesterification reaction conducted by Zhang et al. applied higher reaction temperature, pressure, and higher methanol to oil molar ratio than alkali-catalysed transesterification. Sotoft et al. [44] also reported similar study by using enzyme catalyst for biodiesel production. In this study, Sotoft et al. used 3 CSTRs in series with the reactors and simulation made using Aspen Plus computer simulator. The result showed the desirable yield of solvent free enzyme biodiesel production. In contrast, Kaewcharoenombat et al. [45] performed process simulations of biodiesel with or without a catalyst, purity, and type of feedstock. Although, all the simulations carried out within the specified operating conditions have proven that all process flow diagrams are able of producing high-quality biodiesel within the specified operating conditions. However, every process has some limitations such as alkali and enzyme catalysed transesterification process requires costly raw material.

On the other hand, the supercritical alcohol process requires high-pressure reactors and large amounts of energy to separate the methanol from the feed stream, thus increasing the total costs. Simulation studies are usually accompanied with production cost estimation and impact on the environment. Haas et al. [46] developed a model for estimating the cost of biodiesel production using soybean oils as feedstock. Transesterification method includes biodiesel purification and glycerol recovery sections. Capital and production costs were also estimated.
Figure 4 Flow sheet of biodiesel plant design by enzyme-catalysed transesterification of rapeseed oil

It could be concluded that the costs calculation were suitable for biodiesel derived from soybean oils, but not suitable for biodiesel from other feedstock, as additional processes may be required depending on the oil characteristics. Jegannathan et al. [47] examined the cost of biodiesel production of different types of catalysts. Costs were compared between the alkali and enzymatic-catalysed processes, which are either soluble or enzyme-immobilized. At variance to Haas et al., Jegannathan et al. also performed batch operations of biodiesel.

They discovered that the cost of alkali catalysed process was lower compared to enzymatic-catalysed process. They also suggested that, if the immobilized catalyst could be again reused, its production cost could strike the alkali catalysed production cost. Similar work was done by Sakai et al. [48] but they included research of different types of process plant refineries and manufacturing cost.

An estimation cost study of biodiesel produced in supercritical process in [49] indicated that the highest cost was incurred on raw materials and labour. If comparison of cost was made on different types of feedstock used. Figure 3-4 shows flow sheet of biodiesel plant design by alkali and enzyme-catalysed transesterification of oil.

4. Conclusion
Recently various studies on development of biodiesel fuel production have been reviewed and discussed. Especially in developing new more active catalysts that are capable of increasing biodiesel yield and purity with speed up the process of biodiesel production. Research should be more focused on the development of super active and strong catalysts and both esterification and transesterification reaction which helps to reduce capital and investment costs and may be advantageous for sustainable development due to the lower consumption of resources. Furthermore, flow sheeting and simulation studies in biodiesel fuel production have shown the importance of obtaining the optimum-operating conditions and verifying experimental results. The availability of powerful process simulators has enabled process engineers to cope with the complex problems of designing processes to produce the highest biodiesel purity. This review has shown that PSE is an excellent approach to systematically design and operate the complex biodiesel production system. Integrated models, methodologies and tools need to be explored through process model and design, simulation, optimization, experimentation and visualization. Therefore, the application of computer aided PSE tools for the synthesis, design, control and modeling of the biodiesel process can further advance the frontier of knowledge in this field.

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Conflicts of interest
The authors have no conflicts of interest to declare.

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