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Studies of biodiesel production using various blends of waste palm cooking oil and castor oil

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Abstract. This study has been conducted using blends of castor oil (CO) and waste palm cooking oil (WPCO) in different proportions to enhance % yield of biodiesel via transesterification. The effects of various blending ratios of WPCO: CO (wt.%), molar ratios of methanol: oil, catalyst concentrations (wt.%), reaction time, reaction temperature and various co-solvents have been investigated to determine the optimal conditions for transesterification reaction. Maximum % yield of biodiesel is obtained at 75:25 (wt.%) of WPCO:CO blend, 9:1 methanol to oil ratio, 1 wt.% KOH catalyst, reaction temperature of 32°C, reaction time of 30 min, using n-hexane as co-solvent. The highest obtained biodiesel yield is 96%. Analysis confirmed 25 FAME components, and the fuel met ASTM standards. Blending non-edible feedstocks for biodiesel production is a sustainable approach to reduce costs and environmental impact.

1 Introduction

The depletion of non-renewable resources like fossil fuels has become a major concern for society, governments, and businesses. As these resources are finite, there is a growing risk of supply instability and potential harm to human health from fossil fuel emissions. To address these issues, governments worldwide are implementing regulations to limit emissions and substitute other renewable sources of energy. This will ensure that the nation's future energy needs are met. According to [1], non-renewable energy sources such as fossil fuels are getting depleted.

Biodiesel, a renewable fuel derived from vegetable fats and those derived from animals, can be a good substitute for petrodiesel. Its accessibility, renewability, non-toxicity, reduced emissions, and biodegradability have made it a popular choice in many countries. While similar in properties to petrodiesel, biodiesel is more promising and compatible with existing engines, biodegradability, and reduced harmful emissions like sulfur oxide. As cited in [2], these benefits make biodiesel a valuable option for sustainable transportation.

This experimental work deals with the isolation of biodiesel obtained by blending waste palm cooking oil and castor oil. The high viscosity of castor oil can be reduced by combining with oil such as palm oil having lesser viscosity, to get flow properties similar to that of biodiesel. Such blending helps to make it more resistant to oxidation and degradation. Additionally, using waste palm cooking oil in biodiesel production helps to recycle waste

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and minimize its environmental impact. By incorporating this waste material, it can be recycled or subjected to additional processing, production of biodiesel becomes ecofriendly and environmentally sustainable process.

2 Research methods

2.1 Materials

Sodium hydroxide, potassium hydroxide, hexane, tetra hydro furan, diethyl ether, methanol, ethanol, and phenolphthalein.

2.2 Experimental procedure

2.2.1 Blending of feedstock

In this study, waste palm cooking oil was mixed with castor oil in various weight ratios such as 50:50 (wt%), 75:25 (wt%), and 25:75 (wt%). A mechanical stirrer was used with 1500 rpm for 30 min, at a temperature of 60°C [3].

2.2.2 Esterification

When the free fatty acid content of the oil mixture is > 2 mg KOH/g oil, biodiesel yield will reduce due to soap formation. To prevent this, an acid-catalyzed esterification will reduce the FFA content to an acceptable level. The basic reaction conditions for esterification in this study is 1000 ml of oil, methanol:oil ratio of 30% by volume, a catalyst concentration of 1% (vol%), magnetic stirring using a magnetic bar at 900 rpm at 50 °C and 6 h [4].

2.2.3 Transesterification

This research involved the production of biodiesel using approximately 150 g of oil mixtures of WPCO and CO. An oil blending ratio of 75:25 (wt.%) WPCO : CO was used. The oil blends were heated to 60°C in a magnetic stirrer with methanol : oil molar ratio of 9 :1. Methanol and n-hexane were used as co-solvents separately and mixed with oil mixture at 1:1 wt.% ratio. Solid 1 wt.% KOH was added to the methanol and co-solvent solution and stirred until completely dissolved. The oil mixture was heated to 60°C while being stirred in a magnetic stirrer at 600 rpm for 60 min [5].

2.2.4 Separation and water washing

After transferring the mixture to separatory funnel, and allowed for settling to occur for several hours, two distinct layers formed. Glycerin at the bottom was first removed, followed by the methyl ester at the top. The methyl ester was washed with 500 ml of distilled water to eliminate any remaining alcohol, co-solvent, and soap. To remove moisture, the purified biodiesel was then mixed with anhydrous sodium chloride and filtered.

2.2.5 Optimization of Biodiesel

The transesterification process was repeated several times with varying experimental conditions to optimize the parameters for highest % yield of biodiesel, which included the oil blending ratios, methanol : oil molar ratio, reaction time, reaction temperature, catalyst concentration, and the effect of co-solvent (Table 1). The optimal conditions identified were then used consistently for the remaining experiments. The biodiesel produced under these optimal conditions was further characterized.

2.3 Characterization of biodiesel

The biodiesel produced using was characterized by measuring its calorific value, pH, acid value, saponification value, moisture content, and comparing these values with the ASTM standards for petrodiesel. The biodiesel composition of Fatty acid methyl esters was analyzed using gas chromatography-mass spectroscopy to determine the highest %yield of biodiesel.

3 Results and analysis

3.1 Optimization of variables for transesterification

The experiments were conducted one factor at a time to investigate how each parameter affected the yield of the biodiesel produced.

3.1.1 Effect of blending ratio of WPCO and CO

The oil blending ratio of 75:25 (wt.%) WPCO to CO attributed to highest %yield of biodiesel (84%) when compared to other oil blending ratios of 25:75 (wt.%) with % yield of 56% and 50:50 (wt.%) with % yield of 61%. Blending of viscous CO with WPCO of lower viscosity can reduce the cost and time of the esterification process before transesterification [6]. To achieve the experiment's objective, the WPCO was esterified to reduce its high acid value, which may have been caused by repeated use and exposure to heat, negatively affecting the transesterification process. The esterification process effectively lowered the acid value. Using a higher proportion of esterified WPCO with a moderate acid value and a lower proportion of CO, whose acid value was determined according to ASTM D 6751, is ideal for increasing biodiesel production while reducing feedstock costs.

3.1.2 Effect of methanol to oil molar ratio

The molar ratio of methanol to oil of 6:1 (wt.%) resulted in 65% yield of biodiesel, suggesting that the alcohol amount was insufficient for the reaction. The highest %yield of biodiesel (81%) was obtained for methanol to oil molar ratio of 9 :1 (wt.%). Increasing the methanol ratio beyond 9:1 led to lower %yields due to difficulties in separating methyl ester from glycerin and the formation of soap, which occurred at a molar ratio of 12:1 with %yield of 61%. This is attributed to the formation of mono-glycerides and reducing %yield of biodiesel [7].

3.1.3 Effect of catalyst concentration

The effect of catalyst concentration was studied with 0.5, 1.0 and 2.0 (wt.%). Highest %yield of 85% was obtained at 1% (wt.%) whereas, for 0.5 (wt.%), 45.28% yield was obtained and for 2.0 (wt.%), 65.33% yield was obtained A catalyst concentration of 2 wt.% resulted in soap formation. High catalyst concentrations exceeding 1 wt.% were found to lead to soap formation due to fatty acid residues, which create emulsions between water and soap, thereby reducing ester yields. Conversely, the lowest catalyst concentration of 0.5 (wt.%) produced the lowest biodiesel yield, as insufficient catalysts limit the availability of active sites for collisions between triglyceride molecules, hindering their transformation into biodiesel [8].

3.1.4 Effect of reaction time

The highest %yield of biodiesel (85%) was obtained for a reaction time of 30 min. By increasing the reaction time to 60 min, %yield of biodiesel decreased to 81%. By further increasing the reaction time to 120 min, %yield of biodiesel decreased drastically to 52%. This is attributed to methyl ester undergoing hydrolysis, thereby reducing the desired product [9]. Moisture content, likely present in the feedstock or catalyst, can contribute to hydrolysis during extended reaction times, negatively impacting the transesterification process and lowering biodiesel production.

3.1.5 Effect of reaction temperature

The highest %yield of biodiesel (86%) was obtained at 32°C. %yield of biodiesel decreased to 81% at 50°C and 65°C. This may be attributed to formation of glycerol as byproduct. Additionally, higher temperatures can lead to saponification reactions. As noted in [10], methanol can evaporate at high temperatures, further reducing methyl ester yield. Lower reaction temperatures can lead to reduced energy consumption and, consequently, lower production costs.

3.1.6 Effect of co-solvent

The highest %yield of biodiesel (96%) was obtained with the help of n-hexane as co-solvent followed by 93% for THF and 90% for DEE. Hexane enhances the miscibility of the mixture of oils, allowing for higher recovery of unreacted methanol during the reaction. Additionally, n-hexane reduces the viscosity of the reaction mixture, enhancing mixing and stirring, which contributes to increased yields through improved mass transfer and faster reaction rates. Besides increasing %yield of biodiesel, n-hexane makes glycerol less soluble while increasing the solubility of methanol and oil, allowing the transesterification to proceed to completion, thereby increasing the output. Therefore, n-hexane is considered to be the most effective co-solvent compared to THF and DEE [9].

Table 1. Yield of biodiesel produced from the parameters studied.

Parameter studied		**Yield of Biodiesel (%)**
Blending ratio (WPCO : CO wt.%)	50:50	56
	75:25	84
	25:75	61
Molar ratio of Methanol : oil (wt.%)	6:1	65
	9:1	81

	12:1	61
Catalyst concentration (wt.%)	0.1	45
	1.0	85
	2.0	65
Reaction time (min)	30	85
	60	81
	120	52
Reaction temperature (˚C)	21	86
	50	81
	65	81
Type of co-solvent	Diethyl ether	90
	Tetrahydrofuran	93
	n-hexane	96

3.2 Characterization of biodiesel produced

3.2.1 Gas chromatography-mass spectroscopy analysis

The biodiesel produced from mixtures of WPCO and CO contained 99.54% fatty acid methyl esters (FAME) with 0.46% of unwanted contaminants like wax, fatty alcohol, hydrocarbons, and alkanes. The contaminants were likely introduced due to the use of larger ratio of WPCO: CO, even after purification. The predominant FAME components in the biodiesel were oleic methyl ester (35.34%), palmitic methyl ester (26.63%), and ricinoleic methyl ester (24.13%). Palm oil is rich in palmitic acid [11,12] and it contains 10-40% of Oleic acid. Castor seed oil is rich in Ricinoleic acid [13].

Previous studies by [14] and [15] on biodiesel production using castor oil and palm oil, respectively, also identified high levels of oleic methyl ester and palmitic methyl ester in biodiesel samples. Therefore, high FAME components found in biodiesel samples are consistent with the use of a palm oil and castor oil blend as feedstock

3.2.2 Characteristics of derived biodiesel

The characteristics of derived biodiesel were found to be within the acceptable limits, specified by ASTM D6751 standards, evident in Table 2.

Table 2. Characteristics of derived biodiesel.

Characteristics	Value obtained
pH	6.93
Acid value (KOH/g)	0.4
Saponification value (KOH/g)	210.19
Moisture content (%)	0.04
Calorific value (MJ/kg)	40

4 Conclusions

This research successfully optimized %yield of biodiesel by blending WPCO and CO in various proportions, using an alkaline catalyst, and optimizing various reaction parameters. The highest biodiesel yield of 96% was achieved using a 75:25 (wt.%) blend of WPCO and CO, a 9:1 methanol-to-oil ratio, 1 wt.% KOH, a reaction temperature of 32 °C, a reaction time of 30 minutes, and n-hexane as a co-solvent. The resulting biodiesel was analyzed using GC-MS to determine its chemical composition. Twenty-five different FAME and contaminant components were identified. Oleic acid methyl ester (35.34%), palmitic acid methyl ester (26.63%), and ricinoleic acid methyl ester (24.13%) were the major components found in dervived biodiesel. The fuel properties of the biodiesel met ASTM D6751 standards. The research also demonstrated a potential reduction in production costs due to the higher proportion of WPCO in the blend, as WPCO is generally a cheaper feedstock than CO. Biodiesel produced from inedible oils offers both environmental and economic benefits.

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