Production of Biodiesel Using Acetone as a Co-Solvent

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Abstract— *Transportation of products and people account for around 80% of global energy use, implying a high reliance on fossil fuels in our daily life. CO_2 is a greenhouse gas produced by the combustion of fossil fuels, which contributes to global warming and deforestation. As a result, the quest for sustainable, renewable alternative fuels such as biodiesel is becoming increasingly important. In this research, researchers have used waste cooking oil (acid value 1.86 mg KOH / g) to produce biodiesel. Acetone was used as a co-solvent to overcome the mass transfer barrier. Biodiesel production was increased by adjusting the acetone-to-methanol molar ratio, reaction temperature, reaction time, and stirring speed. The optimum reaction parameters were 20% methanol-to-oil volume ratio, 1 wt. % KOH, 0.6: 1 acetone-to-methanol molar ratio, 10-minute reaction duration, 40°C reaction temperature, and 600 rpm stirring speed. These conditions yielded 98.46 wt. % biodiesel. Co-solvent biodiesel satisfies ASTM standards under ideal conditions.*

Keywords— *Acetone, Biodiesel, Co-solvent, Transesterification, Waste cooking oil.*

I. INTRODUCTION

Numerous facets of daily life are dependent on fossil fuel, most notably the transportation of products and people, accounting for around 80% of global energy use. Numerous manufacturing firms rely on diesel engines or diesel boilers. Automobiles and ships used for transportation also consume a significant amount of fossil fuel. This scenario necessitates a heavy dependence on fossil fuels to meet everyday demands. On the other hand, fossil fuels are a finite source of energy. Additionally, they significantly contribute to global warming and deforestation. This has accelerated the search for sustainable alternative fuels such as biodiesel in response to the rising need for energy to replace fossil fuels [1]. Biodiesel is made via the transesterification of various feedstocks, including edible, non-edible, and waste oils. Compared to edible vegetable and plant oils, petro-diesel is much less expensive. However, because feedstock costs contribute to between 70% and 95% of total manufacturing costs, using waste cooking oil (WCO) as a feedstock for biodiesel lowers manufacturing costs [2, 3]. The benefits of recycling WCO for biodiesel production include economic effectiveness and pollution avoidance since haphazard disposal of WCO cause various issues, including water and soil pollution, disruptions to the aquatic ecology, and human health risks [4]. Thus, biodiesel production from WCO is advantageous both environmentally and economically since it is less hazardous synthesis and a low-cost feedstock.

Biodiesel fuels are non-toxic, biodegradable, and environmentally friendly renewable fuels that may be easily generated from oils and fats through a transesterification process (Fig. 1) with methanol or ethanol in the presence of an acid or alkaline catalyst [5].
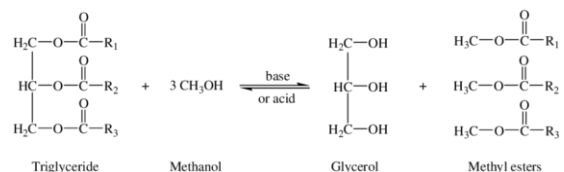

Fig. 1. A schematic representation of the transesterification reaction [4]

There are various challenges with this approach of transesterification. The fundamental challenge is that the reactants (oils and alcohols) are not readily miscible due to their chemical structures. The oil disperses in the methanol medium, reducing the collision rate of the glycerides and methoxides (the mixture of methanol and an alkaline catalyst such as KOH or NaOH). This lowers molecular collisions and reactions, resulting in longer reaction times, higher operational and labor costs, and higher fixed capital expenditures [6]. To avoid this issue, a traditional mechanical stirring approach is utilized to increase mass transfer between the oil and the alcohol at the boiling point of the alcohol. A co-solvent, such as diethyl ether, tetrahydrofuran, acetone, or 1,4-dioxane, is predicted to boost the oil's solubility in the alcohol medium by establishing a homogenous system. As a result of molecular-molecular interaction increase, the outcomes can result in a higher fatty acid methyl ester (FAME) yield during the shorter contact period [7, 8]. Alcohol, fatty acids, and triglycerides are highly soluble in co-solvent. The co-solvent utilized should be water-free. The solubility of the oil will be increased by adding a co-solvent. The chosen co-solvent should have a boiling point close to methanol, which simplifies the reaction's termination process [7].

The presence of acetone as a co-solvent increases the mutual solubility of methanol and oil and accelerates the reaction, resulting in a higher yield of FAME. Furthermore, the co-solvent accelerates the phase separation between FAME and the by-product glycerol upon completion of the reaction [9]. Acetone is an aprotic solvent with an

intermediate polarity that dissolves both highly polar methanol and non-polar WCO triglyceride to form a homogeneous reaction system that accelerates the transesterification reaction between methanol and triglycerides [7]. Compared to the traditional alkali-catalyzed transesterification, using KOH is more environmentally friendly and beneficial. Acetone can also stabilize the methoxide ions formed by KOH and methanol. These methoxide ions are a reactive intermediate in the S_N2 mechanism, which converts triglycerides to methyl esters [7]. Therefore, in this study, acetone was used as a co-solvent in alkali-catalyzed transesterification of WCO to investigate the effect on biodiesel production.

II. METHODOLOGY

Transesterification:

Filtration and preheating at 110°C were used to remove suspended material and moisture content from WCO. ASTM D664-07 determined the acid value of WCO to be 1.86 mg KOH / g. As the acid value was less than 2 mg KOH / g, direct transesterification in a closed container was conducted. Transesterification was accomplished by pre-mixing 100ml of WCO with acetone as a co-solvent on a magnetic stirrer for 3 minutes to achieve single phase formation. To promote the formation of potassium methoxide, methanol (20 v / v based on oil volume) and KOH (1 wt. % based on oil weight) were combined. The methoxide was then added to the mixture of WCO and acetone and stirred continuously for desirable reaction time at a desirable temperature. After the reaction time was completed, the reaction mixture was transferred to a separation funnel, and left to separate into two phases. The upper phase comprised predominantly of acetone, FAME, triglyceride, diglyceride and monoglyceride, whereas the lower phase consisted primarily of residual methanol and glycerol. The upper phase was rinsed with hot water to remove residual acetone and methanol from FAME. Any remaining water was removed using a 20-minute heating process at a temperature of 110°C. Washing and drying were performed until the pH of biodiesel was about 7. Biodiesel yield percentage was calculated as shown in (1).

$$Biodiesl\ yield\ \% = \frac{Biodiesel\ dry\ weight}{WCO\ dry\ weight} \times 100\% \qquad (1)$$

Process optimization:

In order to find the optimized reaction conditions for higher biodiesel yield, the influence of co-solvent-to-methanol molar ratio (0.2: 1, 0.4: 1, 0.6: 1, 0.8: 1, 1: 1), time of reaction (5, 10, 15, 20, 25, 30 minutes), temperature of reaction (30, 40, 50, 60, 70℃) and speed of reaction (150, 300, 450, 600, 750 rpm) were studied.

At the laboratory, the physical characteristics of the biodiesel were evaluated for flash point, density, kinematic viscosity and chemical characteristic of acid value. Followed by the ASTM analytical technique, identical conditions were maintained for all samples.

III. RESULTS AND DISCUSSION

Effect of co-solvent-to-methanol molar ratio:

The effect of the co-solvent-to-methanol molar ratio on the methanolysis of WCO was investigated. As illustrated in Fig. 2, various acetone-to-methanol molar ratios (0.2: 1, 0.4: 1, 0.6: 1, 0.8: 1, and 1: 1) were investigated when acetone was used as a co-solvent, while all other variables remained constant. The results indicate that increased yields of biodiesel were obtained with increasing the molar ratio of acetone-to-methanol. At acetone-to-methanol molar ratios less than 0.6: 1, the reaction mixture was not homogenous, and the production of FAME was sluggish. After 30 minutes, the FAME yields were 90.24%, 93.14%, 94.28% and 91.15%, respectively, when the acetone-to-methanol molar ratio was 0.2: 1, 0.4: 1, 0.8: 1, and 1: 1. The maximum yield (96.39 wt.%) of biodiesel was obtained when the acetone-to-methanol molar ratio was 0.6: 1, which corresponds to 20 wt.% acetone, depending on the weight of oil. This is due to a co-solvent enhancing mass transfer between the reactants, hence increasing the conversion rate. Also, for two reasons, increasing the acetone concentration resulted in shorter phase separation times: first, the viscosity of the mixture was found to be less viscous; and second, the density difference between FAME and glycerol was found to be greater. However, a decrease in FAME conversion was seen as acetone was added to the reaction mixture over 0.6: 1 of molar ratio. This was attributed to dilution of the initial reactants and increased time required for FAME and glycerol phase separation. The length of time required for separation was determined by the concentrations of methanol and glycerol in the reaction mixture because collisions between glycerol and methanol were less likely at high acetone concentrations, making separation of the two phases more difficult. As a result, it was determined that the acetone-to-methanol molar ratio of 0.6: 1 was ideal, and subsequent research was conducted with this ratio to optimize the other characteristics.
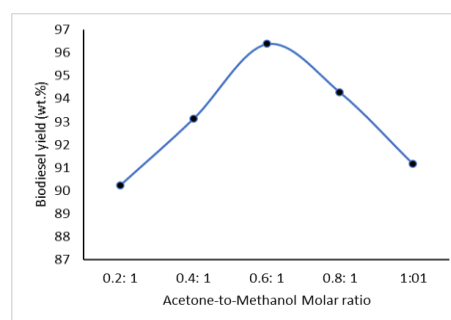

Fig. 1. Effect of co-solvent-to-methanol molar ratio on biodiesel yield (catalyst amount 1 wt. %; methanol-to-oil ratio of 20 v / v%; temperature 30 ± 1°C; time 30 min, speed 600 rpm).

Effect of reaction time:

The reaction time is critical. The reaction rate is typically quite fast in the initial condition; however, for a while but then, it reaches equilibrium. Because the reaction happens at the interface between the oil and the methanol droplets, transesterification takes longer in a heterogeneous system, about 50 minutes. However, in a homogenous environment,

the interaction between triglyceride and methanol happens at the molecular level, resulting in a larger FAME yield and a shorter reaction time. As a result, the effect of acetone as a co-solvent was examined throughout a range of reaction periods (5, 10, 15, 20, 25 and 30 minutes). As illustrated in Fig. 3, as the reaction time grew from 5 to 10 minutes, biodiesel production climbed from 81.34% to 97.25%, with the most significant yield recorded for 10 minutes. At 30°C, on the other hand, increasing the reaction time, particularly after 10 minutes, results in a slight reduction in yield. Based on current research, it is expected that as response time grows, the yield of biodiesel increases initially before declining slightly. This indicator may point to reverse reactions, which are most commonly triggered by extended reaction times and problematic. In the presence of a high reaction temperature, interactions between fatty acids and the three hydroxyl groups in glycerol result in triglycerides and water molecules. Consequently, it was determined that 10 minutes was the optimal reaction time. As a result, the subsequent study was carried out utilizing a 10-minute reaction time to improve other parameters.
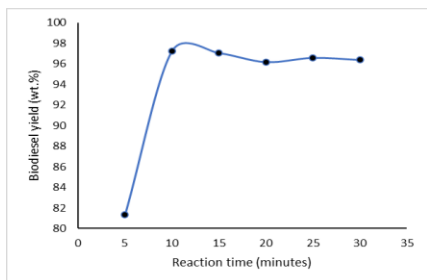

Fig. 3. Effect of reaction time on biodiesel yield (catalyst amount 1 wt.%; methanol-to-oil ratio of 20 v / v%; acetone-to-methanol molar ratio of 0.6: 1; temperature 30 ± 1°C; speed 600 rpm).

Effect of reaction temperature:

Chemical characteristics of the co-solvent used in the transesterification reaction have been shown to affect biodiesel synthesis substantially. Because vegetable oils and animal fats have a high viscosity, methanolysis is typically conducted near the boiling point of methanol, 65°C, to minimize viscosity, boost mass transfer, and increase the reactivity of the reactants [10]. As a result, the co-solvent and temperature are critical variables that must be optimized during transesterification. The WCO transesterification in the presence of a co-solvent was carried out at a range of temperatures (30, 40, 50, 60, and 70°C) to explore the effect of temperature on transesterification in the presence of acetone. Fig. 4 illustrates the yield of biodiesel actively encouraged at various reaction temperatures while maintaining constant other factors. Additionally, increased temperatures result in the evaporation of acetone, which consumes more energy and positively affects soap formation. As a result of these considerations, the optimal temperature for transesterification was set to 40°C, contributing the highest FAME yield of 98.46%. Despite this, the researchers observed that the highest biodiesel yields were produced at temperatures far lower than the boiling point of methanol. Moreover, this result is important from a financial perspective since it decreases the costs of manufacturing. On the other hand, temperatures more significant than 50°C, are favorable for beginning saponification side reactions in the presence of a homogenous base catalyst such as KOH. As a result, some esters are transformed into soap, which reduces the quantity of biodiesel that may be generated [11, 12]. As a result, the optimum temperature for the reaction was determined to be 40°C. Therefore, the subsequent study was carried out at a reaction temperature of 40°C in order to optimize other variables.
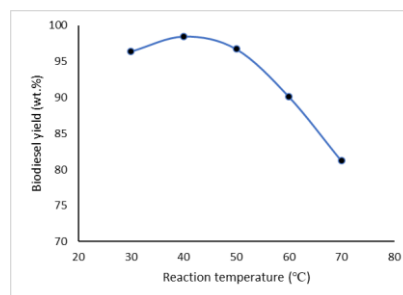

Fig. 4. Effect of reaction temperature on biodiesel yield (catalyst amount 1 wt. %; methanol-to-oil ratio of 20 v / v%; acetone-to-methanol molar ratio of 0.6: 1; time 10 min, speed 600 rpm).

Effect of stirring speed:

Mass transfer limitations are fundamental in the transesterification reaction because of the limited solubility of methanol in the oil. It is important to note that alcohol and oil mix at the beginning of the reaction to form a two-phase liquid system; the process is diffusion-controlled, but oil and methanol have poor diffusion, resulting in a relatively slow reaction rate. Although the methyl esters are produced to serve as a mutual solvent for the reagents, stirring the mixture is necessary to achieve the appropriate reaction rate. In contrast, when acetone was used as a co-solvent in the biodiesel synthesis process, the stirring speed did not influence the yield, as illustrated in Fig. 5. This finding suggests that the miscibility of WCO and methanol was increased due to the inclusion of acetone as a co-solvent, resulting in a virtually homogenous transesterification process. Consequently, stirring speed did not affect transesterification in the presence of a co-solvent in the experiments carried out.
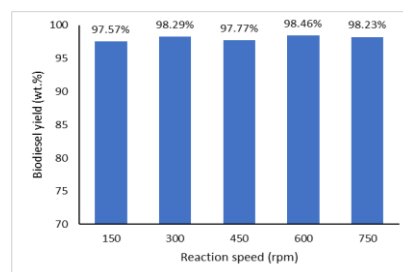

Fig. 5. Effect of reaction speed on biodiesel yield (catalyst amount 1 wt.%; methanol-to-oil ratio of 20 v / v%; acetone-to-methanol molar ratio of 0.6: 1; time 10 min, temperature 40 ± 1°C).

Effect of acetone on biodiesel production:

Using methanol and KOH as homogeneous catalysts, the direct transesterification of WCO was explored with and without the addition of acetone as co-solvent. Fig. 6 shows

that direct transesterification with acetone yielded 98.46 wt.% of the maximum amount of biodiesel compared to transesterification (66.28 wt.%) without acetone under the same reaction conditions; methanol-to-oil volume ratio of 20 %, co-solvent-to-methanol molar ratio of 0.6: 1, 1 wt.% KOH, 40°C, for 10 minutes, reaction speed at 600 rpm. Moreover, the addition of acetone reduced the time it took to separate from the glycerol mixture after the reaction had ended, as described in the earlier literature. As previously stated, improving reaction conditions in the absence of a co-solvent is required for yields comparable to those obtained with a co-solvent; hence, the reaction time, temperature, and agitation speed must all be increased, resulting in higher production costs. As a result, all of these findings demonstrate that co-solvents have a positive effect on improving the miscibility of methanol and oil. Moreover, it has capability of improving the mass transfer rate between the reactants during the transesterification reaction, thereby facilitating a high biodiesel yield under minor reaction conditions which induce cost reduction.
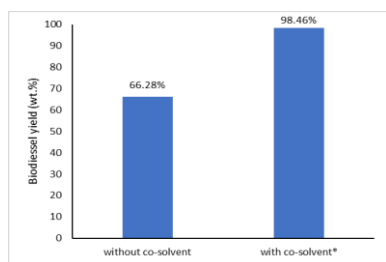

Fig. 6. Effect of co-solvent on biodiesel yield (catalyst amount 1 wt.%; methanol-to-oil ratio of 20 v / v%; time 10 min, temperature 40 ± 1°C; reaction speed 600 rpm; *acetone-to-methanol molar ratio of 0.6: 1).

Physiochemical properties of biodiesel:

FAME produced from WCO in the presence of acetone as a co-solvent was investigated using the American Society for Testing and Materials (ASTM) D6751 standard to evaluate the physical and chemical properties of the compound. The manufactured biodiesel complied with the ASTM standards, under optimal conditions, which included 1 wt.% of KOH; a methanol-to-oil ratio of 20 v / v %; a reaction time of 10 minutes; a reaction temperature of 40 ± 1°C; a reaction speed of 600 rpm; and an acetone-to-methanol molar ratio of 0.6: 1, as shown in Table 1. The co-solvent used in this experiment, acetone, has excellent potential for biodiesel production as demonstrated by this result.

TABLE 1. Physiochemical Properties of Biodiesel

Physicochemical property	WCO methyl ester	ASTM D6751 Biodiesel
Acid value (mg KOH / g)	0.25	<0.5
Flash point (°C)	155	>130
Density at 15°C (g / cm^3)	0.887	0.860-0.900
Kinematic Viscosity (cSt at 40°C)	3.78	1.9-6.0

IV. CONCLUSION

The transesterification reaction for the production of biodiesel from WCO has been discussed in detail using acetone as a co-solvent. After parameter optimization, 98.46%

of biodiesel yield was achieved by utilizing a 0.6: 1 molar ratio of acetone-to-methanol, a 20 v / v% methanol-to-oil ratio, 1 wt.% of KOH, and a 40 ± 1°C temperature during a 10-minute reaction period. When compared to other conventional procedures, this technology significantly reduces the reaction temperature and time. When acetone was used as a co-solvent in biodiesel synthesis, the stirring speed had a minor effect on the yield. The physical-chemical characteristics of the produced methyl ester were found to be within the ASTM limit. As a result, FAME produced in the presence of acetone from WCO was of superior quality and economically viable.

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