

Biodiesel Production & Comparison Of Fuel Properties From Waste Beef Fat By Pyrolysis & Transesterification Methods

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Abstract:

The present-day global warming around the world is due to the usage of fossil fuels in many industrial applications especially in the transportation sector. The need of the hour is to find an alternate for fossil fuel by replacing it with biodiesel made up of animal's waste fat. By the pyrolysis and transesterification method's the beef fat was converted into a biodiesel with acidic and base environment. Produced biodiesel was tested with the help of ASTM standards with the fossil fuel physicochemical properties. The current study presents a commercial alternative to lessen the ecological impact of waste animal (beef) fat while also providing an environmentally beneficial answer to the global issue of air pollution.

Keywords: Beef fat, Pyrolysis, transesterification, bio-diesel

1. INTRODUCTION

As the global appetite for energy continues to grow, concerns over the environmental consequences of fossil fuel use have spurred significant interest in alternative, sustainable energy solutions. Historically, fossil fuels have been the dominant energy source, supplying over 80% of the power used across key industries and transportation sectors. However, reliance on these non-renewable resources not only accelerates their depletion but also contributes to rising levels of carbon dioxide and other greenhouse gases. This environmental impact has intensified the urgency to transition toward cleaner and more sustainable energy systems. As a result, research and innovation in renewable energy technologies have become a global priority.[1] Currently, fossil fuels provide around 90% of the world's energy demands. However, forecasts indicate that by 2040, the percentage of renewable energy sources may increase dramatically, perhaps serving as much as half of the world's energy requirements [2,3]. Despite this modest share, they are expected to play a crucial role in future energy systems. Not only do they offer a sustainable energy source, but they also help curb greenhouse gas emissions significantly. As the world shifts away from fossil fuels, waste-based biofuels are emerging as a vital component of the clean energy transition [4]. In response to growing environmental concerns, the scientific community is actively exploring sustainable and eco-friendly alternatives to fossil fuels. Efforts are being made to enhance the use of renewable energy sources such as wind, solar, hydro, ocean, and tidal power. However, these sources alone are not yet sufficient to fully replace conventional fossil fuels. This underscores the urgent need for practical, renewable green fuel. Biofuels—such as bioethanol, biodiesel, and biogas—are increasingly being recognized as promising solutions to meet future energy demands [5].

Biodiesel is emerging as a crucial biofuel for energy generation, recognized for its compatibility with existing diesel engines without requiring significant modifications. It reduces particulates, sulfur, hydrocarbons, and carbon monoxide emissions by having a higher oxygen content and a lower carbon-to-hydrogen ratio than normal diesel. Chemically, it is made up of monoalkyl esters derived from long-chain fatty acids by reacting oils with acid, base, or enzyme catalysts. Biodiesel, derived from edible and non-edible oils or other triglyceride-rich materials, is biodegradable, non-toxic, and carbon-neutral. Its manufacturing is mostly based on the transesterification process, with heterogeneous catalysts preferred for their efficiency, reusability, and cost advantages. To address industrial-scale demand, improved reactor systems have been created to improve production efficiency and economic feasibility. Compared to petrodiesel, biodiesel has a greater cetane number, a higher flash point, better lubrication, and a lower viscosity. It is also biodegradable, non-toxic, and emits fewer greenhouse gases [6-8]. Longer engine life is supported by improved combustion efficiency and a shorter ignition delay. Biodiesel is a growing area of research to promote its sustainable use because it may be used directly or blended with petrodiesel in existing diesel engines with no modification [9-11]. Biodiesel is often extracted from an array of raw materials, including vegetable oils, animal fats, algae, and leftover cooking oil. The primary feedstocks utilized to produce biodiesel are soybean oil (30%), rapeseed oil (25%), palm oil (18%), other vegetable oils (11%), waste cooking oil

(10%), and animal fats (6%), in decreasing order, according to the USDA-Biofuels Annual Report 2015[12]. However, the use of edible oils as biodiesel feedstocks has drawn criticism due to concerns about the conflict between fuel creation and food production. This is due to the possibility that burning these oils for energy might lead to increased food prices and a shortage of essential food sources. This has sparked debates about the sustainability and ethical implications of using precious food supplies as fuel [13]. All feedstocks have advantages and disadvantages based on cost, availability, sustainability, and energy yield [14]. The use of different raw materials expands the foundation of sources of clean energy whilst decreasing the dependence on fossil fuels. Nevertheless, feedstock makes for nearly 80% of the entire biodiesel manufacturing expenses. The extensive usage of edible oils, which account for around 95% of the manufacturing of biodiesel, is coming under growing criticism because of the continuing worldwide food crisis. Consequently, the present trend is producing biodiesel from cheap, non-edible oil [15]. The great efficiency and potential of feedstocks such as waste cooking oil, coconut oil, microalgae, palm oil, jatropha, pork lard, chicken fat, fish oil, lamb meat, and tallow in the manufacturing of biodiesel are drawing attention [16]. The yield, quality, cost, and environmental effect of producing biodiesel are all significantly influenced by the raw material selection. The feedstock's fatty acid content has a significant impact on the finished product's characteristics and functionality. While biodiesel with more saturated fatty acids usually performs better in colder temperatures, biodiesel with more unsaturated fatty acids tends to give better oxidative stability. Concerns about sustainability and the economy are driving an increasing trend toward the use of inexpensive, non-edible oils in the manufacturing of biodiesel [17]. Researchers have consistently enhanced biodiesel production methods to boost productivity, fuel quality, and cost-effectiveness. Vegetable oils are used extensively, however because of their high viscosity and poor oxidative stability, they pose challenges. This is handled by four fundamental conversion processes: dilution, micro-emulsification, transesterification, and pyrolysis. These techniques have been improved to make it easier to produce biodiesel on a wide scale at a reasonable cost [18-19]. Blending works well for preserving the energy content and fluidity of fuel, but it is not the best option for low-volatile, high-viscosity oils. Engine problems including cooking, carbon buildup, and oil gelling can result from using just vegetable oil. Therefore, to make biodiesel a viable alternative fuel, economical methods are required [20]. Alcohol, surfactants, and vegetable or animal oils are combined in micro-emulsification to lower viscosity. Alcohols having colloidal structures, such as methanol, ethanol, butanol, or hexanol, are used to create micro-emulsions (1-150 nm). These fuels do not burn completely, nevertheless, because of their low cetane levels [21-22]. Using a process called pyrolysis, feedstocks like vegetable or animal fats or other materials high in triglycerides are heated to high temperatures (usually between 300 and 1300°C) without the presence of oxygen.

This process, known as heat breakdown, breaks down long-chain compounds and large, saturated molecules into smaller, simpler molecules. Based on the temperature range and catalysts utilized, pyrolysis can provide a variety of by-products, including alkanes, alkenes, alkadienes, aromatics, carboxylic acids, and trace quantities of gases. Based on temperature, pyrolysis is often divided into three categories: flash pyrolysis (1050-1300 K), rapid pyrolysis (850-1250 K), and traditional pyrolysis (550-900 K). The process is thought to be effective, environmentally benign, and waste-free. It can produce biodiesel with desirable fuel qualities such a high cetane number, low viscosity, and acceptable levels of sulfur, water content, and copper corrosion. But several undesirable characteristics are also produced by the process, including increased ash content, residual carbon, and raised points. Pyrolysis has several benefits, but it also uses a lot of energy, which drives up manufacturing prices. These restrictions have encouraged scientists to keep looking for more economical and energy-efficient methods of producing biodiesel in a sustainable manner [23-25]. One of the most popular and effective processes for making biodiesel is transesterification. Usually with a catalyst present, it entails the reaction of alcohol with vegetable oil or other triacylglycerols to provide glycerol as a byproduct and long-chain fatty acid alkyl esters (biodiesel)[26]. In transesterification for the generation of biodiesel, methanol, ethanol, propanol, butanol, and amyl alcohol are frequently utilized; however, methanol is the most favored because of its short carbon chain, high polarity, and affordability. The transesterification process often employs a variety of catalysts, including biocatalysts like enzymes, heterogeneous solid catalysts, and homogeneous acids and bases [18]. About 4000 times quicker than acid-catalyzed transesterification, base-catalyzed transesterification occurs. The kind and load (%) of catalyst employed, the temperature of the reaction, and the alcohol-to-oil ratio (ATOR) are important variables that impact the reaction. According to many research, the most popular process for producing biodiesel is transesterification. This procedure yields biodiesel with greater cetane numbers, lower emissions, and better combustion efficiency that satisfies ASTM D6751 and EN 14214 fuel specifications [24&27]. Finding sustainable and reasonably priced alternatives is crucial since the cost of raw materials contributes significantly to the whole

cost of producing biodiesel. Waste animal fat is still a mostly untapped feedstock to produce biodiesel, especially cow consumable fat. This study uses both pyrolysis and transesterification techniques to examine the viability of beef edible fat as a diesel substitute. During transesterification, which is generally considered to be an effective method for producing biodiesel on a big scale, acid and base catalysts were used. To determine its feasibility, the resultant biodiesel was further examined and contrasted with commercial diesel using important fuel characteristics.

2. MATERIALS AND METHODOLOGY

2.1. Bio-diesel Production from beef fat

The feedstock beef fat was bought from a nearby butcher shop, and all the chemicals utilized are analytical grade. Before undergoing the transesterification and pyrolysis processes, the obtained fat needs to be pre-processed to boost the generation of biodiesel. To do this, the fat must be coarsely chopped into tiny pieces, as indicated by the flow chart in Figure 1, and then put in a 3-hole flask with a thermometer attached, as illustrated in Figure 2a. In the preprocessing step, water content and nonfatty macro residues are removed, the pH is adjusted, and the fat is liquefied for handling. Fatty acid molecules that have broken away from the glycerol backbone of triglycerides during the hydrolysis process are known as free fatty acids (FFAs). These FFAs play a crucial role in assessing the suitability and quality of fats for the generation of biodiesel. Because of its distinctive yellowish hue, fat with an FFA level of less than 15% is frequently referred to as yellow grease. Although yellow grease is regarded as a lower-grade feedstock and is usually made from leftover cooking oils or animal fats, it can still be utilized to produce biodiesel with the right preprocessing. Brown grease is a low-quality fat characterized by its dark brown to black colour and is primarily composed of heavily oxidized lipids with free fatty acid (FFA) levels exceeding 15%. Its high FFA content and significant degradation make it less desirable for biodiesel production, as it poses greater challenges during processing. In this study, a thermal extraction method is employed, which involves first melting the fat into a liquid state. Heat is then applied to assist in separating the fat from the solid matrix, allowing for efficient recovery and preparation for further processing. As seen in the figures 1 and 2, a condenser, gas arrester, and thermometer were added to the flask along with the fat. The beef fat was heated to 80°C on a hot plate, and for three hours, the molecules were broken down by a mechanical stirrer running at a steady 1500 rpm. After that, the fat was converted to an oil that contained impurities, and at last, just oil was extracted from it. Ethanol and sulfuric acid were added to the fat during the production process to reduce it to oil. After cooling the system, we saw that the oil had solidified into a rock-like substance. After that, we utilized methanol as alcohol and carried out the same procedure three more times to produce biodiesel from beef fat. Pyrolysis is a thermal degradation process that involves breaking down organic matter by applying heat in an environment with little or no oxygen. Through this technique, solid organic substances are transformed into liquid and gaseous byproducts, while any inorganic components originally bonded within the material are also released[28]. Pyrolysis produces bio-oil, non-condensable gases, and char, with bio-oil being the main focus for its fuel and chemical potential. Its yield and quality depend on key factors like temperature and reaction time, which influence the breakdown of materials and the distribution of products[29]. Slow pyrolysis process under 400°C has been in this research work based on previous literatures.

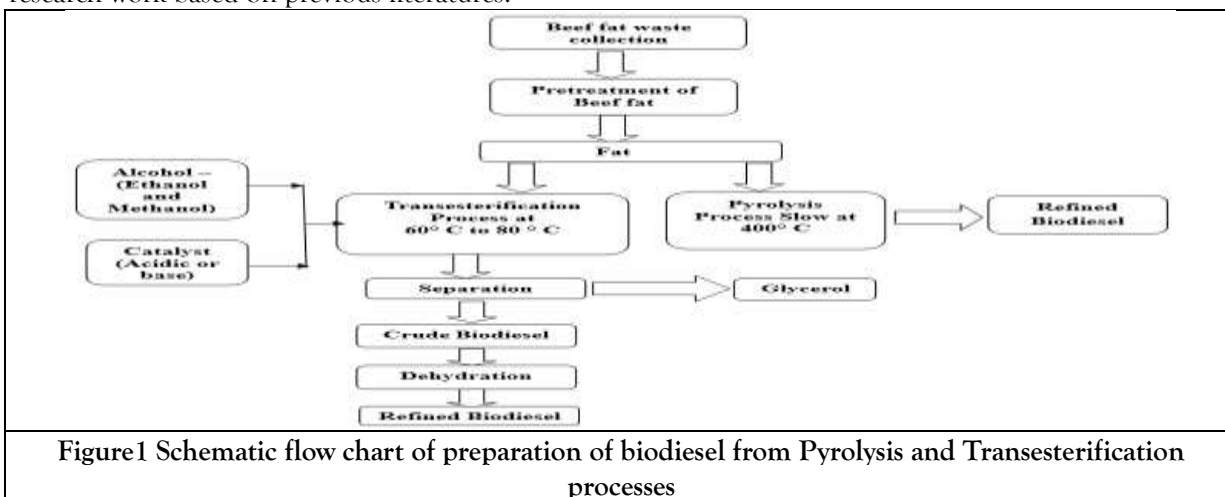


Figure1 Schematic flow chart of preparation of biodiesel from Pyrolysis and Transesterification processes



Figure 2 a: Esterification Process setup



Figure 2 b collected biodiesel and glycerine

Table 2: Comparison of the physiochemical properties of biodiesel with ASTM standards.

Sl. No:	Property of fuel	ASTM D6751 standards and test method	Test method	Diesel	Transesterification method Biodiesel	Pyrolysis Biodiesel
1.	Specific gravity (g/l)	0.86–0.9 (D1298)	IS:1448(part-4) 1990 RA2002	0.8326	0.8719	0.881
2.	Kinematic viscosity (mm ² /sec)	1.90–6 (D445)	IS:1448: part-25: Sec 1:2018(ISO 3104:1994)	5.7	8.75 @ 40°C	5.67 @ 40°C
3.	Acid number (mg/KOH)	0.5 (maximum) (D664)		0.35	n/a	0.45
4.	Cetane number	47 (minimum) (D613)		52.25	n/a	75
5.	Calorific value (MJ/Kg)	35–43 (D240)	IS1350(Part-II)1970 RA 2000	42.5	42.24	43.47
6.	Flash point (°C)	93 (minimum) (D93)	IS:1448 (Part-69) 2019 (ISO 2592:2017) RA 2024	67	31.7	41
7.	Fire point (°C)	143	IS:1448 (Part-69) 2019 (ISO 2592:2017) RA 2024	74	39.0	28

8.	Pour point (°C)	15 to 10 (D97)	IS:1448 (Part-10/Sec-1) 2012 ISO 3015:1992	-13	4	9
9.	Cloud Point (°C)	3 to 12 (D2500)	IS:1448 (Part-10/Sec-1) 2012 ISO 3015:1992	9	19	12
10.	Moisture content (vol %)	0.05 (max) (D2709)	IS:1448 (Part-40) 1987	0.01	1.18	0.035
11.	Ash content	0.01 (D482)	IS:1448 (Part-4) 1984 RA2002	0.01	0.0016	0.007
12.	Total acid number		IS:1448 (Part-1/Sec-1) 2002		7.60 mg of KOH/gm	8.41 mg of KOH/gm

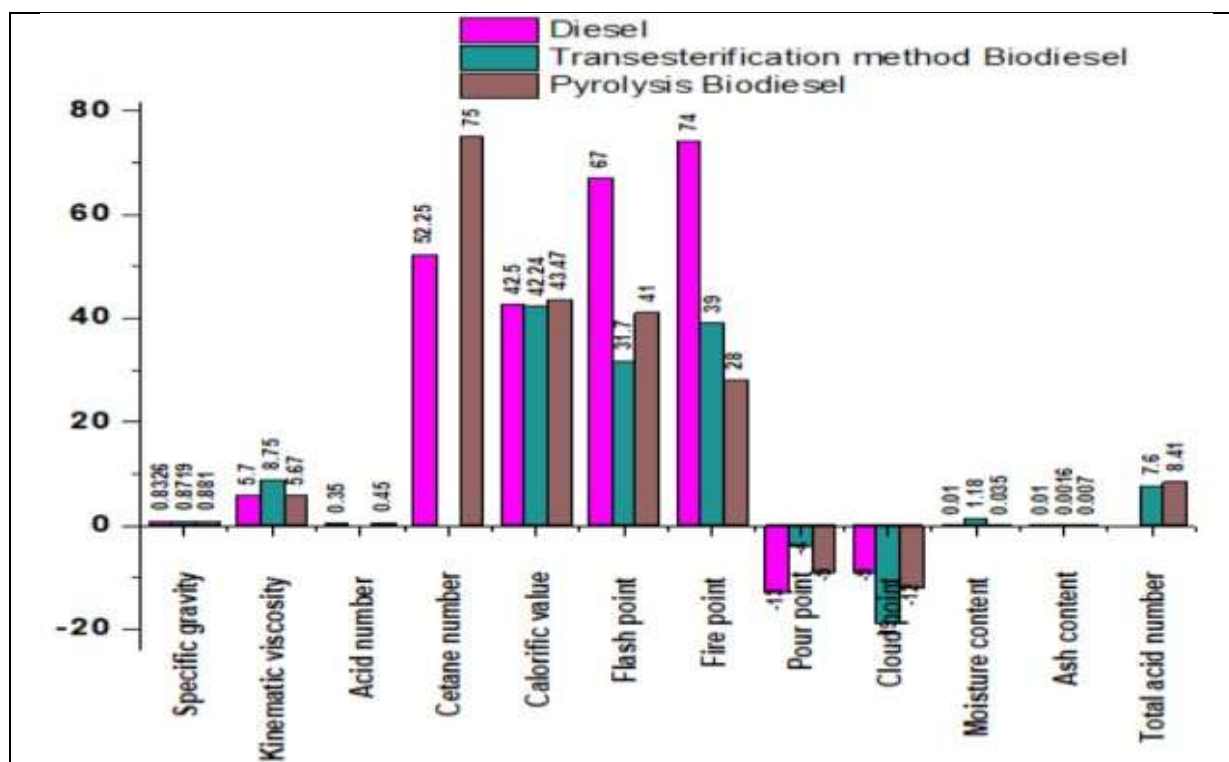


Figure Bar chart represents the Diesel, Transesterification method biodiesel, and Pyrolysis biodiesel

Table 2 values have been referred from [30]

2. Physical and Chemical Traits of Biodiesel Produced from Waste Beef Tallow:

- 2.1. **Specific gravity:** The specific gravity of the prepared samples showed good results and aligned well with the earlier findings reported by Tat in 2000 [31].
- 2.2. **Kinematic viscosity:** The biodiesels produced by both processes had produced much higher than the previous literature of Gautam 2020 [32] and Jambulingam et al. (2020)[33].
- 2.3. **Acid number:** The biodiesel samples developed in this study exhibited enhanced performance relative to both pure and diesel-blended biodiesel samples at various mixing ratios, as reported by Jambulingam et al. (2020) [33].
- 2.4. **Cetane number:** Our research yielded a higher cetane number compared to the findings reported by Gautam (2020)[32] and Jambulingam et al. (2020)[33], and fadhil et al [34] of waste chicken fat and oil.
- 2.5. **Calorific value:** Our results closely matched the findings of Jambulingam et al. (2020)[33], which involved various diesel blends with differing concentration percentages and also be higher than the Srinivasan et al 2019 investigations over beef tallow[35].
- 2.6. **Flash and Fire point:** The biodiesel prepared through the pyrolysis process exhibited a lower flash point compared to the findings reported by Gautam (2020)[32]. Additionally, our recorded flash point values were significantly lower than those of TME, TEE, and TMEE reported by Jambulingam et al. (2020)[33]. The

previous literatures with waste beef tallow oil, waste vegetable oil, Cyprinus carpio fish oil, and microalgae spirulina oil were higher than our present data and reported by Nagappan et al 2021 [36], Singh et al 2017 [37], Fadhil et al 2015 [38], and raja et al [39]. Okwundu 2019 investigated and shown that higher flash and fire points than the present results and indicating that lower values indicates potential risks in handling.[40]

2.7. Pour point and Cloud point: The findings from our study indicate marginally lower values in comparison to those presented in the earlier work by Jambulingam et al. (2020)[33].

Biodiesel can be made to cost about the same as regular diesel by using inexpensive feedstocks like beef fats.

Benefits of using biodiesel-Renewable Resource [41], Reduced Greenhouse Gas Emissions [42], Biodegradability [43], Energy Security [44], Waste Utilization [45], Engine Performance and Lubricity [46], Compatibility [47] and Infrastructure [48], Carbon Neutrality [49-52].

6. CONCLUSION

Biodiesel can be produced through various methods, including transesterification and pyrolysis. However, the transesterification process is generally preferred due to the superior quality of the resulting biodiesel. In transesterification, triglycerides in feedstocks like beef tallow react with alcohol (typically methanol) in the presence of a catalyst to form methyl esters (biodiesel) and glycerol. This method yields biodiesel with improved physicochemical properties such as lower viscosity, higher cetane number, better oxidative stability, and more consistent combustion characteristics. In contrast, pyrolysis involves the thermal decomposition of organic material in the absence of oxygen, producing a complex mixture of hydrocarbons, including bio-oil, gases, and char. While pyrolysis is advantageous in terms of feedstock flexibility and the potential to produce multiple products, the resulting bio-oil typically has lower fuel quality, higher acidity, and requires extensive upgrading before use in engines.

Beef tallow biodiesel produced via transesterification exhibits a high flash point, enhancing safety during storage and transport. Its high cetane number also improves ignition quality and combustion efficiency, making beef tallow methyl esters suitable for blending with conventional diesel fuels. Experimental studies have confirmed that beef tallow biodiesel produced by transesterification meets ASTM D6751 standards, supporting its potential as a sustainable substitute for petroleum diesel. Nonetheless, to further improve production efficiency and reduce costs, ongoing research is focused on optimizing the use of heterogeneous catalysts and low-cost lipase enzymes in the transesterification process.

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