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Non-edible Neem oil: an evaluation of engine performance and prospective use in outboarddiesel engines

S.B. Mohapatra (Professor, Centurion University), P. Das (Founder Science Foundation), R.C. Mohanty (Professor, Centurion University),
Dhaneswar Swain, Ipsita Mishra,Smita Satpathy, (Research scholars, Centurion university).

Abstract: *The need to decrease the consumption of materials and energy and to promote the use of renewable resources, such as bio fuels, stresses the importance of evaluating the performance based on the second law of thermodynamics.Developing countries like India depend heavily on oil import of about 125 Mt per annum (7:1 diesel/gasoline).Diesel being the main transport fuel in India, finding a suitable alternative to diesel is an urgent need. Stringent emission norms in addition to the depletion of petroleum fuels have necessitated the search for alternate fuels for diesel engines. Abundant researches have been undertaken in above context inferring a proximal use of bio fuels as an additive to petroleum diesel in various proportional blends. The use of bio fuel in absolute mode is still imperative because of itshigher density, viscosity, poor filtration, lowervolatility and poor cold flow properties. These problems can be addressed by using various suppressants like ethanol, kerosene, petroleum diesel and commercial Lubrizol. The present experimental investigation was carried out on a small(5HP) naturally aspirated direct injection (DI) diesel engine, fuelling theengine with Neem oil methyl ester(NOME) and its proportional blends with kerosene(NOMEK20),diesel(NOMED20) and absolute petroleum diesel. The performance and combustion characteristics of the engine at various loadsare compared and analyzed.*

I. Introduction

Azadirachtaindica (Neem) tree belongs to the Meliaceaefamily. It is a multipurpose and an evergreen tree, 12–18 m tall,which can grow in almost all kinds of soil including clay, saline,alkaline, dry, stony, shallow soils and even on solid having highcalcareous soil. It is native to India, Pakistan, Sri Lanka, Burma,Malaya, Indonesia, Japan, and the tropical regions of Australia.It thrives well in arid and semi-arid climate with maximum shadetemperature as high as 491^{o}C and the rainfall is as low as 250 mm.It can be raised by directly sowing its seed or by transplanting nursery-raised seedlings in monsoon rains. It reaches maximumproductivity after 15 years and has a life span of 150–200 years.Planting is usually done at a density of 400 plants per hectare.The productivity of Neem oil mainly varies from 2 to 4 t/ha/yr anda mature Neem tree produces 30–50 kg fruit. The seed of the fruitcontains 20–30 wt% oil and kernels contain 40–50% of an acridgreen to brown coloured oil[1, 3, 4, 5, 6].

Petroleum diesel and gasoline consist of blends of hundreds of different chemicals of varying hydrocarbon chains, many of these are hazardous and toxic. Carbon monoxide (produced when combustion is inefficient or incomplete), nitrogen oxides (produced when combustion occurs at very high temperatures), sulfur oxides (produced when elemental sulphur is present in the fuel), and particulates that are generally produced during combustion are other specific emissions of concern. So it is time to search for its alternative fuels [7].Neem comprises mainly of triglycerides and large amounts of triterpenoid compounds. It contains four significant saturated fatty acids, of which two are palmitic acid and two are stearic acid. It also contains polyunsaturated fatty acids such as oleic acid and linoleic acids [8]. Anand et al.,[9] reported anincrease in particulate matter emissions for blends of neemmethyl esters with diesel.Md.NurunNabi et al., [10] investigated the combustion and exhaustgas emission characteristics when the engine was fuelled withblends of methylesters ofNeemoiland diesel.Fromthe engine test results, K. Pramanik[11] reportedthat upto 50% Neemoil could be substituted for dieselfor useinadieselengine without any major operational difficulties.Though manyresearchers [12, 13]have taken efforts toaddress the issuesof biodiesel,the technologyis yettobefully exploited.

Outboard engine emissions have recently been regulated and they are classified as non-road engines. Marineengines account for about 30% of non-road engines, butas they are found in coastal areas (ports, recreational areas, lakes, rivers, etc.), the local levels of pollutants may become concentrated.Marine diesel engine manufacturers in the UnitedStates, Europe and Japan have all recognized the growingrole of biodiesel as a viable fuel component, and in mostcases, as a fully alternative fuel (100%)[14]. Exhaust emission limits have been set for carbon monoxide, hydrocarbons, nitrogen oxides and other pollutants.Exhaust emissions are measured in accordance with theharmonised standard ISO 8178-1:1996[15]. All EU stateswere required to apply Directive 2003/44/EC[16] from 1January 2005; and came into force on 1 January2006.

The emission analysis of diesel engines operating on methyl esters of vegetable oils and its blends with diesel have been published by several authors [17,18,19,20,21]. Most of them haveinferred substantial reductions in CO, HC and PM emissions along with higher NOx emissions in the exhaust.The imperative notion is that the high oxygencontent of methyl esters of vegetable oils leads to more complete combustion andlower emissions. However, this higher oxygen contentalso leads to lower calorific values, which may result in significant power losses and the increase of specific fuel consumption. Furthermore, the direct application of purebiodiesel (BD) or pure methyl-ester (ME) as an alternativein conventional diesel engines has encountered severalother drawbacks due to the technical problems related toits higher density, viscosity, poor filtration, lowervolatility and poor cold flow properties.The first researchwas by Novak and Kraus[21] dates from the early 1970s on biodegradability and toxicity of biodiesel in aquatic environments. Since then, profuse researches have been followed up. After studying the biodegradability of severalkinds of biodiesel and their comparison with commercialdiesel and their blends, Zhang et al.[22] concluded thatbiodiesel is easily biodegradable in aquatic environmentsand has a higher biodegradability than commercial diesel. Research performed by Cytoculturerevealed that 37% of the vessels surveyed chose to use biodiesel for environmental reasons, 33% for mechanical reasons (normally related to better lubricating properties of biodiesel), while 33% basedtheir decision on subjective reasons, such as safety upondirect contact with the skin and lower smoke level. VonWedel[14] also studied biodiesel toxicity in humans. The present study is todetermine the extenttowhich blendingcanbe done with ethanol, kerosene, diesel and commercial Lubrizol withoutscarifying much in the performance and emission characteristics of an outboard diesel engine whenfuelled withblends of esterified Neemoilwithoutanyengine modifications or adulteration.

II. Impetus to present study

The lack of technological transformation in agriculture has drastically reduced income earning opportunities.Adoption of innovative technologies can lead to sustainable utilisation of labour, particularly in the arid and semi-arid regions.A holistic and system-wide approach is required in the diagnosis of constraints and opportunities for productivity improvement, in small scale farming, and poverty reduction.Technology and productivity focused agricultural strategies in post-independence India have experienced measured success in selected pockets as revealed by many studies.India is one of the countries where the present level of energy consumption, by world standards, is very low. The estimate of annual energyconsumption in India is about 330 Million Tones Oil Equivalent (MTOE) for the year 2004. Accordingly, the per capita consumption of energy is about 305 Kilogram Oil Equivalent (KGOE).Oil constitutes over 35% of the primary energy consumption in India.The present level of demand isabout 120 million metric tons of oil equivalent. Lack of access to electricity and modern cooking fuels constitutes energy poverty.Poverty and energy deprivation go hand-in-hand with energy expenses, accounting for a significant proportion of household incomes.While access to low-cost, clean, safe, modern and sustainable energy technologies is a priority to small scale farmers and agro-communities residing in villages. In the above context providing minimum energy access to small scale peasants in tilling, reaping, sowing, harvesting, irrigating, power generating and fishing by using small outboard diesel engines is impetus to the present study Fig.1.

Fig. 1 Outboard engines at work

III. Chemistry of preparation (NOME)

3.1.Removal of gums and alkaloids

The crude Neem oil was centrifuged at 9500rpm in a REMI Model-24 centrifuge machine and the supernatant oil was collected free from heavy contaminates, 25 ml methanolic H_3PO_4 solution (12% v/v) was homogenized with 100 ml crude oil and allowed to stand for overnight. Next day, the oil was separated from methanol layer and precipitated compounds are filtered through silica gel (60–120 mesh) under suction.The filtrate, consisted of methanol and phosphoric acid, could be recycled three times for degumming Neem oil. This makes the process economically more viable.After degumming, oil was kept overnight with 0.1% aqueous sodium hydroxide solution. Next day, aqueous portion was discarded and oil was washed twice with water to remove residual alkali. Then oil was heated on boiling water for 1 hour and then passed through warmed (warmed at 105^0C in an oven before use) anhydrous Na_2SO_3 to remove moisture from oil.Resultant oil was stored as refined alkaloid-free Neem oil (RNO).After the whole process, 96% of the CNO was converted to RNO.

3.2 Two step esterification

For esterification, degummed and alkaloid free oil (RNO) was mixed with sulphuric acid and methanol in the proportion of 50:10:1 (oil:CH_3OH:H_2SO_4, v/v/v) and stirred in a magnetic stirrer(5lit capacity) at 1000 rpm at 65^0C for 3 hours. After completion of esterification process, two layers were separated within 30 min.The lower layer was discarded and followed by neutralization with methanolic costic soda solution and methanol was recovered from oil.The neutral oil was then mixed with sodium hydroxide and methanol in a ratio of 50:10:0.2 (oil:methanol:alkali) and stirred well mechanically at 900 rpm for 4 hours at 55^0C. After transesterification, oil was separated from lower layer by separating funnel and washed with hot water three to five times to remove impurities, and resultant transesterified oil (TEO) was stored for further analysis.After two-step transesterification, 90% of the RNO was converted to TEO.

IV. Properties susceptible to combustion (NOME)

The most of the properties of NOME are comparable topetroleum based diesel fuel; improvement of its cold flow characteristic still remains one of the major challenges whileusing NOME as an alternative fuel for diesel engines.Three cold flow improvers were selected for testing: ethanol, kerosene and an experimental pour point depressantwhich was developed by Lubrizol. The product is sold as Lubrizol7671 to enhance the cold flow properties of NOME and blendswith recommended treat levels of 1–2%. Ethanol has been chosenas a cold flow improver since it has a very low solidifyingtemperature of the order of -114^0C and is highly soluble inNOME. Properties of ethanol like density and viscosity matchwell with that of NOME.Effects of ethanol–dieselblended biodiesel (NOME, NOME E10,NOME E20,NOME E10 D10) were also studied Fig.2.

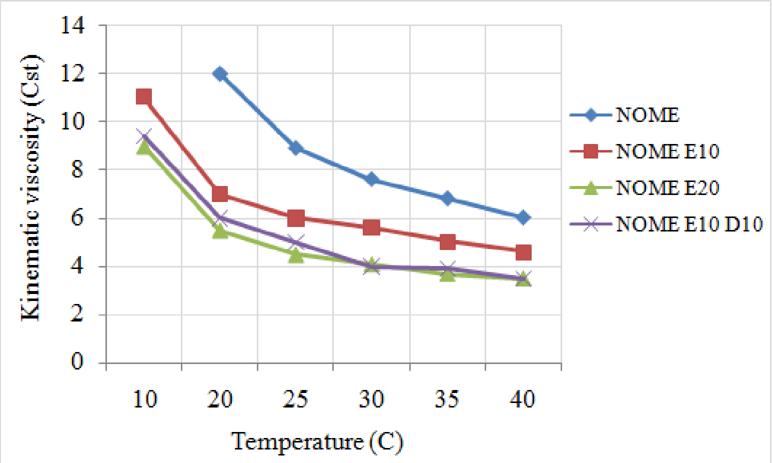

Fig. 2 Variation of kinematic viscosity of ethanol blended NOME in low temperature region

Same criteria were applicable forkerosene.The lowtemperature operability of NOME and its blends with ethanol andkerosene were carried out following the ASTM standards D-2500,D-97 procedures, respectively. Four concentrations of ethanol andkerosene blends, i.e. 5%, 10%, 15% and 20%, were tested with NOME for cold flow studies. To enhance the coldweather functionality of NOME, the effect of commercialadditive from Lubrizol (Lubrizol 7671) with the amount of 0.5%,1%, 1.5%, 2%, 2.5%, 3%, 3.5% and 4% was also studied Figs.3 and 4.

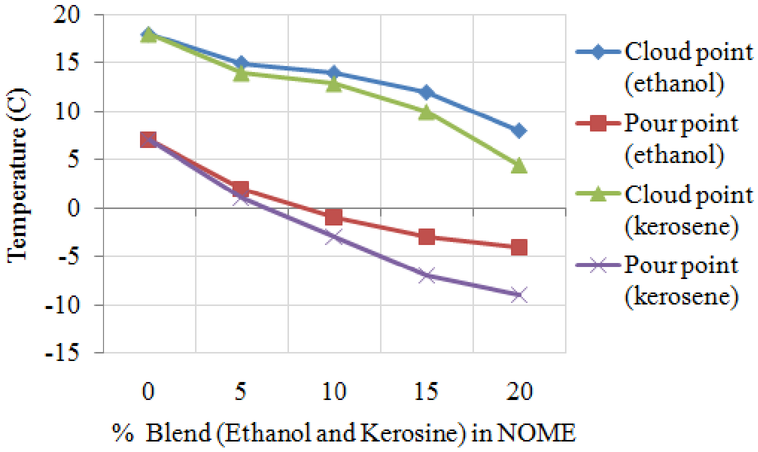

Fig. 3 Effect of ethanol and kerosene on cold flow properties of NOME

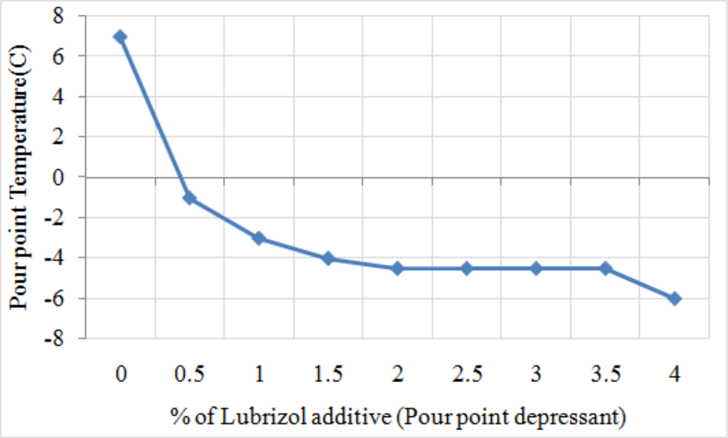

Fig. 4 Effect of Lubrizol additive (commercial pour point depressant) on NOME

Since the kerosene concentration up to 20%in NOME shows better cold flow properties,viscosity, and cost effective, its effect onperformance and emission was studied with NOMEK20,NOMED20,NOME and petroleum diesel Fig.5.

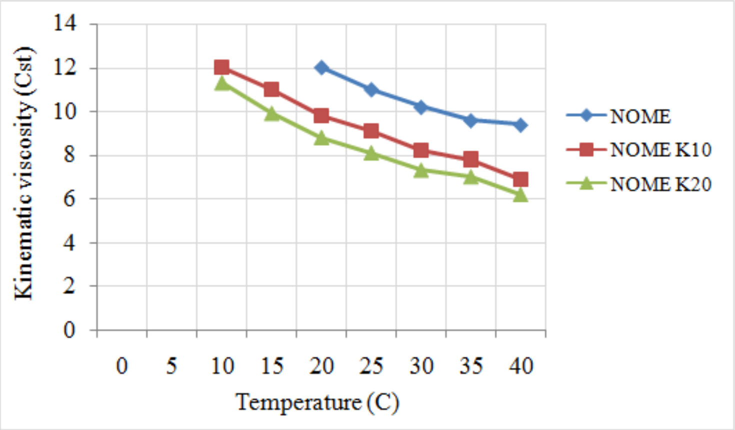

Fig. 5 Variation of kinematic viscosity of kerosene blended NOME at low temperature region

Profuse researches have been undertaken using blends of NOME with diesel. So far B-10 and B-20 have shown very good engine performances close to diesel. The practical problem concerning its use as an absolute fuel with consistent quality is a concern because of poor cold flow properties, high viscosity, high flash and fire point values. However blending kerosene up to 20% with NOME substantially depresses the pour point, cloud point, viscosity, flash point and fire point Table 1 and 2.

Table 1: Properties of NOME, diesel and kerosene blends

Sl.No.	Blend	Kinematic viscosity @40^0C (cst)	Flash point	Fire point	Specific gravity	Calorific value
1	B-10	4.4	74	80	0.877	43800
2	B-20	4.5	80	85	0.878	43000
3	B-30	4.6	100	105	0.880	42100
4	B-40	4.7	120	126	0.882	41200
5	B-50	4.8	130	136	0.884	40500
6	NOMEK20	6.19	88	93	0.867	43700
7	NOMED20	7.81	135	140	0.850	43600
8	NOME	9.4	188	194	0.87	40198
9	Diesel	4	70	76	0.853	44755

Table 2: Standardisation of properties

Sl. No.	Properties	Standard	Biodiesel range	Experimental value(NOME)
1	Kinematic viscosity (Cst) @40^0C	ASTM D445	1.9-6.0	9.4
2	Flash point(^{0}C)	ASTM D93	>130	188
3	Density (kg/m^3)	ASTM D4052	870 -900	870
4	Cloud point(^{0}C)	IS:1448(P 10)	-3 to 12	11
5	Pour point(^{0}C)	IS:1448(P 10)	-15 to10	7
6	Ash,% w/w	IS:1448(P 4)	0.5max	0.004
7	Carbon residue % w/w	IS:1448(P 8)	0.05max	0.08

V. Engine setup

Table 3: 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

A four stroke,water cooled and single cylinder engine coupled with edicurrent dynamometer was used for present study Fig. 5.The engine was computerised with engine soft(software) to measure the engine performance parameters.AVL gas analyser was employed to note the exhaust emissions such as carbon dioxide, hydrocarbon,carbon monoxide,oxygen, and nitrous oxides. Performance and emission parameters were noted for NOME,NOMEK20,NOMED20 and Petroleum diesel.The reference study was based on petrolium diesel to interpret the data for comparison.The test was conducted at 1500 rpm with varing loads.

Fig. 6 Variable compression ratio test rig

VI. Engine performance analysis

6.1Brake power

The brake power of NOMEK20 stands high subsequent to petroleum diesel with increasing load on the engine. NOME shows inferior values subsequent to NOMEK20 and NOMED20 due to high viscosity, flash or fire point and low calorific value, with a power loss close to 5%.NOMEK20 shows a power loss of 2%.So kerosene blend up to 20% can be recommended for outboard diesel engines without any modification or adulteration.

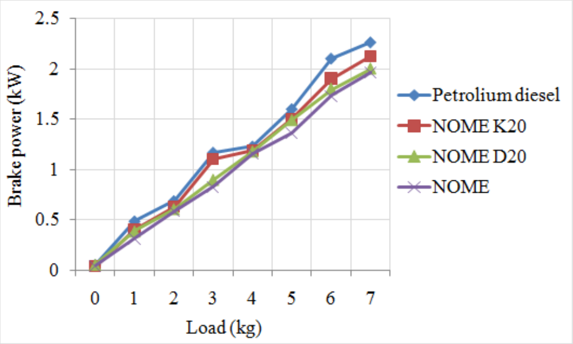

Fig. 7 Variation of brake power with load

6.2 Brake meaneffective pressure

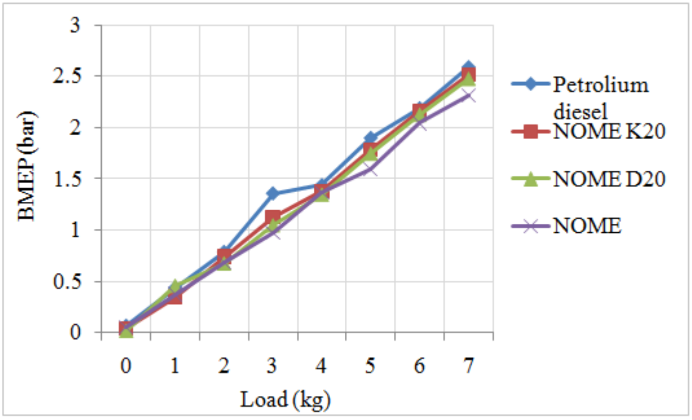

Fig. 8 Variation of BMEP with load

The BMEP of NOMEbudges below subsequent to absolute diesel, NOMEK20, and NOMED20 with increasing load on the engine. This is due to high viscosity, flash point and low calorific value. A pressure loss nearly equal to 4% is obtained at the highest load of 7kg performed by the engine. However NOMEK20 shows a pressure loss of 1% at the same load.Hence NOMEK20 can be recommended as an absolute fuel for outboard diesel engines without any modification or adulteration.

6.3 Brake thermal efficiency

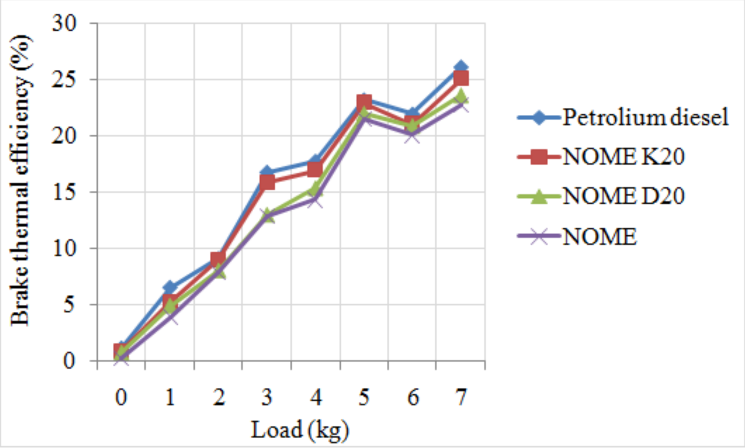

Fig. 9 Variation of brake thermal efficiency with load

NOMEK20 push over the thermal efficiencies of NOME and NIMED20 subsequent to absolute diesel with increase in load on the engine. NOMEK20 shows a thermal efficiency loss near to 2%.This may be attributed to a blend concentration of kerosene up to 20% which is a low cost depressant of poor cold flow properties, viscosity, and flash or fire point.Hence NOMEK20 can be recommended as an absolute fuel for outboard diesel engines without any modification or adulteration.

6.4 Specific fuel consumption

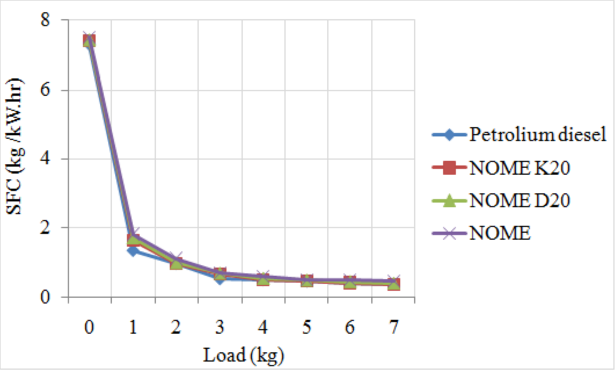

Fig. 10 Variation of SFC with load

With increase in load, the fuel consumption per unit power generation decreases which is a desired engine performance.NOMEK20 pushes over NOMED20 and NOME subsequent to absolute diesel which may be attributed to a blend concentration of kerosene up to 20%, a low cost depressant of poor cold flow properties,viscosity and flash or fire point.Hence NOMEK20 can be recommended as an absolute fuel for outboard diesel engines without any modification or adulteration.

VII. Engine emission analysis

7.1 Emission analysis of NOMEK20

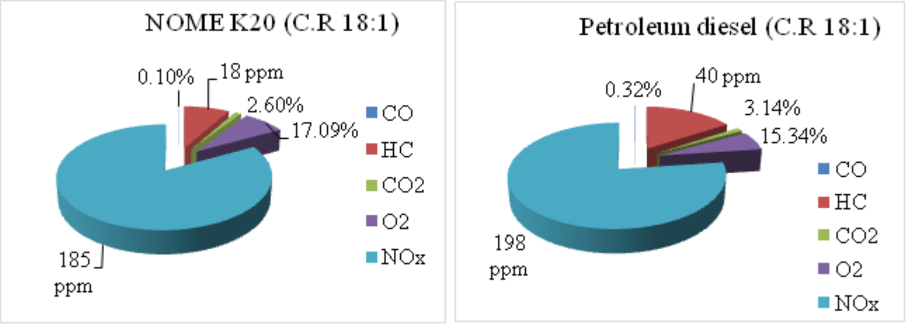

Fig. 11 Emission comparison of NOME K20 with petroleum diesel

The combustion of NOMEK20 exhibits 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. However research says the hazardous emissions are more biodegradable in aquatic environments than petroleum diesel. Hence NOMEK20 can be recommended as an environmental friendly absolute fuel in outboard diesel engines without any modification or adulteration.

7.2 Emission analysis of NOMED20

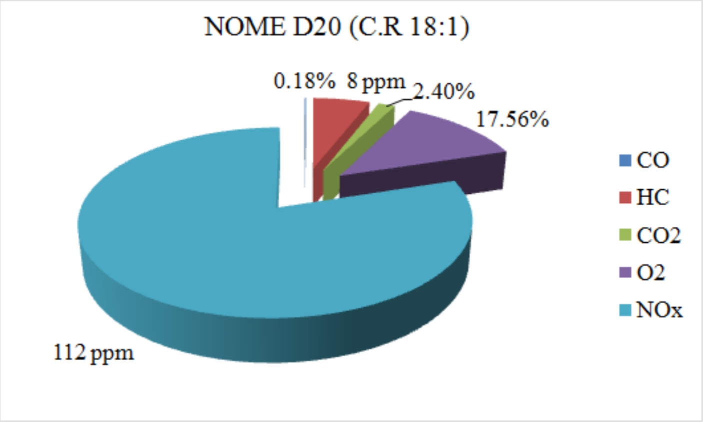

Fig. 12 Emissions of NOME D20 combustion

Combustion of NOMED20 depicts emissions of CO andCO_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 indicates a proximal combustion to petroleum diesel with fewer emissions. However NOMED20 is endowed with poorer cold flow properties, higher viscosity, and higher flash point attributing a combustion durability problem, clogging of fuel filter in long run. Preheating up to 60^0C may mitigate the problem. Hence NOMEK20 is the best absolute fuel next to petroleum diesel in outboard diesel engines without any modification or adulteration.

7.3 Emission analysis of NOME

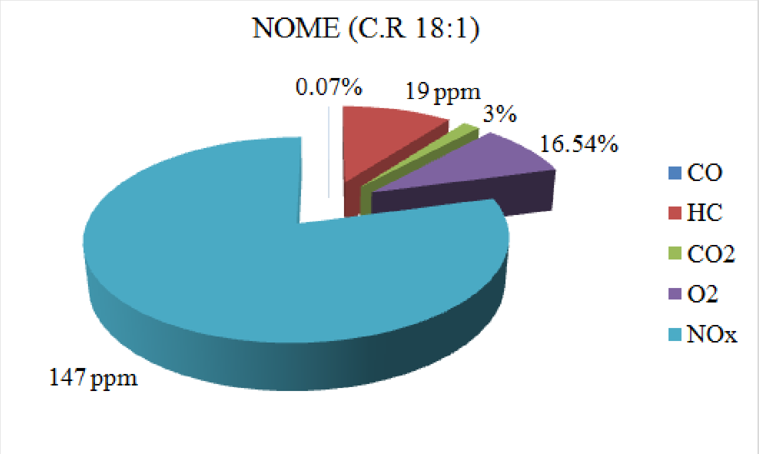

Fig. 13 Emissions of NOME combustion

Combustion of NOME depicts emissions of CO and CO_2, close to 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 NOME endowed with poorest cold flow properties, highest viscosity, and highest flash point attributing to a combustion durability problem, clogging of fuel filter in long run. Preheating up to 100^0C may mitigate the problem. Hence NOMEK20 is the best absolute fuel next to petroleum diesel in outboard diesel engines without any modification or adulteration.

VIII. Conclusion

This study experimentally analyzed the remission of poor cold flow performances, viscosity, flash and fire points by blending with ethanol, petroleum diesel, commercial Lubrizol and kerosene. Kerosene blend up to 20% concentration in NOME proved to be the best depressant of combustion problems. Engine performances and Exhaust emissions of NOME,NOMEK20,NOMED20 and petroleum diesel inferred NOMEK20 to be the best absolute fuel next to petroleum diesel in outboard diesel engines, compensating 80% of total diesel combustion. Hazardous emissions are more biodegradable in aquatic environments. So out board engines fuelled with NOMEK20 can be recommended for tilling, reaping, harvesting, fishing, mechanical pressing and small power generation units up to 10 kW in rural or tribal biota without any engine modifications.

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