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Biodiesel production from waste cooking oil using a stirred batch reactor

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ABSTRACT: In recent years, biofuels have been more interested due to rising prices of fossil fuels. Meanwhile, the methyl esters of fatty acids, which are called biodiesel, because of relatively simple production process, same characteristics with diesel fuel and no modifications need to the engine, has became as a replacement for diesel fuel. Design, construction and optimization of biodiesel production process are main objectives of this research. Waste cooking oil used as feedstock and methanol as alcohol with molar ratio of 1:6 in the presence of potassium hydroxide as a catalyst with 1% by weight waste cooking oil. In order to optimize the production process, two parameters of stirring velocity in 3 treatments (650, 550 and 450 rpm) and reaction time in 6 treatments (10, 20,30,40,50 and 60 min) was investigated. The results show that more than 95% of ester conversion occurred in the first 30 minutes. Biodiesel production increased in stirring velocity of 650 rpm and reached its maximum. Thus, reaction time of 30 min and stirring velocity of 650 rpm is optimal for biodiesel production from waste cooking oils in a batch stirring reactor.

Keywords: alkaline catalyst; biodiesel; biofuel; esterification; transestrification.

INTRODUCTION

Most of the world's need for energy resources are supplied from petroleum, coal and natural gas, with the exception of nuclear power, hydroelectric and solar energy, these resources are limited and due to the high intensity of energy consumption in the world, access to these resources increasingly reduced. Today the use of non-petroleum energy sources in many countries has been seriously investigated. Substituting biofuels instead of petroleum liquid fuels investigated in two groups. The first group are gasoline substituted fuels such as ethanol and other alternative fuel substituted of gas oil such as biodiesel, which are used in pure form or blended with diesel fuel in compression ignition engines (CI). Biodiesel, fatty acid alkyl esters (mainly methyl ester) is a result of trans-esterification reaction between triglycerides with an alcohol in the presence of a catalyst. Biodiesel as an alternative and renewable fuel source, can be used in diesel engines to reduce air pollution and dependence on fossil fuels. (6)

Three main methods which has been developed to convert vegetable oil to biodiesel fuel, include:

- Pyrolysis
- Micro – Emulsification
- Trans esterification

Several processes for biodiesel production has been presented, but the method of trans-esterification with alkaline catalyst in a batch reactor, can produce high percentage of methyl ester with a relatively low cost. Transesterification method for biodiesel production, causes the oxygen molecules remain inside the fuel and it will become an oxygenated fuel. (7)Trans-esterification in general is performed using three methods such as alkaline, acid and with enzyme (lipase enzyme) catalyst. Alkaline catalyst is the most common and cheapest, which is usually performed with (NaoH) and (KoH). Among different biodiesel production methods, transesterification with alkaline catalyst is commonly used. (1)

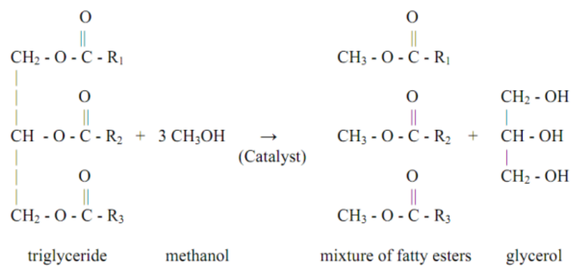

Figure 1. Transesterification process

Alkaline catalysts, are known as the most widely used catalysts for biodiesel production. Shorter conversion time is one of the advantages of this type catalyst when compared with acid one. (9) However, for waste cooking oil with high free fatty acid content, esterification step with acid catalysts or basic pretreatment is required. The alkaline catalysts for feedstock with 3% of free fatty acid are appropriate. (8) The most common reactor for biodiesel production, is the batch reactor which reacts at temperatures near the boiling point of alcohol. (9) However, for large-scale industrial production of biodiesel using a continuous-flow reactor can lower production costs in compared to batch reactors. (10) Highina, et al, used batch reactor to produce biodiesel from Jatropha oil. They concluded that, 93% of triglycerides has been converted to the methyl esters as a result of using batch reactor (4). In some literature, batch reactors are used for biodiesel production from vegetable oils and in some studies they compared both batch and continuous flow processes. Continues flow reactor replaced with the batch one, and it was indicated that both reactors performed similarly on an industrial scale (5). The easiest way to produce biodiesel is using the batch stirred tank reactor (STR), with triglyceride to alcohol ratio in the range of 4:1 - 20:1 (often 6:1) under optimum temperature of 60℃. Operating temperature in the range between25-85 ℃ is reported. The reactor may be gas tighten and equipped with a methanol condenser (7).

The objective of this research is to find an optimal mixing time and stirrer velocity to produce biodiesel from waste cooking oil by using stirred tank batch reactor. Therefore, tests based on variable stirring velocity factor and reaction time, at 3 and 6 levels respectively was performed under optimum temperature condition.

MATERIALS AND METHODS

Reactor is sole part of the process in biodiesel production which chemical reaction takes place inside it. Batch and continuous reactors can be divided into two categories. (Figure 2 shows the batch reactor schematically). Batch reactors simply made of a tank which equipped with stirrer. Tank is filled with the reactants (in this case waste cooking oil, alcohol, and catalyst), and then stirrer acts for a while. After the time required has elapsed, reactor contents drained and then processed.

Figure 3. stirrer designed in solidworks

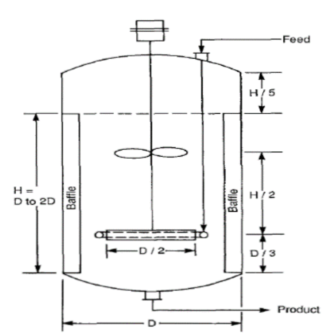

Figure 2. schematic of the batch reactor

Beginning the process with the reactive substances and then leaving the processed materials is the main feature of batch reactors. In batch reactor we used the tank filled with reactive substances, then mix intensively and finally the mixed component has been left. In the any moment, relative composition of objects inside the reactor is uniform.

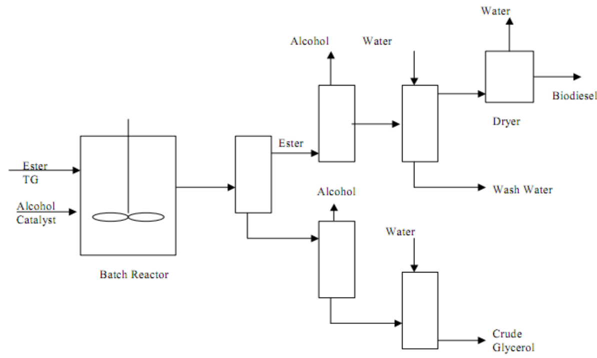

Figure 4. Biodiesel production process using batch reactor

The tank designed for reactor has capacity of 30 liters. In order to facilitate phase separation during unloading, end bottom of tank was made in a cone shape. Based on calculations, tanks were built from 3 mm sheet of stainless steel. Reaction tank and water washing tanks were built separately. Methanol is less soluble in oil, when liquids placed inside a container, they will be distributed to, two completely separate part of methanol in upper and the oil in lower part. Therefore, in order to increase the contact surface and mixing of these two materials, stirring with mechanical agitator is indispensable. It should be noted that the mixing time should not be too much, because in many chemical reactions, it leads to degradation of product and produce unwanted materials. Heating system was used for heating liquid and keeping it at a constant temperature.

The heating system for each tank is equipped with a 1000 watt heater element, a temperature sensor and a digital thermometer for monitoring and temperature adjustment. Electrical signals from sensor cause heater switched on or off.

In the power transmission system, an electrical motor with power of the 1.5 KW (2 HP) was used, which power is driven by a belt and pulley to shafts. In order to save on the costs, one electrical motor used for transmitting power to both shafts. Also to change the rotational velocity of the motor, hi run- N100 inverter was used. Both shaft pulley diameter were considered equal to 15cm.

An electro pump of 0.37 KW (0.5 HP) were used to transport raw materials (reactants) and products between tanks. The reactor with all its equipment set up on a framework that was built with 3 × 5 profiles. In the design of the reactor to prevent vertical and horizontal vibrations, two bearings were used for each axis. Due to the weight of the reactor and for ease of transport, reactor was equipped with four breakable wheel.

a b

Figure 5. a) reactor designed in solidworks b) batch stirred tank reactor

To perform the test, the optimal 6:1 molar ratio of oil to alcohol and in presence of KoH as catalyst with amount of 1% oil weight. The experiments based on three levels of the variable factor, stirrer velocity (450, 550 and 650 rpm) and reaction time (10, 20, 30, 40, 50 and 60 min) with temperature (60 ° C), totally in 6 levels was performed. Waste oils were collected from Sari University of Agricultural Sciences and Natural Resources restaurant, and used at a rate of 8 liters per experiment. Due to in the large amounts of free fatty acids (FFAs) and water in waste oil, pretreatment operations is required.

For separating impurities and suspended particles, waste oil was passed through a fine strainer network. Water content in oil will cause production of soap and reduce the efficiency of the reaction and make subsequent steps of biodiesel production difficult such as phase separation. Also have a significant impact on the percent of reactant conversion and the quality of products, in some cases, the water will not lead to reaction progress. Undesirable effect of water is more noticeable at higher temperatures. Water can causes triglycerides hydrolysis into diglycerides and produce free fatty acids, and alkaline catalyst can cause the free fatty acids conversion to the soap.

Two methods for removing water can be used, sedimentation and evaporation of water in oil. In this research we used sedimentation methods. In this method, the oil was heated to 60 ° C and kept at this temperature for 15 minutes. Then the oil is transferred to a settling tank and the water settled down at least in 24 hours. The advantage of this technique comparing with direct evaporation is reduction of free fatty acids production.

Oils with high free fatty acids content of about 0.5 % requires pre-treatment step (esterification). Free fatty acids and water are the two main factors causing the catalytic reaction, resulting in lower values of conversion. And this caused reaction Progress slowly and make it not to react in a reasonable and expected time. For the determination of free fatty acids of waste oils and determine the amount of catalyst required for reaction. With a solution of 0.1 normal potassium hydroxide and phenolphthalein titration process was done.

After reaction ended, the next step is phase separation. Biodiesel and glycerin are products of the reaction. Time required for the separation of more than 90%, is about 3 to 4 hours. About 90% of glycerin, shall be settle in the first 30 minutes. Upper layer is biodiesel and tarnishes bottom layer is glycerin. However, the mixture of biodiesel and glycerin phases is between to layer, also that section should be separated with glycerin. Authorized glycerin content in accordance with ASTM D 6584 should be less than 0.24% of total glycerin production. It should be noted that the time required to separate depend on reaction quality, also reaction which produce more soap is required more time for separation.

RESULTS AND DISCUSSION

Effect of time on the yield of biodiesel production

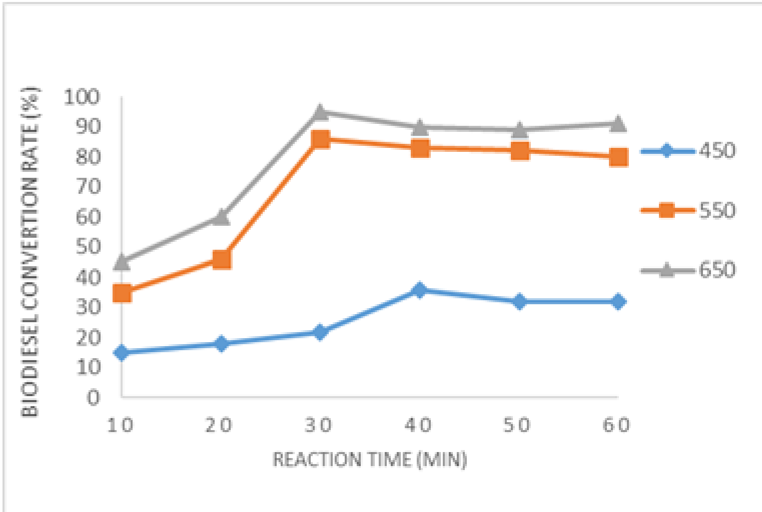

Figure 6. Effect of mixing time on biodiesel conversion rate time

Figure 6 shows the conversion of 90% ester happened in first 30 minutes. Solution is stirred for 60 minutes. The results show that with increasing time after 30 minutes, little change in the conversion rate has been observed. After 30 minutes after process begin, increasing rate of production dropped down and reaction rate reaches equilibrium. Transestrification process begins by mixing between methanol and waste oil in the presence of potassium hydroxide. The rate of reaction initially due to the low solubility of alcohol to oil and in the second stage increases finally, the consumption of reactants decreases and reaches equilibrium.

Effect of stirring velocity on biodiesel production the yield

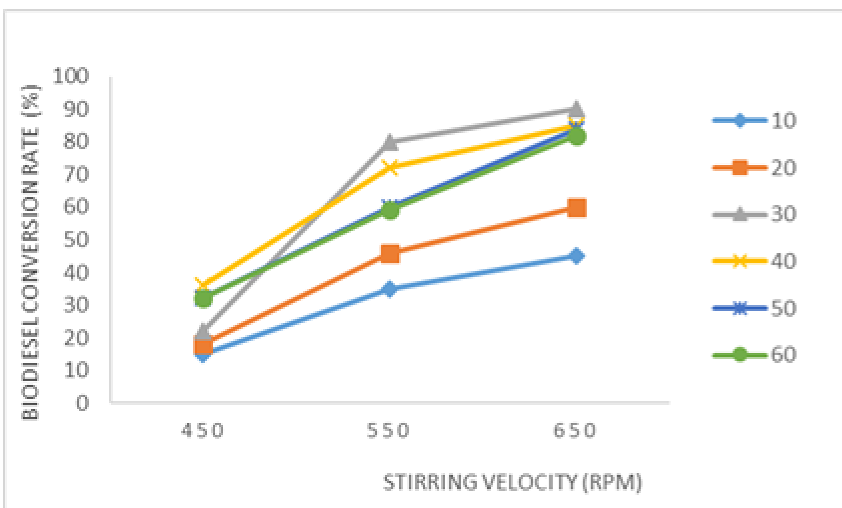

Figure 7. Effect of stirring velocity on biodiesel production the yield

Figure 7 shows, with the increase of stirring velocity, biodiesel production rate increases and reaches its maximum at around 650 rpm. With increasing stirrer speed, collisions between molecules that are insoluble in alcohol and oils and form a homogeneous phase, increased and more mass transfer takes place. Higher stirring velocity, cause higher conversion rate in a lower time. However, excessive stirring rate may reduce the reaction rate.

Conclusions

In this study, we have been designing and manufacturing a batch tank reactor equipped with a mechanical stirrer, in order to convert triglycerides to methyl ester done in less time. Due to the special design of mixing and the mixing of the two phases of oil and alcohol, biodiesel production operation of the reactor at the ideal temperature of 60 ° C, stirring velocity of 650 RPM and with alcohol to oil Molar ratio 6:1 in presence of potassium hydroxide 1% oil by weight as a catalyzers, the less time it's happened. More than 95% of the conversion of triglycerides to methyl ester occurred in the first 30 minutes.

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