

**SYNOPSIS
FOR**

**Study on Biodiesel Production from Used Vegetable
Oil and Raw Vegetable Oils**

**THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY (ENGINEERING)**

BY

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1. Introduction

Petroleum oil consumption is well recognised to have the second highest proportion of all energy resources because to its usage in transportation (land, air, and sea), power plants, building, and industrial operations. According to Kalam et al., 2011, the consumption of diesel fuel is larger than that of other petrol products due to the superior efficiency of diesel engines over other internal combustion engines. As a result, several research attempted to replace fossil diesel fuels with renewable fuels. At the World Exhibition in 1900, Rudolf Diesel displayed a diesel engine powered entirely by peanut oil as verified in a study by Lin et al., 2010. Moreover, the rising concerns over the deterioration of the environment have forced researchers to think of an alternative with properties comparable to that of diesel and an alternative source that is renewable, energy efficient as well as environment-friendly as discussed by Elkelawy, et al., 2020. The study carried out by Rajkumar and Thangaraja, 2019 tells that the transportation sector is the second highest energy-consuming sector in our country. The major concerns are the emission of oxides of nitrogen and smoke which are detrimental to our health and environment. According to Workman, 2022 the third largest crude oil importer in the world is India. The Economic Times, 2022 shared the fact that India had spent USD 119.2 billion on the import of crude oil in the financial year (2021-2022) which turns out to be a huge burden on the economy of our nation. The burning of crude oil contributes to air pollution and global warming as well.

2. Aims and Objectives

The research concerns biodiesel production from used vegetable oil collected from different sources. The collection of oil is from different sources the type of oil does not remain constant. Since the yield depends upon the type of oil used, each transesterification is carried out with only one kind of oil without any mix. This research aims at the production of biodiesel from used vegetable oils and raw oils of different kinds by a very simple and economic process that can be scaled up for large-scale production. In order to achieve this, optimization of the process parameters becomes one of the crucial steps. Apart from the optimization by trial-and-error procedure, a statistical approach can also be adapted to study the interactive effect of the operating parameters on the yield of biodiesel. Depending upon the kind of oil, the yield, as well as the reaction parameters, will differ. Structural analysis of biodiesel has to be done in order to derive its correlation with the physicochemical properties

of biodiesel. The constituents of fatty acid alkyl ester can be determined by gas chromatography.

Another interesting approach can be taken to decrease the cost of production of biodiesel. The ambient temperature of the tropical region enables to provide sufficient temperature for the transesterification process. This can be investigated in detail by discussing the ‘with heat’ and ‘without heat’ conditions. The properties of biodiesel can also be further investigated to determine its closeness to the standard properties. The engine performance of a compression ignition (CI) engine can be evaluated with blended samples of biodiesel from different kinds of feedstock. The aims and objectives of the study are as follows.

- **Biodiesel production from different types of used vegetable oils and raw vegetable oils(non-edible).**
- **To optimise the yield of biodiesel by changing the operating parameters within the given range.**
- **Optimisation of process parameters of biodiesel production from used vegetable oils by response surface methodology.**
- **To study the performance of a diesel engine fuelled with biodiesel blends produced from different used vegetable oils blended with diesel.**
- **Comparison of the yield and properties of biodiesel from used vegetable oil of different plant-based feedstock.**
- **Feasibility of biodiesel production from different used vegetable oils under ambient temperature conditions.**
- **Comparative study of the differences in the components of the fatty acid alkyl ester from each kind of source in with-heat and without-heat conditions by performing gas chromatography of each sample.**

3. Chapter 3

The following steps have been followed to produce biodiesel from used vegetable oil and raw oils in the chemical laboratory of the Department of School of Energy Studies, Jadavpur University, Kolkata.

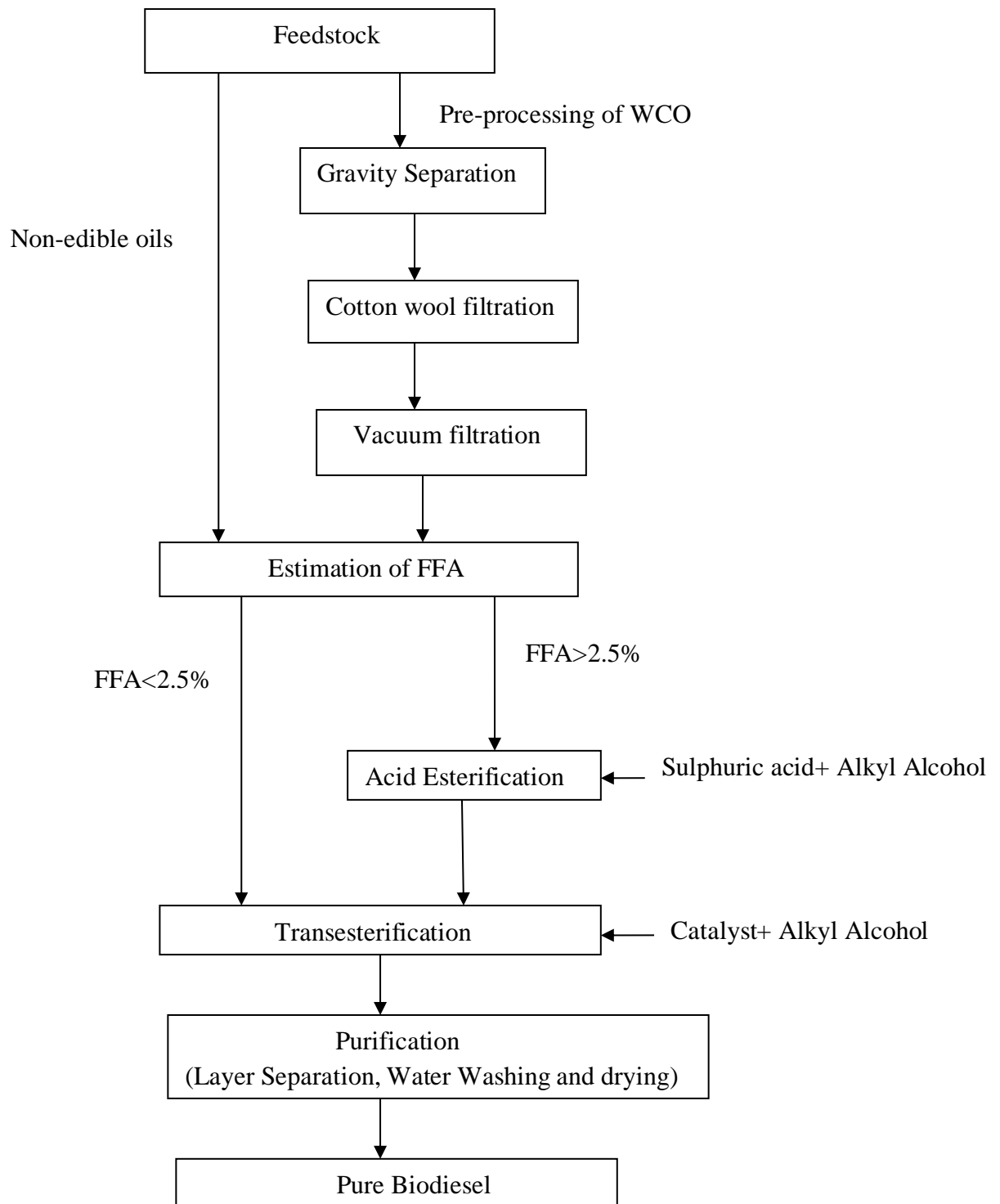


Fig. 1 Steps of biodiesel Production

The estimation of properties like density, flash point, fire point, viscosity and calorific value are required to know the feasibility of the use of the biodiesel produced in diesel engines.

The production of biodiesel involves a series of steps. The steps are uniform for any given set of parameters of biodiesel production. All the materials required during the process have been mentioned here. The formulae required at different stages will be used to calculate the required quantities. The equations derived in this section can be used throughout this study. The various instruments used for the calculation of various properties of biodiesel have also been discussed here. The generalised formulae have been mentioned here. They can be directly applied wherever required.

The methodologies which have been discussed here have been repeatedly used in the chapters. In order to prevent repetition of concepts, the generalised concepts have been mentioned here and they can be referred in the rest of the chapters.

4. Chapter 4

The present study helps to determine whether the collection of oils from various identified and non-identified sources from the streets of Kolkata can produce biodiesel or not. The mixture of oil from unknown sources will show the properties of biodiesel with reasonable productivity. But parameters giving optimum yield have to be regulated. Therefore, used oil of one kind has been adopted to study the optimisation along with other non-edible oils in the later part of this chapter. Oils of a single kind have been collected from fixed sources as well, in order to verify the properties and the cost of production. The study in this chapter helps to determine whether the collection of oils from various identified and non-identified sources from the streets of Kolkata can lead to the production of biodiesel or not. It includes the comparison of the properties of biodiesel from used oils from different known and unknown sources and non-edible oils. Mostly palm oil and soybean oil are used in the market. But since palm oil can cause health-related issues, many shops are reluctant in sharing the source oil used. Hence, without knowing or having proof of the source, it cannot be used for further investigation. The used vegetable oil of one kind was readily available and was collected from Jadavpur University Guest House, Kolkata, 700132, West Bengal.

Objectives of the Present Chapter

- **Biodiesel production from used vegetable oil (mixed).**
- **Biodiesel production from linseed oil (raw).**
- **Biodiesel production from mahua oil (raw).**
- **Biodiesel production from used vegetable oil (soybean).**

- **Optimisation of the biodiesel produced from used vegetable oils and raw vegetable oils.**

Table 1. Optimised properties of biodiesel prepared from different types of feedstock and their yields

Oil	Density (kg/m ³)	Viscosity (m ² /sec)*10 ⁻⁶	Yield (%)
Used vegetable oil (mixed)	870	5.90	86
Linseed oil (raw)	872	5.90	90
Mahua oil (raw)	880	6.10	92
Used vegetable oil (soybean)	850	5.11	97

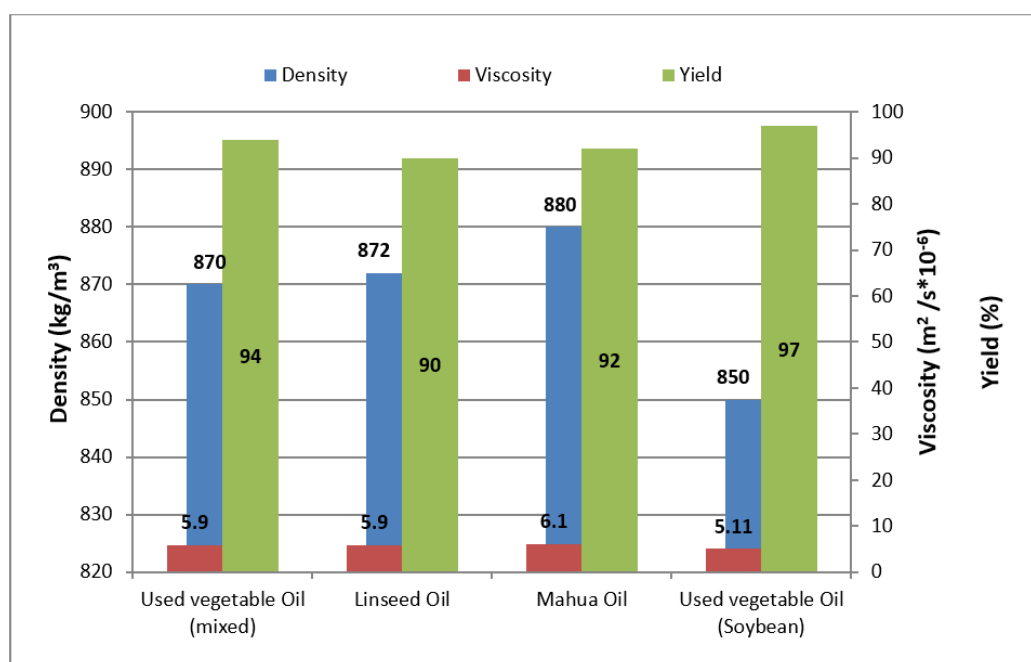


Fig. 2 Comparison of properties of biodiesel produced from used vegetable oil (mixed), linseed oil, mahua oil, used vegetable oil (soybean oil)

It can be very well observed that the density and viscosity are the least and yield is the highest in case of biodiesel from used vegetable oil (soybean). Therefore, it can be concluded that, out of all the raw oils and mixed oils, the biodiesel from used oil (soybean) has given the optimum yield and has shown impressive results in terms of physicochemical properties.

Used vegetable oil collected from shops selling fritters can be used to produce biodiesel as it is not a food source and is mostly thrown away. The collection of oil has to be streamlined for the procurement of oil. The optimised yield has to be obtained for in order to decrease the cost of production. The optimised yield of biodiesel prepared from used vegetable oil (soybean) obtained is 96% - 97%.

5. Chapter 5

According to Kumari and Gupta, 2019, a collection of statistical and mathematical tools called the response surface methodology (RSM), which is based on the design of experiments, are used to plan trials and optimise the impact of process factors. RSM recognises the influence of process factors on the removal process and minimises the number of trials.

Objectives of the Present Chapter

- **Prediction of the optimum level of the process parameters**
- **Study of the interactive effects of the operating parameters on the yield**
- **Selection of the optimum parameters for optimum yield based on statistical analysis**
- **Determination of the properties of the optimum biodiesel sample**

The main objective of the present chapter is to compare the experimental yield with the predicted yield obtained via statistical analysis. This optimization has been done using RSM. In the design matrix, the operating parameters are varied in different ranges at three levels in order to find the optimized yield of the product.

The experimental runs to be performed in the laboratory was obtained from the BBD design. A mathematical model following a second-order polynomial equation (5.1) was used to generate the predicted response as reported by Hamze et al., 2015.

The general form of full quadratic model is mentioned below:

$$\mu = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j \quad \text{-----(1)}$$

where the volumetric yield of biodiesel produced from used vegetable oil(soybean) is μ , β_0 represents the offset term, β_i represents the linear effect, β_{ii} represents the squared effect, β_{ij} represents the interaction effect, X_i is the i th independent variable and X_j is the j th independent variable.

Table 2. Experimental design for the optimization of process parameters of biodiesel production from used vegetable oil(soybean). (Minitab Software Version 17.0)

Experimental Run	Temperature (T)	Catalyst Concentration (C)	Molar ratio (M)	Experimental Yield(%v)	Predicted Yield(%v)
1	60.0(1)	1.0(0)	9(1)	89.0	90.181
2	60.0(1)	0.5(-1)	6(0)	83.0	80.108
3	25.0(-1)	1.0(0)	9(1)	65.7	62.142
4	42.5(0)	1.5(1)	3(-1)	72.5	70.842
5	42.5(0)	0.5(-1)	3(-1)	63.0	62.335
6	42.5(0)	1.5(1)	9(1)	86.7	87.180
7	42.5(0)	1.0(0)	6(0)	87.4	87.577
8	42.5(0)	1.0(0)	6(0)	87.6	87.577
9	25.0(-1)	0.5(-1)	6(0)	47.6	49.420
10	42.5(0)	1.0(0)	6(0)	88.0	87.577
11	25.0(-1)	1.0(0)	3(-1)	56.3	54.942
12	25.0(-1)	1.5(1)	6(0)	67.0	69.715
13	42.5(0)	0.5(-1)	9(1)	71.0	72.493
14	60.0(1)	1.0(0)	3(-1)	67.5	70.885
15	60.0(1)	1.5(1)	6(0)	85.0	83.008

The study of this chapter has been conducted to minimise the cost of production and obtain the best-fit data for obtaining the optimised yield. The main focus of the study in this chapter is to verify the yield obtained statistically and study the interactive effects of the process variables which ultimately decide the yield for each set of parameters. According, to the ANOVA results catalyst concentration and temperature are the most effective factors regarding biodiesel production. RSM based on Box Benken Design was used to obtain the optimum conditions for optimised yield. The optimised yield of 93.408% was obtained at the temperature of 52^oC, catalyst concentration of 1.157% w/w of oil and molar ratio of 7.7:1. Here the molar ratio is lesser than that of Chapter 4 for biodiesel from used vegetable oil(soybean). The properties of the feedstock are responsible here for the amount of each parameter required for the optimised yield. As discussed, the feedstock used for the study in this chapter had a greater percentage of impurities. This affects the percentage yield of biodiesel. With the change in the sample of feedstock, the yield gets affected. The properties and chemical analysis of biodiesel give a detailed idea about the nature of the oil that has been produced. The properties fall within the standard ranges mentioned; hence it qualifies for commercial use in engines in blended form.

6. Chapter 6

It has been confirmed in Chapter 4 that when compared to non-edible oils, used soyabean oil gives an appreciable yield in comparison to non-edible oils. This chapter deals with the study of CI engine performance with biodiesel from used soyabean oil, used rice bran oil, and used sunflower oil as discussed in Chapter 4.

Objectives of the Present Chapter

- **Study of engine performance when run on diesel blended with biodiesel produced from used soybean oil.**
- **Study of engine performance when run on diesel blended with biodiesel produced from used sunflower oil.**
- **Study of engine performance when run on diesel blended with biodiesel produced from used rice bran oil.**

Table 3. Physicochemical properties of biodiesels produced from different types of used vegetable oils and diesel

Parameters	Diesel	USOME	URBME	USUME
Density at 15°C (kg/m ³)	839.0	868.80	886.1	873.7
Viscosity at 40°C (mm ² /sec)	2.91	3.910	4.281	4.317
Flash Point (°C)	76	164	180	172
Calorific Value (MJ/Kg)	43.98	38.7	39.20	38.4

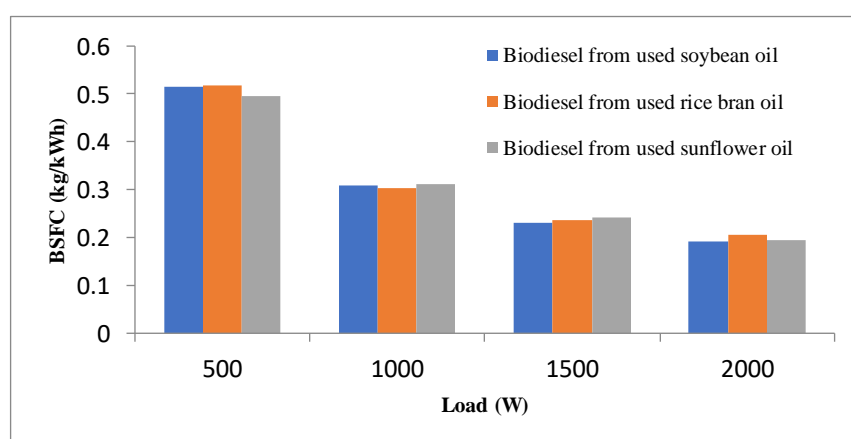


Fig. 3. Comparison of BSFC vs Load for B20 blend of the three different biodiesels

For all three types of biodiesel blended fuels, the BSFCs are higher than that of diesel under all loading conditions and are higher than diesel for all the blends at a given load. It was observed that BSFC reduces with an increase in engine load. As the load of the engine increases, the efficiency and combustion quality of the engine also increases.

7. Chapter 7

In the study of this chapter biodiesel from each used vegetable oil has been produced with and without the application of heat during the process of transesterification keeping the process parameters the same.

Objectives of the Present Chapter

- **Qualitative analysis of biodiesel produced from used vegetable oil (soybean) by the method of gas chromatography with and without application of heat.**
- **Qualitative analysis of biodiesel produced from used vegetable oil (rice bran) by the method of gas chromatography with and without application of heat.**
- **Qualitative analysis of biodiesel produced from used vegetable oil (sunflower) by the method of gas chromatography with and without application of heat.**
- **Comparison of the properties of the biodiesel produced from different types of vegetable oils based on the percentage of saturation and unsaturation of the fatty acid methyl esters.**
- **Justification for the biodiesel produced under ambient temperature conditions from used vegetable oil (soybean).**
- **Comparison of the fuel properties of biodiesel produced from fresh vegetable oils and used vegetable oils.**

The data here shows that the viscosity of soybean oil methyl ester is the lowest even when without heat data is considered. The others have viscosity a little higher than that of SOME. The flash point of SOME is 154⁰C and under without heat condition is 159⁰C, which is the lowest when compared to the flash points of other samples of biodiesel. The fire point also shows the same trend. But the calorific value of URBME under with heat and without heat conditions is the highest. The properties of the biodiesel as discussed by Sinha et al., show that out of all the oils, the biodiesel from soybean oil gives the best result, but the biodiesel from two other oils which are sunflower oil and rice bran oil shows fuel properties that ensures their use as biodiesel in the diesel engines as well.

Table 4. Fuel properties of biodiesel

Property	Biodiesel produced in this study from used vegetable oil						Biodiesel produced from fresh vegetable oil (Sinha et al., 2008)		
	Used SOME	Used RBME	Used SUME	Used SOME	Used RBME	Used SUME	SOME	SUME	RBME
	with heat	with heat	with heat	without heat	without heat	without heat			
Density kg/m ³ (30°C)	.868	.886	.873	.875	.879	.878	.884	.880	.877
Viscosity cSt (40°C)	3.91	4.317	4.281	3.767	4.310	4.410	4.08	4.2	5.29
Flash Point (°C)	154	178	170	159	180	172	141	164	183
Fire Point (°C)	170	186	182	175	198	192	171	183	196
Calorific Value (MJ/Kg)	38.7	39.20	38.40	38.49	39.05	38.00	39.8	40.1	42.2

8. Chapter 8

This chapter discusses the conclusions of all the chapters. This chapter contains the schematic diagram of proposed industrial set up of biodiesel production from used vegetable oil under ambient temperature conditions.

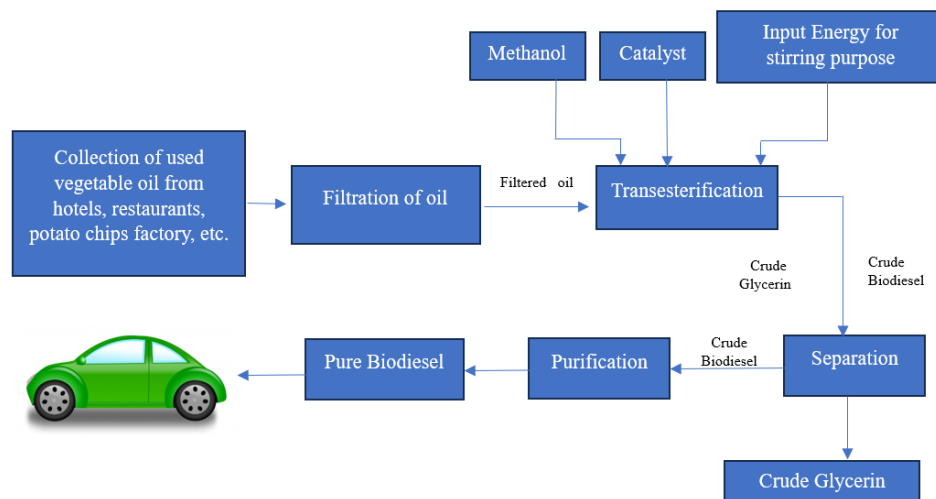


Fig. 4 Proposed biodiesel production from used vegetable oil at ambient temperature without application of heat

Nomenclature

CI: Compression Engine

RSM: Response Surface Methodology

ANOVA: Analysis of Variance

SOME: Soybean Oil Methyl Ester

SUME: Sunflower Oil Methyl Ester

RBME: Rice Bran Oil Methyl Ester

USOME: Used Soybean Oil Methyl Ester

USUME: Used Sunflower Oil Methyl Ester

URBME: Used Rice Bran Oil Methyl Ester

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2. Name, Designation & Institution of Supervisor:

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3. List of Publications:

Peer-Reviewed / UGC approved Journals

- i) **Waste To Energy Conversion Through Biodiesel Production From Waste Cooking Oil and Its Optimisation**, Indian Journal of Env. Protection; 2021; 41(5); 503-512
- ii) **Optimisation of process parameters of Biodiesel Production from different kinds of feedstock**, Materials Today Proceedings; 2018; 5(11); 23043-23050
- iii) **Biodiesel Production form Used Vegetable Oil Collected From Shops Selling Fritters in Kolkata**, Energy Procedia; 2014; 54; 161-165

Book Chapter

- i) **An Evaluation of Engine Performance of a Compression Ignition Engine with Biodiesel Produced from Different Kinds of Feedstock**, 2021. Advances in Water Resources Management for Sustainable Use. Lecture Notes in Civil Engineering. 131, 469-480

4. List of Patents: Nil

5. List of Presentations in National / International Conferences:

- i) **An Evaluation of Engine Performance of a Compression Ignition Engine with Biodiesel Produced from Different Kinds of Feedstock**, International Conference on Sustainable Water Resources Management Under Changed Climate 2020, March 13-15, 2020, Jadavpur University, Kolkata

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