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BIODIESEL SYNTHESIS FROM THE USED COOKING OIL USING CaO CATALYST DERIVED FROM WASTE ANIMAL BONES

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Abstract. The synthesis of biodiesel from the used cooking oil with CaO catalyst from waste animal bones has been investigated. The content of free fatty acids (FFA) in the used cooking oil was reduced by adsorption using activated charcoal from a salak peel. Biodiesel synthesis was carried out *via* transesterification using CaO catalyst. The CaO catalyst was obtained from waste animal bones calcined in the Ney Vulcan furnace. The effect of calcination temperature was studied in the range of 873–1273 K. The effect of catalyst loading was investigated by varying within the range of 1–9 wt %. The methanol to oil molar ratio was investigated in the range from 6:1 to 18:1. The effect of the transesterification reaction time was studied with a time variation of 1–5 h. The optimum operating conditions were determined. Under these conditions, the yield of biodiesel produced was 97.56 % with an ester content of 96.06 %. It was shown that the physicochemical properties of biodiesel produced meet the standards.

Keywords: biodiesel, CaO catalyst, transesterification, used cooking oil, waste animal bones.

1. Introduction

Biodiesel is one alternative fuel that can replace diesel fuel. Biodiesel can be obtained from a variety of renewable natural resources, such as vegetable oils or animal fats [1]. Biodiesel is produced by reacting vegetable oils or animal fats with alcohols such as methanol and ethanol. Biodiesel has several advantages compared to diesel fuel which is renewable, environmentally friendly, non-toxic, can be degraded biologically, contains very little amount of sulfur and polycyclic aromatic hydrocarbon compounds so that it is safe for vehicles, and can be used directly without changing the engine [2-4].

Basically, the biodiesel production process is very simple. Biodiesel is produced through a process called free fatty acid esterification reaction or transesterification reaction of triglycerides with alcohol using a catalyst and from this reaction, fatty acid methyl/ethyl ester and glycerol are produced [5].

Biodiesel can be made from various types of oil, such as palm oil, castor oil, soybean oil, coconut oil, hazelnut oil, jatropha oil, and various vegetable oils containing triglycerides. The used cooking oil is a waste oil derived from the types of cooking oil such as corn oil, vegetable oil, samin oil and so on. The used cooking oil has the potential to be processed into biodiesel because until now the utilization has not been optimal. However, the used cooking oil still contains impurities and has a high level of free fatty acids (FFA > 1 %) so it must be treated first before being processed into biodiesel [6].

An adsorption using activated charcoal is among the methods to reduce the FFA content in used cooking oil. Salak peel is one of the ingredients that can be used as an activated charcoal. Utilization of a salak peel has not been widely developed, so it needs to be studied more deeply.

The production of biodiesel from the used cooking oil can be conducted through a transesterification reaction. Transesterification reactions can be carried out with homogeneous catalysts, heterogeneous catalysts, and enzyme catalysts. Homogeneous catalysts can use alkaline catalysts (NaOH, KOH, *etc.*) or acid catalysts (H_2SO_4, HCl, *etc.*) [7]. Base catalysts require shorter transesterification time, however, homogeneous base catalysts have disadvantages. Homogeneous base catalysts can react with fatty acids to form soap, which will reduce the yield of biodiesel and inhibit the process of separation between glycerol and water [7, 8]. The use of acid catalysts can produce high biodiesel yields but requires a longer reaction time compared to base catalysts. Apart from requiring a long time, the ratio of methanol to the used oil must be large and high temperatures are needed [9].

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There are so many disadvantages of homogeneous catalysts that the heterogeneous catalysts for biodiesel production were developed. The most widely used heterogeneous catalyst is the CaO catalyst. CaO catalyst can be obtained through $CaCO_3$ calcination process. Studies show that CaO catalysts are mostly made from egg-shells. Wei *et al.* [10] examined the use of CaO catalysts in biodiesel production using CaO from chicken egg-shells and obtained a biodiesel yield of 95 %. Chen *et al.* [11] used CaO catalyst for biodiesel production using ostrich egg-shells and obtained biodiesel yield of 92.7 %. Some researchers also use waste shells such as mollusk [12], Pomacea sp. shell [13], shrimp shell [14], waste mud crab shells and cockle shells [15], oyster shell [16], *etc*. Utilization of this waste as a raw material in making catalysts will solve the problem of waste and increase economic value.

From many studies on CaO catalysts for biodiesel production, there are still few studies investigating CaO catalysts made from waste animal bones [17-19]. Bone is one of the many sources of calcium. The utilization of waste animal bones is environmental-friendly and will be a cost-effective raw material for catalyst production.

The purpose of this study was to investigate the effect of catalyst calcination temperature, the molar ratio of methanol to oil, catalyst loading and the reaction time of transesterification on the yield of biodiesel produced from the used cooking oil using CaO catalyst derived from waste animal bones. GCMS analysis was carried out to determine fatty acid alkyl esters (FAAE) content in the biodiesel products with the highest yield. The physicochemical properties of biodiesel produced under optimal conditions will be compared with those reported in the literature.

2. Experimental

2.1. Materials

The raw material used in this study was used cooking oil. The used cooking oil and waste animal bones were obtained from fried chicken restaurant waste in Semarang, Indonesia. Meanwhile, salak peel used as an adsorbent was attained from fruit market waste around Semarang, Indonesia. Methanol (99%), potassium hydroxide (KOH) and hydrochloric acid (HCl, 37%) were received from Merck.

2.2. Preparing Activated Charcoal from Salak Peel

Salak peel from fruit market waste was cleaned with distilled water and dried in an oven. The dried salak peel was crushed and heated in the furnace at 873 K for 1 h. The resulting product was impregnated with 20% KOH solution. After impregnation the product was dried in the oven for overnight at 378 K. Then it was activated in the furnace for 1 h at 1073 K. The produced activated charcoal was washed using demineralized water (pH was regulated with HCl solution until 6-7) and then was dried in the oven overnight.

2.3. Preparing CaO Catalyst from Waste Animal Bones

Waste animal bones were washed thoroughly and dried in the oven overnight. Then they were crushed and mashed to a size of 100 mesh. The waste animal bone powder was calcined in the furnace for 3 h. The effect of calcination temperature was investigated by varying the temperatures of 873, 973, 1073, 1173 and 1273 K.

2.4. Procedure

The used cooking oil was pre-treated to reduce the FFA content. Pre-treatment was carried out by adsorbing the used cooking oil with activated charcoal produced from salak peel. The used cooking oil from fried chicken restaurant was first filtered to remove impurities. 250 g of used cooking oil was heated to 353 K. 10 g of activated charcoal adsorbent was added to the oil and stirred at 500 rpm for 80 min. Then the mixture was separated by filtering using Whatman 42 filter paper and the filtrate was used as a raw material for biodiesel production.

The used cooking oil from the pretreatment was reacted with methanol in a three-necked flask. CaO catalyst from waste animal bones was put into the mixed reactant. The mixture of reactants and catalysts was stirred at a speed of 400 rpm and heated to reach a reaction temperature of 338 K. The effect of methanol to oil molar ratio was studied varying the ratio as 6:1, 9:1, 12:1, 15:1, and 18:1. The effect of catalyst loading was investigated by varying the value as 1, 3, 5, 7, and 9 wt % relative to oil. The transesterification process was carried out according to the specified time after the reaction temperature reached 338 K. The reactant mixture was kept under stirring until the transesterification reaction time was complete. The effect of the transesterification time was studied in the range of 1–5 h. The resulting solution was separated from the catalyst and contained unreacted methanol, biodiesel and glycerol. The solution was put into a separating funnel and left overnight. Three layers were formed in the separating funnel. The top layer was unreacted methanol, the middle layer was biodiesel and the bottom layer was glycerol. Biodiesel was analyzed by GCMS. The yields of biodiesel and FAAE were calculated according to Eqs. (1) and (2).

$$\text{Yield}_{\text{biodiesel}} = \frac{\text{weight of biodiesel product}}{\text{weight of used cooking oil}} \cdot 100\% \quad (1)$$

$$\text{Yield}_{\text{FAAE}} = \frac{\%_{\text{GC area FAAE}} \cdot \text{weight of biodiesel product}}{\text{weight of used cooking oil}} \cdot 100\% \quad (2)$$

2.5. FFA Analysis

FFA analysis was carried out to determine the FFA content of used cooking oil, before and after its adsorbtion with the activated charcoal from the salak peel. The FFA analysis was done by titration using 0.1N KOH. Free fatty acid was calculated according to Eq. (3).

$$FFA = \frac{V_{KOH} \cdot N_{KOH} \cdot MW_{fatty\ acid}}{m_{sample}} \cdot 100\% \quad (3)$$

where V_{KOH} is a volume of titrant, ml; N_{KOH} is a normality of KOH, mmol/ml; $MW_{fatty\ acid}$ is a molecular weight of fatty acid, mg/mmol; m_{sample} is the weight of the used cooking oil sample, mg.

3. Results and Discussion

3.1. Analysis of FFA Content in the Used Cooking Oil

FFA content in the used cooking oil was 6.16 %. The FFA limit for the transesterification process is < 3 % [20]. Therefore, the FFA value in the used cooking oil must be reduced. This was done by the adsorption method using the activated charcoal from the salak peel. Based on the results of a study conducted by Buchori *et al.* [21], the FFA adsorption process with the activated charcoal from the salak peel was carried out for 80 min with 10 g of the activated charcoal. The adsorption results showed a decrease in FFA value to 0.224 %, which meets the requirements for the transesterification process. Therefore, oil is ready to be used for the transesterification process.

3.2. Effect of Calcination Temperature on the Biodiesel Yield

The transesterification process is a process where oil and methanol are reacted to produce biodiesel using a catalyst. The catalyst used in this study was CaO. The catalyst was obtained from the calcination of waste animal bones. The calcination temperatures were 873, 973, 1073, 1173, and 1273 K. The transesterification process was carried out at 338 K with a reaction time of 2 h. The biodiesel yields are presented in Fig. 1.

Fig. 1 shows that the biodiesel yield increases with increasing the calcination temperature. This indicates that the catalytic activity of the CaO catalyst increases when the calcination temperature increases from 873 to 1173 K. The maximum biodiesel yield of 94.64 % was achieved at the calcination temperature of 1173 K. However, further increase in temperature decreases the biodiesel yield from 94.64 to 86.41 %. The results of this study are in accordance with the research conducted by Wei *et al.* [10] on the synthesis of biodiesel using CaO catalyst from waste egg-shells within the temperature range of 473–1273 K. It was found that the catalyst is very active at the calcination temperature of 1073–1273 K; the biodiesel yield was 97-99 %. The research conducted by Nisar *et al.* [22] showed the same results. They used CaO catalyst from the waste animal bone with calcination temperatures of 773–1373 K. The results showed that when converting Jatropha oil into biodiesel the catalyst worked optimally at 1173 K; the biodiesel yield was 91.6 %. Theoretically, the catalyst will work actively if calcined at its optimum temperature, when more active sites are formed so that it accelerates the occurrence of the reaction and increases the yield of biodiesel [22]. Calcination which is carried out below the optimum temperature does not provide maximum CaO formation, consequently, the catalytic activity is still low. However, animal bones calcined at high temperatures (exceeding 1273 K) increase the sintering effect which ultimately reduces the surface area and basicity of the catalyst and hence leads to the catalyst activity decrease [22, 23].

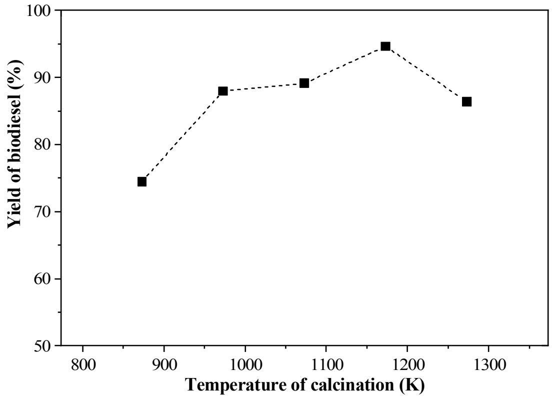

Fig. 1. Effect of calcination temperature on the biodiesel yield (T = 338 K; P = 0.1 MPa; catalyst loading = 7 wt %, molar ratio of methanol:oil = 15:1, reaction time = 2 h)

3.3. Effect of Methanol to Oil Molar Ratio on the Biodiesel Yield

The transesterification reaction was carried out at a temperature of 338 K, a catalyst loading of 7 %, and a reaction time of 2 h. The effect of molar ratio of methanol to oil on the biodiesel yield is depicted in Fig. 2. The ratio was varied as 6:1, 9:1, 12:1, 15:1, and 18:1.

Fig. 2 shows that the biodiesel yield increases significantly with increasing a molar ratio of methanol to oil and reaches a maximum (95.54 %) at the ratio of 12:1.

Further increase in methanol:oil ratio (above 12:1) at first slightly decreases the biodiesel yield to 94.64 % and then significantly decreases it to 90.26 %.

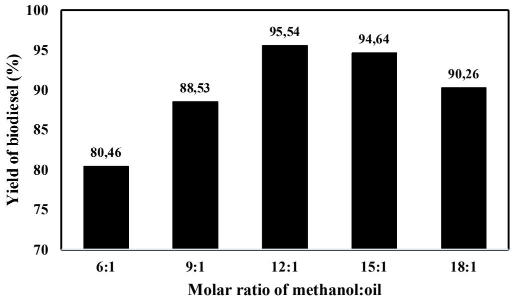

Fig. 2. Effect of methanol:oil molar ratio on the biodiesel yield ($T = 338$ K; $P = 0.1$ MPa; catalyst loading = 7 wt %, reaction time = 2 h)

The transesterification reaction is a reversible reaction where 1 mole of oil reacts with 3 moles of methanol to produce 3 moles of fatty acid methyl ester and 1 mole of glycerol. Methanol excess is needed to shift the reaction equilibrium towards the product [5, 24]. When the molar ratio of methanol to oil reaches 12:1 the methanol excess encourages the formation of methoxy species on the CaO surface so that the reaction equilibrium shifts in the forward direction, thus increasing the yield of biodiesel [12, 19]. However, further increase in the molar ratio (above 12:1), does not encourage a reaction. The reason is that glycerol produced during the reaction mostly dissolves in methanol excess. This inhibits the reaction of methanol against reactants and catalysts which ultimately complicates the separation of glycerol [12]. High amounts of methanol are also associated with a catalyst deactivation [22]. Therefore, excessive use of methanol can shift the equilibrium in the reverse direction which causes a decrease in biodiesel yield [18, 24, 25].

The results of this study are in line with the research conducted by Viriya-Empikul *et al.* [12]. They found that the molar ratio of methanol to oil reached optimum at 12:1 using CaO catalyst derived from the waste shell. Different results were obtained from the research conducted by Farooq *et al.* [18] and Maneerung *et al.* [24] who obtained the optimum molar ratio at 15:1. Meanwhile, research conducted by Obadiah *et al.* [19] showed that the optimum molar ratio was achieved at 18:1 in the production of biodiesel from palm oil. The difference in results is explained by using different type of feedstocks and sample preparation [26].

3.4. Effect of Catalyst Loading on the Biodiesel Yield

Biodiesel yield is influenced by a catalyst loading [27]. The effect of catalyst loading on the yield of biodiesel was studied by varying at 1, 3, 5, 7, and 9 wt %, and the results are shown in Fig. 3.

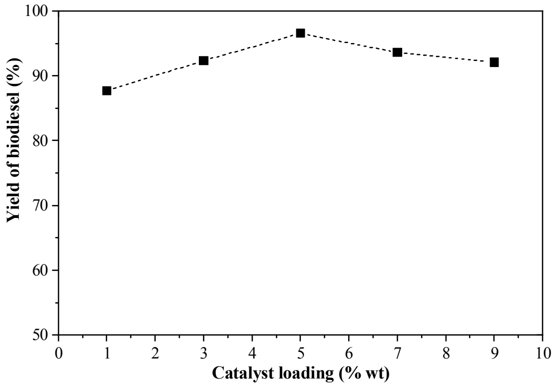

Fig. 3. Effect of catalyst loading on the biodiesel yield ($T = 338$ K; $P = 0.1$ MPa; molar ratio of methanol:oil = 12:1, reaction time = 2 h)

Fig. 3 shows that the biodiesel yield increases with increasing the catalyst loading from 1 to 5 wt %. Biodiesel yield increases from 87.7 to 96.54 % and achieved a maximum of 96.54 % at 5 wt % of the catalyst. However, the increase in the catalyst loading above 5 wt % reduces the biodiesel yield from 96.54 to 92.1 %. The decrease in the biodiesel yield is due to an increase in the viscosity of the reaction mixture [28]. Increased viscosity inhibits mass transfer in a heterogeneous reaction system. The catalyst excess also causes poor diffusion of reactants in the methanol-oil-catalyst system [24] due to the formation of soap which inhibits the reaction process [18].

The results of this study are in accordance with the research conducted by Farooq *et al.* [18] who found the optimum amount of catalyst as 5 wt %. Meanwhile, Maneerung *et al.* [24] obtained the maximum biodiesel yield at a catalyst loading of 7.5 wt %. In this study, the optimum catalyst loading was achieved at 5 wt %.

3.5. Effect of Reaction Time on the Biodiesel Yield

Biodiesel yield is also influenced by the reaction time [27]. The effect of reaction time on the yield of biodiesel was investigated by varying at 1, 2, 3, 4, and 5 h, and the results are depicted in Fig. 4.

Fig. 4 shows that the biodiesel yield increases with increasing the reaction time. The longer the reaction time, the higher the biodiesel yield. This is caused by the fact that the longer transesterification time, more oil reacts with methanol. In addition, the longer the transesterification period provides the opportunity for molecules between reactants to collide with one another. The optimum biodiesel yield of 97.01 % was achieved at the reaction time of 3 h. However, with increasing the reaction time, the yield of biodiesel obtained increases slightly and tends to be constant. The increase in reaction time above 3 h does not produce a significant biodiesel yield. So, the optimum reaction time in this study was 3 h.

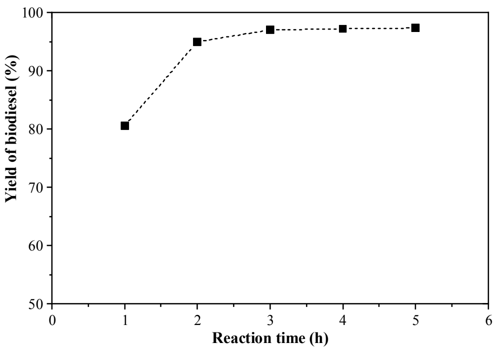

Fig. 4. Effect of reaction time on the biodiesel yield ($T = 338$ K; $P = 0.1$ MPa; catalyst loading = 5 wt %, molar ratio of methanol:oil = 12:1)

The results of this study are consistent with research conducted by Nisar *et al.* [22] where the reaction time of the transesterification process reaches its optimum at 3 h. In the research conducted by Farooq *et al.* [18] the optimum reaction time was 4 h. The same results were obtained in research conducted by Obadiah *et al.* [19]. Different results were obtained by Viriya-Empikul *et al.* [12] who obtained the optimum reaction time of 2 h.

3.6. Effect of Reaction Temperature on the Biodiesel Yield

The reaction temperature greatly influences the reaction rate [29]. The effect of temperature on the yield of biodiesel was studied by varying at 328, 333, 338, 343 and 348 K, and the results are depicted in Fig. 5.

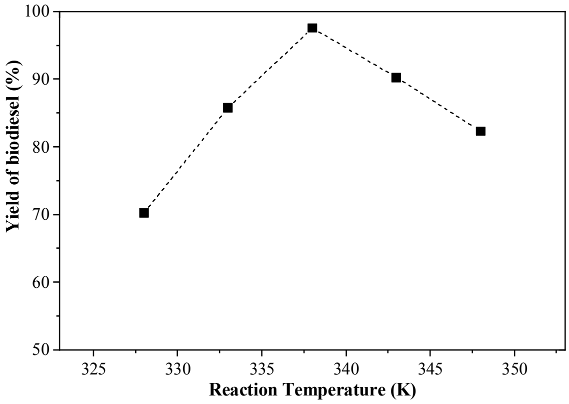

Fig. 5. Effect of reaction temperature on the biodiesel yield ($P = 0.1$ MPa; catalyst loading = 5 wt %, molar ratio of methanol:oil = 12:1, reaction time = 3 h)

Fig. 5 shows that the biodiesel yield increases with increasing reaction temperature and achieves optimal results at 338 K (97.56 %). An increase in reaction temperature above 338 K leads to the reduction in biodiesel yield. Transesterification reaction is an endothermic reaction, so the increase in reaction temperature accelerates the movement of reactant molecules in the system. This fact increases collisions between reactant molecules which ultimately accelerates the reaction rate and produces high yields of biodiesel products [18, 29, 30]. At high temperatures, triglycerides can dissolve well in methanol so that it forms a single phase resulting in the increase in product [29]. However, when the reaction temperature is raised above the optimum temperature (338 K), there is evaporation of methanol and some side reactions such as oil polymerization cause a decrease in biodiesel products yield [30].

3.7. Characterization of Catalyst

Catalyst characterization was performed by X-Ray Diffraction (XRD) analysis using Shimadzu XRD-7000. The diffraction patterns were analyzed in the 2θ range from 10° to 90° with a scanning speed of 4° per min. XRD analysis was performed at the optimum calcination temperature of 1173 K, before and after calcination. The results are presented in Fig. 6.

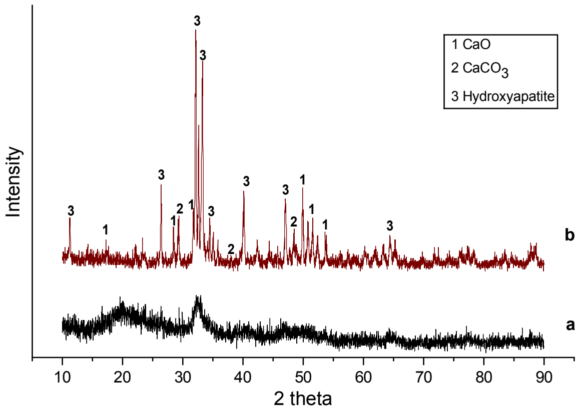

Fig. 6. XRD patterns of the catalyst before calcination (a) and after calcination at 1173 K (b)

Fig. 6 shows that the peak intensity increases after calcination, and therefore crystallinity increases as well. The peaks typical of CaO phase in the catalyst are 17.69°, 28.68°, 32.19°, 50.79°, 52.43°, and 53.71° (JCPDS File No. 37-1497).The presence of hydroxyapatite is marked with peaks at 10.97°, 25.85°, 32.54°, 33.68°, 35.11°, 39.85°, 46.75°, and 65.04°.The peaks at 29.34°, 39.69°, and 48.45° are attributed to the $CaCO_3$ phase [31].

3.8. The Results of FAAE Identification in Biodiesel Products

The best results from this study were then analyzed by GCMS to determine the FAAE content in biodiesel products. GCMS analysis was carried out for biodiesel obtained at the calcination temperature of 1173 K, methanol:oil molar ratio of 12:1, reaction time of 3 h and catalyst loading of 5 wt %. The results of the GCMS analysis are presented in Fig. 7 and Table 1.

As can be seen from Fig. 7 and Table 1, there are 15 peaks (components) in the biodiesel products. However, there are only 9 peaks that represent alkyl esters. The of FAAE content in biodiesel products is 96.06 %. Based on Eq. (3), the FAAE yield obtained is 93.72 %.

Balakrishnan *et al.* [27] studied the synthesis of biodiesel with the used cooking oil as a raw material using a Ba/CaO (3 wt %) catalyst for 3 h at 338 K with a mole ratio of methanol to oil 9:1. They reported the methyl ester yield was found to be 88 %. Meanwhile, Farooq *et al.* [18] studied biodiesel production with the waste cooking oil as a raw material using CaO (5 wt %) derived from the chicken bone. They obtained a biodiesel yield of 89.33 % with 97.91 % of methyl ester. The transesterification process was carried out for 4 h, at 338 K and the methanol:oil ratio of 15:1. Nisar *et al.* [22] obtained biodiesel from Jatropha oil using animal bones modified with potassium hydroxide (KOH) as a catalyst with the yield of fatty acid methyl ester (FAME) of 96.1 % at the reaction temperature of 343 K, reaction time of 3 h, methanol/oil molar ratio of 9:1, calcination temperature of 1173 K and catalyst concentration of 6.0 wt %.

In this study, we obtained the biodiesel yield of 97.56 % with the FAAE content of 96.06 %. This fact indicates that this research can produce high biodiesel yields with high FAAE content. The results of this study prove that both waste cooking oil and waste animal bone can be used for biodiesel synthesis with good results.

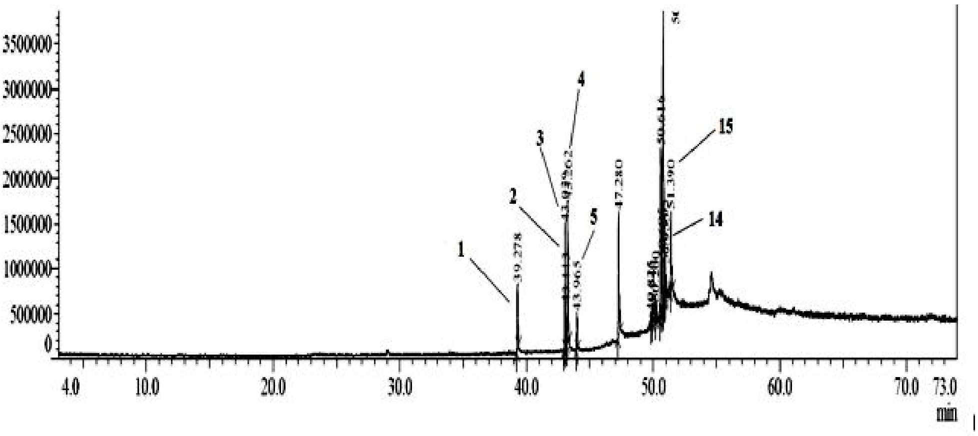

Fig. 7. The results of GCMS analysis of biodiesel products

Table 1

Composition of biodiesel components

Peak	R Time	Composition, %	Name
1	39.278	4.52	Hexadecanoic acid, methyl ester (CAS)
2	43.039	8.18	9,12-Octadecadienoic acid, methyl ester, (E,E)-(CAS)
3	43.113	9.68	9,12,15-Octadecatrienoic acid, methyl ester, (Z,Z,Z)-(CAS)
4	43.262	10.01	9-Octadecenoic acid (Z)-, methyl ester (CAS)
5	43.965	1.33	Octadecanoic acid, methyl ester (CAS)
6	47.280	11.32	Hexadecanoic acid, 2-hydroxy-1,3-propanediyl ester (CAS)
7	49.825	4.45	9-Hexadecenoic acid, methyl ester, (Z)-(CAS)
8	49.940	0.24	O-Acetyljervine
9	50.200	0.99	XX-oxyquinoline
10	50.616	1.09	DI-(9-OCTADECENOYL)-GLYCEROL
11	50.695	0.39	trans-Caryophyllene
12	50.786	39.41	Octadecanoic acid, methyl ester (CAS)
13	50.905	0.54	3-Acetoxy-p-menthan-1-ol
14	50.955	0.69	1,5-Naphthalenediol, decahydro- (CAS)
15	51.390	7.16	Octadecanoic acid, 2-hydroxy-1,3-propanediyl ester (CAS)

Table 2

Physicochemical properties of the biodiesel products under optimal conditions

Properties	Units	Standard	Method	Experimental values
Density at 25 °C	g/cm^3	0.860–0.900	EN 14214	0.876
Kinematic viscosity at 40 °C	mm^2/s	1.9–6.0	ASTM D-6751	4.566
Acid number	mg KOH/g	≤ 0.5	ASTM D-6751	0.42
Ester content	%	> 96.5	ASTM D-6751	96.06
Cetane number	–	min. 47	ASTM D-6751	51.2
Heating value	MJ/kg	39.72	ASTM D-240	43.86

3.9. Physicochemical Properties of the Biodiesel Products

The physicochemical properties of biodiesel were analyzed under optimum conditions and then compared with those reported in the literature (Table 2).

Table 2 shows that the physicochemical properties of the produced biodiesel meet ASTM and EN standards. Only the content of esters is slightly below standard.

The heating value states the amount of heat produced from the combustion of a certain amount of fuel with air/oxygen. The greater the heating value, the less fuel is needed to produce certain amount of heat. Thus, the greater the heating value, the more efficient fuel will be. In our case the heating value was found to be 43.86 MJ/kg which is higher than standard diesel fuel value which is equal to 39.72 MJ/kg.

4. Conclusions

In the current research, the waste animal bone was successfully used as a heterogeneous catalyst in the synthesis of biodiesel using the used cooking oil as a feedstock. The results showed that the biodiesel synthesis was influenced by many factors including a calcination temperature, the molar ratio of methanol to oil, catalyst loading, and reaction time. The highest yield of biodiesel was achieved under optimum reaction conditions, namely calcination temperature of 1173 K, the methanol:oil molar ratio of 12:1, catalyst loading of 5 wt % and reaction time of 3 h. Under these optimum conditions a biodiesel yield of 97.56 % was obtained with an ester content of 96.06 %. Biodiesel produced under optimum conditions was characterized and its physicochemical properties were compared with the standards reported in the literature. The results indicate that the physicochemical properties of the biodiesel produced fulfill the standards. This shows that the catalyst from waste animal bone is a potential, economical and environmentally friendly catalyst for biodiesel production.

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СИНТЕЗ БІОДИЗЕЛЯ З ВИКОРИСТАНОЇ КУЛІНАРНОЇ ОЛІЇ ЗА УЧАСТЮ КАТАЛІЗАТОРА CaO ОДЕРЖАНОГО З ВІДХОДІВ КОСТЕЙ ТВАРИН

Анотація. *Проведено синтез біодизеля з використаної кулінарної олії з каталізатором CaO одержаним з відходів кісток тварин. За допомогою активованого вугілля, одержаного із шкірки салаку, в процесі адсорбування знижено вміст вільних жирних кислот (FFA) у використаному кулінарному маслі. Синтез біодизеля проводили внаслідок переестерифікації з використанням каталізатора CaO. Каталізатор CaO отримували з відходів кісток тварин, прожарених у печі. Вплив чинників на вихід біодизеля досліджено в наступних інтервалах: температура прожарювання (873–1273 K), завантаження каталізатора (1–9 мас. %), мольне співвідношення метанолу до олії (від 6:1 до 18:1) і час переестерифікації (1–5 год) і встановлено оптимальні умови. За цих умов вихід отриманого біодизеля становив 97,56 % при вмісті естерів 96,06 %. Показано, що фізико-хімічні властивості одержаного біодизеля відповідають стандартам.*

Ключові слова: *біодизель, каталізатор CaO, переестерифікація, використане олія, відходи кісток тварин.*