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Valorisation of Waste Cooking Oil into Biodiesel: A Comparative Study of Domestic and Cultural Sources with Glycerin Saponification

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ABSTRACT

This study addresses the sustainable manufacture of biodiesel from waste cooking oil (WCO), with a comparative investigation of two principal sources: household kitchen waste and restaurant (cultural) waste. Using 100 mL samples from each source, the study examines the fuel characteristics, efficiency, and usage of by-products in the biodiesel synthesis process. Methanol and sodium hydroxide were used in a base-catalyzed transesterification process to create biodiesel, which was then evaluated for important physicochemical characteristics such as density, viscosity, acid value, flash point, moisture content, and pH. According to the findings, domestic WCO often generates biodiesel with more stable and appealing fuel qualities because of reduced levels of water contamination, free fatty acid production, and degradation. However, restaurant WCO produced biodiesel with increased acid values and moisture content after being heated repeatedly and exposed to food remnants; further pre-treatment was necessary for the best conversion. The study highlights the value-added use of crude glycerin, a by-product of the transesterification process, in addition to the creation of biodiesel. In order to create bio-soap, crude glycerin was saponified, showcasing a useful and environmentally responsible method of waste management and circular economy principles. The physical properties of the bio-soap were assessed, and the results showed that it was suitable for use in industrial or domestic cleaning applications. All things considered, the study shows how WCO can be used as a raw material for secondary products as well as an alternative fuel source, improving sustainability. The comparative study encourages the integrated use of waste oils in green energy and product development by offering insights into feedstock quality, processing requirements, and resource recovery.

1. INTRODUCTION

Energy resources are vital for enhancing national development and economic success. Unfortunately, the accessible energy resources, notably the petroleum reserves, are constrained to specific places of the planet and now, they are depleting at a quicker pace owing to rapid usage with an increase in the global population (M. Manfroni et al., 2021, T. kivevele et al., 2020). Fossil fuels are depleting rapidly, highlighting the urgent need to develop alternative energy sources to meet the rising energy demand (Premkumar S et al., 2023).

Biodiesel is an infinite, biodegradable, and ecologically friendly fuel created from vegetable oils of various types or fats of different kinds of animals used in compression ignition engines. Biodiesel is a form of biofuel that may be used as an alternative fuel for diesel engines ("Spootin S et al., 2021). The basic ingredients required to create biodiesel originate from spent cooking oil, animal fats, and vegetable oils (Susvira D, 2022). Making biodiesel from used cooking oil has several advantages, such as lowering greenhouse gas emissions, decreasing waste production, and offering a sustainable energy source (Omar & Amin, 2011).

Using waste cooking oil (WCO) as a feedstock for biodiesel has been found to be an economical and ecologically friendly solution because it doesn't require land use or generate waste (A. Talebian-kiakalaish et al., 2013), (E. Emmanouilidou et al., 2024).

The main by-product of the biodiesel synthesis process is glycerol. Glycerol is a hygroscopic liquid that can mix in any amount with water. Glycerin is a by-product of the transesterification of triglycerides, such as animal fats or vegetable oils, which results in the production of fatty acid methyl esters (FAMEs) (Fauzi et al., 2012). Creating environmentally safe (eco-friendly) procedures and using waste and by-products to produce organic materials are given a lot of attention ("Clauser, 2021"").

Conventional soap is usually produced by saponification of fats and oils using alkaline chemicals such as sodium hydroxide (Chatzifragkou & Papanikolaou, 2012). Due to increasing focus on environmental sustainability and resource optimisation, research has focused on alternative soap production raw materials (Elsayed et al., 2023)). Use of crude glycerin in soap production presents a twofold advantage: lowering the cost of production and presenting an eco-friendly disposal route for waste biodiesel (Mythili et al., 2011).

AIM AND OBJECTIVE

- Collection of the waste cooking oil from two different source.

- Purification of waste cooking oil.
- Biodiesel production from waste cooking oil.
- Formulation of Biodiesel and crude glycerin.
- Comparative analysis of Fuel property test and Testing quality of Biodiesel.
- Saponification of crude glycerin.
- Comparative analysis of the properties of biosoap produced.

2. MATERIAL AND METHODOLOGY

2.1 BIODIESEL PRODUCTION

Waste cooking oil (WCO) form two source, sodium hydroxide (NaOH), methanol (CH3OH), A thermometer, tripod stand, separating funnel and helical condenser, a weighing balance, beakers, filter paper, stirrer, measuring cylinder, a separating funnel, conical flasks, heating mantle, and a helical condenser are used for experiments.

Methodology

The production methodology can be depicted in the following step as shown in figure 1.

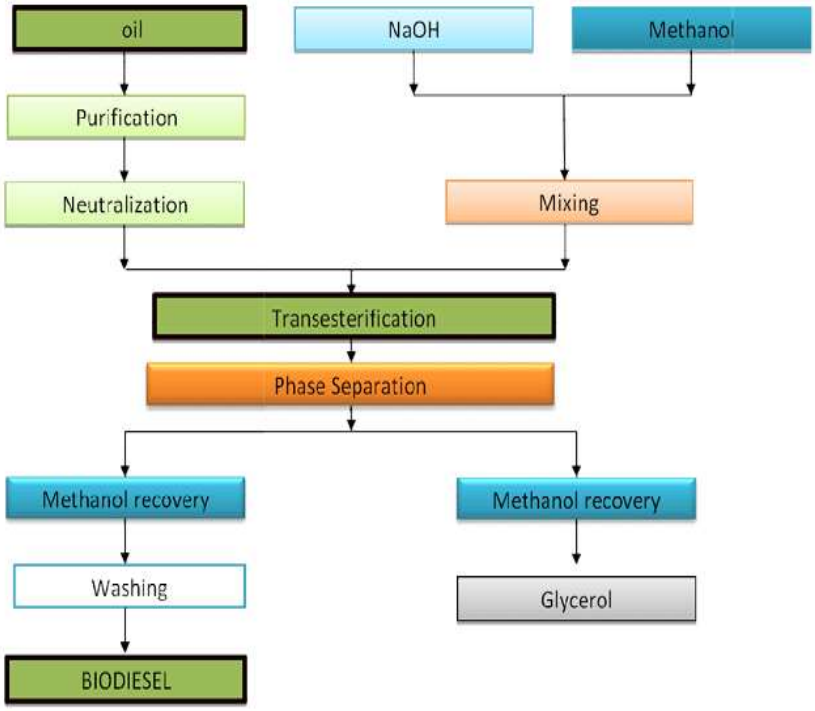

Fig. 1. Flow chart (Abdul Kareem et al., 2024)

- **Waste Cooking oil (WCO) Pre-Treatment Process**

Laboratory-scale production of biodiesel from used cooking oil (WCO)

Waste cooking oil is gathered from two distinct household sources (a residence, which is domestic, and a food stall, which is cultural) and designated as samples I and II, respectively. Whatman filter paper is used to filter the used cooking oil. In order to filter waste cooking oil, the filter paper and tripod stand are used. The used cooking oil was heated in a microwave oven to around 105 °C for three to five minutes before any water content was successfully removed.

- **Transesterification of Pre-treated WCO**

Transesterification is the process of converting triglycerides (fats and oils) into biodiesel (fatty acid methyl or ethyl esters) and glycerol. This reaction can be facilitated by an alkali, acidic, or enzymatic catalyst; sodium hydroxide (NaOH), a strong base, and potassium hydroxide (KOH), another strong base, are the most often used catalysts. This method is a somewhat easy and effective technique to make biodiesel.

Samples 1 and 2 each included 100 milliliters of waste frying oil, 20 milliliters of methanol, and one gram of sodium hydroxide. Heating the oil and then rinsing it with hot water removed the organic pollutants and impurities from 100ml of wasted cooking oil. Using a magnetic stirrer, sodium hydroxide and methanol are combined. Using a magnetic stirrer, sodium hydroxide is fully dissolved in methanol (Hossain A.B.M.S. et al., 2010). A heating mantle is used in the reactor to heat the oil sample to between 55 and 65 °C. Once the oil reaches the desired temperature, catalyst and methanol are added. It takes one hour and thirty minutes to respond (Joana M. Dias et al., 2008). Glycerol is quite viscous, thus it settles in the bottom of the beaker once the solution is added (Arjun B. Chhetri et al., 2008). The solution was placed in the beaker. It takes an hour to separate, and after that, two layers are visible. J.M. Marchetti et al. (2007) state that the strata are distinct. According to Rahadianti et al. (Khale S. AlQdah and Wail M. Adaileh, 2012). Because 65ºC is thought to be the ideal temperature for transesterification, it is used in the transesterification process to create biodiesel. A catalyst (NaOH) concentration of 1% by weight was present, and the oil to methanol ratio was 6:1.

Steps: The visual presentation of steps for production of Biodiesel from waste cooking oil is illustrated here –

Fig. 2 NaOH

Fig. 3 Methanol

Fig. 4 NaOH and methanol mixture

Step 1. Determination of catalyst and methanol and mixing them.

Fig. 5 Heating mantle

Fig. 6 Measuring temperature of WCO

Step 2. Heating of oil up to 65 Oc.

Fig. 7 Mixture of WCO, catalyst and methanol

Step 3. Mixing up of WCO, catalyst and methanol.

Fig. 8 Separating layers

Step 4. Glycerol layer and Biodiesel layer is separating keeping it for 12h.

Fuel Property test of Biodiesel

The physicochemical properties of the biodiesel sample 1 and 2 were compared to ASTM standards through thorough fuel characterization, their fuel properties are tested listed below.

- **Density @ 27°C (g/ml)**

Density of the biodiesel is measured by a simplified weighing machine using a measuring cylinder and thermometer.

Density of biodiesel= $\frac{Mass\ of\ biodiesel}{Volume\ of\ biodiesel}$

- **Flash Point (°C)**

The temperature at which biodiesel releases enough vapour to briefly ignite is known as the fuel's flash point, and it is determined using a simplified open flame test.

- **Acid Value (mg KOH/g)**

Titration with a potassium hydroxide solution is used to determine the acid value, which measures the amount of free fatty acids (FFAs) in the biodiesel.

- **PH (Approximate)**

The pH of biodiesel is not generally included in ASTM fuel specifications. During the water-washing stage of the biodiesel production process, pH is checked using a pH indicator strips.

- **Moisture Content (%)**

Oven-drying techniques is frequently used to measure it. Equipment used if hot air oven. Weigh empty beaker and add known amount of biodiesel, placed it to oven at 90-100Oc for 1 hour, cool and weigh again.

Moisture content (%) = ($\frac{Initial\ weight - Final\ weigh}{Initial\ weight}$) 100

Testing quality

To test the quality of the biodiesel produced from waste cooking oil sample 1 and sample 2.

- **Washing test** –successful if water and oil are totally separated. Washing of oil 3-4 times with distilled water till water gets clear when it settled 30 min and their totally separated.
- **Methanol test** (225 ml methanol, 25 ml of oil)– This test will successful when oil it totally soluble with added methanol.

2.2 BIOSOAP PRODUCTION

For biosoap production, crude glycerin/glycerol obtained as a by-product from biodiesel production from waste cooking oil is taken, lye sodium hydroxide (NaOH), water, and lemon juice, equipment like beaker, moulds, stirrer, heating mantle are used to make good quality of soap.

Methodology

20 ml of crude glycerine of sample 1 and 2 which was obtained after the transesterification process of biodiesel was placed in a beaker. The glycerine was heated to 65^oC (because the methanol boiling point is 64.70C) to remove the excess methanol present in the crude glycerin, later it was cooled to room temperature. Simultaneously, the lye sodium hydroxide solution was prepared by mixing of 1.2gm of NaOH in 10ml of distilled water. Finally, the lye solution was added to the above cooled methanol removed crude glycerine into the mould with a plastic sheet and allowed to settle for 6 hours. The

soap bar was removed from the mould by inverting on a plane good surface. The circular shaped soaps were obtained. The obtained crude glycerine soaps were allowed to cure for 10 days. The same procedure was fallowed for the other sample i.e. sample 2 (crude glycerine obtained in the biodiesel production of CWCO).

Steps: The visual presentation of steps for production of Biosoap from crude glycerin is illustrated-

Fig. 9 Crude Glycerin

Fig. 10 Heating crude glycerin

Step 1 of heating crude glycerin in Heating mantle.

Fig. 11 Crude Glycerin and mixture of NaOH and water

Step 2 mixing of crude glycerin and mixture of NaOH and water.

Physical properties test of biosoap

The physicochemical properties of the biosoap sample 1 and 2 were compared, their fuel properties are tested listed below.

- **PH (approximate)**

The pH of the soap was tested by mixing of small piece of soap with distilled water. Later, the pH of the soap was recorded using the pH paper.

- **Foam formation**

Foam formation is seen by dissolving 1gm of soap into 10ml of water and shake vigorously and foam is produced.

3. RESULT AND DISCUSSION

3.1 Percentage Yield

Table 3.1 Percentage yield of the biodiesel produced from both sample.

Feedstock	**Initial Oil Volume (ml)**	**Biodiesel Volume (ml)**	**Glycerol Volume (ml)**	**Biodiesel Yield (%)**
Domestic Waste Cooking Oil	100 ml	80 ml	20 ml	80%
Cultural Waste Cooking Oil	100 ml	78 ml	21ml	78%

Fig. 12 layers separated

Fig. 13 Separation of glycerol and Biodiesel

3.2 Visual Observation and Physical Properties of Biodiesel

Physical characteristics including color, clarity, and odor can be used to assess the quality of biodiesel in an initial stage. Table 3.2 displays the characteristics of the biodiesel generated from both feed supplies.

Parameter	**DWCO Biodiesel**	**CWCO Biodiesel**
Color	Dark yellow	Light yellow to brown
Clarity	Clear and transparent	Slightly turbid
Odor	Mild odor	Unpleasant odor
Settling Time (hours)	24	24

Fig. 14 Showing Biodiesel produced from waste cooking oil from both the sample (domestic and cultural)

3.3 Fuel Properties of the Biodiesel Produced

To compare the physicochemical characteristics of the biodiesel samples with ASTM standards, a thorough fuel characterization was carried out listed below in table 3.3

Properties	**DWCO Biodiesel**	**CWCO Biodiesel**	**ASTM D6751 Standard**
Density @ 27°C (g/ml)	0.88	0.89	0.86 – 0.91
Flash Point (°C)	164	161	≥130
Acid Value (mg KOH/g)	0.39	0.55	<0.50 (recommended)
pH (approximate)	6.9	6.4	Neutral (6.5–7.0)
Moisture Content (%)	0.03	0.08	<0.06 (ideal)

Testing quality

Table 3.4 Testing quality of biodiesel of both samples

Test	**DWCO**	**CWCO**
Washing test	+	+
Methanol test	+	+

3.4 Crude Glycerin Characteristics

Properties of crude glycerin like volume, appearance, odor, pH, are listed below in the table 3.5.

Parameter	**DWCO Glycerin**	**CWCO Glycerin**
Volume (per 100 ml oil)	20 ml	21 ml
Appearance	Light brown, viscous	brown, thick
Odor	Mild	Strong
pH	~10.1	~10.4
Impurities	Methanol, soap, FFAs	More soap and FFAs

Fig. 15 Crude Glycerin obtained from Biodiesel Production

3.5 Physical and Sensory Evaluation of Soap

The physical properties and sensory evaluation of the biosoap produced from crude glycerin, a by-product of transesterification process is listed in table 3.6. Some of the properties are evaluated bye sense or by visualizing the biosoap produced from both the sample and are then compared.

Parameter	**DWCO-Based Bio-soap**	**CWCO-Based Bio-soap**
Color	Light brown	Dark brown
Texture	Smooth, slightly soft	Little Coarse
Odor	Mild, soapy	Strong, unpleasant
Curing Time (days)	6	8
Foam Formation	Moderate	Low to Moderate
Lather Stability	Good	Fair
pH (10% solution)	8.5	9.1

Fig. 16 Biosoap produced from crude glycerin

3.6 Comparison with Commercial Soap and Literature

The Comparison of bio-soap produced from crude glycerin with commercial and literature is listed below in the table 3.7. Research shows that unrefined glycerine can be utilized to make soap, particularly for household and commercial cleaning applications, with comparable quality results when used appropriately (Azizi et al., 2016; Canoira et al., 2008).

Parameter	**Bio-soap (This Study)**	**Commercial Soap**	**Literature Range**
pH	8.5–9.1	6.5–8.0	9–10 (glycerine soaps)
Foam Quality	Moderate	High	Moderate to High
Appearance	Rough, opaque	Smooth, colored	Varies
Ingredient Cost	Very low	Moderate to high	Low (in similar studies)

4. CONCLUSION

The sustainable conversion of waste resources, namely cooking oils from homes and restaurants, into biodiesel and the subsequent use of the crude glycerin byproduct for the creation of bio soap were the subjects of this dissertation. Cooking oils from household and cultural waste are both suitable feedstocks for small-scale biodiesel synthesis; nevertheless, the yield and quality of the finished biodiesel product were significantly impacted by the source and quality of the waste oil. The primary objective was to evaluate the viability of employing readily available and affordable techniques to produce biofuels and value-added goods from commonly wasted kitchen garbage.

While cultural waste cooking oil produced 78% of the biodiesel, home waste cooking oil produced 80%. Domestic oils, which are subjected to fewer frying cycles and heat oxidation, are thought to have a lower amount of free fatty acids (FFA) and to degrade less. Lower conversion efficiency and partial saponification resulted from greater amounts of contaminants and FFAs in restaurant oils, which are frequently reused. Both variations of the biodiesel were found to meet important ASTM D6751 requirements, such as appropriate density, flash point according to physicochemical examinations of the samples. Nevertheless, the biodiesel made from restaurant oil showed darker coloring and greater acid values, suggesting further pre-treatment such acid esterification is required if it is to be used commercially or on a wider scale.

The study's second phase focussed on using crude glycerin, a by-product of the production of biodiesel, to make bio-soap. The feasibility of a zero-waste bio-refinery concept was evaluated using crude glycerine that was extracted from both oil sources without purification. The resulting soaps were solid, useful, and showed a reasonable capacity for cleaning and foaming. Compared to the soap made from restaurant oil glycerine, which was darker, more brittle, and had a greater rancid smell, the soap made from domestic oil glycerine was lighter in color, smoother to the touch, and had a gentler smell. These variations were directly related to the glycerine's quality, which was impacted by the feedstock oil.

This study effectively showed that the synthesis of biodiesel from used cooking oils and bio-soap from crude glycerine may be coupled to create an environmentally friendly, affordable, and sustainable approach. By turning trash into energy and useful products, it promotes the idea of a circular economy and lessens the environmental impact of improperly disposing of old cooking oils.

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