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Process system engineering in biodiesel production: A review

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ABSTRACT

Biodiesel is fast becoming a popular alternative to fossil fuels, as it is natural, renewable and has low toxic emissions. Strategies that have been adopted to ensure continued growth of the biodiesel industry are policy development, reduction of biodiesel tax, offset funding for incremental fuel cost from CO_2 emission fuel and support for research and development of potential biodiesel feedstocks. Recent innovations of biodiesel processes are focused on the development of more efficient catalysts and in the utilization of novel reaction media such as supercritical fluids as well as on a variety of oil feedstocks such as virgin and waste oils. Biodiesel production involves complex processes which require systematic process design and optimization. The main aim of designing biodiesel plants is to maxime conversion of ethyl or methyl esters at the lowest capital cost of the plant. The design should also consider safety and environmental concerns. Process system engineering (PSE) is a systematic approach to design and analyze complex processes by using a variety of PSE tools for the optimization of biodiesel production. This paper reviews the latest PSE tools used in development of novel biodiesel processes. It describes the main PSE elements such as process model development and product design, simulation of biodiesel processes, optimization of biodiesel synthesis, and integration of reactor and separation systems. This review also highlights the sustainability of biodiesel production.

Contents

1. Introduction

Fossil fuels remain as the main source of energy. Recent production of fossil fuels has reached up to 79% compared to other energy sources as shown in Fig. 1 [1]. However, the demand for fossil fuel as a primary energy source is exceeding its production, due to rising consumption of fossil fuel energy up to 83% in November 2010.

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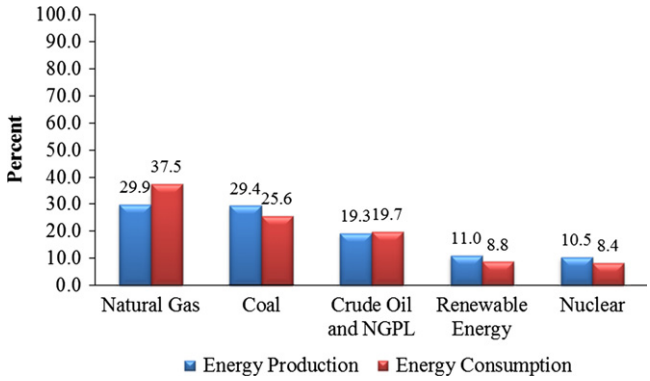

Fig. 1. World primary energy production and consumption in November 2010, per source.

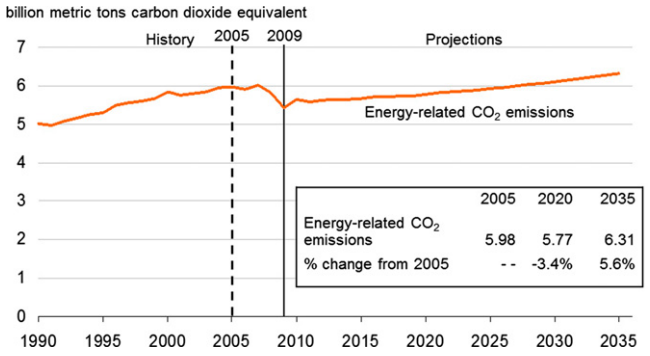

Fig. 2. U.S Energy-related carbon dioxide emissions from 1990 to 2035.

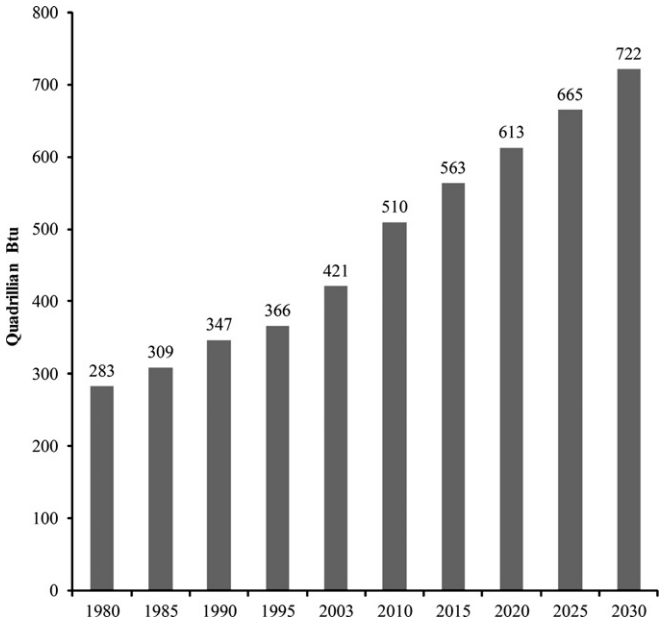

Fig. 3. World projections of energy consumption, 2003 to 2030.

Consumption of fossil fuel will cause adverse consequences especially to the natural environment. Combustion of fossil fuel increased the formation of carbon dioxide and by-products in the atmosphere and significantly caused the depletion of the ozone layer and increased global warming. This indicates that carbon and by-products emissions are directly proportional to energy consumption. The vulnerable ozone layers diminish in line with rapid industrial growth. As projected in Fig. 2, the energy related carbon dioxide emission shall continue to gradually rise until the year 2035 [2].

Energy consumption would certainly increase in the future in line with increasing population (Fig. 3) [2]. Thus, seeking alternatives to fossil fuels is vital. In addition to sustainable energy policy, renewable energy is an option to reduce dependencies on fossil fuels. Wind, hydro, solar, biomass, biofuel, geothermal and ocean energy are amongst the renewable energy resources that can help to supply energy for electrical power generation and transportation sectors. These natural power sources offer alternative means that can simultaneously save the environment and reduce reliance on fossil fuels.

Process system engineering (PSE) has long been recognized as a promising method to design and operate efficient and sustainable chemical process plants. It is a comprehensive, iterative and recursive problem solving process [3]. PSE offers solution to complex engineering system by enabling the use of viable tools and techniques to better manage and comprehend the complexity of the system. This article shall henceforth review every aspect of process system engineering such as model development, design, simulation and optimization as well as combinations of these elements that can be fruitfully used in improving the processes for biodiesel production.

2. Biodiesel production

Biodiesel is the most common biofuel used in Europe and internationally owing to its ready availability and renewability. Biodiesel is diesel fuel derived from natural and renewable sources for diesel engines that meet the specifications of ASTM D 6751. Biodiesel is produced from oils and fats, consisting of methyl or ethyl esters. Several methods have been employed to transform the oils and fats into biodiesel such as pyrolysis, microemulsion and transesterification. The transesterification reaction process of oils and fats is a common method used to produce biodiesel. It is often catalysed by either an acid, a base or an enzymatic catalyst. The process is a reversible reaction, as shown in Fig. 4 [4]. Excess amount of alcohol can help to accelerate the conversion of glycerides.

Biodiesel can be derived from various types of feedstock. Examples of biodiesel sources are: almond, andiroba (*Carapaguianensis*), babassu (*Orbignia* sp.), barley, camelina (Camelina *sativa*), coconut, copra, cumaru (*Dipteryxodorata*), *Cynaracardunculus*, fish oil, groundnut, Jatropha curcas, karanja (*Pongamiaglabra*), laurel, *Lesquerellafendleri, Madhucaindica*, microalgae (*Chlorella vulgaris*), oat, piqui (*Caryocar* sp.), poppy seed, rice, rubberseed, sesame, sorghum, tobacco seed, and wheat [5]. Among popular choice of vegetable oils for biodiesel are soybean oil [6], waste cooking oil [7], rapeseed oil [8], palm oil [9], sunflower oil [10]; and the canola, corn, olive and linseed oils.

Even though biodiesel can be derived from various types of feedstock, the production processes may differ depending on the properties of the oil. Biodiesel derived from feedstock with high fatty acids value normally require pre-treatment process called esterification before the transesterification reaction [11]. Thus, important properties of triglycerides for biodiesel preparation such as fatty acids value, saponification value and water content

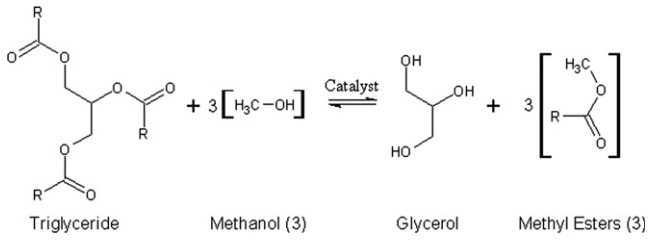

Fig. 4. Transesterification of triglycerides with alcohol.