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Production of Biodiesel from Eruca Sativa (Taramira) and Its Utilization in DI Diesel Engine for Examining the Exhaust Emissions

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Abstract**:** ***Increasing demand of the carbon fuels in daily life and the global environmental degradation has led to the biodiesel production from non-edible oils because they has high potential as ecological, clean, facile and renewable fuel. In present study, oil is extracted from dried Eruca sativa seeds using mechanical expellers, the oil yield obtained is calculated. By alkaline transesterification, the obtained oil is converted into biodiesel. The physicochemical properties of Eruca sativa biodiesel are tested following ASTM test methods, all the properties satisfies and meet the ASTM D-6751 biodiesel standard specifications. The gas chromatography technique is used for the analysis of fatty acid composition of the biodiesel, which shows that the erucic acid has higher percentage composition. Emission characteristics (i.e. carbon monoxide, carbon dioxide, hydro carbon, nitrogen oxide and smoke) of diesel engine are analyzed for the biodiesel and its blends (i.e. B10, B20, B30, B40 and B100) and are compared with the petroleum diesel. From the emission results obtained it is observed that, the CO and CO_2 emissions are lower for B10 and B20 blends whereas the HC emissions are lesser than diesel for all the blends. For B10, B20 and B30 blends the NO_X emission and smoke opacity has been reduced when compared to diesel.***

Keywords : Eruca sativa, biodiesel, transesterification, physicochemical properties, diesel engine, emission

Abbreviations:

B10	***10%ES biodiesel***
B20	***20%ES biodiesel***
B30	***30%ES biodiesel***
B40	***40%ES biodiesel***
B100	***100%ES biodiesel***
CO	***Carbon monoxide***
CO_2	***Carbon dixide***
CV	***Calorific value***
DI	***Direct injection***
ES	***Eruca sativa***
ESME	***Eruca sativa methyl ester***
FAME	***Fatty acid methyl ester***
FFA	***Free fatty acid***
HC	***Hydro carbon***
NO_X	***Nitrogen oxide***

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I. INTRODUCTION

A. Air pollution -A review

The major health problem that we are facing at planetary level is due to air pollution [1]. As per the data from the World Health Organization's Global Air Pollution Observatory, Among 20 cities of world which has the higher annual level of particulate matter < 2.5 µm in diameter ($PM_{2.5}$), 13 cities belongs to India [2]. Since the past decade globally, a large rise in number of vehicles among the people which uses fossil fuels [3]. Burning of fossil fuels (like oil, gasoline and coal) is the one of the major sources that is responsible for air pollution and environmental dilapidation [4], [5], which releases smoke related particulate matter, unburnt hydrocarbons, oxides of nitrogen and sulfur, at the same time a significant amount of carbon dioxide is also released, which will intensifies the green house effects. The health problems that we are facing due to air pollution are acute lower respiratory illness, lung cancer, distortion, cerebrovascular disease(stroke), chronic obstructive pulmonary disease, mutation of human body Ischemic heart disease, and mortality in adults [6], [7].

B. Fossil fuel -A review

Energy is the primary catalyst of any country's socioeconomic development. The demand of energy is increasing rapidly as the World's population is increasing and it has reached upto 7.4 billion in 2016 [8]. Since the dawn of the industrial revolution, fossil fuel is the chief contributor to worldwide energy demand and remains as primary source of the worldwide energy supply scenario [9], [10], because the consumption of crude oil (34.01%) is higher when compared with other resources like nuclear (5.28%), hydro (6.54%), natural gas (24.13%) and coal (30.02%) [11]. India occupies 3rd place in the consumption of mineral diesel in world, and there will be further increase in consumption of diesel due to rapid motorization and industrialization [12]. For oil importing countries like India, the increase in oil price have an adverse effect on the gross domestic product (GDP) of the country [13]–[15]. Exhaustion of fossil fuels limit the maximum level of anthropogenic global warming, while constraints of the energy pose a threat to economy [16], [17].

C. Biodiesel -A solution

Biodiesel is known to be biodegradable, non-toxic, green fuel with a low emission profile [18], and renewable alternative to substitute fossil fuels, that can potentially be used in the CI engines, which can be produced from animal fat, vegetable oil and alcohols [19].

"Oil from sun" is a very old idea, It was the first time, in 1911 Rudolf Diesel has operated his invented diesel engine using peanut oil [20]. Developing countries like India is desirable to manufacture biodiesel from oil of non-edible seeds, and that can be grown extensively in the country's wasteland [21]. The key benefit of utilizing biodiesel as fuel is decreased exhaust gas emissions, as the CO, CO_2, Unburnt HC and smoke emissions are reduced. There are several methods for converting vegetable oil into biodiesel, among them transesterification is considered to be the convenient method [22]. For transformation of oil to biodiesel FFA value plays a significant role and its value should be less than 2%.

D. Eruca sativa -A source of biodiesel

Eruca sativa commonly known as Taramira, is a part of the same family of mustard Brasssicaceae [23]. It is an erect annual herb, contains non-edible seeds [24]. It is distributed in India, Middle east and from North Africa to Southern Europe. It is known that Eruca sativa is considered as an essential oil seed for the drought and semi-drought areas and due to its better resistance to diseases, drought condition of climate and poor condition of soil it has attracted more attention [25].

Several studies on the production of biodiesel from ES oil have been carried out. During enzymatic transesterification catalyzed by Novazyme-435 and A. niger lipase the biodiesel yield obtained were ranged from 64.3 to 98.3 and 17.3 to 56.4%, respectively, and the reaction time required for biodiesel production was 60 h [26]. For transesterification with Candida rugosa lipase enzyme using response surface methodology, biodiesel yield was 65% for the reaction time of 66 h [27]. During the use of two phase enzymatic membrane reactor, with poly acrylonitrile ultrafiltration membrane biodiesel yield was 100% [28].

II. MATERIALS AND METHODS

A. Materials

Eruca sativa seeds were procured from seeds selling shop named Saviagro, Rajasthan (India). Chemical reagents such as n-Hexane, Isopropyl alcohol, Methanol, Sodium hydroxide, whatman filter paper, Phenolphthalein indicator and Distilled water purchased from a local pharmaceutical, which are of analytical grade. The oil extraction and transesterification was carried out at Bio-fuel research center in Central University of Karnataka (CUK), Gulbarga (India).

B. Oil extraction

The mechanical presses technique is the convenient method for oil extraction because it can extract 68-80% of the oil [29]. In this method an engine driven screw press type expeller is used. The dried seeds were fed to the expeller, due to the pressure exerted on seeds by the screw press of the expeller, oil comes out of it. The seed cake obtained was recirculated in the expeller so that complete oil gets extracted. The oil obtained was golden brown in color.

C. Transesterification for ES biodiesel production

The FFA value of ES oil was found and is less than unity. Hence, alkali based transesterification was carried out. During this process, oil was heated in a 2000mL three necked round bottom flask, provided with thermometer, condenser, sampling outlet and magnetic stirrer. When the temperature of oil reached 65 °C, methanol (1:6 Molar ratio of oil) and sodium hydroxide (NaOH) (3.5 g/liter of ES oil) as the catalyst were added. At 1200 rpm and 65 °C, the mixture was stirred for 2 hrs. Then whole mixture has been transferred to the separating funnel and kept for settling. Glycerin settles down leaving behind the methyl ester, as it is having high density [30]. The methyl ester or biodiesel was removed and washed with warm water 8-10 times until the pH of water after washing matches with pH of water before washing, so that the impurities like excess catalyst, methanol and soap formed during transesterification are removed [12].

D. Physicochemical properties

The produced ES biodiesel was tested by following ASTM D-6751 standard methods in a certified laboratory, for estimating and evaluating its physical and chemical fuel properties. All properties have been analyzed in three replicates and results are average of these values.

E. Analysis of FAME by Gas chromatography

The FAME composition profile of ES biodiesel analyzed using Gas chromatography(GC) technique by using the Agilent-6890 Gas chromatography system (Agilent Technologies, USA), which have been fitted with a flame ionization detector and HP-50 capillary column (0.53mm × 30mm, 0.5μm film). During this process the carrier gas used was pure Nitrogen, with the flow rate of 4 mL/min. 250 °C and 280 °C temperatures were maintained for injector and detector respectively. Further, the sample size 1μL, split ratio (1:50) and the program of column temperature 80 to 240 °C at 5 °C/min was used.

F. Blend preparation

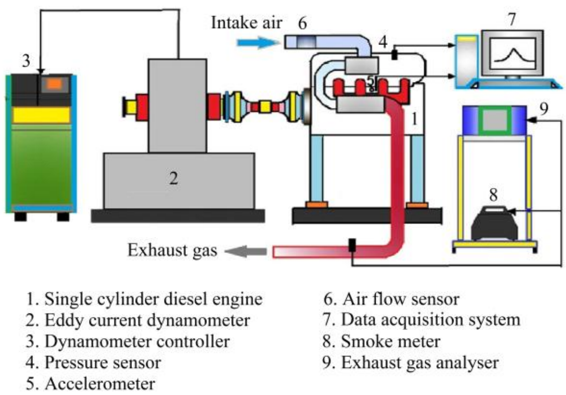

Fig. 1.Schematic of engine setup

ES biodiesel has been mixed with base diesel in a pre-decided percentage proportions of volume to prepare various ES biodiesel blends. The blends prepared are B10, B20, B30, B40 and B100.

G. Blend preparation

Table- 1: Test engine specifications

Parameter	Specifications
Make and model	Kirloskar, TV1
General details	Four stroke, constant speed, variable compression ratio diesel engine.
Rated power	3.5 kW @ 1500 rpm
Number of cylinder	One
Compression ratio range	12:1 – 18:1
Injection variation	0-25 °BTDC
Bore × Stroke	87.5 mm × 110 mm
Swept volume	661.45 cc
Cooling system	Water cooled
Calorimeter	Type pipe in pipe
Temperature sensor	Type-K thermocouple
Loading	Eddy current type dynamometer
Load sensor	Strain guage load sensor

In this study, the emissions were measured for kirloskar TV-1 model, single cylinder, direct injection diesel engine. The representation of the test engine setup employed is shown in Figure 1. Technical specifications of the engine are listed in Table 1. Airrex HG-540 exhaust gas analyzer was used to assess emissions of HC, CO, CO_2 and NO_X. The smoke opacity has been measured with the use of AVL-437 smoke meter. The analyzers various measuring parameters and their accuracies are listed in Table 2.

Table- 2: Gas analyzer and smoke meter range, percentage uncertainties and accuracy

Instrument	Range	Accuracy	Percentage uncertainties
Airrex HG-540 5 Gas Analyzer	CO : 0-9.99% vol	± 0.001% vol	± 0.5
	CO_2 : 0-20 % vol	± 0.01 % vol	± 5.0
	HC : 0-15000 ppm	± 1 ppm	± 5.0
	NO_X: 0-5000 ppm	± 1ppm	± 10.0
AVL-437 smoke meter	0-100 %	± 0.02 %	± 0.1

Engine at the start was fueled with base diesel and is allowed to warm up until steady state conditions has been reached. After reaching the operating condition, emission test was carried out by gradually changing the load applied from 0 to 12 kg on the engine, then the test were conducted for ES biodiesel blends like B10, B20, B30, B40 and B100.

III. RESULTS AND DISCUSSION

A. Oil and biodiesel yield

The results showed that the oil yield obtained from Eruca sativa seeds by use of mechanical expeller ranged from 30 to 35% and after transesterification the ES biodiesel yield is found to be 89 to 91%.

Table- 3: Physicochemical properties of ES biodiesel, comparing with ASTM limits, petro diesel and other biodiesel

Property	Unit	ASTM D-6751 limit [31]	ES biodiesel	Petro-diesel [32], [33]	Jatropha FAME [34], [35]	Pongamia FAME [29]
Acid value	mg KOH/g	Max. 0.5	0.379	0.17	0.4	0.42
Calorific value	MJ/kg	Above 37.656	43.459	45.58	37.5	34
Carbon residue	% mass	Max. 0.05	0.027	0.0187	0.2	-
Cloud point	°C	-3 to 12.0	3.7	2.0	9	7
Density at 15 °C	kg/m^3	860-890	880	839	862	931
Flash point	°C	Min. 130	134	71.5	174	205
Iodine value	g/100g	-	78	-	94	52
Kinematic viscosity at 40 °C	mm^2/s	1.90-6.0	5.9	2.91	4.8	6.13
Pour point	°C	-15 to 10	-2.2	1.0	4	3
Refractive index	-	-	1.4659	1.3	1.4652	-
Saponification value	mg KOH/g	-	134	-	198	197
Sediment	% mass	0.01	<0.001	-	<0.003	<0.005
Sulfated ash	% mass	Max. 0.02	0.013	-	0.012	0.026
Sulfur	% mass	Max.0.05	0.026	0.05	0.02	0.03
Water content	% vol	Max. 0.05	0.009	-	0.025	<0.005

Cetane Number	-	Min. 47	48 [36]	46.2	57	55
Oxidation stability	hrs.	Min. 3	6 [36]	8	7.1	10.3

B. Physicochemical properties of Eruca sativa biodiesel

The ES biodiesel physicochemical properties are summarized in Table 3, in which they are compared with standard limits of ASTM D-6751, diesel and biodiesels like jatropha and pongamia. It can be observed from the table that, all the properties of ES biodiesel satisfies ASTM D-6751 standard specifications. The acid value of ESME (0.379 mg KOH/g) is comparatively lower than the other biodiesel, low acid value indicates the freshness of oil. The CV of ES biodiesel is 43.459 MJ/kg, when compared to CV of other biodiesel it is higher. Flash point of ESME (134 °C) satisfies the limits but comparatively lower than other biodiesel. Carbon residues (0.027), which indicate contamination by possible failure in transesterification process or residues, showed values within limits. Kinematic viscosity of ESME (5.9 mm2/s) is nearer to the upper limit of ASTM, whereas the cloud point (3.7 °C) and pour point (-2.2 °C) are within limits.

C. ES biodiesel Fatty acid composition

Characteristics of the different fatty acid esters that biodiesel consist of , determine the general fuel characteristics of the biodiesel fuel [37], [38]. Table 4. shows the FAME composition ES biodiesel obtained by Gas chromatography technique. The analysis reveals that ESME primarily contains monounsaturated fatty acid (62.5%) while polyunsaturated fatty acids represent 23.9%. Therefore, total unsaturated fatty acid is 86.4%, whereas the level of saturated fatty acid is found to be 13.6%. It is observed that erucic acid has the higher percentage in ESME (38.6%).

Table- 2: Eruca sativa methyl ester fatty acid composition

Types of fatty acids	Chemical Structure	Formula	Percentage content (%)
Palmitic acid	16:00	$C_{16}H_{32}O_2$	9.8
Palmitoleic acid	16:01	$C_{16}H_{30}O_2$	0.2
Stearic acid	18:00	$C_{18}H_{36}O_2$	2.1
Oleic acid	18:01	$C_{18}H_{34}O_2$	12.3
Linoleic acid	18:02	$C_{18}H_{32}O_2$	10.6
Linolenic acid	18:03	$C_{18}H_{30}O_2$	12.9
Gondoic acid	20:01	$C_{20}H_{38}O_2$	11.4
Dihomo-γ-linoleic acid	20:02	$C_{20}H_{34}O_2$	0.4
Behenic acid	22:00	$C_{22}H_{44}O_2$	1.7
Erucic acid	22:01	$C_{22}H_{42}O_2$	38.6
Saturated fatty acid		--	13.6
Mono-unsaturated fatty acid		--	62.5
Poly-unsaturated fatty acid		--	23.9

D. Emission characteristics

Diesel engine emission characteristics are analyzed for all blends ESME i.e. B10, B20, B30, B40 and B100 fuels and compared with base diesel. All the emission results are collected, presented and discussed in this section.

1. Carbon monoxide emission

The Carbon monoxide emission is a poisonous gas which is odorless and colorless. The major causes for CO emission from engine are low flame temperature and too rich fuel air ratio. High oxygen level present and elevated cetane number of biodiesel will decrease the CO emission at full load. Fig. 2 represents the CO emission variation for diesel and ES biodiesel blends for different engine loadings. It is observed that the CO emissions follows increasing trend directly proportional to the biodiesel percentage in the blend. At 25 % of rated load, CO emission for all the ESME blends is found to be lower than base diesel. However at rated load the CO emissions for B10 and B20 blends are less by 11.94% and 7.46% respectively when compared to base diesel. This could be due to the fact that higher content of oxygen in the biodiesel [39], which makes easy burning of the fuel in the cylinder at higher temperature [40].

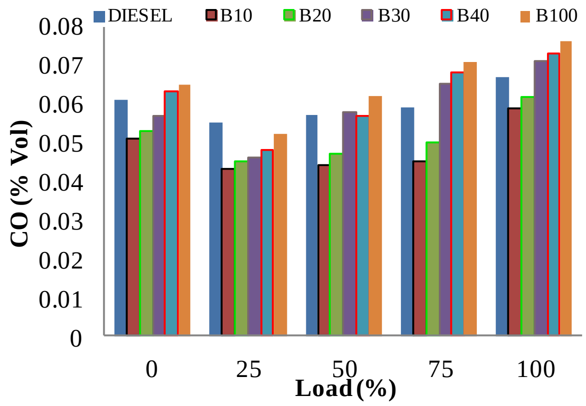

Fig. 2: Variation of CO emission with load

2. Carbon dioxide emission

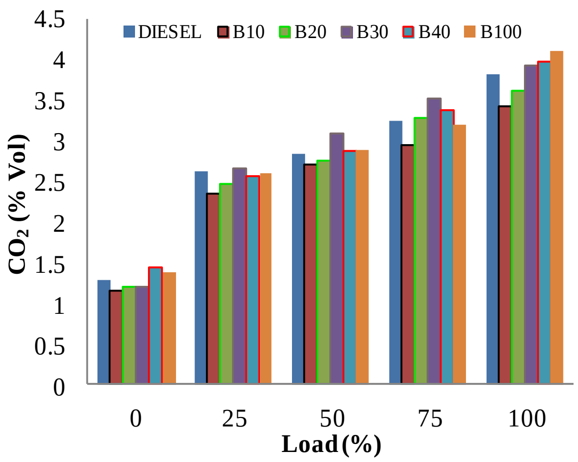

Fig. 3: Variation of CO2 emission with load

Carbon dioxide emission is the main factor which shows the particular fuels combustion efficiency. If CO_2 emission is higher, it refers to the fuel complete combustion.

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Fig. 3 depicts the emission characteristic of carbon dioxide with respect to load. It can be seen from the figure, as load on the engine is increased, there is rise in CO_2 emissions. The Blends B10 and B20 shows less CO_2 emissions at all loading conditions, and at 100% load 10.44% and 5.48% lower CO_2 emission than diesel. This is due to the incomplete oxidation of CO which may be caused by late burning of fuel [41]. The other blends like B30, B40 and B100 show CO_2 emission higher than diesel at rated load by 2.61%, 3.91% and 7.57% respectively, the increasing of CO_2 emission is might be due to surplus content of oxygen in the molecular structure [42].

3. Hydrocarbon emission

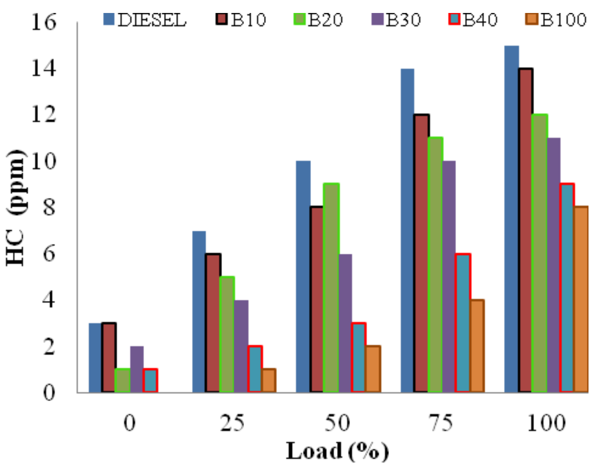

Fig. 4: Variation of HC emission with load

HC emission is caused by the partially burned or completely unburned fuel. Many researchers studies shows a significant reduction in the HC emissions when replacing diesel with biodiesel [43]. HC emission variation with load is shown in Fig. 4. From these results it is observed that the HC emission reduces as the percentage of biodiesel added to the diesel increase and they follow the same trend. At maximum load diesel has the higher and B100 has the lower HC emissions. It is also confirmed that B40 and B100 reduced 40% and 46.67% respectively of un-burnt HC emission whereas B10, B20 and B30 blends showed 6.67%, 20% and 26.67% reduction in HC emissions at full load condition when compared to diesel base line. The biodiesel addition to the diesel will increase the oxygen content, due to which it enhance the combustion reaction resulting in high combustion temperature and lowers the HC emission [40]

4. Nitrogen oxide emission

Nitric oxide (NO) and nitrogen dioxide (NO_2) emission is represented by a generic term NO_X emissions. In general, nitrogen in the combustion chamber do not reacts with oxygen. However, the rise of temperature in the cylinder causes nitrogen to react with oxygen resulting in the emission of NO_X [44]. The change in nitrogen oxide emission at different load is shown in Fig. 5. From which it is to be noted that the NO_X emissions are lower for ES biodiesel blends B10, B20 and B30 when compared to base diesel. This NO_X emission reduction can be attributed to lower combustion temperature caused by the blends lower heat release rate and which may be due to the poor blend and air mixing [45]. NO_X emissions reduced on an average by 12.70%, 2.31% and 6.18% for blends B10, B20 and B30 respectively compared to diesel. On the other hand for blends B40 and B100, NO_X emission increases compared to diesel by 9.95% and 6.43% respectively. Excess oxygen present in biofuel and increase in combustion chamber temperature would have aggravated the situation [19].

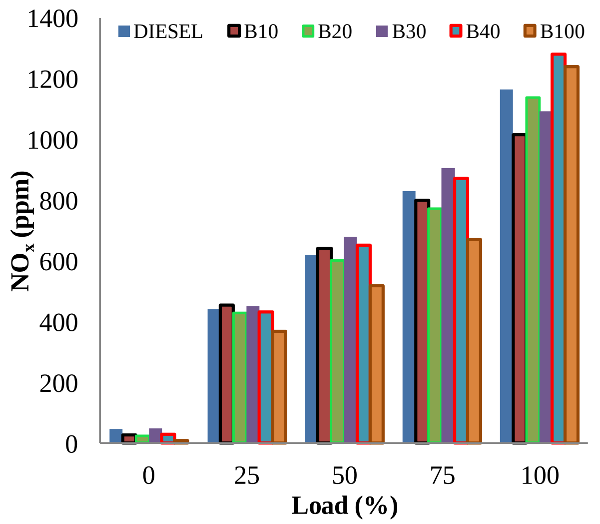

Fig. 5: Variation of NOX emission with load

5. Smoke opacity

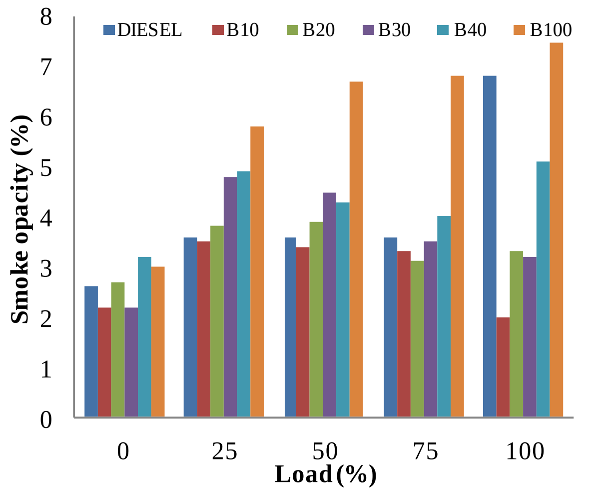

Fig. 6: Variation of Smoke opacity with load

The diesel engine emissions visible product obtained by combustion of fuel is known as smoke. The emission of smoke is due to the high rate of fuel consumption [46] and incomplete combustion of fuel in diffusive combustion phase. The comparison of smoke opacity of ES biodiesel blend and base diesel at different loading is shown in Fig. 6. It is noted from the graph that the smoke opacity at part load conditions for ESME blends is comparatively higher than base diesel, but as the load on engine is increased to maximum level, a significant reduction in the smoke opacity is observed for ESME blends, except the B100 blend which increases as the load increases.

High viscosity of biodiesel blends contributes to poor atomization at part load condition leading to higher opacity. At peak load the smoke opacity is reduced upto 70.5%, 51.47% 52.94% and 25% for B10, B20, B30 and B40 respectively when compared to diesel base line. The formation of smoke at peak loads is reduced due to biodiesel oxygenated nature, which leads to the clean and complete combustion [47].

IV. CONCLUSIONS

The study was performed for production of biodiesel from Eruca sativa and by using it as feedstock the emission characteristics of diesel engine were examined. According to the experimental analyses the following results are summarized as follows:

- The oil yield obtained from Eruca sativa seeds by mechanical expeller is found to be 34%.
- Alkali based transesterification was performed for production of ES biodiesel. The biodiesel yield obtained is 91%.
- All the ES biodiesel properties satisfies and meet ASTM D-6751 standard specification and it has calorific value 43.459 MJ/kg, which is higher than other biodiesel. Therefore, it can be considered as a potential biodiesel feedstock.
- The fatty acid methyl ester composition for ES biodiesel is mainly composed of 38.6% erucic acid, 12.9% linolenic acid and 12.3% oleic acid.
- The CO and CO_2 emission is lower for B10 and B20 blend as compared to that of diesel at all loads.
- The HC emission is accounted to be lower than diesel for all the blends at all loads and it is minimum for B100.
- NO_X emission has been found to be reduced for B10, B20 and B30 ES biodiesel blends compared to diesel.
- Smoke opacity for all the blends is higher than diesel at partial load, while at peak load condition it is lower for all blends except B100.

Finally it can be concluded that, without any alteration Eruca sativa biodiesel and its blends can be used to run the engine. The research also proves that the emissions from the engine, has been reduced by blending with Eruca sativa biodiesel.

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