Renewable Energy 119 (2018) 365–374

Contents lists available at ScienceDirect

Renewable Energy

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

Optimization of biodiesel production as a clean fuel for thermal power plants using renewable energy source

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A R T I C L E I N F O

Article history:
Available online 30 November 2017

Keywords:
Biodiesel
Cost analysis
Design of experiments
Solar collector
Transesterification

A B S T R A C T

The cost of biodiesel production as a renewable source is always an obstacle in industry. In order to overcome this problem, another renewable source, solar collector was used to investigate and optimize the transesterification reaction of rapeseed oil for methyl ester production. Three main factors, which include catalyst (NaOH) concentration, reaction temperature and time, were varied according to a central composite design. The yield of methyl ester as the first response was determined by using NMR method. The second response was the commercial cost of production. In order to reduce fossil energy consumption for electric power as a main part of cost, the solar collector was used to provide heat. The results based on response surface method showed that the best conditions for producing biodiesel in the constant molar ratio of 1:6 oil:methanol were the temperature of 60 °C, NaOH concentration of 0.3% wt/wt and reaction time of 60 min. In these optimum conditions, the yield of methyl ester and the cost of production for one-liter biodiesel were 78.6% and 0.706$, respectively. Also, some chemical and physical properties of biodiesel were compared with those of petro-diesel fuel and biodiesel production without solar collector has been done for achieving price differences.

1. Introduction

Using liquid fuels has grown with increasing world population, especially in the transport sector. Reduction of fossil fuels availability, increasing emissions of greenhouse gases such as carbon dioxide and increasing petroleum fuels prices have increased the need for finding alternative sources of sustainable, renewable, efficient, cost-effective and less greenhouse gas emitting energy [1]. In 2014, as in previous years, using renewable energy sources in power generation and transportation has increased, so that over the past decade increased from 0.9 to 3%. Global production of biofuels in the past increased about 4.7% (4 million barrels of oil equivalent). Biodiesel is one of the superior biofuels that can be a good alternative for common liquid fuels such as diesel [2]. In chemical standpoint, biodiesel is a mixture of fatty acid methyl esters that can be obtained in the reaction of triacylglycerols (triglycerides) with alcohol, in the presence of a catalyst (acidic, basic or enzymes) that is called transesterification. Because of its features such as being renewable, having reduced emissions, high-efficiency of combustion, being biodegradable and improving lubrication and having higher safety, it is more popular than petroleum diesel [3,4]. Biodiesel is considered as a carbon neutral fuel. Another environmental benefit of biodiesel is a very low amount release of sulfur compounds.

Biodiesel is often obtained from biomass oils including vegetable oils. The number of carbon atoms in carbon chain molecules of petro-diesel is 14–18, that is similar to that of vegetable oils. Structural characteristics of biodiesel have made it possible to replace conventional energy sources (petro-diesel). The cost of biodiesel production is generally high. Therefore, the price of pure biodiesel is more than conventional diesel [5]. The price of biodiesel production includes two main components: process price and raw material price. Although many fat and cheap oils, such as waste oils in restaurants and animal fats can be used to produce biodiesel, the main problem of these fats is the existence of large amounts of free fatty acids that make transesterification reaction hard and the cost of producing biodiesel from these materials increases. For biodiesel production, the raw material is preferred to include a large amount of fatty acid triglycerides. Among these materials, rapeseed is a plant that is cultivated widespread throughout the world aiming to animal feed, edible oils and biodiesel production (containing 40% oil in its seeds). Compared to

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https://doi.org/10.1016/j.renene.2017.11.087

other plants, rapeseed oil is preferred for the production of biodiesel because it has higher productivity per unit area of land. Rapeseed is one of the most important oil plants, which after soybean, palm and cottonseed have been ranked fourth in the world. The production of rapeseed oil had a growth rate of 90% during the year 2002–2012 [6].

Producing biodiesel from rapeseed oil has been done. Many factors influence the transesterification reaction, such as the type of oil, the type and amount of catalyst, the type and amount of alcohol, the reaction temperature, time and pressure. Ferella et al. [7] investigated the effect of some parameters on the concentration of triglyceride, diglyceride, and monoglyceride. They examined the effect of potassium hydroxide catalyst in process of producing biodiesel from rapeseed oil. The results showed that highest conversion is observed using 0.6% (w/w) of catalyst, the temperature of 50 °C and 90 min of reaction time. Wang et al. [8] examined the transesterification reaction from rapeseed oil by taking some situations affecting reaction to produce biodiesel. Results showed that the best conditions to achieve maximum FAME content (90%) are: temperature of 65 °C, the molar ratio of methanol:oil 15:1, 180 min, 6% (w/w) catalyst concentration and 270 rpm as stirring speed. However, sufficient information is not available to optimize transesterification process with respect to a wide range of parameters affecting the production of biodiesel from rapeseed oil; therefore, further research in this area is essential.

Conventional vegetable oils and animal fats are saturated and unsaturated monocarboxylic acid esters of glycerides with a trihydric alcohol. These triglycerides can react with alcohol in presence of a catalyst. In transesterification, which is also called alcoholysis, alcohol of ester is replaced with another alcohol. Suitable alcohols include methanol, ethanol, propanol, and butanol [9].

Among these alcohols, ethanol and methanol are more common and cheaper, and methanol has more physical and chemical advantages compared to ethanol [9–11].

The catalyst is intended as a chemical compound to be able to apply acceleration effect and conducting effect on reaction progress that thermodynamically is possible. By increasing the percentage of catalyst, methyl ester production rate increases. In order to study the effect of a catalyst on conversion reaction, potassium hydroxide and sodium hydroxide as the most common catalyst are used in biodiesel industrial production [7,12].

The use of catalyst increases the rate of biodiesel production. However, it has been sometimes absorbed a greater amount of catalyst, which decreases the efficiency of biodiesel production; since the addition of greater amounts of alkaline catalyst causes a reaction between it and triglycerides and then soap production. This is followed by a reduction in production rate and difficulty in the separation process.

Transesterification with this type of catalyst is suitable for the oils that have low free fatty acid content, i.e. less than 0.5 wt% of the oil. Most of the biodiesel producers use sodium hydroxide and potassium hydroxide as a catalyst; however, in some reports, it is found that sodium hydroxide has better performance than potassium hydroxide and in other research reports, the opposite is visible, but most researchers believe that these catalysts have similar performance [13,14]. Due to the high prices of feedstock and biofuels production technology, it is necessary to optimize the production process. Biodiesel production process should be optimized in a way that the value of production would be higher than its cost [3]. Yuan et al. [15] studied biodiesel production from waste rapeseed oil in order to reduce the production cost. Maximum conversion occurred at a temperature of 48 °C, reaction duration of 65 min, and alcohol:oil molar ratio of 6.5:1 in the presence of catalyst concentration 1% (w/w).

Geographic coordinates of Iran have led to the dispersal of renewable resources such as wind, sun, and water [16,17]. Due to the possibility of cultivating biological resources, including microalgae, there is also the possibility of producing biofuels [18]. Due to the increasing population in the world and particularly in Iran and also reduce food supplies such as drinking water and fossil fuels, it is very important to create a modern and renewable system that is able to produce these resources together [19]. In this research, it has been tried to constructing a solar collector and using its heat to produce biofuels.

Also some studies have been made on the use of solar energy to produce biodiesel. Zanotti et al. [20] studies lignocellulosic biodiesel production by solar power and found that biodiesel produced has a net energy output of 52.30 MJ/kg. Zheng et al. [21] provided a conceptual design for the use of solar energy to produce biodiesel. They showed that the adverse environmental impacts of biodiesel production are reduced by this method. Leon et al. [22] devised a method for recovery of methanol consumed in biodiesel production, using solar energy, which can provide more than 90% of its energy.

In our study, the optimization of transesterification reaction for producing biodiesel based on most important factors was investigated. In order to achieve optimum conditions (maximum conversion of oil to methyl ester and minimum cost) and the right combination of factors, response surface methodology was used for experimental design. The heat loss of a solar collector as a renewable energy source provided the heat of reaction of biodiesel production and helped producing another renewable source.

2. Materials and methods

2.1. Material

In this study, crude rapeseed oil (unrefined, from Shadgol Oil Co., Neyshabur, Iran) without any additional material was used. Methanol (purity of 99.8) and sodium hydroxide (pellets pure) for producing biodiesel were purchased from Merck.

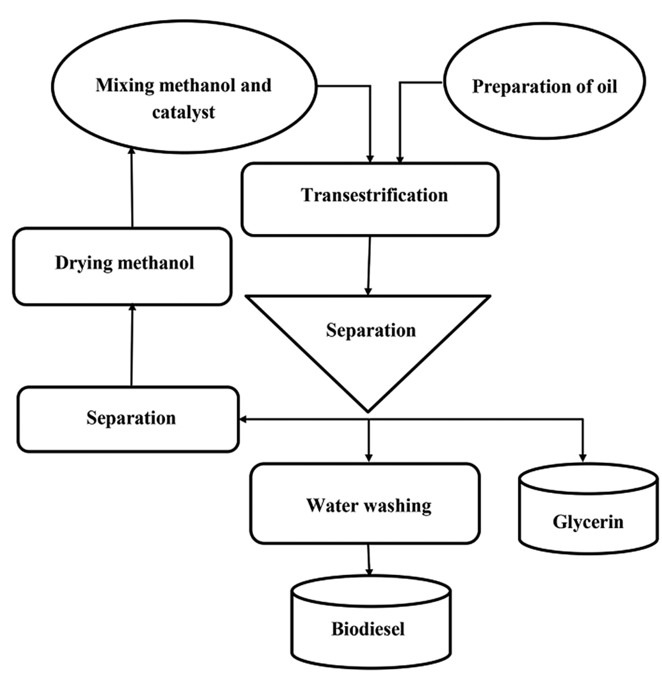

Fig. 1. Production of biodiesel from rapeseed oil.