Fuel xxx (xxxx) xxxx

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Review article

A review on feedstocks, production processes, and yield for different generations of biodiesel

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ARTICLE INFO

Keywords:
Biodiesel
Biodiesel feedstocks
Biodiesel generations
Biodiesel production process
Biodiesel yield

ABSTRACT

Continuous increase in world's population, rapid industrialization, urbanization, and economic growth force for continuously increase in fossil fuel consumption to meet growing energy demand. Continuous emissions from burning of fossil fuel will create the need to find the appropriate and sustainable replacement for fossil fuels. Biodiesel is appropriate alternate solution for diesel engine due to its renewable, non-toxic and eco-friendly nature. According to EASAC biodiesel evolution is classified into four generations. Cultivation in arid and semi arid land or water, crop yield, effect on food supply, yield of biodiesel, energy content, carbon-neutral economy, easy availability, and economic viable are the main factors behind the evolution of biodiesel generations. This article highlights a comprehensive assessment of various feedstocks used for different generation biodiesel production with their advantages and disadvantages. Different production methods for biodiesel with yield calculation are also explained. Algae based third generation feedstocks are better in comparison with first and second generation due to their high energy content, high oil content and less polluting nature. Forth generation of biodiesel produced from synthetic biology, which will enhance the various physiochemical properties of biodiesel to achieve carbon neutral economy. Among the all biodiesel production processes; transesterification is the most suitable process, because it produces biodiesel of high yield, comparable properties with diesel. This process is also feasible as per economic point of view. The energy demand of future can be met by the blending of different generation oil feedstocks.

1. Introduction

Conventional energy sources like fossil fuel, petroleum, coal and methane are non renewable sources. These are main sources of energy at present time and due to larger consumption shortage is about to happen [1]. From 1970 to 2015 energy supply has increased from 6 Gtoe to 15 Gtoe and the consumption of fossil remains high for the primary energy supply. The consumption of fossil fuel was around 86% for production of primary energy in 1973 and in the year 2015, this consumption is about 78%. Oil production will reach to a maximum limit by 2020 and also the consumption will continue to rise, pulled primarily by China and India. Rapid industrialization leads to decrease of fossil fuel reserves [2]. Petroleum, nuclear, wind, coal, solar etc. produced major part of energy for different sectors (agriculture, transport and industry) [3–5]. For these sectors oil consumption in year 1973 is 42% and in 2014 it is 64.5% of total world's oil consumption. The consumption of fossil fuel is increased by 43.33% from last 41 year. [6]. Solar, wind, organic, hydrothermal are renewable energy resources and has great importance at present [1]. Less pollution potential and less contribution in global warming are the key factors that force to switch towards alternate solution. 20% population of European Union faces the problem of high noise production by rail and road traffic [7]. To meet the energy requirements biofuels grabbing the attention of researchers as an alternative of conventional fuel [8,9]. Other factor like high price of energy import, high cost and environmental issues have also created more interest in biofuels. The important properties that an alternative fuel should have the economically feasible, easily available, less environment issues as compared to conventional fuels

Abbreviations: CI, compression ignition; BP, brake power; BT, brake torque; IP, injection pressure; FAME, fatty acid methyl esters; PFCE, photon to fuel conversion efficiency; GCMS, gas chromatography–mass spectroscopy; GCFID, gas chromatography-flame ionization detector; ASTM, American Society of Testing and Materials; HPLC, high-performance liquid chromatography; EASAC, European Academies Science Advisory Council; GHG, Green House Gas; BSFC, brake specific fuel consumption; BTE, brake thermal efficiency; IT, injection timing; MES, microbial electro-synthesis; TG, Triglyceride

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https://doi.org/10.1016/j.fuel.2019.116553
Received 14 July 2019; Received in revised form 5 October 2019; Accepted 30 October 2019

[10]. Rudolf Diesel (inventor of diesel engine) also tested peanut oil in diesel engine as a fuel initially. During the research on alternative fuels this point was notice that the vegetable oils can also used in diesel engines without modifications.

Various harmful matters are emitted from engine exhaust (smoke, un-burnt hydrocarbons, carbon mono oxide, particulate matter and nitrogen oxides), which are very dangerous for human being and environment also. Most harmful pollutants are nitrogen oxide and smoke [11–15]. Accumulation of carbon mono oxide and other gases in the environment are also responsible for change in climatic condition [16]. From 2007 to 2030 the level of CO_2 has been estimated to increase by 80% approximately [17]. Due to reduction in fuel reserves and rising environmental issues has increased the attention of researcher towards the alternative fuels in place of conventional fuels [18–20]. Nowadays several countries have emphasized and encourage the use of alternative fuel like biodiesel fuel by governmental and regulatory pathways by means of both incentives and prescriptive volumetric necessities. From economic and emission quality point of view vegetable oil is the good source of energy as alternative fuels [21–23]. Mono alkyl ester that produced from fatty acid esters of edible oil, non edible oil and waste oils are called biodiesel [24]. Biodiesel can be used directly in engine in pure form or blend with diesel in various proportions to provide alternative solution of fuel in compression ignition (CI) engines. Biodiesel is renewable source of energy, sulfur free, oxygenated, sustainable and biodegradable. In diesel engine no modification is required while using biodiesel as fuel [25–28]. Biodiesel shows less regulated and unregulated emissions as compare to diesel fuel [28,29]. Various reasons for biodiesel used as alternative fuel are focus on reduction of greenhouse gas (GHG) emissions, less effect on global climate, sustainable and renewable energy solution and to get more promising alternate fuel supply to meet the current energy demand. With the help of biodiesel emissions of particulate matter, carbon monoxide, unburned hydrocarbon and carbon dioxide can be reduced [17,18,30]. The parameters of diesel engine performance like brake power (BP), brake torque (BT), brake thermal efficiency (BTE), break specific fuel consumption (BSFC) are also improved [18,21,31]. Fuel economy and emissions from engine is greatly affected by fuel injection system. The parameters of fuel injection systems are injection pressure (IP), injection timing (IT), fueling and injection duration [32,33]. The performance of engine can be improved by recirculating the exhaust gases and it can also reduce the engine emission [34]. Biodiesel produced from raw vegetable oil has its properties almost similar to diesel, so that it can be used as an alternate fuel. The main drawback of biodiesel as compared to diesel are high pour and cloud point, high viscosity, augmented nitrogen oxides emission, less volatility, lower energy content and poor spray characteristics [35]. Many researchers have been done to resolve all the problems of biodiesel fuel by changing feedstocks types, using additives and engine modifications.

The main advantages of biodiesel as compared to diesel fuel are eco-friendly, renewability, high flash point, biodegradability and non-toxicity [36]. Biodiesel has similar properties to petroleum diesel and lower emissions so it can be used in the transport sector as alternate solution to diesel fuel [37,38]. With increase in use of biodiesel could reduce the pollutants and movable carcinogens [39]. Different source of feedstocks like vegetable oils, algal oils, animal fats, microbial oils and waste oils can be used for production of biodiesel [40]. Transesterification, pyrolysis and supercritical fluid method etc are the procedures for the production of biodiesel. From all of these methods the most adoptive method of biodiesel production is transesterification, which produce biodiesel and glycerol as secondary product from the oil [41]. This review article covers different aspects of biodiesel produced from different generation of oil feedstocks. This article discusses about various feedstocks used for biodiesel production and also describes the different production processes and calculation for yield of biodiesel. This review will help researchers to analyze and compare different generations of biodiesel.

2. Generations of biodiesel

All biodiesels have the equal renewable origin and basic. They are produced from photosynthetic conversion of solar energy to chemical energy, which make them isolated from early photosynthesis. In accordance to ASTM, term biodiesel assigned for monoalkyl esters of long-chain fatty acids resulting from edible oils, non-edible oils and waste oils, which produced from transesterification process of triglycerides using methanol and catalyst [42]. Glycerol (glycerin) is formed as by-product during transesterification process. Generally methanol is used to produce biodiesel due to low cost and easy availability. The term B100 means 100% of FAME, while lesser amount, like B20 designate as 'biodiesel blends'. Production of biodiesel depends on solar energy and it is the base of sustainable bioeconomy. Mainly in the transport sector biodiesel is still of primary significance in current societies (in spite of enormous improvement in technology to convert solar energy to electricity with photovoltaic cells).

Major issue regarding renewable fuel is about struggle of land for food and development of fuel. Scientific steps taken for biodiesel development are of covering the feedstocks development, optimum production method, quality and quantity improvement for biodiesel and carbon–neutral economy [43]. According to the EASAC report 2012 biodiesel are usually classified as the first, second and third generation of biodiesel that primarily based on the origin of biodiesel, whereas the fourth generation biodiesel drawn from man-made biological tools and is at infancy level of fundamental research [24]. The production processes used for different generations of biodiesel are shown in Fig. 1.

2.1. First generation biodiesel

First generation biodiesels are produced from the edible feedstocks, example of edible feedstocks are Rapeseed oil, Soybean oil, Coconut oil, Corn oil, Palm oil, Mustard oil, Olive oil, Rice oil, etc. [44]. Various feedstocks used for first generation biodiesel are illustrated in Table 1. Use of edible feedstock for the production of biodiesel is quite popular at beginning of biodiesel era. Availability of crops and comparatively easy conversion procedure are the main benefits of the first generation feedstocks. The risk of limitation in food supply is the main disadvantage in use of these feedstocks that increase the cost of food products [45]. Adaptability to environmental conditions, high cost, and limited area of cultivation are also the obstacles for the production of biodiesel from edible feedstock. These drawbacks constrained users to shift on the further alternate sources for the biodiesel production [46].

2.2. Second generation biodiesel

Second generation biodiesels are produced from the non-edible feedstocks, example of non-edible feedstocks are Neem oil, Jatropha oil, Nagchampa oil, Karanja oil, Calophyllum inophyllum oil, Rubber seed oil, Mahua indica oil etc. [47,48]. Different non-edible feedstocks used for biodiesel production are discussed in Table 1. Drawbacks of first generation feedstocks attract researchers to work on non edible feedstocks. Eco-friendly, less production cost, eradicates food inequality, less requirement of land for farming are the main benefits of second generation biodiesel [44–46]. These oils contain the main benefits of using second generation biodiesel are, no requirement to relay food plants and no requirement of agricultural land only. Disadvantages of second generation fuels is yields of plants, where yield falls for main non-edible plants like Jatropha oil, Jojoba oil and Karanja oil. These feedstocks can cultivate in unimportant lands. That's why it is forced to farm non-edible crops at farming lands; it directly influences economy of society and the food production. To beat the socioeconomic issues of nonedible oil, the researchers paying attention on new alternate solution, which are economically feasible and simply accessible at greater extent. Requirement of additional alcohol amount is also the drawbacks for second generation biodiesel [46].