Investigation of NOx Emissions in Diesel Engine by EGR Technique with Biodiesel as Fuel

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***Abstract*—Biodiesel has become the best alternative fuel to the conventional diesel fuel in the present scenario. It can be extracted from various resources, such as animal fats, vegetable oils and even from waste cooking oil. The largest available sources of oils come from different crops as soya bean, sunflower, palm, ripe seed, honge and jatropa. Since the fossil fuel resources are depleting rapidly, due to the ever-increasing demand, researches are going on at an increasing rate for an alternate. In this context, Biodiesel could be one of the best substitutes for the fuels. Most of the Biodiesels are extracted from non-edible oilseeds and various vegetable oils like palm oil, soya bean oil, sunflower oil etc. Biodiesels are preferred mostly because of their Eco- friendly characteristics such as less harmful and low emissions.**

The present work includes the extraction of Biodiesel from waste cooking oil by Transesterification process, followed by the study of performance and emission characteristics of a single cylinder 4stroke 5.12kw diesel engine, with extracted biodiesel as fuel. The results obtained are compared with the results of conventional diesel as the fuel and found almost nearer to the conventional one. The emissions of NOx with Biodiesel as a fuel is found little less compared to the conventional Diesel fuel. Here more focus is kept on the reduction of NOx emissions to the maximum extent. This is best achieved by introducing the concept of EGR (Exhaust gas recirculation) in the engine performance test. There are two kinds of EGRs (hot and cold), out of these two, Hot EGR found to be the best in reducing NOx emissions to the greater extent, without much affecting the engine efficiencies.

***Keywords*— Exhaust gas recirculation (EGR), Transesterification process, NOx Emission, Bio Diesel, Performance characteristics.**

I. INTRODUCTION

Diesel is a nonrenewable resource. As per the present conditions, the usage of fossil fuels has been increasing rapidly, this may lead to the complete utilization of resources of fossil fuel in few decades. In order to decrease this situation, there is a need to think of alternative energy resources. One such energy resource is BIODIESEL. Biodiesel can be extracted from various resources, such as animal fats, vegetable oil and even from waste cooking oil. The largest available sources of oils come from different crops as soya bean, sunflower, palm, ripe seed, honge and jatropa. The preparation cost of biodiesel is less when compared to fossil fuel. Biodiesel has many environmental benefits than fossil fuels. The emission of NOx is high when fossil fuels are used. In order to reduce the formation of NOx in the combustion chamber, EGR technique is found to be the preferred technique.

Many researchers have been involved in engine testing with biodiesel blends to evaluate improved performances characteristics. Since liquid fuel from vegetable oils are renewable, inexhaustible and environmentally friendly compared to diesel, also diesel emissions like CO_2, CO, NO_x, SO_x and particulate matter (pm), that are currently main sources of environmental pollution, have made researchers look into use of biodiesel from vegetable oils like soya bean, sunflower, palm, ripe seed, honge and jatropa etc., Among such research works, some of the research works on vegetable oils as alternative to diesel fuel are discussed below.

W.Adaileh et al. [1] investigated the performance of diesel engine fueled by a biodiesel extracted from waste cooking oil. A B20 blend produced marginal reductions in the CO, HC, and smoke emissions when compared with standard diesel and B5. **J. Hussain et al**. [2] have studied the Effect of Exhaust Gas Recirculation (EGR) on performance and emission characteristics of a three-cylinder direct Injection Compression Ignition Engine. Later **B. Pattanayak et al**. [3] The Evaluated CI engine performance and emissions by using Karanja oil methyl ester with EGR process. Using EGR technique BSFC goes on increasing and BTE of the engine decreases. **N. Dagar** and I**. H. Shah et al** [4] investigated two-cylinder diesel engine using biodiesel and diesel as fuel with EGR technique. They found that the brake thermal efficiency and specific fuel consumption of diesel engine with biodiesel and its blends were found to be higher than diesel as fuel with 15% EGR rate in percentage of rice-bran biodiesel in the blends. Later **P. Sai Chaitanya et al**. [5] have studied the impact of cold and hot Exhaust Gas Recirculation (EGR) on a diesel engine. From the experiment, authors have found that cold EGR with 15% exhaust gas recirculation is giving optimum engine performance along with the reduction in emissions. further **P. Srinivasa Rao et al**. [6] did an evaluation of performance and emission characteristics of a diesel engine fueled by biodiesel derived from linseed oil. They concluded that the blend L30 gives better performance considering brake thermal efficiency, specific fuel consumption, and emission parameters. The study leads to concentrate on the extraction of biodiesel from the resources as the waste cooking oil which is available at low cost and also encouraged to study its utilization on 4stoke single cylinder diesel engine. Later **W. Zhang et al**. [7] examined the influence of EGR and oxygen-enriched air on diesel engine NO–Smoke emission and combustion characteristic. The researchers have noted that proper combination of exhaust gases recirculation rate and oxygen concentration can achieve low NO–Smoke emission. Later **M. Kassaby et al**. [8] studied the effect of compression ratio on an engine fueled with waste oil produced biodiesel/diesel fuel. CO2 and NOx found increased with compression ratio. Later **K.shok et al**. [9] studied the Combustion Characteristics and Performance of a direct injection diesel engine fueled with Rice-Bran oil derived biodiesel/diesel blends. They concluded that increasing trend BTE decreased with increase in the proportion of biodiesel in the blends. The amount of CO and HC in exhaust emission reduced, whereas NOx increased with increased % of the blend. Later **Achuthanunni V** and **Baiju B** [10] et al investigated a Diesel-Biodiesel fueled compression ignition engine with Exhaust Gas Recirculation (EGR). Biodiesel is an oxygenated fuel and it gives higher NOx emissions. Further **Arjun.s** et al [11] – have studied the Extraction of Biodiesel from the waste cooking oil. By using a method called Transesterification processes. which depends on the amount of free fatty acid and water content in the sample.

The above study leads to concentrate on extraction of biodiesel from the resources as waste cooking oil, which is available at low cost and also encouraged to study its utilization on 4stoke single cylinder diesel engine.

II. BIODIESEL REPARATION

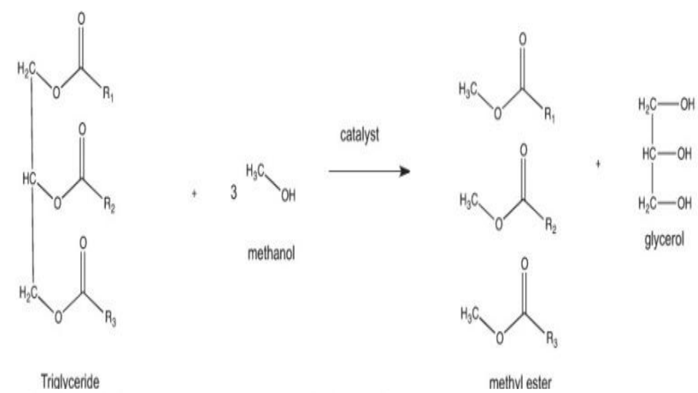
2.1 Extraction methods

The Vegetable oil converted to methyl or ethyl-esters are commonly referred as "biodiesel". Fuels derived from bio-oils are the prominent sources of alternative diesel fuels. Depletion of fossil fuels and less pollution of biodiesel compared to that of diesel fuel has been the reason to use products of vegetable oil. Technically biodiesel is competitive with conventional diesel fuel. Though there are different methods for the extraction of biodiesel from vegetable oils, namely Dilution method, Micro emulsification, Pyrolysis (Thermal cracking), yet Transesterification process is found easier and less expensive and is chosen for the present work. According to this vegetable oils can be converted into usable biofuels in presence of the catalyst (i.e., ethyl or methyl-ester). This would convert vegetable oil to methyl esters, ethyl esters, 2propyl esters, and butyl esters using KOH or NaOH as catalysts, by reducing the viscosity of the vegetable oil. Biodiesel esters have the fuel properties which includes density, viscosity, acid value, iodine value, pour point, cloud point, a gross heat of combustion, and volatility. Biodiesel fuels consume more fuel per power and torque outputs compared to diesel fuel. When compared to diesel, biodiesel has few good properties such as flash point, sulfur content, aromatic content, and biodegradability. Hence without any modification to the existing engine, biodiesel can be used as fuel to any diesel engine.

Viscosities of the vegetable oils are higher than that of diesel fuel. Fuel atomization reduces and penetration increases with the increase in the viscosity. Due to which there are deposits in the engine, injector coking, piston ring sticking and the oil thickening. Different methods are developed to reduce the viscosity of bio-oils such as dilution (blending), micro-emulsification, pyrolysis (thermal cracking) and transesterification.

2.2 Transesterification:

Transesterification is also known as alcoholysis. Animal fats or vegetable oil react with an alcohol produces esters and glycerin. The rate of reaction and yield of the biodiesel can be improved by use of a catalyst. Methanol and ethanol are most commonly used alcohols for transesterification reaction. This is due to the reason, that they react very fast with triglycerides and catalyst (NaOH/KOH) can be easily dissolved and removed by a water wash.



$$\text{Triglyceride} + ROH \leftrightarrow \text{Diglyceride} + RCOOR_1$$

$$\text{Diglyceride} + ROH \leftrightarrow \text{Monoglyceride} + RCOOR_2$$

$$\text{Monoglyceride} + ROH \leftrightarrow \text{Glycerol} + RCOOR_3$$

Figure 1: Transesterification of Triglycerides with Alcohol

2.3 Use of Catalysts in Transesterification

In trans-esterification reaction, there are 2 types of catalysts used: (i) Base catalysts (ii) acid catalysts. Base catalysts are used more over acid catalysts, as they faster rate of reaction compared to the acid catalyst. The reaction using base catalyst can be carried at lower reaction temperatures, compared to acid catalyst they show greater yield production.

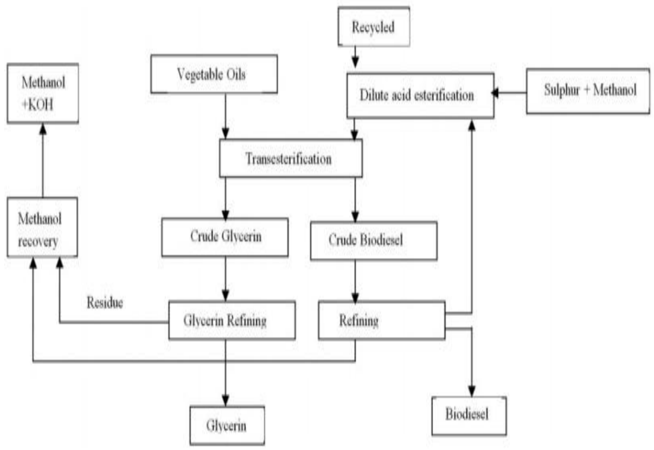


Figure2: Schematic diagram of biodiesel production

Base catalyst is very effectively used for oils having FFA less than 1%. But they can be used even when FFA is more than 1% of the use of more amount of catalyst. Acid catalysts are preferred to be used when base catalyst produce soap formation and this is seen in case of oils with high acid value. Non-edible oils have the acid value less compare to edible oil. When edible oils are used for a long period to fry, their acid value increases. In this case, the use of acid catalysts shows better results.

2.3.1 Base Catalysts

The reaction mechanism for base-catalyzed transesterification is shown in Figure1. The reaction mechanism has three steps. The initial step in the reaction is the formation of tetrahedral by the reaction between carbonyl carbon atom with the anion of the alcohol, then Diglycerides are formed, from which the alkyl ester. Series of catalytic cycle is seen when the catalyst reacts with the alcohol (second molecule) by series of reaction. This yields glycerol from alkyl ester. Base catalysts is broadly classified into two, as 1) Homogeneous and 2) Heterogeneous, based on the phases of the reactants and catalysts as well in the process.

2.3.2 Acid Catalysts

Even though base catalysts are good for transesterification reaction, when the acid value is high, they show poor results. When base catalysts are used, soap formed is difficult for removal. When the acid values of the oils are higher than the working range of base catalysts, the acid catalyst is used. This type of catalyst reaction is carried out in the absence of water. The disadvantage of using acid catalyst is that they need more alcohol and the rate of reaction is very slow. Higher reaction pressures and temperatures are required for completion of the process. Acid catalysts is broadly classified into two, as 1) Homogeneous and 2) Heterogeneous, acid on the phases of the reactants and catalysts as well in the process

2.3.3 Acid-Base Heterogeneous Catalysts

Heterogeneous catalysts both basic and acidic can be used for simultaneously esterify FFA and Trans-esterify TGs to biodiesel. A microwave transesterification reaction using methanol or ethanol can be performed, 6:1 of oil and catalyst are used, acidic silica gel or basic alumina as the catalyst. Using acid catalysts H_2SO_4, an optimum yield can be obtained using immobilized in the presence of SiO_2, and methanol at the temperature of 60^0C for 3 hrs.

2.3.4 Enzyme Catalysts

Enzyme catalysts can be used for transesterification of vegetable oils or animal fats. Use of this catalyst is preferred as there is no soap formation. Hence many problems like purifying, washing of oil, and neutralization are reduced. Even at mild condition enzymatic catalysts reactions. But the problems associated the use of enzyme catalysts are like their higher cost and longtime of reaction. Enzyme catalysts such as lipozyme TLIM, lipozyme, novozym 435, and lipozyme RMIM.

2.4 Purification of Crude Biodiesel

After transesterification reaction is completed, two major products are produced: biodiesel and glycerol. The density of the biodiesel phase is lesser then glycerol phase and hence glycerol settles at the bottom of the reaction vessel, which allows it to separate from the biodiesel. The centrifuge is used to separate biodiesel from glycerol. The catalyst is present in both biodiesel and glycerol at the end of the reaction. So crude biodiesel will be purified before the usage. Three different techniques are used for purification of biodiesel: water washing, dry washing, and membrane extraction.

2.4.1 Water Washing

Glycerol and alcohol are highly soluble in water, so water wash is very effective for removal of both contaminants. Any residual soaps and sodium salts retained can be removed. Mainly warm water is used for water wash method as the precipitation of saturated fatty acid esters is prevented. After washing the solution for the number of times a clean solution is formed. A centrifugal machine can be used for separation of water phase from biodiesel.

2.5 Influence of the Different Parameters on Biodiesel Production

There are important parameters that influence the biodiesel production process. In order to obtain the maximum yield of biodiesel, these parameters must be optimized.

I. Molar Ratio of Alcohol to Oil

The yield of alkyl ester can be increased by improving when the molar ratio of oil to alcohol. It is seen that 6: 1 molar ratio of acid esterification and with 9:1 vegetable-oil to-alcohol molar ratio during esterification are giving optimum ratios for biodiesel.

II. Reaction Temperature

It is the temperature that has to be maintained for the reaction of the oil with alcohol. With the increase in reaction temperature viscosity of the oil decreases. The temperature to be maintained is less than or around the boiling point of methanol. The temperature has to be around 60^0C. If it is increased above boiling point, methanol liberates and the yield decreases.

III. Water and Free Fatty Acid Content

Water in the oil can cause the formation of soap. With the increase in % of water in the oil would cause many problems in FFA. The viscosity of the oil increases with the increase in water content.

2.6 Basic Characteristics of vegetable oil as fuel

- When vegetable oil is to be used as fuel, it should have short ignition delay period, and ignition quality should be high.
- They should have high CV (Calorific value).
- They should have high cetane number.
- Pour point, Cloud point should be below the freezing point of the oil used.
- Viscosity should be low for vegetable oil to be used as fuel.
- Flashpoint of the oil should be high to maintain the temperature of the fuel.
- For a good quality of fuel aniline point should greater than 21^0C.
- Sulphur, Carbon residue and Ash content in the fuel should be less as possible to avoid corrosion and residue formation on the engine parts.

Properties	Waste Cooking Oil	Diesel	Biodiesel	Methanol
Density at 15^0C (Kg/m3)	939	830	911	794
Kinematic viscosity Of 40^0C (CST)	3.65	1.81	2.87	0.585
Flashpoint (^{0}C)	326	53	174	12
Fire point(^{0}C)	383	58	181	15
Calorific value (MJ/Kg)	37.50	42.34	38.70	23.40

Table 1

III. EXPERIMENTATION

3. ENGINE SPECIFICATION

1	Engine	4Ssingle cylinder diesel Engine	**6**	Stroke length	110.00 mm
2	Fuel	Diesel, Biodiesel	**7**	Connecting rod length	234.00 mm
3	Rated power	5.20 kW	**8**	Compression ratio	17.50
4	Rates speed	1500 RPM	**9**	Swept volume	661.45 cc
5	Bore	87.50 mm	**10**	Cooling	Water cooled

Table: 2

The test rig used is a single cylinder, 4 stroke, Diesel engine accompanied by eddy current type dynamometer for loading. It is equipped with necessary instruments to measure combustion pressure and crank angle. These measured quantities are interfaced to computer through engine indicator for Pθ−PV diagrams. Attachments are also made for air flow interfacing, fuel flow, temperature values and loading values. Rotameters are provided for the measurement of water flows. Test apparatus enables the investigation of engine performances like Friction power, brake power, indicated power, IMEP, BMEP, indicated thermal efficiency, volumetric efficiency, brake thermal efficiency, Mechanical efficiency, SFC, and balance of heat generated. "Engine soft" software is enabled for online performance and evaluation.

IV.INVESTIGATION OF RESULTS

LOADS	FUELS	NOx in PPM	% Reduction of NOx
0%	Diesel	167	
0%	Biodiesel with 0%EGR	130	22.155
0%	Biodiesel with10%EGR	120	28.143
0%	Biodiesel with15%EGR	98	41.317
0%	Biodiesel with 20%EGR	82	50.898

Table :3

LOADS	FUELS	NOx in PPM	% Reduction of NOx
25%	Diesel	747	
25%	Biodiesel with 0%EGR	639	14.457
25%	Biodiesel with10%EGR	595	20.348
25%	Biodiesel with15%EGR	548	26.639
25%	Biodiesel with20%EGR	552	26.104

Table :4

LOADS	FUELS	NOx in PPM	% Reduction of NOx
50%	Diesel	1231	
50%	Biodiesel with 0%EGR	1315	6.823↑
50%	Biodiesel with10%EGR	1189	3.411
50%	Biodiesel with15%EGR	1029	16.40
50%	Biodieselwith 20%EGR	972	21.04

Table :5

LOADS	FUELS	NOx in PPM	% Reduction of NOx
75%	Diesel	1987	
75%	Biodiesel with 0%EGR	1811	8.85
75%	Biodiesel with10%EGR	1489	25.062
75%	Biodiesel with15%EGR	1245	37.342
75%	Biodiesel with 20%EGR	1083	45.45

Table :6

LOADS	FUELS	NOx in PPM	% Reduction of NOx
100%	Diesel	2162	
100%	Biodiesel with 0%EGR	2123	1.803
100%	Biodiesel with10%EGR	1518	29.787
100%	Biodiesel with15%EGR	1150	46.808
100%	Biodiesel with 20%EGR	861	60.175

Table :7

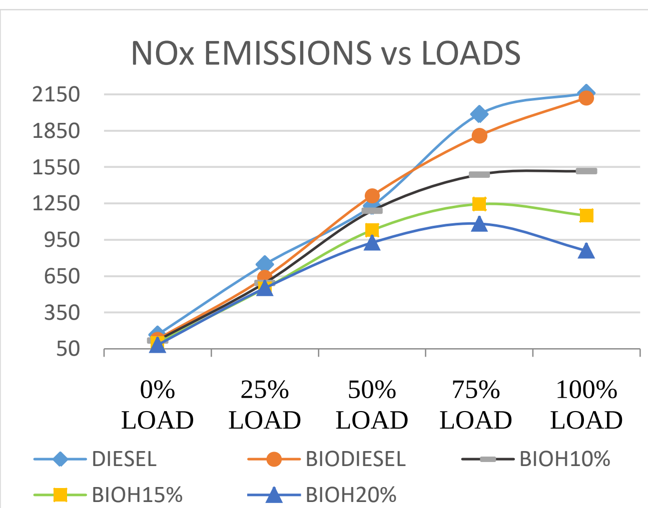


Fig :3

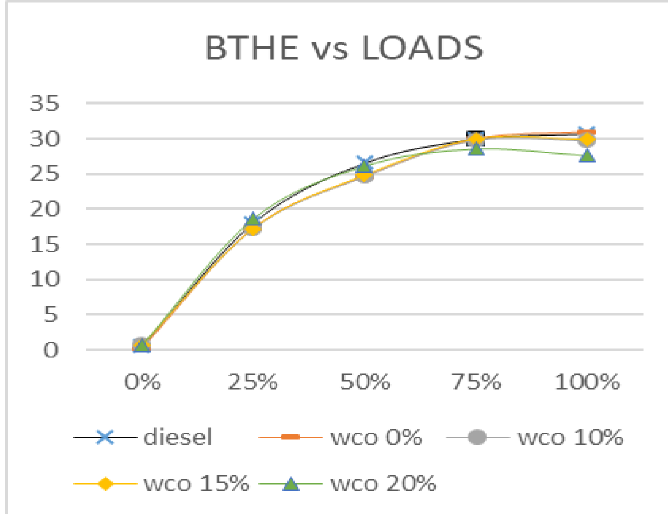


Fig:4

V. CONCLUSION

Production of alternative fuel has become the challenge for many researchers, since past decades, and are achieved to some extent with many advantages as well as drawbacks. The challenges need to be faced, when the alternative fuels are utilized in different applications, especially the performance characteristics of machines with which they run. In this context, the Biodiesel fuel extracted from used cooking oil by transesterification process is taken as a sample, and the performance characteristics of specific CI engine is studied by using this Biodiesel as a fuel. It is found that the performance characteristics of CI engine with Biodiesel as a fuel has come almost nearer to the characteristics of the same engine with conventional Diesel as fuel. The main disadvantage noticed with the biodiesel as a fuel is, little reduction in brake thermal efficiency compared to diesel as fuel. But more focus is made on reduction of %NOx in emissions to greater extent. This lead to a search, for various techniques to reduce % NOx. Hot EGR was found to be more efficient in reducing %NOx in emissions. For this specific application percentage reduction of NOx in emissions are found 50%, 26%, 21%, 45%, and 60% at loads 0%, 25%, 50%, 75%,100% on engine respectively for an optimal value of HOT EGR as 20%.

The future scope of this work could be, the study of performance characteristics and the investigation of % reduction of NOx in emissions on CI engine, by mixing the Biofuel extracted, with different blends in small varying quantities.

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