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Optimizing Biodiesel Production from Camel Bone Fat: Extraction, Transesterification, and Fatty Acid Profiling

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Abstract

The global reliance on fossil fuels has intensified environmental degradation and climate change, necessitating the exploration of renewable energy alternatives. Biodiesel, derived from renewable feedstocks, offers a sustainable solution due to its lower emissions and compatibility with existing infrastructure. This study investigates the production of biodiesel from camel bone fat, an underutilized resource abundant in regions with large camel populations .Camel bones were collected, and their fat was extracted using a moist cooking method, followed by transesterification under varied conditions of catalyst concentration (0.25–1.75% NaOH/KOH), temperature (40–70°C), reaction time (20–140 minutes), and methanol-to-fat molar ratio (4:1–10:1). The results revealed an optimal yield of 96.17% with NaOH and 94.20% with KOH at 1% catalyst concentration, 65°C, 120 minutes, and a 6:1 methanol-to-fat ratio. The produced biodiesel exhibited a high proportion of saturated methyl esters (75.4%), enhancing its stability. The properties of the produced biodiesel such as iodine value, saponification value, density, kinematic viscosity, cetane number, flash point, were measured. These properties were compared with ASTM D6751 and EN 14214 standards, demonstrating acceptable compliance. The analysis confirms that camel bone fat offers a sustainable biodiesel feedstock, promoting waste reduction, local energy generation, and environmental protection through decreased fossil fuel reliance.

Keywords **: Biodiesel, Camel Bone Fat, Transesterification, Renewable Energy, Sustainability.**

I. INTRODUCTION

The global dependence on fossil fuels has driven industrialization but at a steep environmental cost, necessitating urgent shifts to renewables like biodiesel a biodegradable, low-emission alternative compatible with existing diesel infrastructure [1]. Biodiesel is synthesized via transesterification, converting triglycerides from oils or fats into fatty acid methyl esters (FAMEs) [2]. While vegetable oils dominate feedstocks, their high cost and competition with food production [3] have spurred interest in nonedible animal fats. In the Arab world, where camel husbandry is widespread ([4] reports over 35 million camels), camel bone fat a slaughterhouse byproduct remains untapped despite its potential to address waste management and energy needs. Though camel hump fat has been studied [5], bone fat is underexplored, despite constituting 15–20% of camel slaughter waste [6].

This study optimizes biodiesel production from camel bone fat by analyzing transesterification parameters: catalyst type, concentration, temperature, reaction time, and methanol-to-fat ratio. Fatty acid profiles are analyzed via GC-M, and biodiesel properties (viscosity, density, cetane number, flash point, saponification value, iodine value) are benchmarked against ASTM D6751 and EN 14214.

II. MATERIALS AND METHODS

A. Fat Extraction from Camel Bones

Camel bones were collected from local butcher shops in Ouargla, Algeria, thoroughly cleaned to remove residual tissues, and stored at -10°C until further processing. To extract fat, the bones were mechanically cut into small fragments and minced to maximize surface area. The minced bones were then placed in a pressure cooker with a bone-to-water ratio of 1:3 (w/v) and heated at 100°C for 5 hours. After cooling, the extracted fat

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was separated from the aqueous layer using gravitational settling, filtered to remove impurities, and stored at -10°C for subsequent transesterification.

B. Transesterification Process

The transesterification reaction was carried out to convert the extracted camel bone fat into biodiesel (fatty acid methyl esters, FAMEs). The process was optimized by varying the following parameters: reaction temperature (30–75 °C), reaction time (20–160 minutes), catalyst concentration (0.25–1.5% w/w), and methanol-to-fat molar ratio (4:1–9:1).

In the pre-treatment step, the acid value of the extracted fat was determined to ensure it was below 1%, as higher values can hinder the transesterification process. A known amount of camel bone fat was heated to the desired temperature in a round-bottom flask equipped with a condenser to prevent methanol evaporation. NaOH was dissolved in methanol to prepare the catalyst solution, which was then added to the heated fat. The mixture was stirred at 600 rpm for the specified reaction time. After the reaction, the mixture was allowed to settle, and the biodiesel layer was separated from the glycerol layer using a separatory funnel. The biodiesel was washed with distilled water to remove residual catalyst, glycerol, and soap. The final product was dried using anhydrous sodium sulfate (Na_2SO_4) and filtered.

C. Fatty Acid Composition Analysis

The fatty acid composition of the extracted fat and the produced biodiesel was analyzed using a Shimadzu TQ8050 NX gas chromatography-mass spectrometry (GC-MS) system. The temperature parameters were configured as follows: injection port at 250 °C, ion source at 200 °C, and a maximum oven temperature of 350 °C. The carrier gas flow rate was maintained at 0.70 mL/min under split injection mode. For MS detection, mass spectra were acquired in the range of 10–550 m/z over a scan time of 3.5–50 minutes. The fatty acid methyl esters (FAMEs) were identified by comparing their retention times and mass spectral profiles with those of certified FAME standards.

D. Characterization of Biodiesel

The produced biodiesel was characterized according to international standards (ASTM D6751 and EN 14214). The kinematic viscosity was measured using a viscometer at 40 °C, and the density was determined using a density meter at 15.6 °C. The flash point was measured using a Pensky-Martens closed cup apparatus, the cetane number was calculated using the saponification value (SV) and iodine value (IV) of the biodiesel.

III. RESULTS AND DISCUSSION

A. Fatty Acid Characterization of camel bone fat

The analysis of camel bone marrow demonstrated a significant predominance of saturated fatty acids, accounting for 78.91% of the total fat composition. The primary saturated fatty acids identified were palmitic acid (C16:0), stearic acid (C18:0), and myristic acid (C14:0). In contrast, unsaturated fatty acids, including oleic acid (C18:1) and palmitoleic acid (C16:1), comprised 21.1%, resulting in a saturated-to-unsaturated fat ratio of 3.73. These findings align with previous studies on camel fat composition. For instance, Al-Juhaimi et al. [7] reported that saturated fatty acids such as palmitic acid (C16:0) and stearic acid (C18:0) constitute approximately 60-70% of the total fat content, underscoring the oxidative stability of camel fat. Additionally, Kadim et al. [8] emphasized that camel fat is rich in medium-chain fatty acids compared to cattle or sheep fat, contributing to its enhanced stability and reduced susceptibility to oxidation. Furthermore, Kadim et al. [9] highlighted that unsaturated fatty acids, such as oleic acid (C18:1) and palmitoleic acid (C16:1), account for only 20-30% of the total fatty acid profile, reflecting the distinct nutritional properties of camel fat compared to other animal fats . Collectively, these studies suggest that variations in the fatty acid composition of camel fat are influenced by factors such as diet, geographic environment, and age.

B. Alkali-catalyzed transesterification process of camel bone fat

1) Effect of Catalyst Concentration:

Biodiesel yield peaked at 96.17% (NaOH) and 94.20% (KOH) with 1% catalyst concentration under fixed conditions (65°C, 120 min, 6:1 methanol-to-fat ratio). Lower concentrations (<1%) reduced yields (e.g.,

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76.74% at 0.25% NaOH) due to insufficient catalytic activity, while higher concentrations (>1%) triggered saponification, lowering yields (e.g., 85.23% at 1.75% NaOH) (Fig. 1). These findings align with Sbihi et al. [10], who observed similar soap formation trends.

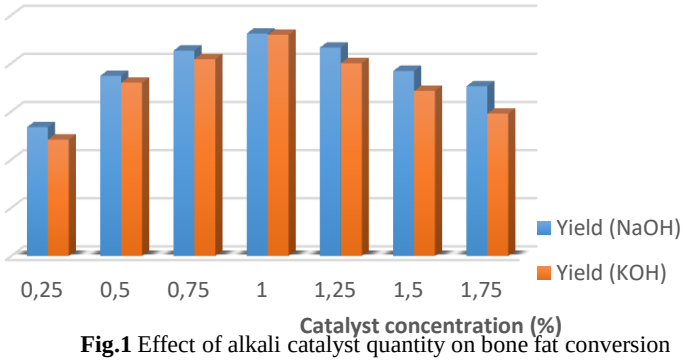

Fig.1 Effect of alkali catalyst quantity on bone fat conversion

2) Effect of Reaction Temperature:

Biodiesel yield was temperature-dependent (40–70°C), peaking at 65°C with 96.17% (NaOH) and 94.20% (KOH) under fixed conditions (1% catalyst, 6:1 methanol ratio, 120 min). Lower temperatures (e.g., 40°C) reduced yields (NaOH: 79.63%; KOH: 80.14%) due to high viscosity [11], while exceeding 65°C decreased efficiency (NaOH: 85.62%; KOH: 80.91%) from methanol evaporation. This aligns with Sbihi et al. [10], who observed similar trends in camel hump fat transesterification.

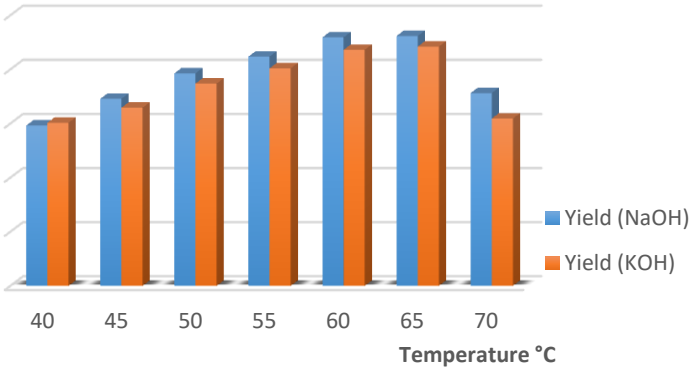

Fig.2 Effect of reaction temperature (°C) on bone fat conversion

3) Effect of Reaction Time:

Optimal yields were achieved at 120 min (96.17% NaOH, 94.20% KOH). Shorter durations (e.g., 20 min) led to incomplete conversion (72.18% KOH), while prolonged reactions (>120 min) slightly reduced yields (93.37% NaOH at 140 min) due to reversible reactions (Fig. 3). This aligns with transesterification kinetics in animal fats [12], and a study by Sbihi, H. et al [10], on camel hump fat.

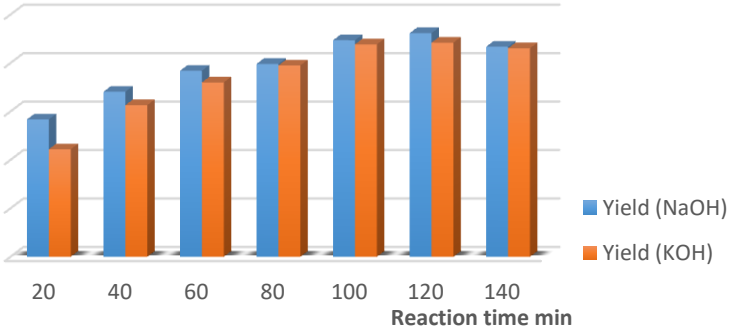

Fig.3 Effect of reaction time (min) on bone fat conversion

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4) Effect of Methanol-to-Fat Molar Ratio:

The methanol-to-fat molar ratio was tested between 4:1 and 10:1 (Fig. 4). Maximum yields of 96.17% (NaOH) and 94.20% (KOH) were achieved at a 6:1 ratio. Lower ratios (e.g., 4:1) reduced yields (70.43% with NaOH), while higher ratios (10:1) decreased efficiency (85.64% with NaOH) due to glycerol separation challenges. These results align with studies emphasizing the need for an optimal ratio (6:1–8:1) to balance reaction efficiency and minimize by-product formation [13], [14].

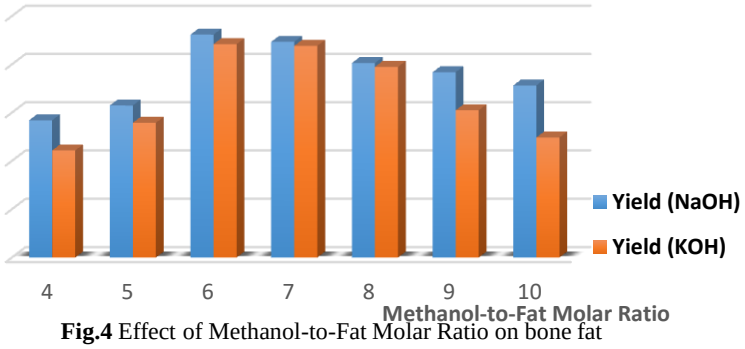

Fig.4 Effect of Methanol-to-Fat Molar Ratio on bone fat conversion

C. Composition of Biodiesel

The biodiesel composition table highlights saturated methyl esters (75.4%), dominated by methyl hexadecanoate (38.44%) and methyl stearate (27.88%). Monounsaturated compounds (23.82%) are primarily cis-9-octadecenoate (19.57%), with minor trans-isomer (2.22%). Polyunsaturated content is minimal (0.77%, methyl 9,12-octadecadienoate). High saturation enhances oxidation stability but compromises cold flow. Monounsaturated esters improve low-temperature flexibility, while low polyunsaturation reduces oxidation risks. Though compositionally balanced for quality biodiesel, saturated ester dominance may necessitate cold-flow additives for optimal performance in chilly climates. This profile suggests a fuel with extended storage stability but potential winter operability challenges without additives.

D. Characterization of Biodiesel

The properties of biodiesel produced from camel bone fat were evaluated according to international standards, revealing a notable balance between physical and chemical characteristics that make it suitable for practical applications. Starting with kinematic viscosity at 40°C, which measured 4.31 mm^2/s, falling within the acceptable range of ASTM D6751 (1.9–6.0 mm^2/s), confirming its ability to flow smoothly in engine systems without obstruction. This was followed by measuring density at 15.6°C, which recorded 0.885 g/cm^3, a value reflecting the dominance of medium-chain saturated fatty acids such as C16:0 and C18:0, contributing to higher density compared to short-chain vegetable oils [15].

In terms of safety, the fuel recorded a high flash point (174°C), exceeding the minimum requirement of standards (≥130°C), making it safe for handling and storage even under normal thermal conditions [16]. Regarding efficiency, the cetane number was calculated using the saponification value (209.4 mg KOH/g) and iodine value (24.05 g I_2/100 g), resulting in a value of 66.95, indicating rapid and stable combustion while reducing engine noise and vibrations [17].

IV. Conclusions

This study successfully converted camel bone fat, an underutilized slaughterhouse byproduct, into high-quality biodiesel through optimized alkali-catalyzed transesterification. Under optimal conditions (1% catalyst concentration, 65°C, 120 min reaction time, and a 6:1 methanol-to-fat ratio), maximum yields of 96.17% with NaOH and 94.20% with KOH were achieved, confirming the superior efficiency of sodium hydroxide.

The produced biodiesel exhibited physicochemical properties compliant with ASTM D6751 and EN 14214 standards, including a kinematic viscosity of 4.31 mm^2/s, cetane number of 66.95, and a high flash point of 174°C. The high proportion of saturated methyl esters (e.g., methyl hexadecanoate 38.44% and methyl stearate 27.88%) enhanced oxidative stability, making the fuel suitable for long-term storage.

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These findings highlight the potential for a circular economy model in camel-rich regions by transforming animal waste into renewable energy, reducing reliance on fossil fuels. Future studies should focus on the economic feasibility of industrial-scale production and evaluate the fuel's impact on engine performance and emissions to ensure its technical and environmental viability.

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