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Reactor Design for Biodiesel Production from Soybean Oil Catalyzed by CaO Nanocatalyst

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ABSTRACT

Biodiesel is an alternative fuel sourced from oil or fat as a substitute for petroleum-based fuels. Biodiesel is a product of the transesterification reaction with the help of a catalyst which serves to speed up the reaction process. Operating parameters used in the biodiesel production process are the operating temperature of 60°C with a pressure of 1 atm and a reaction time of 2 hours with a molar ratio of methanol: oil is 1: 1. The purpose of this study is to design a reactor for the process of biodiesel production using a CaO catalyst. In this study, the reactor design was carried out using the reaction base that had to be carried out by previous researchers with optimized conditions. The results showed that the CSTR design was used as a reactor to react the biodiesel production process with a cooling pad to maintain the temperature because the reaction was exothermic. Based on the design, the CSTR reactor is made of stainless steel with a capacity of 170 m^3. The dimensions of the reactor had a diameter of 6 m and a height of 6 m with a head thickness of 0.4 in. The stirrer used is a six-blade disk type with a diameter of 2.35 m. This reactor design is promising and has good potential to be used in biodiesel production with easy control of temperature and low operating costs.

Keywords: biodiesel production, transesterification, reactor design, CSTR, CaO catalyst

1. INTRODUCTION

The developing customer demands and constantly deteriorating environment have driven people to pay more attention to biodiesel [1]. Biodiesel is well known as a renewable and environment-friendly fuel that can substitute petro-diesel perfectly. Biodiesel is commonly produced by transesterification using an acid or alkali solution as catalysts from biomass sources, such as plant oils and animal fats [2].

In the initial era of biodiesel production, the batch reactor was widely employed. However, it has disadvantages such as large reactor volume, extensive separation process, and high labour costs. [3] Compared with the batch reactor, a continuous reactor offers better performance in improving heat and mass transfer, reducing the production cost, providing a uniform quality of the final product, and supporting industrial-scale production. [4], [5]

The most common continuous-flow system in biodiesel production is the continuous stirred-tank reactor (CSTR). [6] A CSTR is a vessel equipped with feed input (inlet), product outlet (output), an agitator, and a cooling and heating jacket. [7]. In CSTR, the reactor configuration is developed to pump the reactant continuously and efficiently into the reactor. In the beginning, the reactor is loaded with reaction materials, and an adequate agitation process lasts until the reaction process is completed [8]. When comparing CSTR with BR, CSTR provides quality operation to improve thermal and mass transfer, less production cost, provides uniformity of product, and supports scale-up [4][5]. CSTR has been widely used in the industrial-scale biodiesel production due to the sufficient technical knowledge and deep understanding of the operation of CSTR. [8]

Many studies have been carried out regarding the design of CSTR reactors for biodiesel production, including [2] conducting CSTR simulation and optimization research with Aspen plus [9], then conducting Feedback research. Linearization Controller Design for CSTR, and [10] performed CSTR design with HYSYS simulation. In this study, a reactor design for the biodiesel production process was carried out based on the reaction from the research results conducted by [11].

This study aims to design a CSTR-type reactor for biodiesel production using CaO nanoparticles as a catalyst. The method used in this research is a literature study for data collection and reactor design based on reactions from research conducted by [11]. The reactor that has been designed has a capacity of 170 m^3 of stainless steel with 6 m in diameter and 6 m in height using a six-blade disk stirrer with a diameter of 2.35 m. The reactor design that has been made is quite promising for biodiesel production with a CaO catalyst with low operational costs.

2. METHOD

This research was carried out through a problem identification process and a literature review for sources relevant to the study. The next stage was data collection and then continued with reactor design.

The reactor design study conducted was based on research conducted by [11]. The biodiesel production capacity target with the designed reactor is expected to produce 366,219 kg/hour of biodiesel. In this biodiesel production, soybean oil is used, then methanol with a purity of 99%, and a catalyst of CaO nanoparticles with a purity of 97%. Table 1 shows the parameters for making biodiesel from soybean oil that has been carried out by [11].

Table 1. Operational parameters of biodiesel production with CaO nanoparticles as catalyst

Parameter	Value
Reaction Temperature (ºC)	60
Pressure (atm)	1
Methanol: oil ratio	11:1
Amount of CaO catalyst	3,675%
Reaction time (hours)	2
Conversion (%)	97%

3. RESULT AND DISCUSSION

The production process of biodiesel from soybean oil begins with heating oil on the heater (H-1) at a temperature of 105˚C to eliminate the influence of moisture. Then elsewhere, methanol with the catalyst is mixed in the mixer (M-1) while heated at a temperature of 65˚C. Furthermore, oil is pumped into the heat exchanger to lower the temperature and enter the reactor (R-1). In addition, the catalyst and methanol combination is injected into the reactor. The oil and methanol combination will be reacted for 2 hours in the reactor (R-1) at a temperature of 60ºC and a pressure of 1 atm with the help of a CaO catalyst. In this biodiesel production, 171.17 kg/hour of methanol is used as a reactant, and 396.480 kg/hour of oil with a CaO catalyst of 3.675% of the weight of the oil used.

The process of biodiesel formation occurs in the reactor through transesterification and esterification reactions. The transesterification reaction is the primary reaction, while the esterification reaction is a side reaction.

The reactions that occur in the reactor are as follows:

Esterification reaction

$$\text{Fatty Acid} + CH_3OH \rightleftharpoons \text{FAME} + H_2O$$

Transesterification reaction

$$\text{Triglycerides} + 3CH_3OH \rightleftharpoons 3\,\text{FAME} + \text{glycerol}$$

The reaction of the oil with methanol, a stirred flow tank reactor or CSTR was chosen. The CSTR reactor was selected because this reactor is relatively easy to control the temperature, so it is very suitable for isothermal reactions carried out for the production of biodiesel. Continuous stirrer occurs so that the temperature and composition of the mixture in the reactor can be maintained homogeneous and of low operating costs. Then because the catalyst used is very small CaO nanoparticles, no particular specifications are needed to adjust the reactor to the catalyst used. The mechanism of the transesterification reaction using a CaO catalyst is shown in Figure 1. For CSTR reactor design, specifications are presented in Table 2.

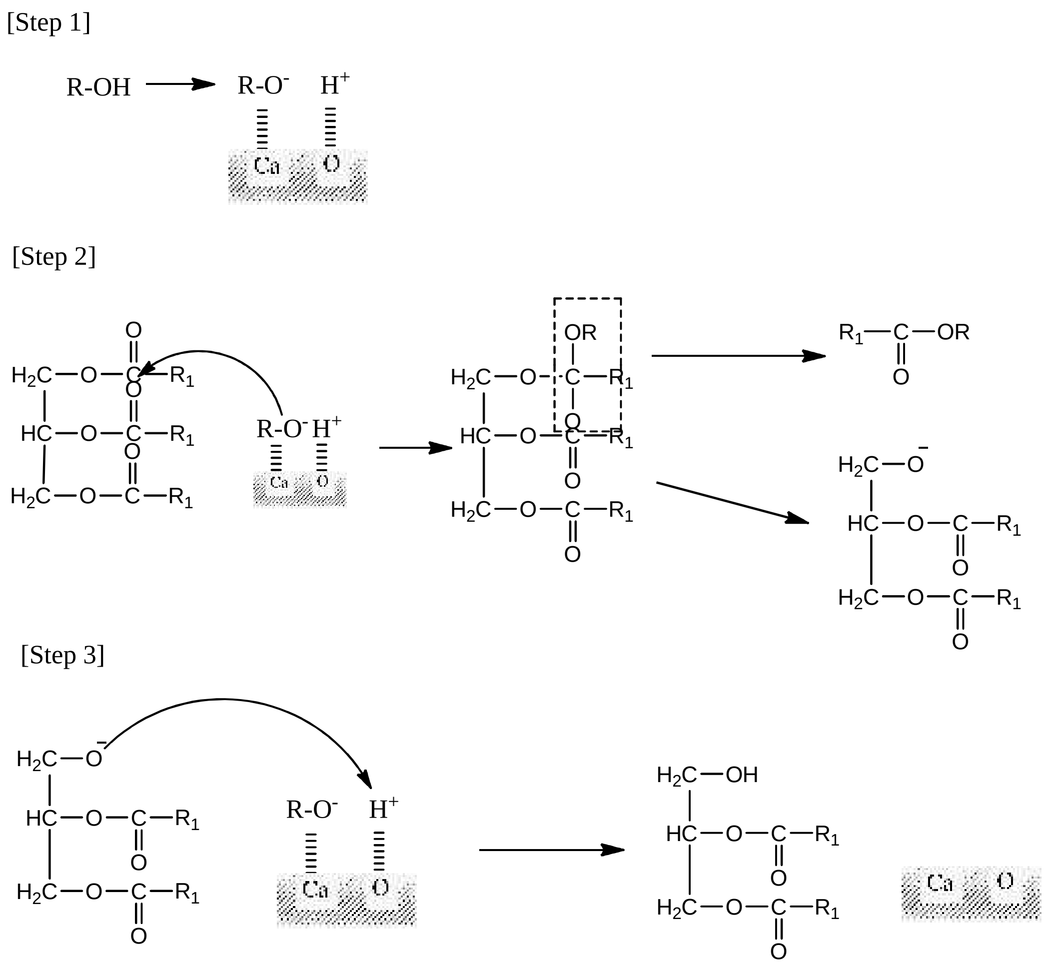

Figure 1. The mechanism of the transesterification reaction with CaO catalyst [12]

Table 2. CSTR reactor design specifications for reacting the oil with methanol

Codetool	R-1
Function	oil with methanol reacting with CaO catalyst to form methyl ester biodiesel
capacity of	170 m^3
reactor type	CSTR
Material	Stainless steel
Operating conditions	60ºC dan 1 atm
Dimensions	
Diameter	6 m
Height	6 m
Shell thickness	0,30 in
Head thickness	0,40 in
Stirrer	
Stirrer type	Six blade disk
Number of stirrer	1
Stirrer diameter	2,35 m
Stirring	600 rpm
Cooling jacket	
Thickness	0,5 in
Diameter	7 m
High	6 m

An illustration of the designed CSTR reactor is shown in Figure 2. Then Figure 3 shows the type of stirrer selected.

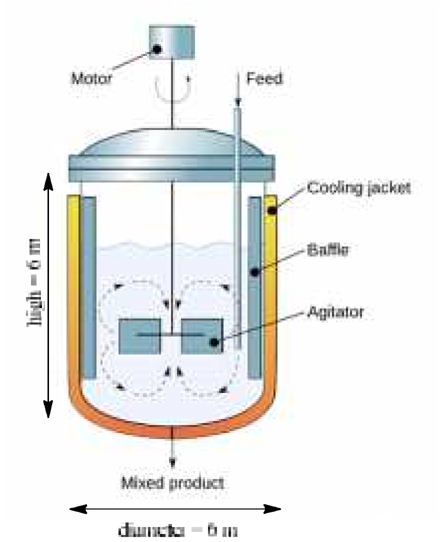

Figure 2. Illustration of CSTR reactor design

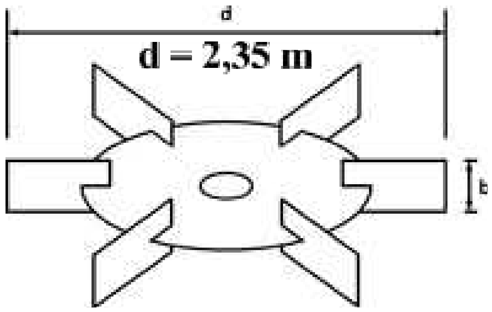

Figure 3. Six-blade disk type stirrer

After the reaction process, the mixture will be pumped into the settling tank (S-1) to separate the biodiesel. Then, the remaining methanol and glycerol, a by-product, will enter the flash drum (F-1) to be separated.

It is necessary to prove the reaction is exothermic or endothermic by calculating the total heat of the reaction (ΔH), which is calculated using the equation $\Delta H_{reaction} = \sum \Delta H_{product} - \sum \Delta H_{reactants}$ using data for each component presented in Table 3.

Table 3. ΔH values for several components [13]

Component	ΔH (Kj/mol)
Triglycerides	-672,0918
CH_3OH	-201,1945
$C_{18}H_{36}O_2$	-626,3119
$C_3H_8O_3$	-582,9225
H_2O	-68,3174

The calculation found that the ΔH values for the esterification and transesterification reactions were -167.578 KJ/mol and -1186.183 KJ/mol, respectively. So both reactions are exothermic. Then ΔG for the esterification reaction is 267.9039 KJ/mol, and the transesterification is -124.6493 KJ/mol. Through equation, van't Hoff known value of the equilibrium constant of the reaction at a temperature of 60°C (operating temperature) is 1.0025, so the reaction that occurs is reversible.

The ΔH is negative during the esterification and transesterification, showing that the reaction is exothermic. Since the reaction is exothermic, an increase in temperature will cause a shift in the equilibrium towards the reactants but can accelerate the reaction. As a result, a cooling jacket is utilized in the design of this reactor to keep the working temperature at 60°C in the reactor at the appropriate level. But if the temperature is lowered so the reaction would slow down, the process uses a temperature of 60°C. The optimum temperature is 60°C for biodiesel production reaction with CaO catalyst obtained by research [11].

With the various parameters above, this CSTR reactor can potentially be used as a reactor for the reaction of biodiesel formation from soybean oil with a CaO catalyst. Since this reactor is easy to control, the temperature is very suitable for the isothermal reaction of biodiesel formation and is also relatively cheap. The scheme of biodiesel production with soybean oil and methanol as the base material with CaO catalyst is shown in Figure 4.

4. CONCLUSIONS

Based on the results of the reactor design that has been carried out for biodiesel production using a CaO catalyst, the CSTR type reactor was selected. The designed CSTR is made of stainless steel with 170 m^3. The dimensions of the reactor are 6 m in diameter and 6 m in height and are covered with a 0.5 in a thick cooling jacket to keep the reactor temperature constant. Then the stirrer in the reactor uses a six-blade disk stirrer. The reactor that has been designed is promising to be applied to produce biodiesel with CaO catalyst on an industrial scale with a relatively low operating cost.

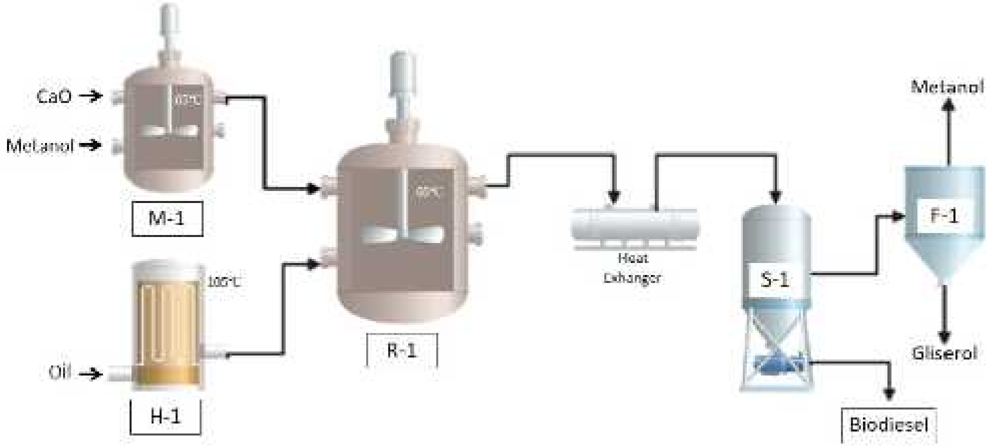

Figure 4. Illustration of biodiesel production flow using CaO nanoparticle catalyst

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