International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Comparative Study of Chemical and Enzymatic Processes for Biodiesel Production from Waste Cooking Oil

Hitesh Sharma[1], Soumya Srivastava[2]

School of Biosciences, Lovely Professional University, Phagwara, Punjab-144411

Abstract: ***Crude oil prices are reaching a new high and there is an acute need for developing alternate fuels which should be economically as well as biologically feasible. In this work, biodiesel was prepared from waste cooking oil collected from a restaurant named Kruncheez (ChanniHimmat, Jammu) by two methods- alkali transesterification and enzymatic transesterification. For alkali transesterification, Methyl alcohol with KOH and NaOH as a catalyst was used for the alkali transesterification process. Lipase enzyme from C. Antarctica was used for the enzymatic production. FT-IR was used for determination of fatty acid content in final biodiesel. The biodiesel was characterized by its physical and fuel properties according to ASTM standards and comparison of both the processes was drawn. The viscosity of the alkali and enzymatic biodiesel was found to be 4.65 and 4.72 cSt at 40°C. The viscosity of waste cooking oil measured at room temperature was 7.2 cSt. The flash point, pour point and cloud point of the alkali and enzymatic biodiesel was found to be 139°C and 131°C, 8°C and 9°C, and 13°C and 11°C, respectively. Acid value of the alkali and enzymatic biodiesel was found to be 0.351 and 0.459 mg-KOH/g.***

Keywords: Waste cooking oil, alternate fuel, biodiesel, Lipase, fuel characterization

1. Introduction

Every house hold across the world, every restaurant, hotel, shops etc. use cooking oil for one purpose or other. Earlier the vegetable oil was exploited for running the engines but there were certain constraints. Vegetable oils have a high viscosity and also competed with the food requirements across the world. So the scientists started exploiting vegetable oil to convert it into biodiesel which had a low viscosity. But the problem still prevailed for the food competency.That is why the idea of production of biodiesel from waste cooking oil came into existence. The advantages of using waste cooking oil is that it is a waste product so no competency for food. It is also pre-processed oil and after cooking more FFA content is reduced from it, so pretreatment methods are usually not required except only filtration.

Biodiesel refers to any diesel fuel which is derived from renewable biomass. More commonly,biodiesel is defined as oxygenated, sulfur-free, non-toxic, biodegradable and eco-friendlyalternative diesel oil. It can also be defined as a fuel composed of mono-alkyl esters of longchain fatty acids derived from renewable sources, like as vegetable oil, animal fat, and usedcooking oil designated as B100, and also it must meet the special requirements such as theASTM and the European standards. One of the most popular processes for producing biodiesel istrans-esterification. Biodiesel is made from a variety of natural oils such as neem, soapnuts, soybeans, rapeseeds, coconuts, and even recycled cooking oil [1].

In the 1930s and also in 1940s, vegetable oils were used as diesel substitutes from time to time,but most commonly in emergency situations. Recently, increasing in crude oil prices, limitedresources of fossil oil and environmental concerns, than there has been a renewed focus onvegetable oils and animal fats to make the biodiesel. The continuously use of petroleum willincrease local air pollution and magnify the global warming problems caused by the carbondioxide [2].

Biodiesel, an alternative diesel fuel, is made from renewable biological sources such as vegetableoils and animal fats. It is biodegradable and non-toxic. It also has low emission profiles and so isenvironmentally beneficial. Importance of biodiesel increases due to:-

1) Rising petroleum prices
2) Limited fossil fuel reserve and
3) Environmental benefits of biodiesel.

Advantages of Biodiesel

a) Biodiesel is the only alternative fuel with the property that low concentration biofuel–petroleum fuel blends will run well in unmodified conventional engines. It can also be storedanywhere petroleum diesel fuel is stored. Biodiesel can be made from domestically produced, renewable oil seed crops such as neem, soapnut and jatropha etc. Biodiesel is safe to handle and easy to transport because it is as biodegradable as sugar and has ahigh flash point compared to petroleum diesel fuel. Biodiesel can be used alone or mixed in anyratio with petroleum diesel [3].
b) Biodiesel mainly emits carbon monoxide, carbon dioxide, and oxides of nitrogen, sulfuroxides and smoke. Combustion of biodiesel alone provides over a 90% reduction in totalunburned hydrocarbons and a 75–90% reduction in polycyclic aromatic hydrocarbons[3].
c) Biodiesel is non-toxic and degrades about four timesfaster than petroleum diesel. Its oxygen content improves the biodegradation process and leadingto an increased level of quick biodegradation [3].

Disadvantages of Biodiesel

a) At present, Biodiesel fuel is about one and a half times more expensive than petro diesel fuel[4].

b) It requires energy to produce biodiesel fuel from soy crops plus, there is the energy of sowing,fertilizing and harvesting [4].
c) Another biodiesel fuel disadvantage is that it has higher viscosity, higher flash point and cloudpoint and higher nitrogen oxide (NO_x emissions) [4].

Different methods used for production of biodiesel

1) Direct use or Blending - Vegetable oil can be used directly as fuel without any changesin the engine. The very first engine by Rudolf Diesel was tested using vegetable oil as dieselfuel. The primary concern with vegetable oil as fuel is its high viscosity which leads to problemin long run as there are carbon deposits, coking and trumpet formation on injectors, thickening, gelling and oil ring sticking [5].

2) Micro emulsions – It is defined as colloidal dispersion of fluid micro-structures (1-150nm) in solvents forming two immiscible phases. The common solvent used is ethanol andmethanol. Micro emulsion is a probable solution to high viscosity of vegetable oil. Theiratomization is relatively easy due to lower viscosity [5].

3) Pyrolysis – It is the conversion of one substance to another by the application of the heat.It is a thermochemical decomposition of organic material at elevated temperatures in the absenceof oxygen. Pyrolysis of organic substances produces gases and liquid products and leaves a solidresidue richer in carbon content. The catalysts are used to speed up the process. Here, the yield ofoil is due to the fact that cracking of larger hydrocarbons cause them to break into simpler and smaller hydrocarbons by radicalic mechanism which are easily condensable to oil in this case [6].

4) Trans-esterification (alcoholysis) – Transesterification (also called alcoholysis) is thereaction of a fat or oil with an alcohol to form esters and glycerol. Transesterification is thedisplacement of alcohol from an ester by another in a process similar to hydrolysis, except thanalcohol is used instead of water. This process has been mostly used to reduce the high viscosity of triglycerides. Transesterification is one of the reversible reactions and proceeds essentially bymixing the reactants. However, the presence of a catalyst (a strong acid or base) will improve theconversion [7].

2. Literature Survey

Sulaimanet. *al.* (2011) designed a pilot plant to produce 1 ton h^{-1} biodiesel (BD) from waste/used vegetable oil using enzymatic approach. Complete material and energy balances were carried out using Excel spreadsheets, and detailed equipment sizing were determined. Immobilized lipase (Novozyme 435) is used as a catalyst in a packed bed bioreactor. The effluent of the reactor is passed though a Liquideliquid extractor to separate the BD from other components. This is followed by a flash dram and a vacuum distillation column for further purification of the product. In addition, an economic feasibility of this process was assessed. The amount of feed streams of waste oil, methanol and t-butanol required were found to be 1138, 130 and 7.6 kg h^{-1}, respectively. The main units in the proposed plant were designed and the economic feasibility of the process was assessed. It was found that the total capital investment required is about US$ 620,000, which will be paid back within four years of operation [8].

Srivathsan *et. al.* (2008) studied that the production of biodiesel by transesterification process employing alkali catalyst has been industrially accepted for its high conversion and reaction rates. Recently, enzymatic transesterification has attracted much attention for biodiesel production as it produces high purity product and enables easy separation from the byproduct, glycerol. But the cost of enzyme remains a barrier for its industrial implementation. In order to increase the cost effectiveness of the process, immobilization of enzyme in a suitable biomass support particle and that has resulted in considerable increase in efficiency. But the activity of immobilized enzyme is inhibited by methanol and glycerol which are present in the reacting mixture. The use of t-butanol as solvent, continuous removal of glycerol, stepwise addition of methanol are found to reduce the inhibitory effects thereby increasing the cost effectiveness of the process [9].

Fjerbaek *et. al.* (2009) studied that Biodiesel production is presently employed industrially onlyin a 20,000 tons/year pilot plant in China. This review presents a critical analysis of the current status of research in this area andaccentuates the main obstacles to the widespread use of enzymes for commercial biodieseltransesterification. Improved results for enzymatic catalysis are seen with respect to increasedyield, reaction time and stability, but the performance and price of the enzymes need furtheradvances for them to become attractive industrially for biodiesel production. Critical aspectssuch as mass transfer limitations, use of solvents and water activity are discussed together withprocess considerations and evaluation of possible reactor configurations, if industrial productionwith enzymes is to be carried out [10].

Zhang *et al.* (2003) developed four different continuous process flow sheets for biodiesel production from virgin vegetable oil or waste cooking oil under alkaline or acidic conditions on acommercial scale. Detailed operating conditions and equipment designs for each process wereobtained. A technological assessment of these four processes was carried out to evaluate theirtechnical benefits and limitations. Analysis showed that the alkali-catalyzed process using virginvegetable oil as the raw material required the fewest and smallest process equipment units but ata higher raw material cost than the other processes. The use of waste cooking oil to producebiodiesel reduced the raw material cost. The acid-catalyzed process using waste cooking oilproved to be technically feasible with less complexity than the alkali-catalyzed process usingwaste cooking oil, thereby making it a competitive alternative to commercial biodieselproduction by the alkali-catalyzed process [11].

Ghaly*et. al*. (2010) observed that the research on the production of biodiesel has increasedsignificantly in recent years because of the need for an alternative fuel which endows withbiodegradability, low toxicity and renewability. Plant oils, animal fats, microalgal oils and waste products such as animal rendering, fish processing waste and cooking oils have been employed as feed stocks for biodiesel production. In order to design an economically and environmentallysustainable biodiesel production process, a proper understanding of the factors affecting theprocess and

their relative importance is necessary. A comprehensive review of the literature onthe subject of biodiesel production was carried out. Traditionally biodiesel has been produced using either acid or base catalysts. The multi-step purification of end products, waste water treatment and energy demand of the conventional process has lead to search for alternativeoption for production of biodiesel. The use the enzyme lipase as a biocatalyst for the transesterification reaction step in biodiesel production has been extensively investigated. Lipaseis produced by all living organisms and can be used intracellularly or extracellularly. To date, themost popular microbes used for their lipases have been filamentous fungi and recombinantbacteria. A summary of lipases used in transesterification and their optimum operatingconditions is provided. In addition to the choice of lipase employed, factors which make thetransesterification process feasible and ready for commercialization are: enzyme modification,the selection of feedstock and alcohol, use of common solvents, pretreatment of the lipase,alcohol to oil molar ratio, water activity/content and reaction temperature. Optimization of theseparameters is necessary in order toreduce the cost of biodiesel production. Use of no/low costwaste materials as feed stocks will have double environmental benefits by reducing theenvironmental pollution potential of the wastes and producing an environmentally friendly fuel [12].

Royon *et. al*. (2007) studied the enzymatic production of biodiesel by methanolysis of cotton seed oil using immobilized *Candida antarctica* lipase as catalyst in *t*-butanol solvent. Methyl ester production and triacylglycerol disappearance were followed by HPLCchromatography. It was found, using a batch system, that enzyme inhibition caused byundissolved methanol was eliminated by adding *t*-butanol to the reaction medium, which alsogave a noticeable increase of reaction rate and ester yield. The eVect of *t*-butanol, methanol concentration and temperature on this system was determined. A methanolysis yield of 97% wasobserved after 24 h at 50 °C with a reaction mixture containing 32.5% *t*-butanol, 13.5%methanol, 54% oil and 0.017 g enzyme (g oil)¡1. With the same mixture, a 95% ester yield was obtained using a one-step Waxed bed continuous reactor with a Xow rate of 9.6ml h¡1 (genzyme)¡1. Experiments with the continuous reactor over 500 h did not show any appreciabledecrease in ester yields [13].

Chhetri*et. al*. (2008) observed the need for developing alternate fuels due to increase in crudeoil prices. Alternate fuels should be economically attractive in order to compete with currentlyused fossil fuels. In this work, biodiesel (ethyl ester) was prepared from waste cooking oilcollected from a local restaurant in Halifax, Nova Scotia, Canada. Ethyl alcohol with sodiumhydroxide as a catalyst was used for the transesterification process. The fatty acid composition ofthe final biodiesel esters was determined by gas chromatography. The biodiesel wascharacterized by its physical and fuel properties including density, viscosity, acid value, flashpoint, cloud point, pour point, cetane index, water and sediment content, total and free glycerin content, diglycerides and monoglycerides, phosphorus content and sulfur content according toASTM standards. The viscosity of the biodiesel ethyl ester was found to be 5.03 mm^2/sec at40°C. The viscosity of waste cooking oil measured in room temperature (at 21°C) was 72mm2/sec. From the tests, the flash point was found to be 164°C, the phosphorous content was 2ppm, those of calcium and magnesium were 1 ppm combined, water and sediment was 0 %,sulfur content was 2 ppm, total acid number was 0.29 mgKOH/g, cetane index was 61, cloudpoint was -1°C and pour point was -16°C. Production of biodiesel from waste cooking oils fordiesel substitute is particularly important because of the decreasing trend of economical oilreserves, environmental problems caused due to fossil fuel use and the high price of petroleumproducts in the international market [14].

Gerpen *et. al.* (2005) illustrated that biodiesel is an alternative diesel fuel that is produced fromvegetable oils and animal fats. It consists of the monoalkyl esters formed by a catalyzed reactionof the triglycerides in the oil or fat with a simple monohydric alcohol. The reaction conditions generally involve a trade-off between reaction time and temperature as reaction completeness isthe most critical fuel quality parameter. Much of the process complexity originates fromcontaminants in the feedstock, such as water and free fatty acids, or impurities in the finalproduct, such as methanol, free glycerol, and soap. Processes have been developed to produce biodiesel from high free fatty acid feed stocks, such as recycled restaurant grease, animal fats, and soap stock [15].

Yii-Der *et. al.* (2007) assessed and analysed the economic costs of three biodiesel plants withcapacities of 8000, 30,000 and 100 000 tons per year. The plants employ continuous processesusing the raw material of soybean oil and an alkali catalyst. Six major economic cost factorswere computed and examined. These include the fixed capital cost (FCC), total manufacturingcost (TMC), total capital investment cost (TCC), net annual profit after taxes (NNP), after-taxrate of return (ARR), and biodiesel break-even price (BBP). The net annual profit after taxes(NNP) and after-tax rate of return (ARR) of plants with capacities of 8000, 30 000, and 100 000tons year−1 are 24×10^3, 1975×10^3, and 8879×10^3U.S. dollars (USD), and 10.44, 40.23,and 67.38%, respectively. The values of BBP of the three plants are 862, 724, and 678 USD perton. The plant with a capacity of 100 000 tons per year is economically feasible, providing moreattractive ARR with a lower BBP and a higher NNP. Among the system variables of the plantcapacity, plants examined yields of glycerine and biodiesel and price of feedstock oil and dieselwere found to be the most significant variables affecting the economic viability of themanufacture of biodiesel. This study aims at the need to obtain useful information for economiccost analysis and assessment of the production process of biodiesel using soybean oil. Soybeanoil provides an appropriate indication for the promotion of biodiesel in the future; it is targeting the reduction of the cost of feedstock oil with the increase of the yields of valuable products witha reasonable plant capacity [16].

3. Aim and Objectives

Aim

This research involves the production of biodiesel by three processes (acidic, alkali andenzymatic) and comparison of yield and efficiencies of all processes with each other at differentphysical and chemical conditions.

Objectives

1) To produce biodiesel from waste cooking oil.
2) To determine the fuel properties of Biodiesel obtained from the waste cooking oil andcompare the values with standard.
3) To determine how the physico-chemical properties of biodiesel which affect the quality of thebiodiesel.

Research Methodology

The main goal of this study is to achieve the maximum conversion of biodiesel from the oilhaving high Free Fatty Acid (FFA) content by using a two-step catalyzed transesterificationmethod (acid method followed by alkali method) and enzymatic transesterification. For thisstudy, waste cooking oil was used as sample oil. Collection of the waste cooking oil sample hasbeen done from a restaurant in Jammu (Kruncheez).

Biodiesel Production

Transesterification Process

This process also called Alcoholysis. In this process, the displacement of alcohol from an esterby another alcohol in a process similar to hydrolysis. This process reduces the viscosity oftriglyceride of oils. Both the oils have high Free Fatty Acid content, therefore we are using atwo-step catalyzed Trans esterification method (Acid method followed by alkali method) [17].

1. Pretreatment method: With the help of this method, the high free fatty acid content ofoils is reduced below 3% by using acid pretreatment. It comprises the pre-heating of oilin water bath at 60 °C for 30 minutes and add acid catalyst mixture (10 ml Sulphuric acidmixed with 200 ml methanol/ liter oil samples) to pre-heated oil and proceed the setup onmagnetic stirrer with heating plate for 60 to 90 minutes at 60 ºC for 300 rpm. A molarratio of oil to alcohol (1:4, 1:5, 1:6) were considered for evaluating the better yields.After the reaction, the sample shows two distinct layers in which upper ester layer andlower glycerol layer. Once the upper layer gets separated, the glycerol is taken out as abyproduct and upper layer is further use for alkali catalyzed method [17].

2. Alkali or Base catalyzed method: The acid treated oil samples were heated and alkalicatalyst mixture (7.5 gram KOH with 200 ml Methanol/litre oil) was added. Keep this ona magnetic stirrer with heating plate for 60 to 90 minutes at 60 ºC for 300 rpm. A molarratio of oil to alcohol (1:4, 1:5, 1:6) were considered for evaluating the better yields. Theoil mixture was shaked and incubated on a magnetic stirrer hot plate at 60 ºC for 1-2hours. At last the oil samples show two distinct layers as that of acid catalyzed method.The top layer of oil sample was measured and it was saved for other purification process [17].

3. Enzyme based method: Lipase enzyme is used for this purpose. It can be performed byusing enzyme directly or in industrial processes by immobilization of enzyme and stepwise addition of alcohol. It was first of all reported by Shimada et. al. withimmobilization of *Candida* cells in an Ion exchange resin. It involves three step additionof mixture of oil:methanol at 1:1 mol/mol. Involves two step batch and three step flowreaction with reaction mixture of 1:3 mol/mol and after elution we get 90-93% of methylesters. The overall conversion of this process is approx. 97%. With this method, lipasecan be used for 100 days without loss in activity. Lipase enzyme can be directly used forproduction of biodiesel from waste cooking oil. 10 mg of Lipase enzyme can be used forthe production of biodiesel from 100 ml WCO at 35°C with mixing at 200 rpm for 48hours and the process efficiency is around 85-90% [8].

Purification of Product

After the trans-esterification process, the ester layer may contain small amount of unreactedcatalyst, methanol and glycerol. With the help of hot water treatment method, we can remove allthe impurities. This method is repeated for 4-6 times until the water layer becomes clear. Equalamount of hot distilled water is used to remove the impurities from the sample [17].

Drying of Product

After the purification step, the ester layer may contain some amount of methanol and water.Methanol has a tendency to lower the flash point and the water content is responsible for thegrowth of the biological organisms and they also increase the acid value of the fuel. So, the esterlayer is heated at 100°c for 15 to 30 min in the hot plate with stirrer to remove the water andmethanol from the biodiesel [17].

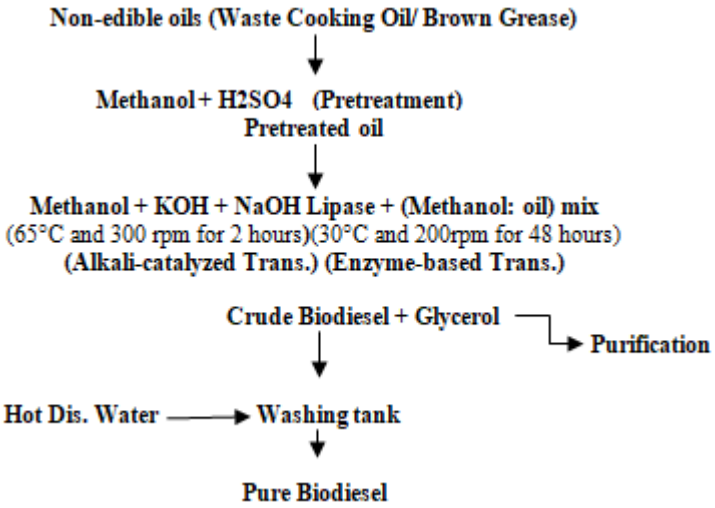

Figure 1: Flow chart of Biodiesel production from Waste cooking oil. [17]

Characterization of Oil

Following standards [13] were followed for characterization studies:

Table 1: Characterization standards used

S. No.	*Characteristic*	*ASTM standard used*
1.	Density	ASTM D-1298-(99)
2.	Specific Gravity	ASTM D-854
3.	pH	ASTM D-1293
4.	Saponification Value	ASTM D 5558-95
5.	Acid Value	ASTM D974
6.	Free Fatty Acid (FFA)	ASTM D-5555(95)
7.	Iodine Value	ASTM D-5768
8.	Pour Point	ASTM D-97
9.	Ash Content	ASTM D-483
10.	Kinematic Viscosity	ASTM D445-97
11.	Carbon Residue Content	ASTM D-664
12.	Cloud Point	ASTM D-2500
13.	Fire Point	ASTM D-93
14.	Flash Point	ASTM D-93

4. Results and Discussions

Yield results

With the help of previous research son biodiesel production, two methods were designed for the same. The production results of both the biodiesels are given below with comparative analysis:

Table 2: Maximum yield of alkali and enzymatic biodiesel with different molar ratio of oilto alcohol

Molar Ratioof Oil to Alcohol	*Maximum Yield (%) Beforewashing*		*Maximum Yield (%) Afterwashing*	
	AlkaliBiodiesel	*EnzymaticBiodiesel*	*AlkaliBiodiesel*	*EnzymaticBiodiesel*
1:4	71.12	-	Saponification taking place	-
1:5	75.43	-	Saponificationtaking place	-
1:6	83.31	79.20	71.98	66.91

Detection of biodiesel

The biodiesel product is analysed the peaks which is appeared in Fourier Transform Infrared Spectroscopy (FTIR) for alkali and enzymatic biodiesel with diesel fuel is shown in below the figures respectively. The information regarding the peaks for both alkali and enzymatic biodiesel sample are discussed in table.

Table 3: FTIR analysis of enzymatic biodiesel

Enzymatic Biodiesel Frequency	*Diesel Frequency*	*Bonds*	*Functional Groups*	*Type of Vibration*	*PeakIntensity*
721.43	723.33	C–H	Alkanes	Rock	Medium
1365.5	1375.29	C–H	Alkanes	Rock	Medium
1616.21	1649.19	–C=C–	Alkenes	Stretch	Medium
1759.74	1743.71	C=O	Esters, Saturated Aliphatic	Stretch	Strong
2862.46	2856.67	C–H	Alkanes	Stretch	Medium
2928.11	2924.18	C–H	Alkanes	Stretch	Medium

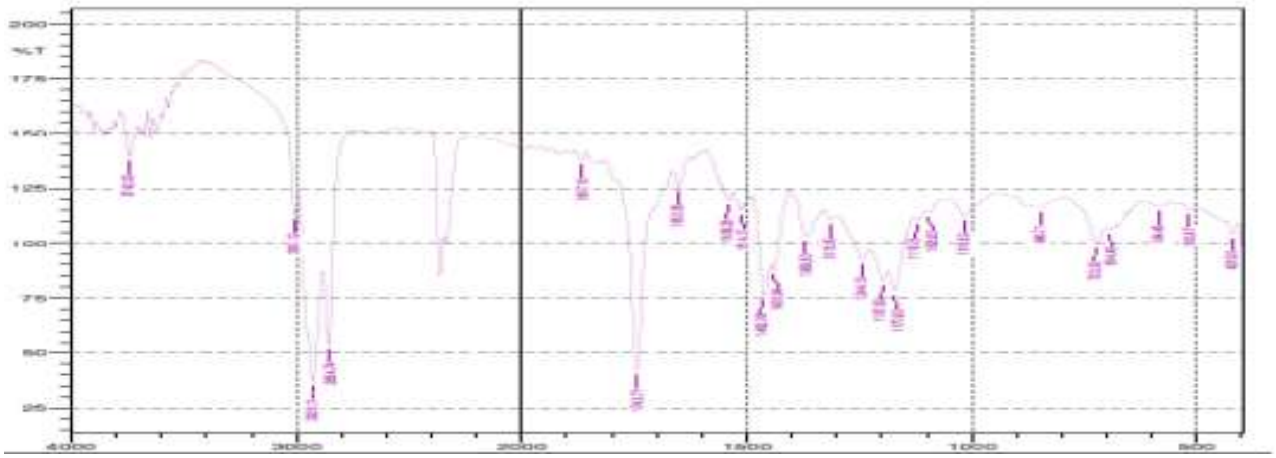

Figure 2: FTIR spectra for Enzymatic Biodiesel

Table 4: FTIR analysis of Alkali biodiesel

Alkali Biodiesel Frequency	*Diesel Frequency*	*Bonds*	*Functional Groups*	*Type of Vibration*	*PeakIntensity*
694.40	671.25	C≡C–H:C–H	Alkynes	Bend	Broad & Strong
723.33	723.33	C–H	Alkanes	Rock	Medium
1369.5	1375.29	C–H	Alkanes	Rock	Medium
1462.09	1460.16	C–H	Alkanes	Bend	Medium
1616.21	1649.19	–C=C–	Alkenes	Stretch	Medium
1759.74	1743.71	C=O	Esters, Saturated Aliphatic	Stretch	Strong
2862.46	2856.67	C–H	Alkanes	Stretch	Medium
2928.11	2924.18	C–H	Alkanes	Stretch	Medium

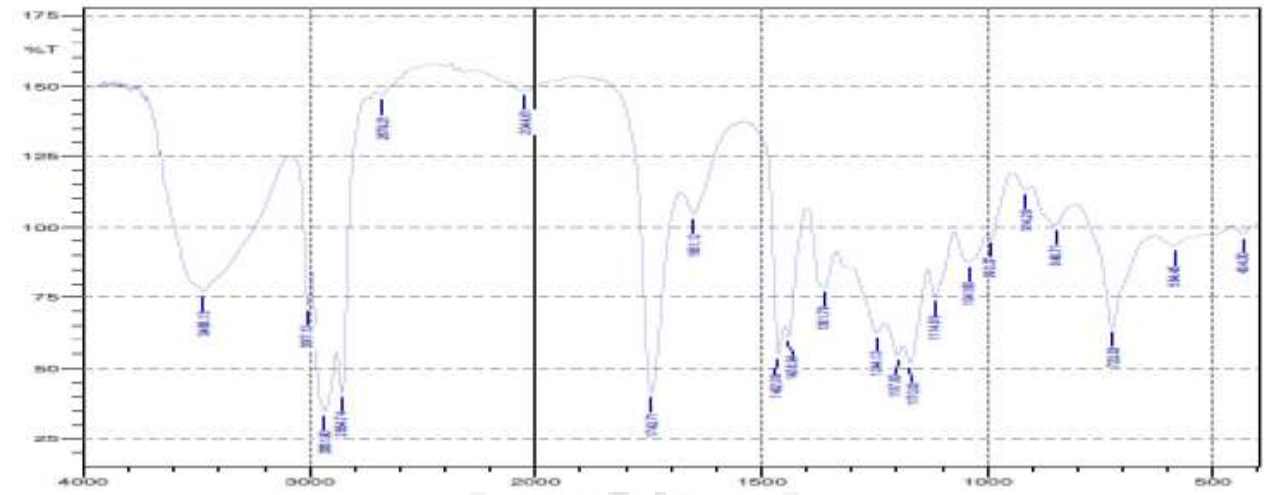

Figure 3: FTIR spectra for Alkali Biodiesel

Physico-chemical properties

The determination of physical and chemical properties was done using various ASTM standard methods. The following table shows the characterization of biodiesel produced from both methods:

Table 5: Physiochemical properties of Alkali and Enzymatic Biodiesel

S. No.	*Physico-chemical Properties*	*Enzyme-based Biodiesel*	*Alkali-basedBiodiesel*	*BiodieselStandards(ASTM)*
1	Density at 40°C(Kg/m3)	898.9	891	920
2	Specific Gravity at 40°C(g/cm3)	0.879	0.873	0.860 – 0.900
3	Saponification Value(mg KOH/g)	191.8	172.5	191 – 202
4	Acid Value(mg KOH/g)	0.459	0.351	0. 80 (max)
5	Free Fatty Acid(mg KOH/g)	0.2295	0.1755	----
6	Iodine Value(g I_2/g)	86.54	74.36	82 – 98
7	Carbon Residue Content(wt %)	0.0426	0.0403	(0.050 max)
8	Kinematic Viscosity at 40°C(cSt)	4.72	4.65	1.9 – 6.0
9	Cloud Point(°C)	11	13	-3 to 12
10	Pour Point(°C)	9	8	-15 to 10
11	Fire Point(°C)	184	195	----
12	Flash Point(°C)	131	139	130 (min)

13	Ash Content(wt %)	0.03811	0.03227	0.02 (max)
14	pH	7.2	7.1	7

In the production step, biodiesel production was done. The yield obtained from both the processes was high but comparatively alkali process yielded high content of biodiesel than that of the enzymatic process. Before purification, the yield obtained in alkali process was 83.31% whereas the yield obtained in enzymatic process was 79.20%. After purification, the yield obtained *i.e.* Pure Biodiesel was 71.98% from alkali process and 66.91% from enzymatic process. The results stated above clearly show that the alkali-based transesterification is more efficient in production of biodiesel than the enzyme-based transesterification. In the characterization step, both the biodiesel samples were characterized for different parameters. The characterization study clearly reveals that the biodiesel produced from alkali process is more suitable for usage in biodiesel-based engines than that of the enzymatic process due to high FFA content in the enzymatic biodiesel. This high FFA content results in viscous nature of biodiesel which leads to serious problems in a diesel engine. With respect to the other parameters like pour point, flash point, saponification value etc., the biodiesel produced from alkali process is more suitable for usage in biodiesel-based engines than that of the enzymatic process. Pour point and flash point of alkali biodiesel is high than the enzymatic biodiesel whereas the saponification value of alkali biodiesel is less than that of enzymatic biodiesel which clearly signifies the higher efficiency of alkali biodiesel. Also other parameters determined by physicochemical characteristics also state clearly that the biodiesel produced from WCO by alkali method is better than that of the enzymatic method. Flow characteristics of alkali biodiesel are also better than the enzymatic one as the kinematic viscosity as well as the density of alkali biodiesel is less than that of enzymatic biodiesel.

Performing transesterification on this form of waste cooking oil is a challenging job but still the results obtained were quite promising. These results show that the brown grease can be a potential source for the production of biodiesel even on an industrial scale.

5. Conclusion

Today, the cost of biodiesel is two to three times greater than the fossil fuels because the maximum part of cost of biodiesel production is depend on the cost of feed stocks. The competition of biodiesel depends on the cost of feed stocks and its conversion technology. From the results obtained by the production and characterization of the biodiesel produced by alkali-based and enzyme-based transesterification of waste cooking oil, we conclude that both the technologies were efficient in production of biodiesel. The raw material we used was a novel raw material *i.e.* Brown grease, which is such form of cooking oil that has been obtained after continuous usage and after some time it becomes non-edible. This oil is very viscous in nature and if directly used in a motor engine, can cause serious damages to the engine. The main advantage of using brown grease is that it is a waste material so no raw material cost is there and also no Food v/s Fuel issues.

The characterization study of the biodiesel for both the processes was done and the results obtained clearly justify that the biodiesel produced by alkali-based transesterification is better than that of the enzyme-based method. Industrially, enzyme-based transesterification has two main advantages:

1) The main advantage which was there in enzymatic biodiesel is that the production of waste water is minimal. This leads to less purification cost than the alkali biodiesel.
2) Enzyme-based method possesses a quality, which attracts the industrial scale production, it is a one-step reaction process as it doesn't require any pretreatment method. This can lead to cost reduction of the process.

But the biggest hurdle that is associated with enzymatic method utilization at industrial scale is the production of Lipase enzyme which is expensive, thus increasing the cost of production. So, certain organizations are using immobilization of lipase enzyme or whole cell immobilization technique. With this technology, lipase enzyme can be used for more than 15-20 cycles, thus reducing the cost of catalyst for repeated production of biodiesel. Biodiesel from various sources is an emerging alternative for fossil fuels. Various research organizations and researchers are currently working on developing an efficient technology for production as well as designing such a diesel engine which can run on fossil fuel as well as biodiesel. As the viscosity of biodiesel is high, so it requires modification in the engine such that viscosity can be reduced. Glycerol is a byproduct of biodiesel industries that is produced in a higher amount during the biodiesel production from the oils. According to literature, if 100 Kg of biodiesel produced with the help of transesterification process of oils than 10 Kg crude glycerol is also generated. Generally, glycerol is a low price byproduct which can be used for the production of value added products like hydrogen, poly-glycerol, acrolein and liquid chemicals. The production of these products may help to decrease the price of biodiesel and also improve the market of glycerol. For the development of economy of biodiesel, it is important to ensure the higher price for the byproducts of biodiesel.

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Author Profile

Hitesh Sharma, is the corresponding author. He is resident of Jammu, J&K. Presently working as a Senior research fellow at CSIR-IIIM, Jammu. He completed B.Tech. in Industrial Biotechnology from Shri Mata Vaishno Devi University, Katra in 2012 and M.Tech. in Biotechnology from Lovely Professional University, Punjab in 2014. He qualified GATE in 2014 with an AIR 252. His interest is in renewable energy and want to pursue a career in same. The shown research work has been done as his Master's project. He is currently working in fermentation technology and enzymology.

Saumya Srivastava, working as an Assistant professor at Lovely Professional University, Punjab. She is project supervisor for M.Tech. degree. She has done her M.Tech. Biotechnology from Integral University, Lucknow. A young and very energetic supervisor, always looking out for answers for every question. She has motivated her scholars to research in this field.