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Non-Edible Castor Oil – An Esoteric Potential Foliage of Methyl and Ethyl Ester, a Sustainable additive Package for Agricultural Diesel Engines

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Abstract

Ever augmenting world energy demand rationalise to prolific urbanization, better living standards and increasing population. When society is cognizant of depleting reserves of fossil fuels beside the deteriorating global climate, it is apparent that biodiesel promises to make a handsome contribution to the future energy demands of the domestic and industrial economies. Among different edible (crop based) and non-edible potential foliages of biodiesel (mono alkyl esters) castor is an esoteric potential of sustainable energy and promising substitute for crop-based biodiesel. The present work investigates the possibility of a novel fuel additive package synthesized from castor oil for agricultural diesel engines. The research challenge of fuelling diesel engines with crude castor oil in absolute package concerns its high viscosity. The mechanism of transesterification using lower or higher alcohols subsides the viscosity of crude castor oil to an acceptable range and other properties were evaluated using diesel as baseline fuel. In present investigation, castor oil methyl and ethyl esters (COME and COEE) were synthesized using both methanol and ethanol. The physical and chemical properties of COME and COEE were proximal and COME revealed a little higher viscosity than that of COEE. Low temperature operability (cloud point and pour point) of COEE were better than those of COME. Engine performance and exhaust emission characteristics were analysed using additive package to diesel such as COME20, COEE20 and absolute package of COME, COEE, with petroleum diesel being the standard fuel. Results inferred that COME yielded a little higher power than that of COEE and hazardous emissions of COEE being slightly lower than that of COME. The research work concludes that both COME and COEE can be used as an additive package (20%) to petroleum diesel in agricultural CI engines without any modification in engine hardware. However absolute package of COME and COEE to agricultural CI engines extends the research work to an aesthetical change in engine hardware facilitating preheat up to 60-100^{0}C overcoming cold weather operability.

Keywords: Non-Edible Castor Oil, Esoteric Potential Foliage, Sustainable, Additive, Package, Agricultural Diesel Engines.

Introduction

The draining out reserves of fossil fuels and the tainted environmental concerns has made renewable energy a promising future source of alternative energy[1,2]. It is renewable, biodegradable, environmental friendly, non-toxic, portable, readily available and eco-friendly fuel[3-6]. Research by Ramadhas AS et al revealed that no expressive adulteration were reported in tests with urban transportation engines running on B20 with fuel consumption being only 2–5% higher than that of conventional diesel[7]. A 200 h engine tests with soybean oil methyl, ethyl and butyl esters on John Deere (4239T Model) engine inferred a proximal performance with petroleum diesel; Wagner et al[8]. However the challenge of low temperature operability by fuelling absolute package of esters in diesel engines was still imperative. The present work is based on selecting Indian wild castor, an esoteric potential foliage of sustainable energy source and analyzing the possibility of a novel fuel additive package synthesized from castor oil for agricultural diesel engines with pros and cons. Both COME and COEE were synthesised by transesterification reaction using homogeneous acid–base catalyst.

Castor oil: Castor (*Ricinus communis*) is a rarefied non edible potential foliage of sustainable energy source among other oil seeds belonging to Eurphorbiaceae family which can grow in arid and semi arid lands[9-10].This esoteric potential sustainable energy source is grown in many countries like United States, India, China, Central Africa, Brazil and Australia with different cultivation methods having oil content about 46–55%[11-14]. Castor oil is toxic to human consumption, moisture absorbing, viscous with principal constituent being triglyceride which includes approximately 80–90% of ricinoleic acid (12-hydroxy-*cis*-octadec-9-enoic acid), 3–6% linoleic acid, 2–4% oleic acid, and 1–5% saturated fatty acids. The seeds of this foliage harvested from 12,600 km^2 of arid and semi arid lands around the world lead to an average yield of 902 kg/ha, no competition with edible crops hence is an esoteric potential of sustainable energy source[15,16]. Figure-1 shows the wild Indian castor plant fruits and seeds.

Figure-1
Castor plant with fruits and seeds

Materials and Methods

Substrates used: The wild Indian castor seeds were collected from tribal peoples of western Odisha, Kalahandi district India. Oil was extracted from seeds by a mechanical expeller in the laboratory, filtered to separate the residues and the resultant oil obtained called crude oil. The crude oil thus obtained is allowed to react chemically with methanolic ortho-phosphoric acid (H_3PO_4) solution and centrifuged at high rpm to remove alkaloids and gum from it.

A homogeneous solution of 25 ml methanolic H_3PO_4 (12%, v/v) with 100 ml crude oil was prepared and allowed to stand overnight. Next day the oil was separated from methanol layer and sediments are filtered through silica gel (60–120 mesh) under suction. The resultant oil thus obtained is called refined alkaloid free castor oil (RCO). Properties of RCO were presented in Table-1.

Transesterification requirement was ascertained as shown in Table-2. The properties of RCO was compared with that of methyl and ethyl esters of same after transesterification as presented in Table-3. Engine performance of COME20, COEE20 absolute COME and COEE was evaluated in a Kirloskar TV1 naturally aspirated engine using petroleum diesel as base line fuel. The exhaust emissions were also noted employing an AVL make gas analyser.

Preparation chemistry (COME, COEE): The present work is aimed to investigate the substantial difference in reaction mechanisms existing between synthesis of COME and COEE using methanol and ethanol separately by same method. Secondly the engine performance and exhaust emission characteristics were analysed using ester blends such as COME20, COEE20 and absolute COME, COEE, with petroleum diesel being the standard fuel. Refined castor oil (RCO) has very high free fatty acid (FFA) composition. Single step esterification of high FFA content oil using base catalysts cannot convert the RCO to mono alkyl esters because the base catalyst react with FFA(moisture absorbing) to produce soaps which prevents the separation of esters and glycerine. Using acid catalysts, esters could be produced from high FFA content oils with reaction time substantially larger and effectively convert FFA to esters[17]. So COME and COEE were synthesised by transesterification reaction using homogeneous acid–base catalyst. A meticulous review of the existing literature survey unveils that only esoteric researchers worked with the production of mono alkyl esters (biodiesel) from non edible vegetable oils having high FFA composition[17-24].

Table-1
Properties of refined castor oil

Free fatty acid (wt %)	0.619
Density Kinamatic viscosity @40^{0}C	0.93 gm/cm^3 61.3 cst
Acid value	28mg of KOH/gm of oil
Saponification value	182.2(mg KOH/gm of oil)
Unsaponifiable matter	2.7 (w/w %)
Iodine value	68 g I_2/100 gm

Transesterification: A magnetic stirrer of 1000 ml capacity facilitating temperature and speed control was selected for transesterification reaction. Initially the stirrer speed was set at 600 rpm to eliminate possibility of mass transfer. The temperature of the stirrer was set at 30^0C and catalyst (H_2SO_4, KOH) diluted in ethyl alcohol was added to the reactor with pressure and stirrer speed set constant. After the reaction time of 90 min a high conversion to ester (biodiesel) was achieved quickly. The same method was followed to obtain methyl ester by changing over to methanol. The transesterification requirement ascertained for producing the esters was shown in Table-2.

Table-2
Transesterification requirement

Transesterification requirement	COEE	COME
Castor oil	500 gm	500 gm
Ethanol (6:1) with respect to oil	175 gm	150 gm
Temperature	75^0C (±3^0C)	65^0C (±3^0C)
KOH (1%) H_2SO_4 (1%)	5 gm 5 gm	5 gm 5 gm
Time period	90 min	60 min
RPM	600	600

Properties prone to combustion (COME, COEE)

Baiju B. et al say fatty acid esters type and molecular structure determines biodiesel fuel properties[25]. The pertinent physicochemical properties of the COME and COEE sample were evaluated as per ASTM standards (Table-3) and compared with that of petroleum diesel. The ascertained transesterification process improved the COME and COEE properties as conspicuous from Table-3. Viscosity of the COME and COEE was drastically reduced and was proximal to that of petroleum diesel. The flash point also plummets from an absurd value to an acceptable range satisfying IS: 15607 specifications (Table-3). These properties clearly indicate the effective combustion of COME and COEE in a diesel engine without any engine modification. However poor cold flow properties (Cloud point and pour point) are still imperative which can be addressed by using COME and COEE as an additive (20%) to petroleum diesel. The absolute COME and COEE can be fuelled to the engine with modification in engine hard ware facilitating preheat up to 60-100^0C.

Engine Setup

Kirloskar make four stroke, naturally aspirated, water cooled and single cylinder diesel engine coupled with edicurrent dynamometer was employed for present study Figure-2. The engine was computerised with engine soft (software) to measure the engine performance parameters. AVL make gas analyser was employed to note the exhaust emissions such as carbon dioxide, unburnt hydrocarbon, carbon monoxide, oxygen, and nitrous oxides. Performance and emission parameters were noted by fuelling COME20,COEE20, absolute COME, COEE and petroleum diesel for analysis. The reference study was based on petrolium diesel to interpret the data for comparison. The test was conducted at 1500 rpm with varing loads. Table-4 shows the engine specifications.

Table-3
Physicochemical properties of COME and COEE

Property	Unit	IS:15607 specification	COME	COEE	Test methods
Density@ 15^0C	gm/cm^3	0.87-0.90	0.86	0.86	IS:1448
Kinamatic viscosity @40^0C	cst	3.5-5.0	7.1	6.5	ASTM D445
Flash point	^{0}C	≥ 120	165	176	ASTM D 93
Cetane number	---	≥ 51	55.6	54.6	ASTM D 613
Acid value	mgKOH/gm	≤ 0.5	0.45	0.47	ASTM D 974
Iodine value	$gmI_2/100gm$		84.5	84.5	ASTM D 1510
Cloud point	^{0}C	-------	13	11	ASTM D2500
Pour point	^{0}C	--------	6	5	ASTM D2500

Table-4
Engine specification

Engine	**Kirloskar TV1**
General details	4 stroke CI water cooled single cylinder computerised
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5 : 1 (varing from 16:1 to 18:1)
Displacement	661 cc
Power	3.5 kW
RPM	1500

Engine Performance Analysis

Brake power: The increase in brake power with load is shown in Figure-3. The brake power of COME20 stands high subsequent to petroleum diesel with increasing load on the engine. COEE20 shows slight inferior values subsequent to COME20. Absolute COME have a little bit higher brake power than that of COEE. All these facts is addressed to higher viscosity, flash or fire point and low calorific value. However the power loss is very negligible close to 5%. The low temperature operability persists in using COME and COEE in absolute mode. Hence additive package of COME20 and COEE20 can be recommended for fuelling agricultural diesel engines without any modification or adulteration nevertheless negligible power loss. Absolute package of COME and COEE can be used in agricultural diesel engines with little modification in engine hard ware facilitating preheat up to 60-100^{0}C.

Brake mean effective pressure: The change in BMEP with load is shown in Figure-4. The BMEP of absolute COEE lies below subsequent to petroleum diesel, COME20, COEE20 and absolute COME with increasing load on the engine. This is attributed to higher viscosity, flash point and low calorific value than that of petroleum diesel. A pressure loss nearly equal to 4% is obtained at the highest load of 7 kg performed by the engine. Furthermore the low temperature operability of absolute COME and COEE is still imperative. However COME20 and COEE20 show a pressure loss of 1% at the same load with best cold flow properties close to diesel. Hence an additive package of COME20 and COEE20 can be recommended for agricultural diesel engines without any modification or adulteration, nevertheless negligible pressure loss. Absolute package of COME and COEE can be used in agricultural diesel engines with little modification in engine hardware facilitating preheat up to 60-100^{0}C.

Brake thermal efficiency: The change in brake thermal efficiency with load is given in Figure-5. Brake thermal efficiencies of COME20 lies over that of COEE20, absolute COME and COEE subsequent to petroleum diesel with increase in load on the engine. COME20 shows a thermal efficiency loss near to 2% and COEE20 shows an efficiency loss of 3%. Absolute COME and COEE show an efficiency loss about 5%. This may be attributed to higher viscosity, flash point and low calorific value than that of petroleum diesel. However the low temperature operability of absolute COME and COEE is imperative. Hence COME20 and COEE20 can be recommended as an additive fuel package for agricultural diesel engines without any modification or adulteration, nevertheless negligible loss. Absolute package of COME and COEE can be used in agricultural diesel engines with little modification in engine hardware facilitating preheat up to 60-100^{0}C.

Figure-2
Variable compression ratio test rig

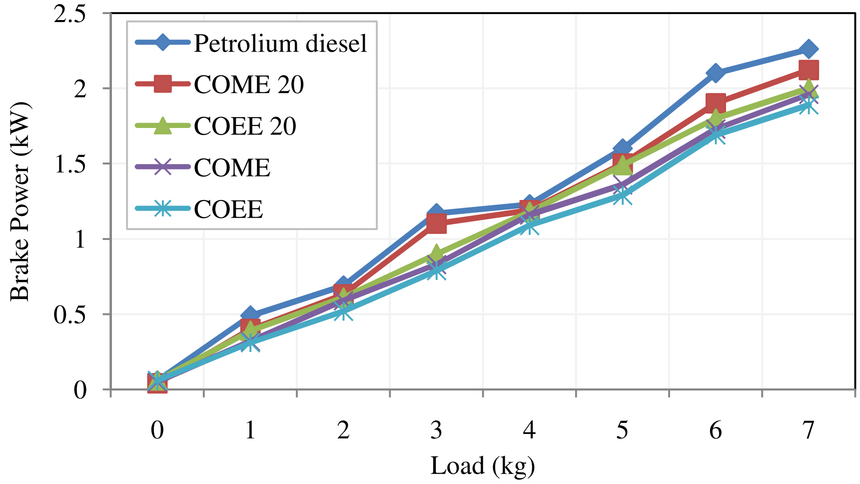


Figure-3
Variation of brake power with load

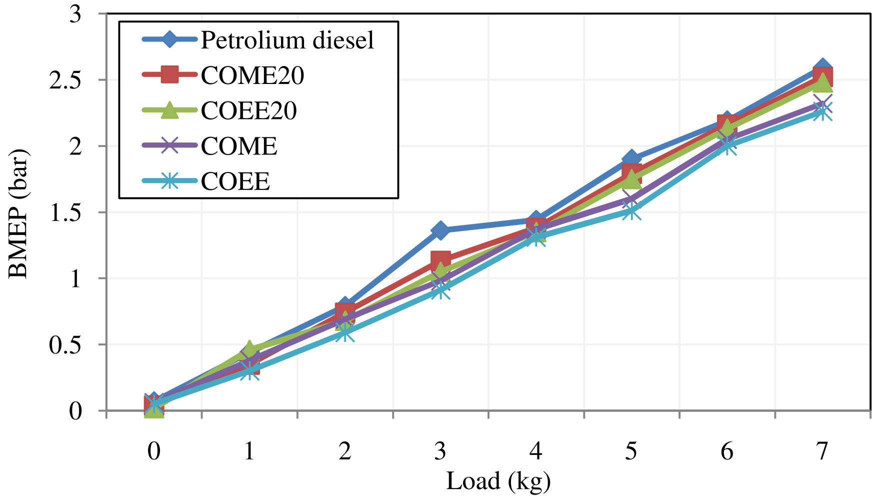


Figure-4
Variation of brake mean effective pressure with load

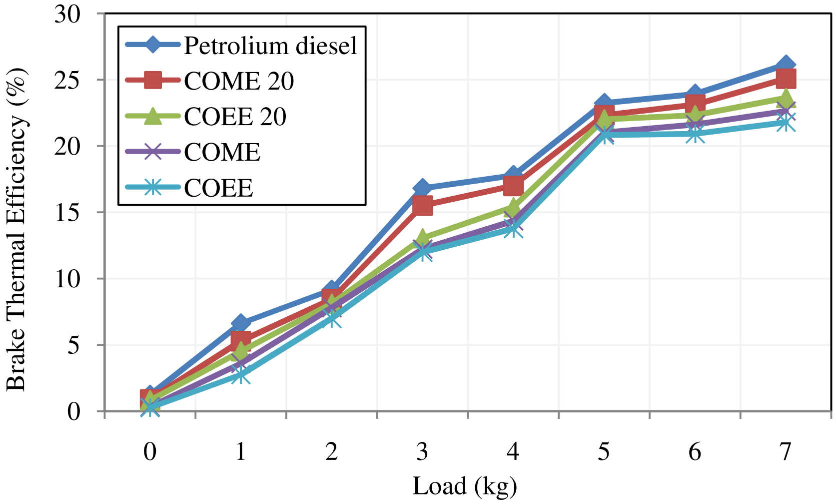


Figure-5
Variation of BTE with load

Specific fuel consumption: The change in specific fuel consumption with load is presented in Figure-6. With increase in load, the fuel consumption per unit power generation decreases which is a desired engine performance. COEE20 has a slightly more fuel consumption than that of COME20.Absolute, COME and COEE has slightly more fuel consumption than that of petroleum diesel which may be attributed to a low calorific value. Hence COME20 and COEE20 can be recommended as an additive fuel package for agricultural diesel engines without any modification or adulteration, nevertheless slightly higher fuel consumption per unit power generation. Absolute package of COME and COEE can be used in agricultural engines with little modification in engine hardware facilitating preheat up to 60-100^{0}C.

Engine Emission Analysis

Emission analysis of COME20: The emission comparison of COME20 with petroleum diesel is shown in Figure-7 (a and b). The combustion of COME20 reveals emissions of CO and CO_2, less in comparison to petroleum diesel. Hazardous unburnt hydrocarbon and nitrous oxide is also less than that of petroleum diesel. Free oxygen release is 2% more than that of petroleum diesel which indicates a proximal combustion to petroleum diesel with fewer emissions. Hence COME20 can be recommended as an environmental friendly additive fuel package for agricultural diesel engines without any modification or adulteration.

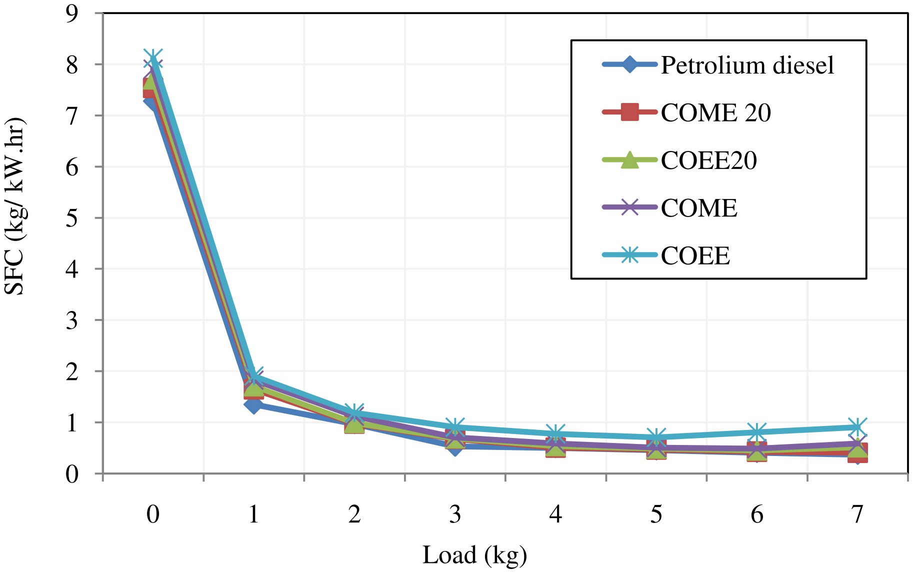
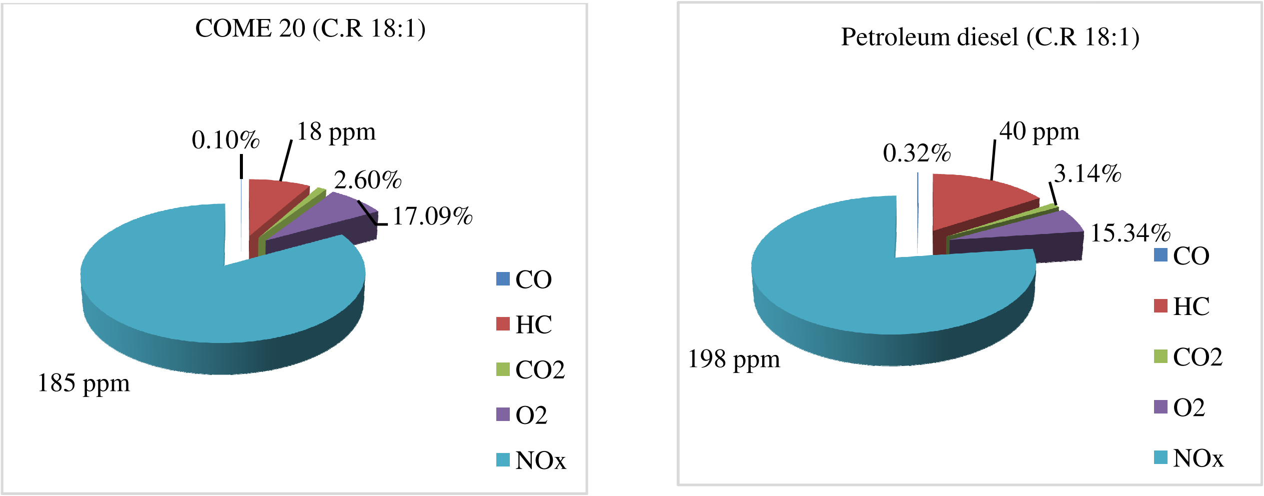


Figure-6
Variation of SFC with load



(a) (b)

Figure-7
Emission comparison of COME20 with petroleum diesel

Emission analysis of COEE20: The emissions of COEE20 combustion is shown in Figure-8. Combustion of COEE20 depicts emissions of CO and CO_2, less in comparison to petroleum diesel. Hazardous unburnt hydrocarbon and nitrous oxide is also less than that of petroleum diesel and COME20. Free oxygen release is 2% more than that of petroleum diesel indicates a proximal combustion to petroleum diesel with fewer emissions. Hence COEE20 is another additive fuel package next to COME20 and petroleum diesel in agricultural diesel engines without any modification or adulteration.

Emission analysis of absolute COME and COEE: The emissions of absolute COME and COEE combustion are shown in Figure- 9 (a and b). Combustion of COME and COEE depicts emissions of CO and CO_2, less than petroleum diesel. Hazardous unburnt hydrocarbon and nitrous oxide is less than that of petroleum diesel. Free oxygen release is nearly 2% more than that of petroleum diesel indicates a proximal combustion to petroleum diesel with fewer emissions. However poor cold weather operability is still imperative. Preheating up to 60-100^0C may mitigate the problem. Hence COME and COEE are best environmental friendly absolute fuel package next to petroleum diesel in agricultural diesel engines with little modification in hardware design. Exhaust gas may be utilised for preheating which needs an aesthetic change in muffler design.

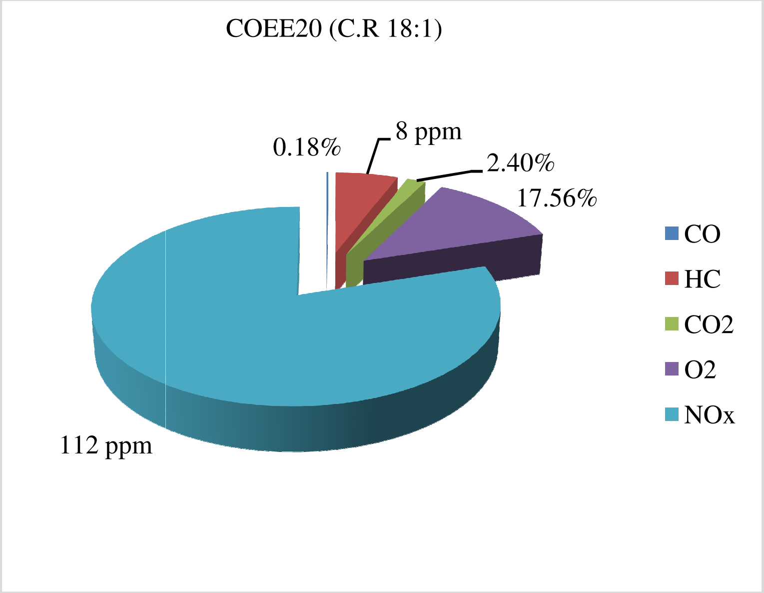
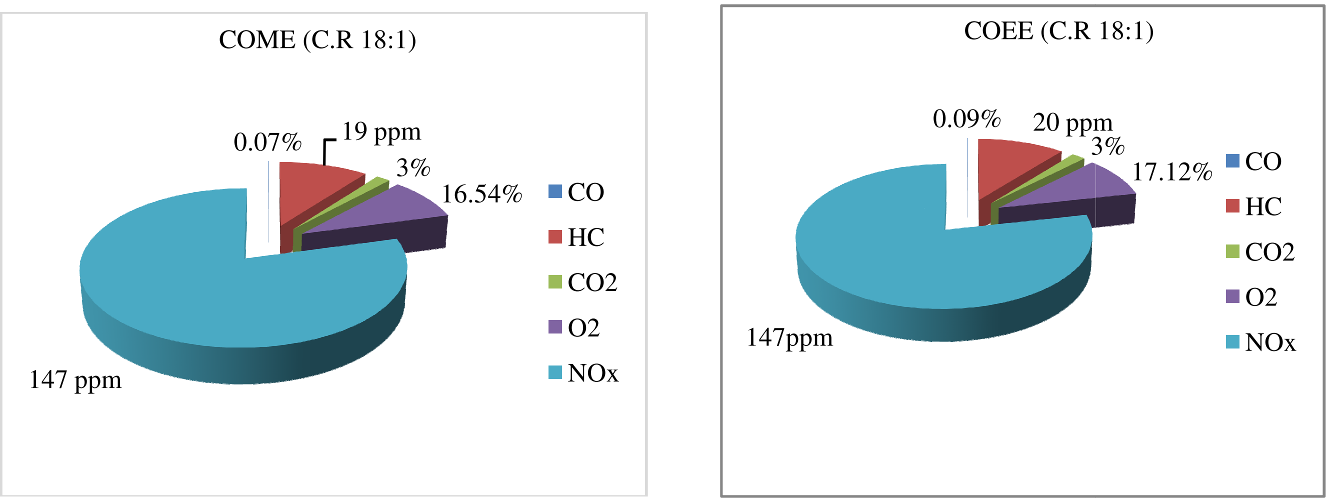


Figure-8
Emissions of COEE20 combustion



(a) (b)

Figure-9
Emissions of COME and COEE combustion

Conclusion

To provide an economic fuel additive package by pragmatic fuel synthesis from an esoteric potential energy source (Castor oil) was investigated in this work. Improved physicochemical properties by an optimised transesterification method unveiled a susceptible engine performance and plummeting hazardous emissions to well below than that of petroleum diesel. The effects of castor methyl/ethyl esters in a rigorous engine test were examined both in absolute and additive package to ensure the paradigm. The summarised conclusions of this work are: i. Kirloskar make diesel engine operates with natural breathing on COME20 and COEE20 without any engine modification and knocking. ii. The rigorous engine test fuelled with COME20 and COEE20 concluded an engine performance proximal to that of petroleum diesel with negligible power loss, fuel consumption with safer emissions. iii. Combustion of absolute package (absolute COME and COEE) led to durability and cold weather operability problem. iv. In cognizance to ever draining out petroleum reserves the additive package of COME20 and COEE20 can meet 20% of global petroleum consumption.

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