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Fuelling a Small Capacity Diesel Engine with Ethyl Ester of Industrial Rice Bran Oil

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Abstract: *Fast depletion of petroleum fossil fuels coupled with increasing environmental concerns have necessitated the use of renewable, cleaner alternative fuels for use in transportation, agriculture and industrial sectors. Biodiesel is fast gaining momentum as a viable alternative fuel not only in India but worldwide. This study reports two-stage formulation process to convert industrial grade RBO into ethyl ester (biodiesel), physio-chemical characterization of biodiesel and evaluation of performance and emission characteristics of a Compression Ignition engine using biodiesel and its blends with diesel fuel. Maximum yield of 91% of biodiesel was achieved in two stage formulation process. As biodiesel proportion with diesel was increased up to 30%, engine performance improved. However, beyond 30% substitution of biodiesel in diesel, there was no further improvement in the performance. The emission level of UBHC, CO and smoke were significantly lesser with use of biodiesel with diesel as compared to neat diesel operation. However,* NO_x *emission in general was found to be higher in case of biodiesel-diesel blends as compared to diesel fuel.*

Keywords: *Biodiesel, Rice bran oil, Transesterification, Esterification*

Abbreviation

BSEC	:	Brake Specific Energy Consumption
BTE	:	Brake Thermal Efficiency
CO	:	Carbon Mono-oxide
CO_2	:	Carbon Dioxide
Mtoe	:	Million tonnes of oil equivalent
NO_x	:	Nitrogen Oxides
n-PAHs	:	Nitro-poly aromatic hydrocarbons
PAHs	:	Poly aromatic hydrocarbons
PM	:	Particulate Matter
RBO	:	Rice Bran Oil
SOF	:	Soluble organic fraction
THC	:	Total Hydro Carbon
UBHC	:	Un-burnt Hydro Carbon

Introduction

Energy sources are the main driver of economic growth and social development of a country. There has been an exponential increase in the consumption of fossil fuels both in developed and developing nations. Oil and gas provide more than half of the total global energy demands and there is an ever increasing gap between the supply and demand of these fuels owing to rapid industralization and urban development. It is estimated that these fuels shall be completely exhausted by the turn of 22nd Century. The emissions from the combustion of these fuels such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx) and sulphur-containing residues are the principal causes of global warming and many countries have passed legislation to arrest their adverse environmental consequences and present emphasis is essentially focused on environmental friendly energy sources [1].

India, one of the fastest growing economies of the world, does not have large reserves of petroleum products and is heavily dependent upon the import of crude petroleum to meet its rising need for automobiles, agricultural and several other industrial applications. India has imported 110.86 million ton of crude oil (76% of its requirement) during 2006-2007 causing 2,19,991 crores of rupees burden on foreign exchequer. The demand of crude oil and country's crude oil import bill has increased substantially in last four decades (Table 1).

India, the world's second most populous nation, has seen its population explode from 357 million in 1950 to approximately 1.129 billion in 2007 [4]. To meet the energy demand of about 16% of the world's population, India is required to use both renewable and exhaustible energy resources. The primary energy consumption of India is increasing exponentially due to rapid economic growth and has increased from 296 million tonnes of oil equivalent (Mtoe) in 1998 to 423.2. Mtoe in 2006 (Table 2).

Table 1. Production and Demand of Crude Petroleum in India [2,3]

Year	Production Million ton	Import Million ton	Total Million ton	Import As % of total	Import value Rs. Crore
1971	6.8	11.7	18.5	63.	107
1981	10.5	16.2	26.7	61	3349
1991	33	20.7	53.7	39	6118
2000	32	57.9	89.9	64	30,695
2003-04	33.4	90.4	123.8	73	81,000
2006-07	33.99	110.86	144.85	76.5	2,19,991

Table 2. Primary energy consumption of India and World [5]

Year	India, (Mtoe)	World, (Mtoe)
1998	296.0	8925.9
2002	320.4	9285
2001	324.2	9348.2
2003	348.2	9832.2
2005	387.3	10537
2006	423.2	10878.5

The Coal accounts for major share in primary energy consumption of India followed by oil and natural gas (Table 3).

Reserves to production (R/P) ratio for crude oil and natural gas was 19.3 and 33.9 respectively at the end of year 2006 (Table 4).

Internal Combustion (IC) engines form an indispensable part of industrial growth and modernized agricultural sector. The diesel engine finds wide usage in the fields of transportation, power generation, agriculture, earth moving machines and several industries due to its inherent fuel economy, ease in operation and maintenance and long life. However, diesel emission contains carcinogenic components, such as carbonyl compounds (formaldehyde), light aromatic hydrocarbons (benzene), poly aromatic hydrocarbons (PAHs) and nitro-poly aromatic hydrocarbons (n-PAHs). Although diesel engine produces lesser amount of CO and total hydrocarbon compounds (THC) than spark ignition (SI) engine, it forms large quantities of fine particulate matter (PM). Diesel particles mainly consists of carbonaceous material, soluble organic fraction (SOF), sulphates and traces of metals. Some constituents of SOF (PAHs and nitro-PAHs) are mutagenic and/or carcinogenic [6,7].

Indian economy is essentially diesel driven and the consumption of diesel fuel is four to five times that of motor-gasoline (Table 5). This trend is characteristically different from several developed economies.

Table 3. Primary energy consumption of India and World fuel wise (Mtoe) [5]

	Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Total
India	120.3	35.8	237.7	4.0	25.4	[illegible]23.3
World	3889.8	2574.9	3090.1	635.5	688.1	[illegible]0878.5

Table 4. Reserves of fossil fuels and R/P ratios for India and World in 2006 [5]

	Reserve		R/P ratios	
	India	World	India	World
Coal (billion tonnes)	92.44	909.06	207	147
Crude oil (billion tonnes)	0.8	164.5	19.3	40.5
Natural gas (trillion cubic meters)	1.08	181.46	33.9	63.3

Table 5. Comsumption of Gasoline and Diesel in India [3]

Year	Gasoline consumption (Mt)	Diesel consumption (Mt)	Ratio of diesel/ gasoline
1997-98	5.182	36.07	6.96
2000-01	6.613	37.95	5.73
2002-03	7.57	36.64	4.84
2004-05	8.25	39.65	4.80
2006-07	9.28	42.86	4.61

The use of alternative fuels have been effectively utilized for partial or complete substitution of conventional petroleum fuels in diesel engines to address the issues of fossil fuel depletion and environmental degradation. However, a long-term regular use of alternative fuels requires identification of large and long-term resource base to ensure availability and justify the investment. Such fuels should be renewable, compatible for use in existing engines and associated systems (such as fuel tank, pumps and hoses) as well other existing fuel storage, transportation and retail infrastructure. Amongst several renewable fuels, particularly biodiesel is getting more attention in India [8-16]. Biodiesel has several outstanding advantages among other renewable and clean engine fuels. The main driving forces behind the implementation of biodiesel in the country are rural economy, energy security, employment generation and environmental concerns. Being biodegradable, the production of biodiesel is considered to havean edge over fossil fuels. Many researchers have reported reductions in harmful exhaust emissions as well as a comparable engine performance with the use of biodiesel as a fuel in diesel engines [17-21].

In Indian circumstances, only such plant sources can be considered for biodiesel production which are essentially non-edible oil and are available in appreciable quantities. Rice bran oil (RBO) offers significant potential as an alternative low-cost feedback for biodiesel production. High viscosity of RBO may contribute to the formation of carbon deposits in the engines, incomplete fuel combustion and result in reducing the life of an engine if used in neat form. Therefore, main objective of present study is to decrease viscosity of RBO by converting it into ethyl ester, and to evaluate engine performance using ethyl ester of RBO as a fuel. RBO, extracted from rice bran (Fig. 1), is a by product of the pearling process of rice and comprises pericarp, aleurone layer, embryo and some endosperm. Bran (8% of milled rice) contains: oil, 15-20; wax, 0.4-1.5; protein, 5-8; soluble carbohydrates, 40-50; and fibre, 5-8%. Rice bran is invariably high in FFAs. After milling, enzyme in the bran is activated and starts to hydrolyze the oil contained in the bran, which produces excessive FFA. Physico-chemical properties of RBO are: specific gravity, 0.916-0.921; refractive Index at 25°C, 1.470-1.473; acid value, 4-120; saponification value, 181-189; iodine value, 99-108; peroxide value, 2 max; and unsaponifiable matter, 3-5% [22].

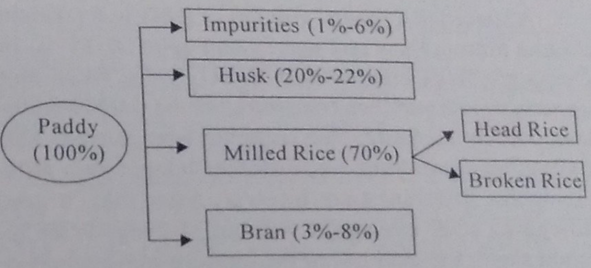

Fig. 1. Composition of rice bran

Most of the biodiesel all over world is made by reacting methanol with vegetable oil. However, in Indian context production of ethyl ester has more relevance than methyl ester due to the large scale cultivation of sugar cane and sweet sorghum for production of ethanol.

Many researchers have tried producing ethyl ester from different vegetable oils [23-25]. However, most of the work has been done with edible vegetable oil whereas more potential exists in India for production of biodiesel from non-edible feedstocks such as industrial rice bran oil.

2. Materials

The industrial grade high FFA RBO was procured from a local oil trader of Delhi, India and commercially available diesel oil was purchased from the nearby petrol pump. All reagents used were of LR Grade.

3. Experimental Procedure

The acid no. of the RBO was evaluated by ASTM D-664 to quantify the FFA content in the oil. The acid no. was determined as 85 which was very high and indicated high FFA content (around 42.5%) in the oil. Therefore it was not considered suitable to make biodiesel from this oil through base catalyzed transesterification process. RBO was converted into its ethyl ester by the two stage process i.e. Two Stage Integrated Pre-esterification of Free Fatty Acid and Base Catalyzed Transsesterification Process.

In the first stage, RBO was reacted with ethyl alcohol in the presence of an acid catalyst (sulfuric acid) to convert the FFA into fatty ester. Different values of alcohol/oil molar ratio, catalyst amount, stirring speed and temperature were selected in a view to optimize the process parameters. After first stage was completed, KOH was taken as a catalyst for the second stage and different values of alcohol/oil molar ratio, catalyst amount, stirring speed and temperature were selected in a view to optimize the process parameters in second stage also. Table 6 summarizes the different process parameters selected for both first as well as second stage.

A specified amount (1000 g) of RBO was taken in a round bottom flask and was heated up to 50-75 °C. In a separate flask ethanol and H_2SO_4 were taken and properly mixed and then transferred to the round bottom flask containing RBO. The contents were stirred. The mixture was maintained at different temperature with stirring for different time interval. After that, it was allowed to cool overnight without stirring. Prior to second stage, the acid no. of the mixture was evaluated and since the acid no. was found to be less than 1, the second stage was started. During this stage, 1000 g of the mixture obtained from the first stage was taken in a round bottom flask and heated up to different temperature. Ethanol and KOH was properly mixed in other flask and was introduced into the round bottom flask containing the mixture from first stage. The mixture was stirred vigorously for different time interval and then allowed to cool overnight. The separation of glycerol was made by the introduction of warm water at 60°C to the mixture. The glycerol and soap formed during the process settled down at the bottom along with the water and ethyl ester was on the top. The top layer was removed with the help of a separating funnel and washed two times with water and dried.

After a series of exhaustive experiments, the following process parameters (Table 7) were evaluated as the optimal process parameters.

The different blend of ethyl ester with diesel [illegible] volumetric basis (Table 8) were prepared.

Table 8. Different fuel blends

Sl. No.	Nomenclature	Ree diesel blend (v/v)	
		REE (%)	Diesel (%)
1.	D 100	00	100
2.	REE 10	10	90
3.	REE 20	20	80
4.	REE 30	30	70
5.	REE 40	40	60
6.	REE 60	60	40
7.	REE 80	80	20
8.	REE 100	100	00

The physio-chemical characterization of ethyl e[illegible] of rice bran oil and diesel was carried in accorda[illegible] with appropriate ASTM standards and all the propert[illegible] of ethyl ester were found under prescribed lim[illegible] (Table 9).

4. Engine Test

The single cylinder, direct injection, diesel engi[illegible] (M/s Perry & Co., India) used for this study wa[illegible] 4kWh Gen-Set used for agricultural purpose and [illegible] many small and medium scale commercial purposes[illegible] was a single cylinder, four stroke, vertical, water-coo[illegible] engine having a bore and stroke of 85 & 110m[illegible] respectively. The compression ratio was 16.7. At ra[illegible] speed of 1500 rpm, it developed 4kWh power with die[illegible]

Table 6. Selected process parameters

Stage	catalyst Type	Catalyst Conc. (% wt/wt of oil)	Alcohol/Oil molar ratio	Temp. (°C)	[illegible]	Speed (rpm)
I	H_2SO_4	1, 2, 3, 4 and 5%	6:1, 12:1 18:1 and 24:1	50, 55, 60, 65, 70 and 75°C	[illegible]	125, 250, [illegible]0 and 625
II	KOH	0.25, 0.5, 0.75, 1, 1.5 and 2%	3:1, 6:1, 9:1 and 12.1	50, 55, 60, 65, 70, and 75°C	[illegible]	[illegible]5, 250, 375, [illegible]0 and 625

Table 7. Optimized process parameters

Stage	catalyst Type	Catalyst Conc. (% wt/wt of oil)	Alcohol/Oil molar ratio	Temp. (°C)	Speed (rpm)	Yield %
I	H_2SO_4	4	18:1	75°C	500	53
II	KOH	3	12:1	75°C	500	91

Table 9. Physico-chemical properties of different test fuels

Stage	ASTM Method	Diesel	REE 100	REE 30
Higher Calorific Value (KJ/Kg)	D-4809	44585	41641	4370
Density (kg/m^3)	D-4052	0.831	0.868	0.841
Kinematic Viscosity @ 40°C (mm^2/S)	D-445	3.21	4.97	3.72
Acid No. (mg.KOH/gm)	D-664	0.2	0.067	0.083
Cloud Point	D-2500	-12	2	-9
Pour Point °C	D-97	-17°C	-6°C	-13
Flash Point °C	D-93	76°C	136°C	85
Water Content (Karl Fisher)	D-1744	120	328	197
Copper Strip Corrosion	D-130	1A	1A	1A
Ramsbottom Carbon Residue, % wt	D-524	0.05%	0.028%	0.031%
Cetane Mumber	D-613	47.2	52.8	50.7
Lubricity (HFFR Test)	D-6079	450	263	262
Elemental Analysis				
C, %		86.71	77.05	83.61
H, %		12.98	12.66	12.85
O, % (by difference)		0.31	10.29	3.54
N, ppm		5	7	3
Sulfur Content (ppm)	D-2622	340	11	246
Phosphorus, ppm	D-4951	3	7	4
Distillation Characteristic				
IBP	(D-86)	159	302	203
T10		222	330	231
T50		241	346	267
T90		309	357	337
FBP		336	362	348
API Gravity	D-287	38.77	31.52	36.75
Cetane Index	D-976	47.14	52.54	50.21

as fuel. It had a provision of loading electrically since it was coupled with a single phase alternator through flexible coupling. The inlet valve opens at 4.5° Before Top Dead Center (BTDC) and closes at 35.5° After Bottom Dead Center (ABDC). The exhaust valve opens 35.5° Before Bottom Dead Center (BBDC) and closes 4.5° After Top Dead Center (ATDC). The fuel injection pressure was maintained at 200 bar throughout the experiment. The engine was tested with 20, 40, 60, 80% and full rated output and the rated speed of 1500 rpm only. The engine has run smoothly through the whole study and no major problem was reported.

5. Engine Test Results & Discussions

5.1 Brake Thermal Efficiency

Fig. 2 depicts brake thermal efficiency versus brake mean effective pressure for all selected REE fuel blends. For all the fuels, brake thermal efficiency has the tendency to increase with increase in applied load. This is due to the redcution in heat loss and increase in power developed with increase in load. The figures show a slight improvement in BTE with biodiesel addition up to 30 percent and a decreasing trend beyond 30% substitution level. The molecules of biodiesel contain some amount of oxygen, which takes part in the combustion process. It is observed that after a certain limit with respect to biodiesel blends, the thermal efficiency trend is reverted and it starts decreasing as a function of the concentration of biodiesel in the blend. This may be due to improved combustion with lower percentage substitution of biodiesel in diesel and this effect being offset a higher substitution due to lower calorific value. The maximum thermal efficiency has been observed at 30% substitution of REE in diesel. The lower brake thermal efficiency obtained for B100 could be due to the reduction in calorific value and increase in fuel consumption as compared to lower concentration biodiesel-diesel blends. This indicates that the thermal efficiency is a more representative reflection of the fuel economy by using the diesel equivalent BSFC or energy consumption rate when operated on oxygenated fuels like biodiesel.

The above results are in agreement with the results reported by Ramadhas et al. [13] on rubber seed oil biodiesel. It has been observed that BTE at full load for diesel and REE 100 are 22.1 and 19.35% respectively. For REE 30, its value is 22.06% suggesting that BTE for REE 30 is comparable with diesel.

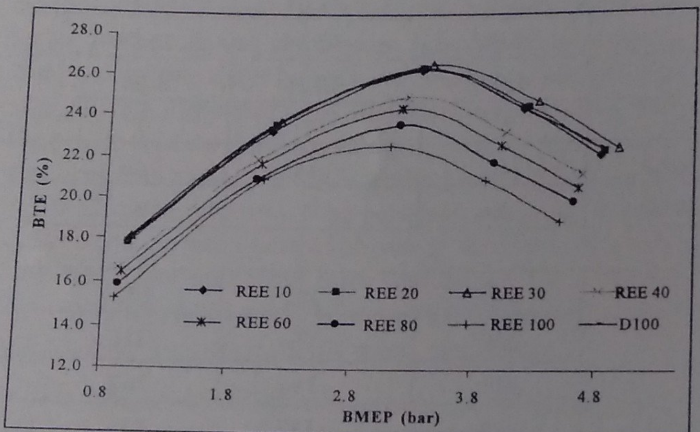

Fig. 2. Brake thermal efficiency vs brake mean effective pressure for REE fuel blends

5.2 Brake Specific Energy Consumption

Brake specific fuel consumption is not a very reliable parameter in respect of a dual fuel engine to compare the two different fuels as the calorific value and specific gravity of the fuels follow different trends. Hence, brake specific energy consumption of a given fuel is a better representation of engine performance. Fig. 3 shows brake specific energy consumption versus brake mean effective pressure for all selected REE fuel blends respectively. It is clear from both the figure that as the load increases, the BSEC decreases for all the fuel blends. REE 30 has exhibited the lowest BSEC at high load. However at low load, the variation is not significant. At the same time, it has been found that the BSEC increases slightly with B40, B60, B80 and B100 fuel blends. Such a trend is due to the fact that biodiesel has inbuilt oxygen content and with higher percentage substitution of biodiesel (40, 60, 80 and 100) in diesel fuel on volumetric basis, the heating value of fuel blends decreases and air-fuel mixture becomes lean resulting in more energy required. For lower percentage substitution of biodiesel in diesel fuel a higher load condition (60, 80% and full load), BSEC were observed to be lower. This was due to higher calorific value of low percentage biodiesel-diesel blends and improved combustion.

It has been found that BSEC for diesel and REE 100 are 16.31 and 19.3. MJ/kW-h respectively. For REE 30 value is 16.31 MJ/kW-h suggesting that BSEC for REE 30 comparable with diesel.

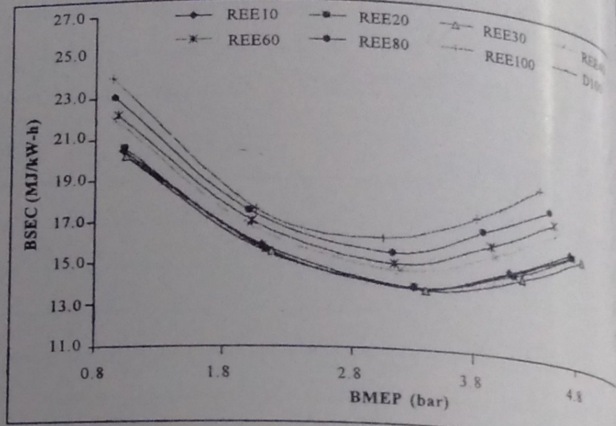

Fig. 3. Brake specific energy consumption vs brake mean effective pressure for REE fuel blends

5.3 Smoke Opacity

Fig. 4 shows the smoke opacity versus brake mean effective pressure for different REE fuel blends. It can be noted that smoke is high mainly at high power output. The high loads imply that more fuel is injected into the combustion chamber and hence incomplete combustion fuel is amplified.

The figure illustrates reduction of 10 to 25% smoke emissions for different biodiesel-diesel blends in comparison to diesel fuel for all load conditions. With increase of biodiesel in biodiesel-diesel fuel blends, smoke decreases at most of the operating conditions. However the maximum smoke reduction has been observed in case of REE 30. The reduction in smoke can be explained by the presence of less carbon with biodiesel based fuels as compared to diesel. In addition to that, biodiesel has more oxygen content contrary to diesel, which has almost no oxygen. The presence of oxygen in the biodiesel is in favour of carbon residual oxidation, which leads to a reduction in smoke opacity.

The smoke is produced mainly in the diffusive combustion phase, the addition of oxygenated fuel such as biodiesel leads to an improvement in diffusive combustion. Moreover, it can be found that smoke opacity decrease

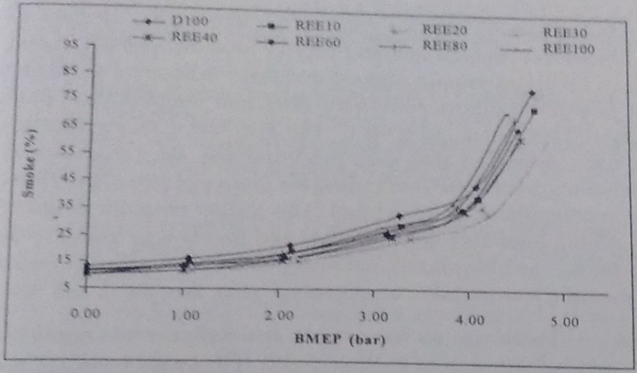

Fig. 4. Smoke opacity vs brake mean effective pressure for REE fuel blends

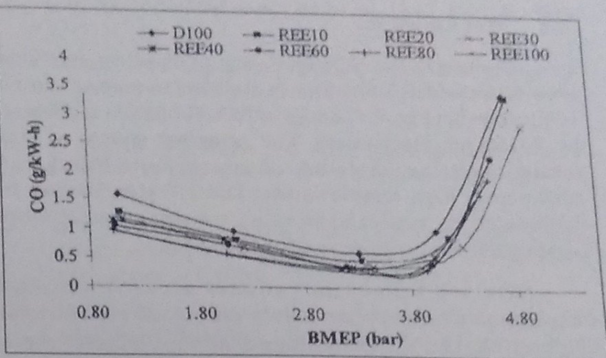

Fig. 5. CO emission vs brake mean effective pressure forREE fuel blends

more at higher loads than that at lower loads for blended fuels. This is quite practical as more fuels are supplied for the large load and short time is available for preparation of the air/fuel mixture as already mentioned. This factor leads to the improvement of combustion quality for blends when compared to diesel fuels. These results are in agreement with the results reported by Puhan et al. [26].

It has been observed that smoke opacity for diesel and REE 100 are 82.4 and 71.2% respectively suggesting that smoke opacity for REE 100 is significantly lower than diesel. In case of REE 30, smoke opacity is 59.9%.

5.4 CO Emissions

Fig. 5 illustrate the brake specific CO emissions versus brake mean effective pressure for different REE fuel blends. For all the test fuels, CO emission decreases slightly with increasing load but at higher load it increases. The increase in CO emission levels at higher load is due to rich mixture at higher load condition than those of lower load which results in incomplete combustion of fuel. The lowest CO emissions have been observed on medium loads for all fuel blends. This is typical with all internal combustion (IC) engines since air/fuel (A/F) ratio decreases with increase in load. The CO emissions increase with increased fuel/air (F/A) ratio greater than the stoichiometric value. CO is the ideal emission product assessor since when a homogeneous mixture is burned at stoichiometric A/F ratio mixture or on the lean side of stoichiometric, the exhaust concentration of CO is negligibly small. The lowest CO emissions have been observed in case of REE100. This is due to increased A/F ratio of higher concentration biodiesel/diesel blends because of inbuilt oxygen content. These results obtained in the present investigations are also similar to the results obtained by Usta [27] in their studies.

It has been found that CO emission for diesel and REE 100 are 3.38 and 1.87 g/kW-h respectively suggesting that CO emission for REE 100 has been significantly lower than neat diesel. In case of REE 30, the CO emission is 2.82 g/kW-h.

5.5 UBHC Emissions

Fig. 6 illustrate the brake specific UBHC emissions versus brake mean effective pressure for different RME and REE fuel blends respectively. Hydrocarbon emissions are mainly caused due to the incomplete combustion of hydrocarbon fuel. It is clear from both the figures that there is significant reduction in UBHC emissions of different biodiesel-diesel blends in comparison to neat diesel fuel at lower and medium load conditions. At 60% load, a reduction of 10.2 and 10.5% in UBHC emissions has been observed in case of RME 100 and REE 100 respectively in comparison to neat diesel. At higher loads, this gain was offset since at higher loads, more fuel is injected resulting in richer air fuel mixture. The pattern of UBHC variation follows the same trend as reported by Canakci [28].

The variation of UBHC emissions of all the test fuels at full load is shown in Fig. 6. It has been found that UBHC emissions of diesel, RME 100 and REE 100 are 0.125, 0.13 and 0.131 g/kW-h respectively suggesting that emissions of REE 100 are similar to diesel. In case of REE 30, UBHC emissions is 0.121 g/kW-h respectively.

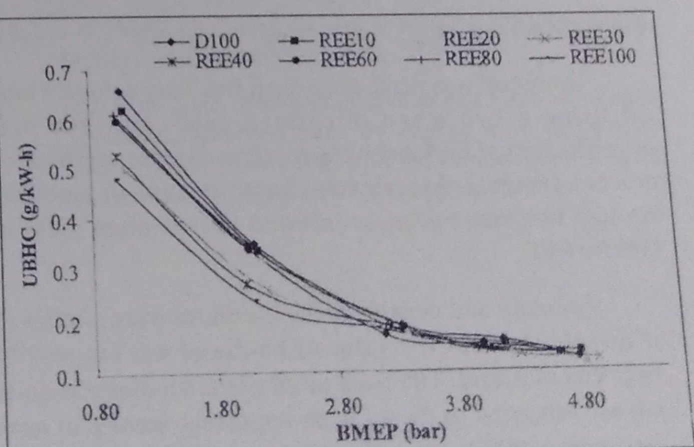

Fig. 6. UBHC emissions vs brake mean effective pressure for REE fuel blends

5.6 NOx Emissions

Brake specific NOx emissions of diesel engine fueled with different REE fuel blends at different load conditions is illustrated in Fig. 7. Kinetics of NOx formation is governed by Zeldovich mechanism. The principal source of NOx formation is the oxidation of atmospheric nitrogen at sufficiently high temperatures. The NOx emissions are determined by equivalence ratio, oxygen concentration, combustion temperature and time [29].

NOx are formed in cylinder areas where high temperature peaks appear mainly during the uncontrolled combustion. The NOx emissions of all the biodiesel-diesel blends have been found higher than diesel at higher loads. It has been found maximum in case of REE 100. It is quite obvious, that with biodiesel addition in diesel more amount of oxygen is present in combustion chamber, leading to formation of higher quantity of NOx in biodiesel fueled engines. The results related to NOx emissions are very much similar to earlier studies reported by Nabi et al. [30]. It has been found that NOx emissions for diesel and REE 100 are 2.41 and 3.29 g/kW-h respectively suggesting that NOx emissions for REE 100 are significantly higher than diesel. In case of REE 30, NOx emissions is 2.67 g/kW-h respectively.

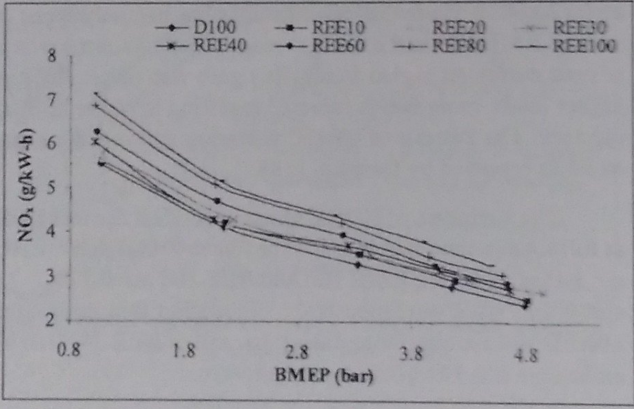

Fig. 7. NOx emissions vs brake mean effective pressure for REE fuel blends

6. Conclusions

Biodiesel was made from high free fatty acid rice bran oil using a two stage integrated acid-catalyzed pre-esterification of FFA and base-catalyzed transesterification process. Optimized parameters for production of biodiesel through two stage process resulted in maximum yield of 91% for REE.

Viscosity and density of the biodiesel were similar to the diesel. The calorific value of biodiesel was around 7% lower that of diesel. The flash point of the biodiesel is quite high as compared to diesel is an important feature in term of reduction of SO_2 from the exhaust emission. The HFFR test suggests that lubricity of biodiesel in comparison to diesel is much higher. The Cetane number, which is the indication of ignition quality, is also higher [illegible] biodiesel made from high FFA rice bran oil. The [illegible] of biodiesel sample suggest that there is no need of [illegible] pour point suppressant in the biodiesel samples [illegible] point was observed as -6°C. The distillation characteristics have indicated that neat biodiesel has very high [illegible] boiling point (IBP) indicating the low volatility of [illegible] in comparison to diesel fuel. The copper strip corrosion [illegible] all the biodiesel-diesel blends and diesel was found [illegible] same. The phosphorus and nitrogen content in the [illegible] sample was found to be slightly higher than the diesel.

There was an increase in brake power of engine [illegible] 30% substitution of REE in diesel. The brake power of [illegible] engine decreases with increase in biodiesel content [illegible] biodiesel-diesel fuel blends beyond 30% substitution [illegible]. The brake power increased by 0.25%, 1.5[illegible]% and [illegible]% [illegible] 10, 20 and 30% substitution REE in diesel. The more brake specific energy consumption was observed for [illegible] blends beyond 30%. However, decrease in BSEC [illegible] substitution of biodiesel was observed. The lower [illegible] specific energy consumption was observed with REE [illegible]. There was an increase in brake thermal efficiency [illegible] biodiesel-diesel blends up to 30% and thereafter [illegible] decreased. The highest brake thermal efficiency [illegible] observed with REE 30. As far as the exhaust emission charactristics are concerned, both CO and HC emission levels was relatively lower over the entire range of [illegible] operation when biodiesel was blended to conventional diesel. NOx emissions were higher with addition of biodiesel. Smoke emission characteristics exhibited a very [illegible] trend. It was substantially reduced up to B30, but [illegible] shown to be higher beyond 30% blending. [illegible] improvement in engine performance and emission characteristics with lower percentage substitution [illegible] biodiesel in diesel fuel was due to better combustion [illegible] fuel blends as compared to diesel fuel due to inbuilt oxygen content of biodiesel.

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