

Biodiesel Raw Material Characterization and its Production Process- A Review

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Abstract:

As fossil fuels deplete, there is an urgent need to develop an alternative fuel to meet the world's energy demands. Biodiesel is one of the greatest accessible resources that has lately come to the fore. The most significant advantage of biodiesel over gasoline and petroleum diesel is its low environmental impact. In terms of regulated pollutants, biodiesel burns similarly to petroleum diesel. Biodiesel, on the other hand, is likely to outperform gasoline in terms of efficiency. Biodiesel is one such fuel that has a lot of promise for compression-ignition engines. Biodiesel, produced from vegetable oils, can be used to substitute diesel fuel. Soybean, rapeseed, and palm oils are currently the most common biodiesel sources. A thorough review has been done in this paper to highlight several elements of the biodiesel production. These include biodiesel feedstocks, extraction and manufacturing methods, biodiesel characteristics and attributes, and difficulties.

Keywords: Biodiesel production, oil extraction, purification, biodiesel feedstock

I. INTRODUCTION

The demand for fossil fuels in the transportation industry is growing, yet natural resources are running out. Scholars are encouraged to look into the availability of alternative energy to replace fossil fuel usage since they are aware of the energy difficulties and climate change caused by burning fossil fuels. Biodiesel is one of them, because it is extremely biodegradable and has a low toxicity level. It may also be used to substitute diesel in a variety of applications, such as internal combustion engines, boilers, and so on. With practically negligible emissions of sulfates, aromatic compounds, and other chemically harmful chemicals to the environment and a little net contribution of carbon dioxide (CO₂), it is expected to offer significant improvements in rural economy. More than 350 oil-bearing crops have been identified as a potential source of biodiesel on a worldwide scale. A diverse range of feedstocks will be a significant element in biodiesel manufacturing [1]. In addition, biodiesel must satisfy two major requirements: cheap production costs and a high production scale. Any country's regional climate, geographical location, local soil characteristics, and agricultural methods are used to determine the availability of feedstock for biodiesel production.

Despite the fact that biodiesel is more expensive than petro-diesel, it is nevertheless produced in small quantities (in comparison to petroleum products and ethanol). The techniques and levels of gasoline taxes impact biodiesel's capacity to compete with petroleum. The expenses of producing biodiesel are frequently higher than those of petroleum diesel. As a result, in today's market, biodiesel is not cost-competitive with petroleum. The cost of biomass feedstock and the price of conversion technology impact the competitiveness of biodiesel. To summarize, there are three ways to reduce unit costs in biodiesel manufacturing processes: upgrading production methods for higher productivity/yield, lowering capital costs, and lowering raw material costs, with feedstock cost being the most important. All of these options necessitate a cost-benefit analysis of different alternative production technologies, catalysts, feedstock types, and biodiesel and glycerol purification processes to determine which is the most cost-effective. There have been a lot of worthwhile studies conducted to assess the economics of biodiesel manufacturing techniques [2].

II. LITERATURE REVIEW

1. Production methods

Many attempts are being made to enhance and improve the characteristics of vegetable oils in order to match the capabilities of diesel fuels. Cold start issues, lesser energy content, increased copper strip corrosion, and

fuel pumping trouble due to higher viscosity are all significant operating drawbacks of biodiesel when compared to petrodiesel [3]. The most commonly linked issues with unrefined vegetable oils have been noted to include excessive viscosity, poor volatility, and polyunsaturated characteristics. Pyrolysis, dilution with hydrocarbons mixing, microemulsion, and transesterification are four ways that can be used to solve production difficulties which are stated above.

1.1 Pyrolysis (thermal cracking)

Due to its high ethylene selectivity in contrast to other heavier paraffins, ethane is one of the finest feedstocks for the thermal cracking process. As shown in Fig. 1, the ethane cracking furnace is made up of convection and radiation portions. At 121°C and 5.9 bars, the feed is delivered into the convection section. At 175°C and 5.7 bars, this stream is diluted with steam (0.3 kg steam/kg ethane). Using hot stack gas, this combination is then warmed to about 500–800°C. The ethane molecules then break apart to generate ethylene, propylene, butadiene, methane, and other chemicals in the radiation portion.

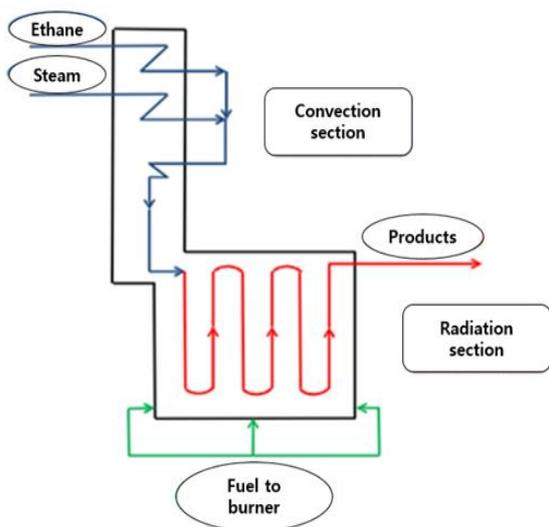


Figure 1. Block Diagram of thermal cracking of ethane [4]

At 700–900°C, this process takes place in radiant tubes that are vertically arranged in a rectangular furnace. The needed heat is provided by forty side burners and forty bottom burners to keep the reactor temperature at this level. Temperature plays a critical role in output concentrations in this process, thus the coil outlet temperature (COT) of these furnaces should be kept constant at 800°C. After that, products with temperatures ranging from 775°C to 885°C exit the furnaces and cool fast in the transfer line exchanger (TLE) to avoid additional side reactions. Finally, as illustrated in Fig. 2, the products are compressed and transferred to subsequent separation stages [4].

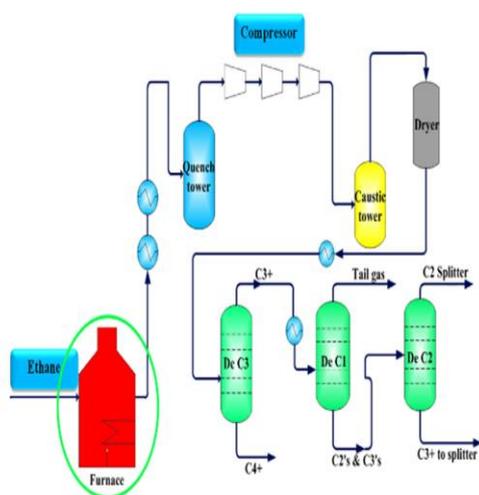


Figure 2. Cracking and separation plant [4]

Ethylene, a key component in the petrochemical industry, is commercially generated by thermal cracking of ethane, ethane–propane combination, or naphtha in the presence of steam. This process is extremely endothermic, requires a lot of energy, and includes a lot of coke production. The huge amount of coke that has been deposited on the inner walls of the tubular cracking reactor causes severe issues, such as a reduction in the rate of heat transmission from the reactor walls. It has previously been recommended that ethane and propane thermal cracking processes be carried out in the presence of restricted oxygen to overcome these issues. Not only is the energy requirement drastically reduced when thermal cracking ethane, propane, or C2–C4 hydrocarbons from natural gas in the presence of steam and limited oxygen, but also the coke formation is eliminated or drastically reduced, and the hydrocarbon conversion can be much higher than 70%. Moreover, Carbon dioxide which can act as a mild oxidant has previously been used in catalytic methane partial oxidation processes such as catalytic CO₂ reforming of methane and oxidative coupling of methane, as well as catalytic oxidative dehydrogenation of ethane or propane. In the presence of CO₂, ethane cracking is a highly endothermic reaction. However, ethane cracking in the presence of both CO₂ and limited O₂ can be mildly endothermic or thermos-neutral, depending on the process conditions, as in the case of the previously described oxy cracking of ethane, due to the coupling of the simultaneously occurring endothermic ethane cracking and exothermic ethane oxidation (mostly to CO and H₂O) reactions in the process, resulting in significant energy savings. In both thermal and oxy cracking of ethane, the presence of CO₂ has a positive impact. Ethane conversion increases when the CO₂/C₂H₆ ratio in the feed increases in both cases; ethane appears to be activated in the presence of CO₂. Because of the production of CO owing to partial combustion of ethane, ethane conversion is higher but ethylene selectivity is lower when restricted O₂ is supplied to the ethane-CO₂ feed at varied process settings. However, when both CO₂ and O₂ are present, the process is predicted to become extremely energy efficient, resulting in significant energy savings for coke-free ethylene synthesis from ethane [5].

1.2 Dilution with hydrocarbons mixing

Vegetable oils are usually diluted with diesel to decrease viscosity and enhance engine efficiency. This technique does not necessitate any chemical processes, and it has been claimed that substituting 100% vegetable oil for diesel fuel is not feasible. A mixture of 20% vegetable oil and 80% diesel fuel, on the other hand, proved successful. Several publications have documented the usage of diesel fuel blends using sunflower oil, coconut oil, African pear seed, rice bran oil, PP (Pistachia Palestine), waste cooking oil, palm oil, soybean oil, cottonseed oil, rubber seed oil, rapeseed oil, J. curcas oil, and P. pinnata oil . For example, in a direct injection diesel engine, Ziejewski et al. examined the effects of a fuel blend of 25% sunflower oil and 75% diesel fuel (25/75 fuel). This mix, according to the authors, is unsuitable for long-term usage in direct injection engines. This is due to the viscosity of 4.88cSt at 313K (maximum specified ASTM value is 4.0cSt at 313K). Vegetable oils and their mixes have traditionally been thought to be difficult to utilize in both direct and indirect diesel engines [1].

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1.4 Microemulsification

Emulsification/microemulsification, a technique for mixing and dispersing two or more immiscible liquids into a homogeneous solution with the use of surfactants (and cosurfactants), is one of the most straightforward and cost-effective techniques to improve bio-oil for engine usage. Because of the micro-explosion anomalies caused by the volatility difference between the interior liquid (e.g., water or bio-oil fraction) and the base fuel, most studies indicate that emulsion/microemulsion fuel has the advantages of reduced pollutants (HC, CO, and NO_x) emissions and improved engine combustion performance [6].

Microemulsions are colloidal dispersions that are transparent and thermodynamically stable, with dispersed-phase particle diameters smaller than one-fourth the wavelength of visible light. Microemulsion-based fuels are occasionally referred to as "hybrid fuels," however hybrid fuels have also been described as mixes of traditional diesel fuel and vegetable oils [7].

1.5 Transsterification

Transesterification, also known as alcoholysis, is the process of displacing alcohol from one ester by another, similar to hydrolysis but alcohol is utilized instead of water. This method has been frequently utilized to decrease triglycerides' high viscosity. Methanolysis refers to the use of methanol in this process. Transesterification is a reversible reaction that is carried out by mixing the reactants. The presence of a catalyst (a strong acid or basic) does, however, speed up the conversion. Catalysts used for the transesterification of triglycerides are classified as alkali, acid, enzyme or heterogeneous catalysts, among which alkali catalysts like sodium hydroxide, sodium methoxide, potassium hydroxide, potassium methoxide are more effective. If the oil has high free fatty acid content and more water, acid catalyzed transesterification is suitable. The acids could be sulfuric acid, phosphoric acid, hydrochloric acid or organic sulfonic acid. Although chemical transesterification using an alkaline catalysis process gives high conversion levels of triglycerides to their corresponding methyl esters in short reaction times, the reaction has several drawbacks: it is energy intensive, recovery of glycerol is difficult, the acidic or alkaline catalyst has to be removed from the product, alkaline waste water require treatment, and free fatty acid and water interfere the reaction. Lipases, for example, may efficiently catalyze the transesterification of triglycerides in both aqueous and non-aqueous environments, overcoming the difficulties stated above. The by-products, such as glycerol, may be simply eliminated without a complicated procedure, and free fatty acids in waste oils and fats can be fully converted to alkyl esters. A lipase catalyst, on the other hand, has a much higher manufacturing cost than an alkaline catalyst [8, 9].

2. Biodiesel feedstock

The following are the four primary kinds of biodiesel feedstock:

- 1) Edible vegetable oil: rapeseed, soybean, peanut, sunflower, palm and coconut oil.
- 2) Non-edible vegetable oil: jatropha, karanja, sea mango, algae and halophytes.
- 3) Waste or recycled oil.
- 4) Animal fats: tallow, yellow grease, chicken fat and by-products from fish oil.

When evaluating different feedstocks, it's critical to keep a few things in mind. A complete life-cycle study should be performed on each feedstock. This analysis considers the following factors: (1) land availability, (2) cultivation practices, (3) energy supply and balance, (4) greenhouse gas emissions, (5) pesticide injections, (6) soil erosion and fertility, (7) contribution to biodiversity value losses, (8) logistic costs (transport and storage), (9) direct economic value of feedstocks including co-products, (10) creation or maintenance of employment, (11) water requirements and water availability, (12) feedstock's impact on air quality[7,9,10,]. Nowadays, edible oils such as rapeseed (84%), sunflower oil (13%), palm oil (1%), soybean oil (1%), and others (2 percent) account for more than 95% of global biodiesel production [1,10,11]. Only a few researchs have been published on non-edible oils generated by wastelands/wild species such as *Pongamia pinnata*, *Jatropha curcas*, *Simarouba glauca*, and others. Although alkaline catalyzed transesterification is a potential area of study for biodiesel generation, it is one of the primary barriers for non-edible oils with high free fatty acid concentration. The use of heterogeneous catalysts in the transesterification of high FFA oil is a new field in the development of appropriate catalysts. Because ethanol is made from renewable biomass, ethanololysis is a key part of biodiesel synthesis. However, the yield of fatty acid ethyl esters is lower than that of methyl esters, and the separation of glycerol is one of the primary constraints in the ethanololysis process. This procedure can be made much better [9]. According to Y. Chisti, microalgae promises to be the only resource of biodiesel that has the ability to entirely replace fossil fuel. Microalgae, unlike other oil crops, develop incredibly quickly and many are particularly oil-rich. Within 24 hours, microalgae usually treble their biomass. During exponential growth, biomass doubling durations can be as low as 3.5 hours. Microalgae can have an oil concentration of up to 80% by weight of dry biomass. Oil concentrations of 20–50 percent are not uncommon. Oil productivity, or the amount of oil generated per unit volume of microalgal broth per day, is determined by algal growth rate and biomass oil content. Biodiesel production requires microalgae with high oil productivity [12].

3. Methods of oil extraction

The seed samples were characterized with moisture levels of 4 percent, 8 percent, and 12 percent, and various techniques of oil extraction were applied to them (on percent dry basis). The treatments were carried out in triplicate, with the results averaged. All of the tests were carried out at room temperature (210 Celsius). There are five extraction methods as below [13, 14]:

3.1 Mechanical screw pressing

A laboratory size manual screw press oil expeller (CaF2IR, Piteba, Netherlands) extracted flax seed oil in three passes. The oil press had a processing capacity of 5 kg/h. Three 50-g samples were produced for each moisture content; they were chilled for 24 hours at 5 °C before being reheated to room temperature under ambient conditions before extracting oil. To measure the average maximum temperature of three passes, a thermometer probe (MS-8221, Maplin Electronics Ltd, UK) was connected to the barrel of the oil expeller.

3.2 Organic solvent extraction method

Analytical grade ethanol (Fisher Scientific, UK) was used to extract oil using an organic solvent. A magnetic hot plate stirrer (CB-302 Stuart, Bibby Scientific Ltd, UK) was used to stir and heat the mixture. Before extracting oil, each 10-g flax seed sample was pulverized for 10 seconds in a coffee grinder (KSM 2, Braun, Germany). The settings were based on Sayyar et al optimum oil extraction technique. Each 10-g sample was soaked overnight in 60 mL of ethanol in a 1:6 (solid to solvent) ratio at room temperature (21 °C and 67 percent relative humidity) with three distinct moisture levels (4 percent, 8 percent, and 12 percent). On the hot plate magnetic stirrer with a reflux device, the entire mixture was stirred at 166 rpm and heated to the boiling point of ethanol (80 °C) for 8 hours. The solids were then allowed to settle for 12 hours. To separate the de-oiled cake from the miscella (oil and solvent mixture), the oil-solvent combination was filtered for 2 minutes with a vacuum filtering assembly (particle retention 1.0 m size, GF/B filter, 47 mm diameter, Whatman, England). The filter was connected to a 3.5-liter-per-minute pump (501S, Watson-Marlow Ltd, England). The oil and solvent combination was collected in a beaker and transported to a 15 L water bath (SBB Aqua 12 Plus, Grant Instruments Ltd., England) to evaporate the ethanol at 80 °C. The oil yield percent (w/w) was calculated after the solvent had evaporated [13, 14].

3.3 Microwave-assisted oil extraction

About 2.5 g powdered flax samples with moisture levels of 4%, 8%, and 12%, produced as previously reported, were combined with ethanol in a 1:3 g/mL (solid to solvent) ratio [14]. Prior to microwave treatment, a thermal paper was used to locate the oven's highest thermal radiation, and all samples were placed in that region for greatest consistency in experimental results. The liquid was placed in a 100-mL flask with a rubber stopper and a minute hole to relieve any excess pressure, then heated in a microwave oven (1025C, Merry Chef Ltd, UK) with an output microwave power and frequency of 1025 W and 2450 MHz, respectively, and operated at 50% power. The thermal treatment was meant to keep the sample temperature from becoming too high for too long. After each 10 s of microwave treatment, a temperature ranging from 55 to 60 °C was observed as measured with an infrared thermometer (RS-1327 K, RS Components Ltd, UK); after each 10 s of microwave treatment, stirring was observed; after each 10 s of microwave treatment, a temperature ranging from 55 to 60 °C was observed as measured with an infrared thermometer (RS-1327 K, RS Components Ltd, UK). The level of solvent in the flask was maintained after each treatment by adding ethanol; roughly 10 mL of ethanol was consumed each sample. For each sample, the total period of microwave treatment was 3 minutes (i.e. 18 10 s). The samples were allowed to settle for 12 hours after the microwave heat treatment. To recover the oil, the supernatant layer containing the oil solvent combination was pipetted from the solid de-oiled cake and evaporated in an 80 °C water bath to recover the oil, which was weighed [13].

3.4. Ultrasound-assisted oil extraction

Ultrasonic power was applied to powdered flax seeds with moisture content of 4 percent, 8 percent, and 12 percent in a 0.6 L bath (T-80, Langford Electronics Ltd, UK). Each 10 g flax seed sample was combined with 100 mL ethanol and placed in the bath for 3 minutes at room temperature at a frequency of 40 kHz. The temperature of the bath was monitored after each sample treatment, and the oil solvent combination was agitated for 1 hour at 250 rpm and allowed to settle for 12 hours before the upper layer was separated to collect the oil extract. The oil solvent combination in the supernatant layer was handled in the same way as previously reported in the MAE. The average power consumption of the rectangular bath was calculated using a power plug in meter (2000 MU, Maplin Electronics Ltd., UK) to compute the strength of the ultrasonic waves (W/cm²). The ratio of input power over the internal surface area of the bath was used to estimate the

intensity of the ultrasonic bath with a 327 cm² internal surface area in contact with the sample. 0.124 W/cm² was calculated as the highest intensity. The findings of this study have significant consequences for the soybean oil industry's future uses. Ultrasound has the potential to enhance productivity and decrease processing costs in the oil extraction process, according to this study. Because of its outstanding oil extraction performance: reduced cost and higher safety features, the hexane and isopropanol mixed solvent (60 percent:40 percent v/v) might possibly be used in soybean oil extraction. Future research will focus on determining the best combination of process parameters (ultrasound intensity, temperature, solvent, and so on) to enhance oil extraction efficiency [15]. According to recent research, ultrasound-assisted extraction can improve extraction efficiency by causing acoustic cavitation and mechanical effects. Acoustic cavitation can break down cell walls, making it easier for the solvent to enter the plant material and release the intracellular product. Another mechanical consequence of ultrasound is the agitation of the extraction solvent, which increases the contact surface area between the solvent and the targeted chemicals by allowing more solvent penetration into the sample matrix. As a result, the major benefits of ultrasound-assisted extraction include shorter extraction times and lower solvent usage [16].

3.5. Combined microwave and ultrasonic-assisted oil extraction

For oil extraction, each 5 g sample of powdered seeds with moisture levels of 4%, 8%, and 12% was exposed to a combined microwave and ultrasonic power treatment. The powdered seeds and ethanol were combined in a 1:3 g/mL ratio and microwaved for 3 minutes, as previously reported. During the treatment, 5 mL of ethanol was supplied to keep the solvent level in the conical flask constant. In all, 20 mL were eaten. After that, the sample was placed in an ultrasonic bath with 80 mL of ethanol and subjected to a 3-minute ultrasonic treatment (0.124 W/cm²). The samples were allowed to settle for 12 hours after the combined treatments.

After testing those five techniques, it was discovered that manual mechanical oil pressing was inefficient; this was due to the manual extraction at least in part, since there was some irregularity in the rotation rate and applied force. Organic solvents are time-consuming to use and, of course, need solvent. To rank the extraction processes, the total energy input needs and total energy output were also evaluated. When the energy efficiency calculations were performed, it was shown that microwave-assisted oil extraction has the highest oil extraction energy efficiency (25.21 percent) when compared to the other procedures. Ultimately, the total energy spent by the microwave-assisted technique for oil extraction showed higher feasibility in improving energy efficiency [13].

4. Purification of unrefined oil

To maintain quality requirements for the end product to be called biodiesel, a number of rules must be followed. Impurities in biodiesel must not be incorporated since they can harm engines by collecting in nozzles and producing incrustations that cause corrosivity. Impurities in the feedstock arise from unsaponifiable elements such as catalyst residues, water, glycerol, and excess alcohol from the process. Other molecules, such as polar compounds, dimers, mono and diacylglycerols, and FFA, will be present when biodiesel is made from WFO. To preserve the quality of biodiesel, these contaminants must be eliminated. Purification techniques for refining crude biodiesel may be categorized into the following categories based on the primary mechanism: (a) wet washing, (b) dry washing, (c) membrane extraction, (d) precipitation, (e) complexation, and (f) simultaneous biodiesel synthesis and purification [17, 18].

4.1 Wet washing

Distilled or acidulated water is used for wet washing (aqueous mineral acid solution). Before entering the wet washing stage, water is utilized at room temperature or as hot as possible, and the surplus alcohol is occasionally removed by distillation or evaporation. Purified ethyl esters of castor oil were compared by water washing at various temperatures and pH levels. When compared to other temperatures (20–90C) in the pH range of 1–7, the results at 30 and 70C with a pH of 2 and 7 indicated a substantial outcome. The benefits of wet washing include a very simple and effective method for purifying biodiesel, very effective removal of glycerol and methanol, and the ability to use aqueous acids. The disadvantages include requiring a large amount of water, drying of washed product is required to remove the trace amount of water, increasing energy costs, and requiring large surface area washing and settling tanks [19, 20].

4.2 Dry-washing

Dry-washing was introduced to replace water-washing with water-free purifying processes that are more ecologically friendly. Waterless washing agents like as adsorbents and acid resins are used to remove contaminants from crude biodiesel. After stirring for 20 minutes at 65°C, crude biodiesel was treated with 2 wt

percent magnesol, and the adsorbent was recovered by filtering. Water washing, on the other hand, had a greater biodiesel yield (96%) than because some biodiesel remained in the column after purification. Protons from the functional groups on the resin are swapped for calcium ions from calcium soaps, glyceroxide, methoxide, and hydroxide, which are thought to make up the leached catalyst. As a result, leached calcium is removed by absorption into cation exchange resin with its aid. The benefits of dry washing include no risk of water in the fuel, continuous operation, a reduction in total production time, and a significant reduction in wastewater. The drawbacks include ion exchange resins that do not remove methanol, the need for additional equipment, and slightly higher operating costs than water washing [21, 22].

4.3 Membrane extraction

Membrane-based separations are common in water purification and protein separation. These membrane technologies are already used widely to separate aqueous solutions, but membrane separation for the treatment of non-aqueous fluids is on the horizon. Organic or inorganic membranes can be used. The latter kind, particularly ceramic membranes, is better appropriate for use with organic solvents because of their chemical and thermal stabilities. Continuous crossflow rejection of triglycerides from fatty acid methylester combination using a ceramic membrane combined with liquid-liquid extraction. An oil emulsion's average pore size was found to be 44 m, with lower and higher limits of 12 m and 400 m, respectively. When compared to other membranes, tubular ceramic membrane and Ultrafiltration membrane are both more efficient and ecologically friendly in the purifying process. The benefits include high separation potential for sodium soaps and alcohols, operational simplicity and flexibility, low energy requirements, easy control and scale-up; the drawbacks include membrane cleaning, increased biodiesel production costs, and decreased throughput due to possible contaminations [23].

4.4 Precipitation

Precipitating agents are used to remove calcium ions from crude biodiesel in this purification procedure. When a precipitating agent, such as oxalic acid or citric acid, is added to calcium-containing crude biodiesel, an insoluble compound forms in the reaction mixture. Filtration or centrifugation can be used to remove the precipitated component from the pure biodiesel. The benefits include a high output of pure biodiesel, a reduced amount of water needed in the process, and easy filtering of the precipitate. The drawbacks include the fact that effective precipitation is dependent on operational parameters, and that further research is required to optimize precipitation circumstances [22].

4.5 Complexation

Individual atom groups, ions, or molecules are combined to form one big ion or molecule by complexation. To remove calcium ions, a complexing agent is employed in this technique for purifying crude biodiesel; thus far, only ethylenediaminetetraacetic acid (EDTA) has been utilized as the complexing agent for decalcifying crude biodiesel. In a 91:1 agent to calcium molar ratio, EDTA forms a compound with calcium ions. Calcium forms a soluble in water combination with EDTA, and calcium stays in solution without ionic interactions. Complexation has several drawbacks, including the difficulty of preparing an aqueous EDTA solution, a low decalcification efficiency, and the fact that EDTA is a toxic chemical [17].

III. CONCLUSION

As seen by the huge number of researchs on the subject, much efforts have been put into improving different elements of biodiesel manufacturing. Various governments have implemented laws and regulations aimed at establishing a sustainable biodiesel sector and ensuring long-term energy security.

The acid catalyzed transesterification process is the most cost efficient of the traditional methods for producing fuel quality biodiesel from cheaper feedstock with greater FFA concentration. Without the need for pretreatment of the feedstock, acid catalysts can catalyze both esterification and transesterification processes. Lower total production costs and a lower biodiesel breakeven price demonstrate this economic viability. Heterogeneous catalysts provide greater benefits than homogeneous catalysts in aspects of reusability, requiring fewer steps for product separation and purification, generating high quality glycerol, and allowing for simple catalyst recovery. Because of these benefits, heterogeneous catalysts are an excellent alternative for lowering biodiesel production unit costs. Again, among the heterogeneous catalysts, heterogeneous acid catalysts have the added benefit of being able to catalyze low-cost feedstocks with greater FFA concentration. Catalysts serve a critical role in accelerating biodiesel synthesis. In the esterification and transesterification processes, catalysts help to convert the crude material into usable biodiesel. The esterification and trans-

esterification processes may take longer without catalysts, which will raise the overall cost of biodiesel manufacturing. Catalysts increase the solubility of alcohol, which speeds up the process.

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