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Process system engineering aspect of bio-alcohol fuel production from biomass via pyrolysis: An overview

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ABSTRACT

Due to depleting petroleum reserves and the environmental impact of fossil fuels, it is important to find alternative sources for transport fuels. An alternative solution is bio-alcohol fuel, which has potential in the transport sector and in electricity generation. Biomass-based sources offer the best solution for transitioning to liquid fuel because of its global availability and energetic gain. Current fuel research and development addresses process engineering trends for improving bio-alcohol production in pyrolysis. This paper addresses developments in modeling simulation, optimization and control systems related to bio-alcohol production. The most promising solutions to bio-alcohol fuel production costs by the generation of valuable co-products are analyzed. These findings are supported by heat and mass transfer in the production of bio-alcohol fuel as well as by economic analysis. Finally, some concluding considerations on current and future research trends in the study of bio-alcohol are presented.

1. Introduction

Biofuels, which can be solid, liquid, or gaseous, are widely used in the transport sector because they are a clean, safe, environmentally friendly, and sustainable source of energy. Biofuels obtained by the conversion of biomass waste are used for their renewable characteristics [1,2]. As noted by Fjerbaek et al. [3], biofuels can lower the emissions of sulfur, carbon monoxide, and hydrocarbons. They are also used for energy supply and to reduce global warming. Meanwhile, the potential impact of biofuels on the industry is represented by the following properties [4–6]:

- The gas emissions with respect to the greenhouse effect were reduced. For an example, the reduction of CO_2 emissions.
- The low composition of sulfur contents in biomass for biofuels will reduce the impact of SO_2 emissions.
- The use of non-renewable sources such as fossil fuels was reduced.
- The use of co-generation power systems through biogas combustion was contributed to development and sustainability in biofuels.

The contribution of bio-alcohol production offered to the biofuels sector has been proven. The primary bio-alcohols produced are methanol (CH_3OH), ethanol (C_2H_5OH), propanol (C_3H_7OH) and butanol (C_4H_9OH) [7]. In fact, the research analysis was done by Energy Policy Act United States which in the year of 2022, the demand of biofuels was intensively increased as shown in Fig. 1. The different sources were categorized and the tremendously preferable in biofuels sector and cellulosic biofuels produced from woods, grasses and non-edible plant matter. Hence, the economic analyses of biomass conversions to form energy were take part in sustain the demand of biofuels. The plant capacity, feedstock cost, product yield, and process configuration were evaluated in techno-economic analysis. As mentioned by Xuan and Lim [9], techno-economic analysis was performed by designing and modeling a process. The estimating of total capital investment, total production cost, and economic criteria were also take consideration. In this manner, the research process was designed from Fig. 2 shows the pathway of energy produced from renewable biomass. This paper examines the technology options in thermochemical conversion that are effective for production of biofuel products from bio-alcohol. The biomass sources can be classified as residues from forests and agriculture, municipal solid wastes and cultivated energy crops [10]. Thermochemical conversion processes such as pyrolysis, gasification and steam gasification are useful for converting biomass to energy [7]. In addition, bio-alcohol development is favored due to ample

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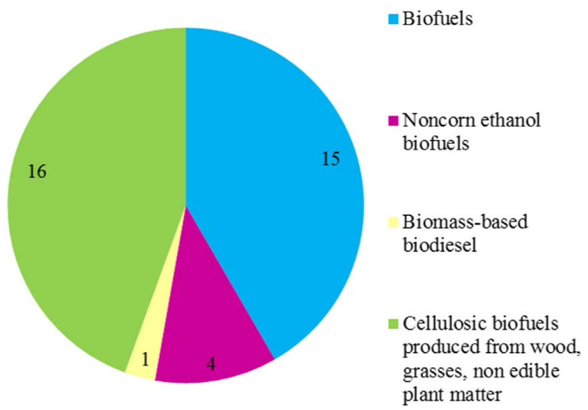

Fig. 1. Demands of biofuels with different sources in billion gallons by year 2022 [8].

availability of biomass resources and economic incentives. The process design for bio-alcohol requires consideration of product quality and advanced technologies. Biomass processing also requires new chemical transformations to improve product quality. These factors present exciting research opportunities in process system engineering (PSE) research (including modeling simulation, optimization, process control, and heat and mass transfer with techno-economic analysis) [11]. However, very few papers have presented the PSE aspect of bio-alcohol production. The objectives of this paper are to highlight the recent progress and future research in the field of PSE particularly for production of bio-alcohol fuel from biomass via pyrolysis. Firstly, this paper presents the various applications of biomass feedstock and bio-alcohol production. Secondly, it covers the importance of PSE, comparison studies of energy performance between bio-alcohol fuel and petroleum fuel and the completeness of research methods. Finally this study discusses the current progress and previous studies on PSE and techno-economic analysis in bio-alcohol production. The aim of this overview is completed with the discussion on current problems and future advances involves in bio-alcohol manufacture.

2. Biomass feedstock and its usage in bio-alcohol production

The lignocellulosic biomass of second generation biofuels was utilized to produce the bio-alcohol (Fig. 3). This feedstock refers to inedible stems and leaves the above-ground plant body. The feedstock were categorize to industry waste, biofuel crops, agriculture wastes and oil crops. The applications of wastes and crops be produced an excellent product of bio-alcohol such as bioethanol, others usage as biogas or bioelectricity. Bio-alcohol is defined as fuel that is biologically produced or biomass that is converted to alcohol. Bioethanol is established as a product of fermentation of starch, sugar and cellulose materials, whereas bio-butanol and bio-propanol are less common. Biological processing is less preferred than thermochemical conversion because thermochemical conversion requires pretreatment steps, is time consuming and represents a large investment [13]. Bio-alcohol in the form of methanol, ethanol, butanol or mixed alcohol fuels is obtained through pyrolysis of biomass agriculture wastes or algal biomass [14]. The most common bio-alcohols produced by pyrolysis are bio-methanol and bioethanol. Bio-methanol is easier to recover from biomass than bio-ethanol. Bio-ethanol forms azeotropes with water and is expensive to purify during recovery. Meanwhile, bio-methanol does not form azeotropes and recycles easily [7]. The current stage of bio-methanol research is focused on identifying the production route that offers the lowest production cost and simplest production process [15]. According to Demirbas [16], pyrolysis is defined as the thermal decomposition of biomass that occurs in the absence of oxygen or when significantly less oxygen than required for complete combustion is supplied. Important developments in the pyrolysis of biomass to biofuels may help resolve the fuel and energy crisis [15,17]. Table 1 shows the various types of pyrolysis. Biomass pyrolysis can be categorized into three subclasses: conventional (slow) pyrolysis, fast pyrolysis, and flash pyrolysis [18,19]. Slow pyrolysis and flash pyrolysis refer to thermal cracking with heating rates of 0.1–10 °C/s and > 1000 °C/s, respectively. The most commonly used process for converting biomass waste to liquid fuels is fast pyrolysis. The high temperature of 400–500 °C is rapidly attained at a rate of 10–200 °C s^{-1} [18] and can produce bio-alcohol. Fig. 4 presents design details of a pyrolysis apparatus. Biomass samples are placed in a stainless steel fixed bed reactor. An electric furnace is used to heat a reactor, and the reactor is monitored with a K-type thermocouple. Nitrogen gas functions as an inert gas to purge air from inside the reactor [20].

3. The importance of process system engineering (PSE)

Energy consumption rates will increase tremendously in the future with increasing population. Energy sources such as wind, biomass, solar, hydro, bio-alcohol for biofuel applications, geothermal and ocean energy are renewable sources for future supply in power generation. The environmental potential is concerned with renewable alternative sources. Fig. 5 presents a projection of worldwide energy consumption. There is a sharply increased of energy demand from year 1980 to 2030. The difference throughout every year ranged 19–30% and projected to up 57% in 2030. The current electricity could not enough to supply the energy demand. As for that, the alternative sources importance for energy recovery in huge amount. Consequently, the importance of PSE

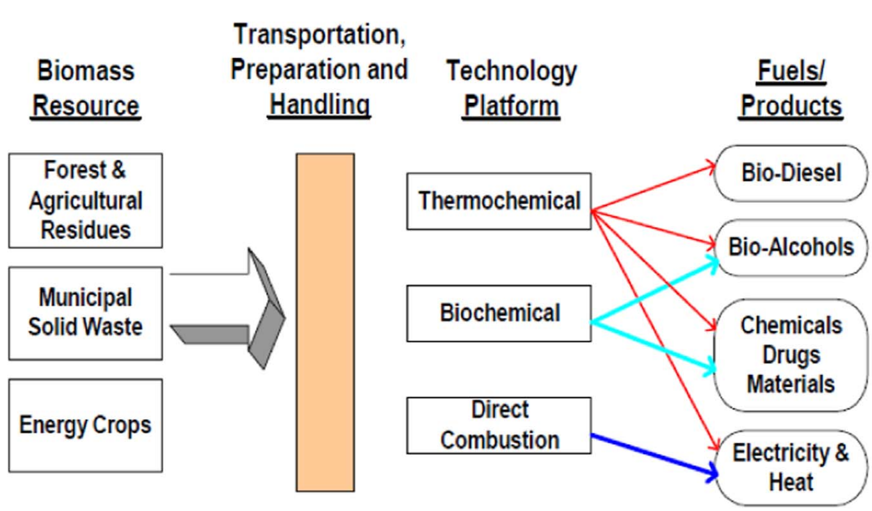

Fig. 2. The pathway of bioenergy produced from renewable biomass sources [10].