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Biodiesel Production & Performance Analysis on CI Engines – A Review

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ABSTRACT

The energy needs of the world have been increasing since the inception of the Industrial revolution. The major sources of energy throughout the world have been fossil fuels, namely coal, petroleum fuels and natural gas. These resources are limited and are depleting fast. The replenishment of these is not possible keeping in mind our enormous requirements of energy, as these are non-renewable. Hence, there is a need of energy sources which are renewable, economic and do not pose a major threat to the environment. Biodiesel fuels have emerged as an option that is renewable and economic. These fuels are used as blends with diesel and can be used to power CI engines. There is a large quantity of used cooking oil that is produced from household, restaurants, etc which is disposed off with no option of reuse. This type of waste oil is available in large quantities and at an economic rate. Thus, if used to create biodiesel, these types of oils can solve two problems – it will give us an economic option of alternative energy resource that is easily available, and will help control environmental pollution that is caused by disposal of these waste oils on land and water resulting in destruction of flora and fauna. In this present review work, we have studied various works done in the field of biodiesel production from various sources and method by researchers around the world. This review work focuses primarily on two aspects: study of biodiesel production by various processes with special focus on trans-esterification process and study of performance/emission characteristics of VCR engines using different blends of biodiesel with normal diesel.

Keywords: *Diesel Engine, Biodiesel, Transesterification*

INTRODUCTION

In the last few decades, we have realised that the conventional fuels like petroleum are declining with such a rapid rate that experts suggest they are not going to last long. This creates a need for alternative energy resources like biodiesel. Biodiesel has a wide scope of being used as a fuel in Compression Ignition engines. Biodiesel blends with diesel fuel can burn and produce the required energy along with controlled pollutants. Biodiesel is mainly produced by vegetable oils like mustard, rapeseed, linseed, soya bean, etc. Many developed countries have started using biofuels as an alternative to conventional fuels as they resolve the crucial problem of fast depleting conventional resources and are also economical. [1]

Emissions analysis of biodiesel fuels has shown that upon burning, biodiesel fuels produce low carbon monoxide and have almost no sulphur. They also have a large amount of oxygen resulting in complete combustion within the CI engines. In India, various studies have been carried out and it has been suggested to use not edible oils for biodiesel production. Jatropha oil is the major source of biodiesel production in India, USA uses Soya Bean and Mustard while European countries make use of Rape seed oil and Sunflower oil. [2] [3]

Various methods of Biodiesel production are being used for different types of vegetable oils namely pyrolysis, transesterification, interesterification, saponification and hydrolysis. These processes are studied and implemented on specific oils based on the characteristics of the compounds present in these oils. In India there is a lot of scope of using waste cooking oils for the production of biodiesel as waste cooking oil is unhygienic to consume and its disposal in the surroundings can cause a threat to the environment. But if this is used for biodiesel production these emit minimal harmful products as gases to the atmosphere.

1.2. GLOBAL PRODUCTION TRENDS OF MAJOR EDIBLE OILS (SCOPE OF WORK)

Source: United States department of Agriculture

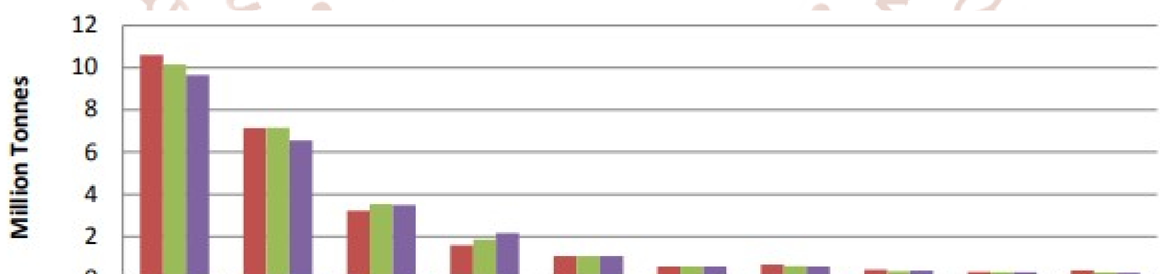
1.2.1 *Groundnut oil*

	China	India	Burma	Nigeria	Sudan	Tanzania	US	Senegal	Argentina	Burkina
2014/15	2.634	1.156	0.27	0.265	0.19	0.133	0.097	0.09	0.077	0.075
2015/16	2.727	0.918	0.27	0.265	0.22	0.133	0.113	0.097	0.076	0.076
2016/17	2.761	0.952	0.27	0.265	0.22	0.133	0.121	0.097	0.078	0.076

Figure 1.1 Worldwide productions on groundnut oil. *Source: US department of Agriculture*

- India's share in global production of Groundnut Oil in 2016-17 may be around 19 percent

1.2.2. *Mustard oil*

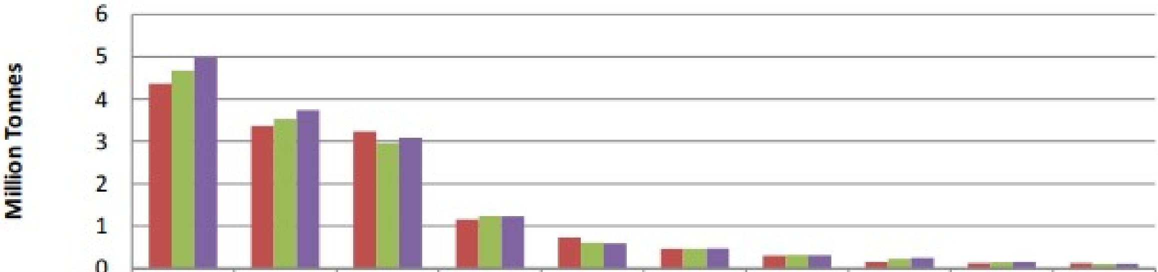


	EU	China	Canada	India	Japan	Mexico	US	Russia	UAE	Pakistan
2014/15	10.603	7.137	3.23	1.596	1.074	0.616	0.704	0.463	0.354	0.435
2015/16	10.157	7.157	3.55	1.862	1.075	0.616	0.632	0.376	0.345	0.316
2016/17	9.656	6.552	3.5	2.166	1.075	0.616	0.615	0.412	0.333	0.312

Figure 1.2 Worldwide productions of mustard oil. *Source: US department of Agriculture*

- India's share in global production of mustard oil in 2016-17 may be around 8.5 percent.

1.2.3 *Sunflower oil*

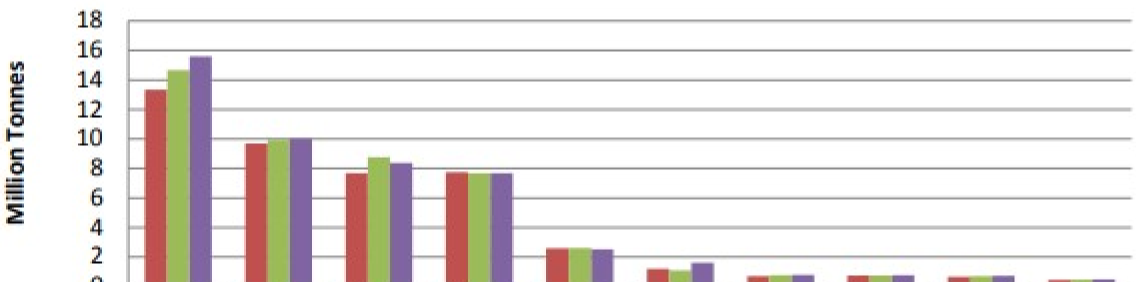


	Ukraine	Russia	EU	Argentina	Turkey	China	South Africa	US	Bolivia	India
2014/15	4.357	3.366	3.232	1.151	0.731	0.466	0.298	0.147	0.123	0.117
2015/16	4.674	3.53	2.958	1.23	0.602	0.466	0.314	0.228	0.142	0.098
2016/17	4.991	3.738	3.084	1.223	0.589	0.475	0.308	0.247	0.151	0.108

Figure 1.3 Worldwide productions of sunflower oil. *Source: US department of Agriculture*

- India's share in global production of sunflower oil in 2016-17 may be around 1.0 percent.

1.2.4 *Soyabean oil*



	China	US	Argentina	Brazil	EU	India	Paraguay	Mexico	Russia	Bolivia
2014/15	13.347	9.706	7.687	7.76	2.584	1.204	0.697	0.745	0.654	0.445
2015/16	14.655	9.934	8.77	7.68	2.622	1.098	0.783	0.76	0.717	0.475
2016/17	15.587	10.034	8.38	7.68	2.527	1.611	0.8	0.766	0.735	0.49

Figure 1.4 Worldwide productions of soyabean oil. *Source: US department of Agriculture*

- India's share in global production of Soybean Oil in 2016-17 may be around 3.5 percent.

Thus, we can observe India is one of the largest producers of edible oils and if utilised properly we can become one of the largest biodiesel producers in the world.

1.3 Sources of Biodiesel production around the world

Following are the major sources of biodiesel production in different countries. This data is based on the data mentioned in various research work carried out in the field of biodiesel production; and its performance and emissions analysis. [2] [3]

Table 1.1 Production of biodiesel in Different countries

S/N	*Country*	*Sources of Biodiesel*
1.	Indonesia	Palm oil
2.	Malaysia	Palm oil
3.	China	Guang pi
4.	Canada	Vegetable oil/ Animal fat
5.	India	Jatropha
6.	Ghana	Palm oil, Palm nut, Coconut oil
7.	Europe	Rape seed oil (>80) and Sunflower oil
8.	USA	Soya Bean (Studies going on for Mustard oil)
9.	Brazil	Soya Bean
10.	Spain	Linseed and Olive oil
11.	France	Sunflower oil
12.	Italy	Sunflower oil
13.	Ireland	Animal fat, Beef tallow
14.	Australia	Animal fat, Beef tallow and Rapeseed
15.	Germany	Rapeseed oil

As we can observe from the data above that Jatropha is the major source of biodiesel production in India. This is because it is non-edible but it is suggested that if we use waste cooking oil for biodiesel production, we can produce biodiesel in more economic ways than that of Jatropha. This lays out a future scope of study on various edible vegetable oils as the source of biodiesel production in India.

1.4. BIODISEL PRODUCTION METHODS APPLICABLE ON VARIOUS SOURCES

Different sources of biodiesel require different procedures for the production of a high calorific value fuel. Some of the processes used for the production of biodiesel are pyrolysis, transesterification, enzymatic transesterification, lipase-catalysed interesterification, saponification, hydrolysis, catalytic pyrolysis, catalytic cracking, etc. Table 2 shows the list of sources and the processes preferred for biodiesel production from respective sources.

Table 1.2 Biodiesel production methods applicable for various types of oils [4, 5, 6, 7, 8, 9, 10]

Sources	**Applicable methods**
Soya beans	Pyrolysis, transesterification
Rapeseed	Enzymatic transesterification
Coconut	Transesterification
Rice bran oil	Lypase-catalysed Interesterification
Barley	Lypase-catalysed Interesterification
Wheat Abutilon	Lypase-catalysed Interesterification
Peanut	Transesterification
Corn	Saponification and Hydrolysis
Olive oil	Transesterification
Peanut oil	Saponification and Hydrolysis
Sunflower oil	Catalytic Pyrolysis
Palm oil	Catalytic cracking
Jatropha	Transesterification

2.0 TRANSESTERIFICATION REACTION

This is a method of biodiesel production that involves use of a four step reaction process. This process is used for production of biodiesel from Soya beans, Coconut, Peanuts, Jatropha, Mustard oil, etc. The first step involved in this process is mixing of alcohol with a catalyst that is generally a strong base like NaOH or KOH. This results in formation of Methoxide.

2.1 CATALYST FORMATION

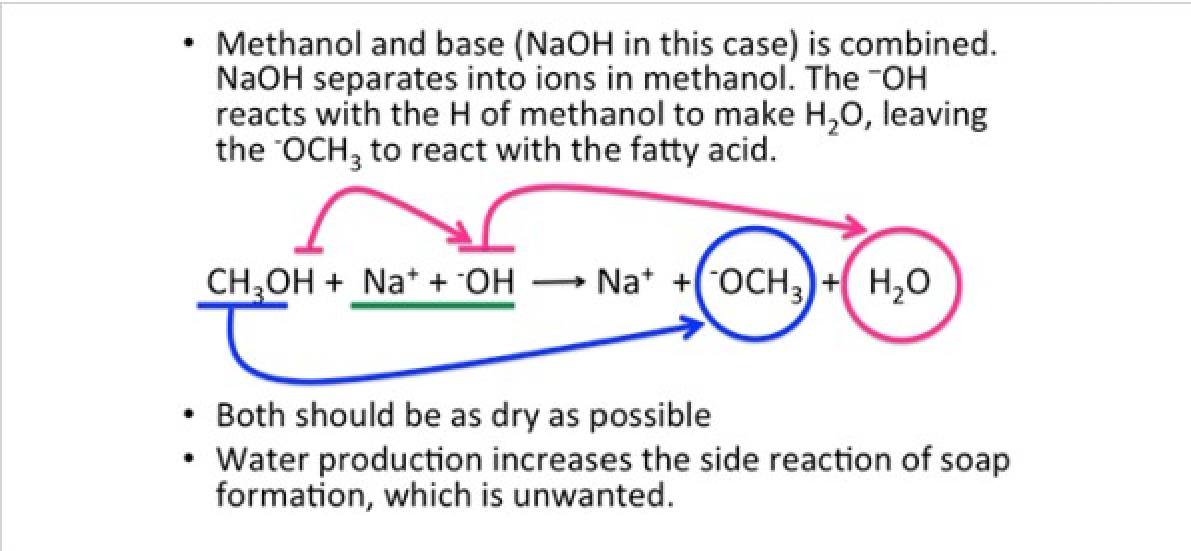


Figure 2.1 Reaction of catalyst formation. *Source: BEEMS Module B4*

While preparation of catalyst, the base NaOH splits into Na+ and OH- ions, thereby the OH- ion reacts with H+ ion from the alcohol to form water, leaving CH_3O- ion for further reaction. Both the alcohol and the base should be dry because any extra water present can react with the fatty acids to form soap which is an unwanted process.

2.2 PREVENTION OF SOAP FORMATION

Excess methanol is used in the reaction as after the catalyst has been produced, methanol still reacts with 3 mol of triglyceride. The three attached carbons with H react with OH- ions and form glycerine and the CH_3 group reacts with the free fatty acid to form the fatty acid methyl ester.

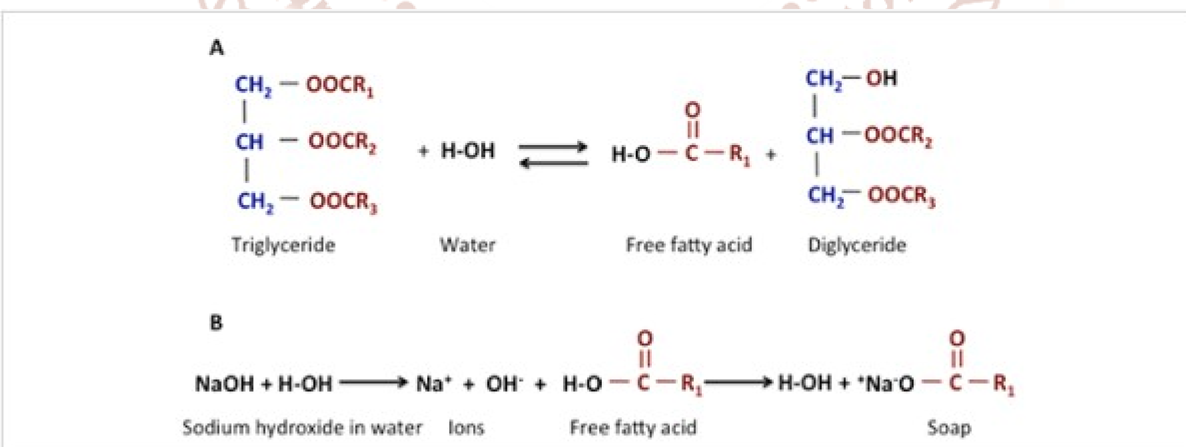


Figure 2.2 Production of soap in presence of extra water. *Source: BEEMS Module B4*

2.3 PRODUCTION OF FATTY ESTERS

A figure showing the detailed process of the complete reaction is shown below. This showcases the exact reaction with fatty acids after the catalyst formation, to form methyl ester as a product.

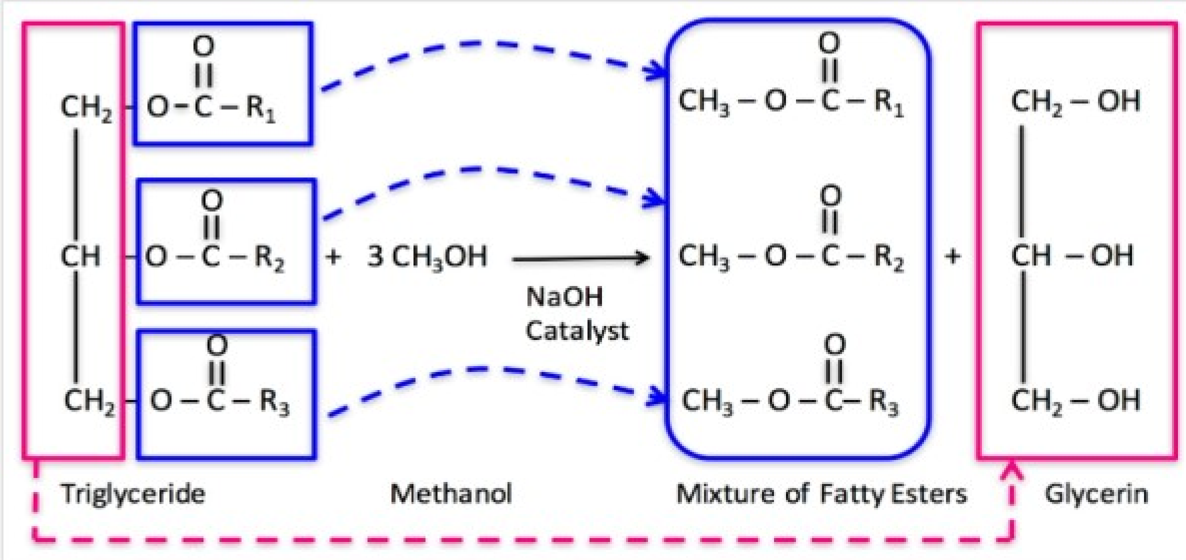


Figure 2.3 Formation of fatty esters. *Source: BEEMS Module B4*

Below is an image showcasing a detailed reaction with the stoichiometric values of the reactants and products in the transesterification reaction.

	Stoichiometric	Typical
Fat or Oil	100 lbs	100 lbs
+		
Alcohol [Methanol]	10 lbs	16-20 lbs
+		
Catalyst [NaOH; 1% w/w oil]	1 lb	1 lb
↓		
Biodiesel [Methyl Ester]	100 lbs	100 lbs
+		
Glycerin	10 lbs	10 lbs

Figure 2.4 Stoichiometric values of reactants and products. *Source: BEEMS Module B4*

Figure 2.5 shows a schematic of the process for making biodiesel. Glycerol is formed and has to be separated from the biodiesel. Both the glycerol and biodiesel need to have alcohol removed and recycled in the process. Water is added to both the biodiesel and glycerol to remove unwanted side products, particularly glycerol, that may remain in the biodiesel. The wash water is separated out similar to solvent extraction (it contains some glycerol), and the trace water is evaporated out of the biodiesel. Acid is added to the glycerol in order to provide neutralized glycerol.

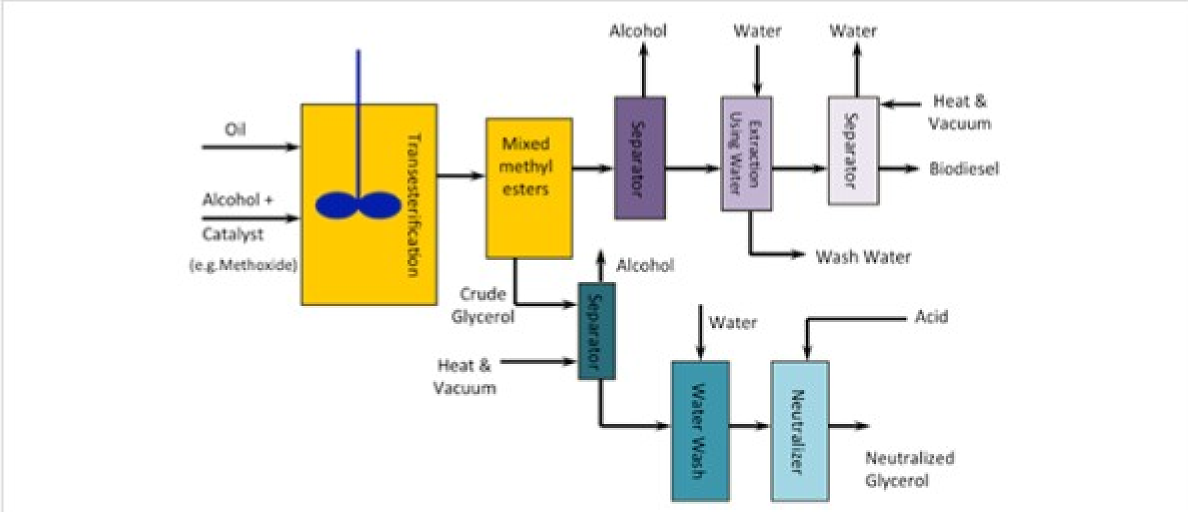


Figure 2.5 Schematic diagram of biodiesel using transesterification process. *Source: BEEMS B4*

3.0 REVIEW OF PAST EXPERIMENTS

Many experiments/researches were carried out to prepare biodiesel via trans-esterification process using different types of organically produced oils. These aimed at obtaining the best suitable source for biodiesel that should serve two criteria, must be cheap and available in abundance.

Researches were also carried out on testing the performance & emission characteristics of various blends of biodiesel with diesel, on a Variable Compression Ratio (VCR) engine. These researches aimed at providing the best solution to the speedy consumption of conventional energy resources, while taking into account the environmental effects of the same. A summary of the experimental results is given below.

3.1 PRODUCTION OF BIODIESEL

Rudolph Diesel first used a vegetable oil (peanut oil) in a diesel engine in 1911. The use of bio-fuels in place of petroleum based fuels can prevent global warming as those have low sulphur, carbon oxides and hydrocarbon emissions. Biodiesel is generally used in blends with normal diesel fuels as it generates more power and is economic as well. Higher the ratio of biodiesel to diesel, the lower the carbon dioxide emission. A 20% biodiesel blend reduces carbon dioxide emissions by 15.66% while using pure biodiesel makes it zero [11].

The use of vegetable oil and animal fat can be done to produce biodiesel fuels but these sources are becoming less economical to use. As vegetable oils are used in the food industry therefore due to an increased demand of these oils in the food industry has led to a hike in their prices. Out of the four major sources of biodiesel production viz. palm oil, jatropha oil, soya bean oil and waste cooking oil, waste cooking oil is the cheapest and most economical raw material for biodiesel production. The kinematic viscosity of waste cooking oil is about 10 times greater, and its density is about 10% higher than that of mineral diesel. Many techniques have been developed to reduce the kinematic viscosity of these oils, viz. pyrolysis, leaning, emulsification and transesterification. Among these techniques, transesterification is the one that is currently used on a wide scale [13].

Leung D.Y.C and Guo Y. [14], compared the transesterification reaction of fresh canola oil and used frying oil. The molar ratio (7:1, methanol/used frying oil), temperature (60° C) and amount of catalyst (1.1 wt% NaOH) was kept high in used frying oil when compared to fresh canola oil where nominal conditions maintained were 315-318 K, 1.0 w/w% NaOH and 6:1 methanol/oil molar ratio. The reaction time observed for used frying oil was 20 min when compared to fresh canola oil reaction time which was 60 min.

Sinha Shailendra et al. [15] calculated the most suitable conditions for transesterification of rice bran oil using methanol and NaOH and adopting mechanical stirring method. The condition was found at 55° C reaction temperature, 1 h reaction time, 9:1 molar ratio of rice bran oil to methanol and 0.75% catalyst (w/w). Further, the physical properties of rice bran methyl ester were tested and compared with other biodiesels and diesel. The result showed that characteristics of rice bran methyl ester obtained were similar to diesel.

Later, Issariyakul Titipong and Dalai K. Ajay [16] studied transesterification of granseed canola oil and canola oil via KOH with methanol, ethanol and a mixture of methanol and ethanol. The reaction was done at 60°C and a stirring speed of 600 rpm for a time period of 90 min. The greenseed canola oil was bleached to remove pigments using different adsorbents. The result revealed that Biodiesel derived from the treated greenseed canola oil .showed an improvement in oxidative stability (induction time of 0.7 h) than that derived from crude greenseed canola oil (induction time of 0.5 h).

Alamu J Oguntola et al. [17], produced the biodiesel from through transesterification of 100g coconut oil, 20.0% ethanol and 0.8% potassium hydroxide catalyst at 65°C reaction temperature with 120 min. reaction time. Yield of biodiesel (10.4%) obtained was low. Further, Tang Ying et al. [18], researched a new method catalyst, benzyl bromide-modified +CaO for production of biodiesel from rapeseed. A 99.2% yield of fatty acid methyl esters in 3h was obtained in comparison to better fat diffusion to the surface of the benzyl bromide-modified CaO.

In a research work done by W. Abdul Md. et al. [19], he chose Cottonseed oil, Mosna oil and Sesame oil to produce biodiesel. In this experiment, transesterification was used for the production. Biodiesel produced from Cottonseed oil at 1:3 molar ratio of oil to methanol was sufficient in amount. The optimum conditions for the methanolysis of crude cotton seed oil were recorded to be: 3:1 molar ratio of methanol to oil and 1.00% (w/w) catalyst. In case of Mosna oil the optimum conditions were 3.5:1 M ratio of methanol to oil and 1.00% (w/w) catalyst. But the amount of biodiesel obtained from these sources was lesser in quantity therefore cottonseed oil proved to a more economic process. For Sesame oil the optimum conditions were recorded to be 3.5:1 M ratio of methanol to oil and 1.00% (w/w) catalyst.

Further, Banerjee M. et al. [20], determined the efficiency of the catalyst bimetallic Gold–silver core–shell nanoparticles towards the production of biodiesel from Sunflower oil using the process of transesterification. The shape and size of nanoparticles was examined using ultra violet ray processes –viz. spectroscopy, transmission electron microscopy (TEM) and energy dispersive X-ray (EDX) analysis. The result of the study showed that at a particular catalyst concentration, reaction time and temperature highest yield of biodiesel (86.9%) was achieved. Moreover, the catalyst showed sustained activity for 3 cycles of repeated use in this kind of transesterification.

Ali N. Eman and Tay Isis Cadence [21], researched the characteristics of biodiesel produced from palm oil using the process of base catalysed transesterification. To find the best conditions for the production of biodiesel three important variables were selected such as reaction temperature 40, 50, and 60°C, reaction time 40, 60 and 80 min. and methoxide ratio 4:1, 6:1 and 8:1. After conducting the experiments at these variables using different combinations, the highest yield of 88% was achieved using reaction temperature 60°C, reaction time 40 minutes and methoxide ratio 6:1.

Further, Azam Mohibbe M. et al. [22], found that FAME of Jatropha was most suitable to use as the source of biodiesel production because of it being economical, having no competition with the food industry and the biodiesel produced was similar in properties to the American and European standards of diesel. Later, Tiwari K. Alok et al. [23], used response surface technique to optimize three important reaction variables, methanol quantity, acid concentration, and reaction time. The optimum conditions of Jatropha oil from 14% to less than 1% was found to be 1.43% v/v sulphuric acid catalyst, 0.28 v/v methanol-to-oil ration and 88 min reaction time at 60 ºC. The properties of biodiesel obtained from Jatropha oil confirmed its similarities to the American, European and German standards.

Kafuku Gerald et al. [24], studied the possibility of converting croton megalocarpus oil to methyl esters (biodiesel) using sulfated tin oxide with enchansed SiO2 as super acid solid catalyst. At 180°C, 2 h and 15:1 methanol to oil molar ratio, the yield of nearly 95% was obtained without any pre-treatment. Further, Padhi S.K. and Singh R.K. [25] produced biodiesel from Mahua oil using the process of esterification. They concluded that the best condition for producing biodiesel were 8% Sodium Methoxide, 0.33% v/v alcohol/oil ratio, 1 hr reaction time, 65°C temperature and 150% v/v excess alcohol. Thus the best conditions for the production of biodiesel from Mahua oil are 8% Sodium Methoxide, 0.33% v/v alcohol/oil ratio, 1 hr reaction time, 65°C temperature and 150% v/v excess alcohol.

Zheng S. et al. [26] studied the kinetics of acid-catalyzed transesterification of waste frying oil. They deduced that at the oil/methanol molar ratio of 1:250 at 70 ºC, the reaction was a pseudo-first-order reaction. High yield of approximately 99% could be achieved at both 70 ºC and 80 ºC keeping the stir at rate of 400 rpm, using a feed molar ratio oil: methanol: acid of 1: 245: 3.8. Later, Wang Yong et al. [27] studied a two- step catalyzed processes for synthesis of bio-diesel by using waste cooking oil from Chinese restaurants. Thus, this became a hot area of study as the use of WCO was economical are produced desired quality of biodiesel.

Later Hossain A.B.M.S. and Boyce A.N. [28] studied the transesterification process for biodiesel production from pure sunflower cooking oil (PSCO) and waste sunflower cooking oil (WSCO). The result showed that there was no difference in the yield of biodiesel produced either from PSCO or WSCO. Later Bakir T. Emaad and Fadhil B. Abdelrahman [29] presented work on single step transesterification and two step transesterification, viz. acid-base and base–base catalyzed transesterification process for production of biodiesel from Chicken fried oil.

Various studies were done on waste cooking oil as an economic source of biodiesel production. The use of WCO has a lot of scope in the field of biodiesel production because it solves the problem of its disposal in the surroundings resulting in pollution. Afterwards, various other researches were done using biodiesel obtained from various feed stocks in blends with diesel oil on CI engine.

3.2 EMISSIONS & PERFORMANCE OF BIODIESEL ON CI ENGINES

Considerable differences were observed in the emissions between biodiesel (derived from rapeseed oil) and normal diesel. The HC emissions were lower for biodiesel owing to higher oxygen content and the NOx emissions were less owing to a lower flame temperature. These results were an outcome of the physical properties of biodiesel such as a higher density, surface tension, boiling point and viscosity [30]. The effect of FIP for Diesel and Linseed Oil Methyl ester diesel blends (B10, B20, B40 and B60) was that the amount of CO2 emission is proportional to the engine load [31].

Biodiesel fuel consumption can be decreased by increasing FIP without increasing NOx emissions [32]. While experimenting, it was found that the NOx emissions had increased while emissions like HC, CO and smoke density were lesser when compared to diesel. Another research completely contradicted the fact showing that there is little to no difference of NOx emissions on running the engine on Jatropha biodiesel blend as compared to normal diesel fuel at low and medium loads [33].

Various studies and experiments suggested that biodiesel obtained from almost every source had the same cetane number, heat of vaporisation and energy density as diesel. Jatropha-Ethanol blends exhibited an increased BTE when compared with normal diesel. BSEC touched the value of the highest 100% for Jatropha methyl ester [34]. Cetane number (CN) measures the ignition quality of a fuel upon its introduction within the cylinder of an IC engine. It gives us a clear idea of the ignition time or the delay in the ignition in the combustion chamber of a diesel engine [35]. Generally, longer and saturated carbon chains have a higher CN. Thus the longer the carbon chain in the feedstock, higher is the cetane number that is obtained. Therefore, the biodiesel obtained from chicken fat will have the highest value of cetane number compared to the biodiesel obtained from any other feedstock [36].

A test done on 4276T Turbo Charged engine using the biodiesel blend of B20 showed that for the same efficiency to be obtained out of the engine, biodiesel blends require a large amount of fuel consumption when compared with normal diesel fuel. Further, a study of cotton seed oil derived biodiesel on diesel engine showed a reduction in the amount of CO, particulate matter and smoke in the exhaust gases but there was a slight increase in NOX emission. Thermal efficiency with Bio diesel was found to be longer (slightly) than diesel due to lower heating value of the latter. Study on single cylinder engine with exhaust gas recirculation using diesel and B100 showed that CO and smoke emission were lesser but NOX emission were higher when using biodiesel and exhaust gas recirculation. A further study on Four cylinder turbocharged (1400 rpm) using normal diesel and B100 showed that there was a considerable reduction in particulate matter, CO and unburnt HC while NOX emission increased by 11.2% and a 13.8% increase in BSFC was observed in case of biodiesel. Another study on adiesel engine using normal diesel fuel and B100 re-confirmed the above results with CO emission reduction by 12%, NOX emission increasing by 20% and an increase in BSFC by 11.4%.

Studies revealed that BSFC increases at low load and there is a decrease observed in higher loads. Upon use of ethanol the calorific value id decreased thus resulting on more efficient combustion of the fuel. BSFC as well as BTE witness an increase because of an increase in the oxygen content [3]. DEE blends of biodiesel significantly reduced viscosity and improved atomisation. This resulted in higher BTE for the blends of Thevetia Peruviana biodiesel, and achieved maximum BTE for the 20% blend [21]. Higher FIP increased atomisation but lower penetration generating faster combustion rates for all blends of Linseed Oil Methyl ester diesel (B10, B20, B40 and B60). B60 has the highest brake power at low and high FIP. BSFC is higher at higher FIPs due to lower brake efficiency [22].

From the review of literature available in the field of biomass usage, many advantages are noticeable.

The following are some of the advantages of using biodiesel as fuel with diesel in I.C. engine in India

- Biodiesel is made from animal and vegetable fat; it can be produced on demand and also causes less pollution than petroleum diesel.
- It can be used in existing diesel engines with little or no modifications at all and can replace fossil fuels to become the most preferred primary transport energy source.
- It improves engine lubrication and increases engine life since it is virtually sulphur free.
- Biodiesel instead of petroleum diesel can reduce greenhouse gases up to 78%.
- It is produced in local refineries which reduce the need to import expensive finished product from other countries.
- Biofuel refineries, which mainly uses vegetable and animal fat into biofuel releases less toxic chemicals, if spilled or released to the environment.
- It is safe to handle, store and transport.
- Biofuels are produced locally and thousands of people are employed in biofuel production plant.
- A nation can save billions by reducing their usage on foreign oil.

The major challenges that face the use of biodiesel as I.C. engine fuels are listed below

- Variation in quality of biodiesel as it varies from oil to oil.
- Biodiesel gels in cold weather but the temperature that it will gel depends on the oil or fat that was used to make it.
- Biofuels are made from animal and vegetable fat, more demand for these products may raise prices for these products and create food crisis in some countries.
- More crops are grown to produce biofuels, more fertilizer is used which can have devastating effect on environment. The excess use of fertilizers can result in soil erosion and can lead to land pollution.
- Biodiesel cleans dirt from the engine. This proves to be an advantage of biofuels but the problem is that this dirt gets collected in fuel filter and clogs it.
- The use of water to produce more crops can put pressure on local water resources.
- It requires much amount of energy to produce biodiesel fuel from soy crops as energy is needed for sowing, fertilizing and harvesting crops.

The major technical areas (with respect to the use of biodiesel as fuels in I.C. engines), which need further attention are listed below

- Development of less expensive quality tests.
- Emission testing with a wide range of biodiesel.
- Studies on developing specific markets such as mining, municipal water supplies, etc. which can specify bio-diesel as the fuel choice for environmentally sensitive areas.
- Co-product utilization like glycerine produced in a beneficial manner.
- Efforts to be focused on responding to fuel system performance, material compatibility and low fuel stability under long term storage.
- Continued engine performance, emissions and durability testing in a variety of engine types

and sizes need to be developed to increase consumer and manufacturer confidence.

- Environmental benefits offered by biodiesel over diesel fuel needs to be popularized.
- Studies are needed to reduce cost and identify potential markets in order to balance cost and availability.

4.0 CONCLUSION

The study of the previous research work done on the production of biodiesel from various feedstocks and using various methods was done. Further we also studied the past literature on various emissions and performance analysis of biodiesel blends on CI engines.

We deduced the following major outcomes:

1. Initially non-edible oils were being used as major feedstocks for biodiesel production. But with the research work done on various waste cooking oils (WCO), these WCO emerged as a good source of biodiesel production owing to their economic and easy availability.
2. In India, initially we used to make use of Jatropha as the major feedstock for biodiesel production but later waste mustard and sunflower oil emerged as better alternatives.
3. The performance of the biodiesel blends was found to be promising and as a good alternative to diesel fuels. The biodiesel obtained from various feedstocks (including WCOs) were analogous to American and European standards. The only observation that went on a slight negative side was that for an equal efficiency to the normal diesel; biodiesel required higher quantity of fuel consumption.
4. There is a lot of scope on the study of WCOs as the feedstock for biodiesel production on different blends and at varying compression ratios to obtain the best blend percentage and the best compression ratio, to achieve the highest grade of productivity and efficiency.

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