Performance, emission and combustion characteristics of DI diesel engine running on blends of honne oil/diesel fuel/kerosene/DMC

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Abstract: Honne oil (tamanu) (H), a non-edible vegetable oil is native for northwards of Northern Marianas islands and the Ryukyu Islands in southern Japan and westward throughout Polynesia. It has remained as an untapped new possible source of alternative fuel that can be used as diesel engine fuel. Literature pertaining to use of vegetable oil in diesel engine with kerosene and dimethyl carbonate (DMC) is scarce. The present research is aimed to investigate experimentally the performance, exhaust emission and combustion characteristics of a direct injection (DI) diesel engine, typically used in agricultural sector, over the entire load range, when fuelled with neat diesel (ND) and blends of diesel fuel (D)/DMC/H/ kerosene (K). DMC/D/H/K blends have a potential to improve the performance and emissions and to be an alternative to ND. Experiments have been conducted when fuelled with H20 (20%H + 80%D), HK (20%H + 40%K + 40%D) and HKD5 (20%H + 40%K + 35D + 5%DMC) to HKD15 in steps of 5% DMC keeping H and K percentages constant. The emissions (CO, HC and smoke density (SD)) of fuel blend HKD15 are found to be lowest, with SD dropping significantly. The NO_x level is slightly higher with HKD5 to HKD15 as compared to ND. The brake thermal efficiency of HKD5 to HKD15 is same and it is higher than that of ND. There is a good trade off between NO_x and SD. Peak cylinder pressure and premixed combustion phase increases as DMC content increase.

Keywords: diesel engine, performance, emissions, combustion, vegetable oil, kerosene, diesel fuel, dimethyl carbonates
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1 Introduction

Diesel engines are widely used throughout the world for powering tactical and non-tactical vehicles and vessels, off-road equipment, engine-generator sets, aircraft ground-support equipment and on a variety of other applications. As the use of diesel engines growing, concern about exhaust emissions is also increasing, particularly emissions of NO_x, smoke and particulate matter (PM). The significant and steadily rising contribution of fossil fuels to global emissions of greenhouse gases is one of the two primary drivers for the increasing focus on alternative transport fuels such as biodiesel. The other is the increasing threat of worldwide fossil fuel scarcity and the implications of this for economic and national security. The substitution of even a small fraction of total consumption by alternative fuels will have a significant impact on the economy and the environment.

Nishimura et al.[1] reported that the basic mechanism involved in the formation of pollutants inside the DI diesel combustion chamber is the mixing and combustion

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of injected fuel. Kouremenos et al.[2] reported that physical properties (KV, density, HV, BP, CN, volatility, self ignition temperature, heat of vaporization) have a considerable effect on both mixing and combustion of injected fuel. Another important finding from Kouremenos et al.[2], was the serious effect of fuel physical properties in particularly, viscosity and density on the performance of the fuel injection system. Increase in injector opening pressure, injection rate (increase in plunger diameter) and static injection timing improves combustion, emission and performance characteristics[3-5].

The high viscosity and low volatility of vegetable oils lead to difficulty in atomizing the fuel and in mixing it with air. The much slower evaporation process for the vegetable oil could considerably affect the combustion process[6]. Hence, only a partial replacement of diesel fuel is possible.

It was reported that use of 100% vegetable oil is also possible in diesel engine as they have a cetane number with heating value close to diesel fuel but show inferior performance and emissions compared to ND[7].

Bari et al.[8] conducted short-term performance tests using crude palm oil (CPO) as a fuel for a diesel engine and CPO showed to be a suitable substitute for diesel fuel. However, prolonged use of CPO reduced maximum power by 20% and minimum bsfc was increased by 26%. The reason, between the diesel fuel and vegetable oil, may be due to the differences in viscosity, density, heating value and the thermal cracking at the temperature encountered by the fuel spray in DI diesel engine. These differences contributing to poor atomization, coking tendencies, carbon deposits, and wear were generally experienced and adversely affected the durability of the engine. Tests revealed that the main reason for engine performance deterioration was 'valve sticking', caused by carbon deposits on the valve seats and stems.

Jianxin et al.[9] reported that in order to meet Euro IV emission regulation, a fuel is required which contains high oxygen content, high cetane number, low sulphur, low aromatic and low boiling point fuel (less than diesel's boiling point) contents. Wang et al.[10] studied the effects of diesel/DME blends on engine's emissions characteristics and their investigations showed that at high loads, the blends reduce smoke significantly with a little penalty on CO and HC emissions compared to ND. NO_x and CO_2 emissions of the blends are decreased compared to ND. Few works are reported on the use of DMC/diesel fuel blend in diesel engine[11,12]. It was concluded that adding DMC in diesel can substantially reduce emission of PM/smoke density without significant effects on NO_x. Also found that the engine's brake thermal efficiency (BTE) increases. The reason may be due to that DMC has no C=C (carbon=carbon) bonds in the molecules, and C is oxygenated easily. Murayama et al.[13] proved DMC to be a suitable oxygenated additive with good blend fuel properties, which reduced smoke density almost linearly with its concentration and was directly related to the oxygen content of the fuel. With 10% of DMC contained in the fuel, smoke reduction of 35%–50% was attainable, and also, apparent reductions of HC and CO densities were attained with NO_x emissions increasing slightly. Maricq et al.[14] carried out investigations on dimethoxymethane and their study results showed that addition of this oxygenate causes a shift in the PM size distribution to smaller diameters and substantial PM reduction. There is no change in NO_x emissions. Zhang et al.[15] found that diesel engine fuelled with DMC can achieve low emissions of PM. The combustion analysis indicated that the ignition delay is longer, but combustion duration is much shorter, and BTE is increased compared to ND. Also, concluded that if injection is delayed, NO_x emissions can be reduced while PM emissions are still reduced significantly. DMC showed good solubility with diesel fuel, no objectionable odour and reported that no fuel line damage even for a year long operation in diesel engine[13]. Noboru et al.[16] used four kinds of oxygenate agents as main fuels and blend with diesel fuel. Significant improvements in smoke, PM, NO_x, HC and BTE were simultaneously achieved. They concluded that the improvements in the emissions and performance may be due to entirely on the oxygen content in the fuels regardless of oxygenate to diesel fuel blend ratio and type of oxygenate. Gong et al.[17] studied the emission characteristics of a diesel engine fuelled with diesel/MEA blends and found that the emissions of smoke, HC and CO decrease. However, little information is available on the use of neat vegetable oil/oxygen compound (methanol) blend in diesel engine[18]. They reported that the performance and emissions of blend of jatropha oil and methanol improved when compared to neat jatropha oil. The reason may due to reduction in viscosity of the blend leads to improved atomization, fuel vaporization and combustion.

Little information is also available on the use of lighter fraction hydrocarbon fuel (kerosene) / diesel fuel / biodiesel blend (clean fuel) in diesel engine[19]. The clean fuel reduced 20% of PM under a wide range of engine conditions including D-13 mode without an increase in NO_x, HC, and CO emissions. The PM emission reduction by biodiesel is mainly dependent on a decrease in the aromatic content replaced by biodiesel and the effect of oxygen in the fuel.

Major part of the deposits in diesel engine exhaust pipe and in-cylinder are due to lubricating oil. These deposits contain significant levels of PAH and hence provide a source of diesel PAH emissions and possible sites for in-cylinder pyrosynthesis of high molecular weight PAH. It was found that the use of kerosene PAH compounds could be volatilized from the exhaust pipe[20,21]. Andrews et al.[21] used kerosene in diesel engines. They concluded that all sulphur levels of kerosene fuel up to the 0.30 wt% would be equivalent to the 0.035 wt% sulfur EPA reference fuel for particulate matter response.

From the literature review it is concluded that properties, in particular viscosity, density, IBP, T90, heating value and self ignition temperature play an important role during IDP in turn premixed combustion again in turn performance and emissions. Properties of neat honne oil can made almost equal to that of ND by blending it with other fuels. Other fuels are selected in such a way that heating value is almost equal to that of ND but self ignition temperature, IBP; viscosity must be lower than that of honne oil and ND so that after blending these properties of blended fuel is almost equal to that of ND.

Hence, a comprehensive investigation on performance, emission and combustion characteristics of blends of honne oil/diesel fuel/kerosene/DMC in DI diesel engines is needed in order to fill the deficiency in the literature. In the present work, a DI diesel engine is chosen to test ND and above mentioned blends in different proportions to investigate rigorously performance, emission and combustion characteristics. A description of honne tree is available in our previous work[22].

2 Materials and methods

2.1 Fuel characterisation

The fuels were characterized by determining their viscosity, density, flash point, cloud point, pour point, distillation temperatures and lower heating value. The important fuel properties of ND and honne oil (H100) and test methods are given in Table 1. The important fuel properties of kerosene and DMC are given in Table 2. Density and heating value of the fuel under consideration are given in Table 3.

Table 1 Important properties of ND and honne oil

Properties	Units	Methods IS 1448	ND	H100
Density at 15℃	kg/m^3	P:16	830	910
Flash point	℃	P:69	56	224
Kinematic viscosity at 40℃	mm^2/s	P:25	3.12	(32.48±2)
Cloud point	℃	P:10	(-8±1)	(-2.5±1)
Pour point	℃	P:10	(-16±1)	(-08±1)
Cetane number (calculation)	-	-	-	51
Distillation temperature	℃	P:18		
IBP			195	298
10%			225	323
50%			280	345
90%			325	365
EP			338	371
Heating value	kJ/kg	P:6	43 000	39 100

Table 2 Properties of DMC[11-13] and kerosene[26]

Variables	DMC	Kerosene
Molecular formula	$C_3H_6O_3$	$C_{12}H_{26}$
	40:07:53	85:15:00
C/H	5.7/1	5.7/1
Molecular structure	CH_3-O-C-O-CH_3 ‖ O	----
Stoichiometric A/F ratio	3.51:1	14.94:1
C: H: O by mass	6:01:08	-----
Molecular weight	90.1	170
Kinematic viscosity, cSt	0.625	2.71
Flash point (close cup)	17℃	37-65℃

Variables	DMC	Kerosene
Boiling point	90.9℃	150-250℃
Auto ignition temperature	220℃	220℃
Density at 15℃/kg·m^{-3}	1 071	795
Heating value/kJ·kg^{-1}	15 780	43 200
Energy density/J·mm^{-3}	16.9	34.34
Cetane number	35-36	----
Oxygen content, weight%	53.3	Nill
Solubility in water Solubility	13.9 g/100 g with water in any proportionate with organic alcohol, esters	Insoluble miscible in petroleum solvents

Table 3 Properties of fuel under consideration

Properties/	Units	Method	H20	HK	HKD5	HKD10	HKD15
%fuel				IS 1448			
%Honne oil			20	20	20	20	20
%Kerosene			0	40	40	40	0
%Diesel			80	40	35	30	25
%DMC			0	0	**5**	10	15
Density at 15℃	kg/m^3	P:16	851	832	839	850	858
Heating value	kJ/kg	P:6	42 292	42 300	41 068	40 012	39 009

2.2 Experimental set up and plan

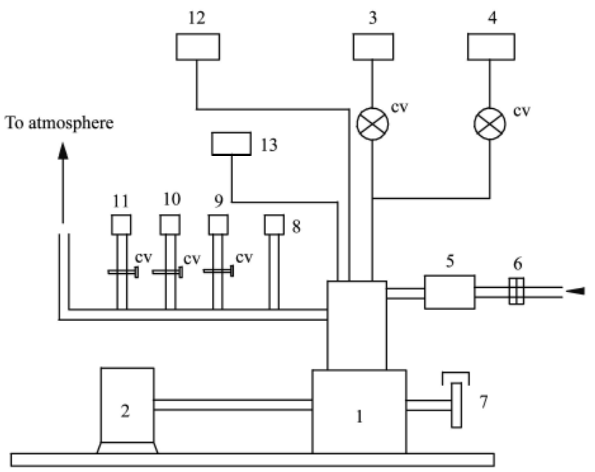
The engine used in the present tests at Basaveshwar Engineering College is a Kirloskar, single-cylinder oil engine. It consists of a test-bed, a diesel engine, an eddy current dynamometer, three fuel tank with a stirrer (one tank is fitted with thermostat controlled heater), a data acquisition system, a computer, an operation panel, the exhaust emission analyzers, a smoke meter, a SO_x meter, and the various sensors to measure the lubricating oil temperature, the exhaust temperature at the manifold, a pressure sensor to measure in-cylinder pressure, a pressure sensor to measure fuel line pressure (placed very near to injector). Two filters are installed: one at the exit of the tank and the other at the fuel pump. These filters had to be changed every 100 h of operation, because they are clogged. The fuel system is modified by adding an additional three-way, hand operated, two position directional control valve which allowed rapid switching between the diesel used as a standard and the test fuels. Fuel is fed to the injector pump under gravity. Lubricating oil temperature is measured by using a thermocouple. The cooling water temperature is maintained constant (65 to 70℃) throughout the research work by controlling the flow rate of water. The injector opening pressure 200 bar (1 bar=10^5 Pa) and static injection advance 23 CA (crank angle) bTDC were kept the same throughout the experimental work. The main characteristics of the engine are listed in Table 4. The photograph and schematic diagram of the experimental setup is shown in Figures 1 and 2 respectively.

The exhaust gas composition was analysed by using exhaust gas analyzer (make: MRU, Germany, model: DELTA 1600 S) and smoke density was measured with smoke opacity meter (make: MRU, Germany, model: Optrans 1600). The specifications of exhaust gas analyzer and uncertainties of measured values are given in the Table 5.

Table 4 Engine specifications

Manufacturer	Kirloskar Oil Engines Ltd., India
Model	TV_SR II, naturally aspirated
Engine	Single cylinder, direct injection diesel engine
Bore/stroke/compression atio	80 mm/110 mm/16.5:1
Speed	1500 r/min, constant
Injection pressure/advance	200 bar / 23^o bTDC (1bar = 10^5 Pa)
Shape of piston	Bowl-in-piston
Dynamometer	Eddy current (Make: Dynaspeed)
Air flow measurement	Air box with U tube
Exhaust gas temperature	RTD thermocouple.
Fuel flow measurement	Burette with digital stopwatch
Type of starting	By hand starting
Governor	Mechanical governing (centrifugal type)
Pressure transducers	
Resolution	0.1 bar for cylinder pressure (Cp)/1 bar for fuel line pressure (Fp)
Type of sensor and maximum pressure	Piezo electric (5 000 PSI for Cp and 10 000 PSI for Fp)
Response time	4 micro seconds
Sampling resolution	1 degree crank angle
Crank angle sensor	360 degree encoder with a resolution of 1 degree

Figure 1 Photograph of the experimental setup



1. Engine 2. Eddycurent dynamometer 3. Diesel tank 4. Honne oil tank 5. Air tank 6. Orifice meter 7. Speed pick up 8. EGT, 9. Smoke meter 10. Exhaust gas analyzer 11. SO_2 meter 12. Computer, display unit (PV, Pθ, NHRR etc) 13. Lubricating oil temperature, CV = control valvel

Figure 2 Line diagram of the test setup

Table 5 Exhaust gas analyzer and smoke opacity specifications and uncertainty of measured values

Exhaust gas	Principle of measurement	Range	Resolution	Accuracy
O_2	Electrochemical	0-22 vol.%	0.01 vol.%	±0.2 vol.%
NO_x	Electrochemical	0-5 000 ppm	1 ppm	±10 ppm (ppm =μmol/mol)
CO	NDIR	0-10 vol.%	0.01 vol.%	±0.03 vol.%
CO_2	NDIR	0-16 vol.%	0.1 vol.%	±0.7 vol.%
HC	NDIR	0-20 000 ppm	1 ppm	±5 ppm
SD				±2%

Measured data	Uncertainty
Speed	±1
Fuel volumetric rate	±1
Torque	±1
EGT	±1
Acid value	±1
Kinematic viscosity	±2.5
Density	±3.5
Cloud and pour point	±1.5
Carbon residue	±0.05
Ash content	±0.05
Distillation temperature	±3
Flash point	±2

The engine tests were conducted for the entire load range (0 to 100% i.e., 0 to 5 hp in steps of 25%) (1 hp = 735.499 W) at constant speed of 1 500 r/min. The engine parameters, such as fuel consumption, air consumption, exhaust gas temperature (EGT) and exhaust gas emissions were measured for all the fuel samples thrice and averaged. The engine was started with diesel fuel and the data was collected after attaining steady state. Then the experiment was switched over to blend of honne oil and diesel fuel and other fuels.

3 Results and discussion

The engine brake thermal efficiency, CO, HC, smoke density (SD) and NO_x are presented against medium (50% and 75% load) and high load (100%) for all the attempts (all the fuels under consideration). In-cylinder pressure and net heat release rate (NHRR) are presented against crank angle.

3.1 Fuel properties and characteristics

The unrefined but filtered honne oil is used as fuel in this study. Most of the physical properties of the vegetable oil (kinematic viscosity (KV), density, cetane number, flash point, bulk modulus etc) are depends on the type and percentage of fatty acids contained in vegetable oil in turn depends on the plant species, on the growth conditions of the tree and geography. The fatty acid composition, saphonifcation value, iodine value and acid value of honne oil are reported in the literature[22] . The viscosity of H100 at 40℃ is 32.48 mm^2/s. The higher viscosity of H100 oil could be attributed to its molecular composition, structure and greater carbon chain length. Density is another important property of vegetable oil. Fuel injection equipment operates on a volume metering system, hence a higher density for vegetable oil results in the delivery of a slightly greater mass of fuel. Density of H100 is higher than ND. The flash point of H100 is better than ND for the engine application. Hence, honne oil is extremely safe to handle. Presence of oxygen in oil improves combustion and reduces emissions but decreases the heating value of the oil. The cloud and pour point of honne oil is within the typical cloud and pour point range of most the vegetable oils and higher than that of ND. Honne oil when subjected to low temperatures, undergo solidification through crystallization and this is a major hurdle for direct use of honne oil in diesel engines. Cetane number is above the minimum limit set by ASTM 6571-08 standards. Ninety percent recovery distillation temperature of honne oil is slightly higher than the maximum limit set by ASTM 6571 – 08 standards.

3.2 Effect on performance parameters

Figure 3 shows the variation of BTE with load. BTE of ND and H20 are almost same, whereas it is higher for HK compared to ND. The reason might be due to the presence of kerosene in the blend leading to better atomisation, vaporisation, mixture formation and combustion (improved premixed combustion phase, Figure 10). The curves also show that in the medium and high load zones, the BTE is almost same for all the percentages of DMC in the blend and it is higher than HK and ND, which is in agreement with the findings of other researchers[10-13,15,16,18,23]. Even though energy density of blended fuel reduces with DMC addition, BTE increased. The reason might be related to:

- Inherent oxygen present in honne oil and DMC[9,11-13,15,16,18,19].
- Reduction in viscosity of the blend[18,19]
- Low boiling point fuel in the blend[9]
- Heating value of kerosene is almost same as that of ND and it is lighter fraction hydrocarbon fuel (boiling point, 150℃)
- Auto ignition temperature of DMC and kerosene (220℃) is lower than that of ND.
- The noticeable reductions in CO, HC, smoke density and EGT indicate that the DMC addition improves combustion efficiency.
- Improved premixed combustion phase (Figure 10).

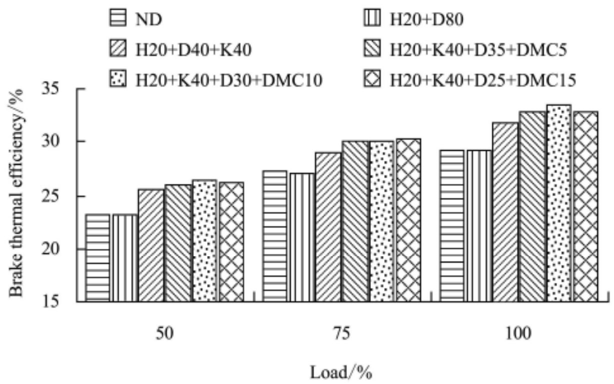


Figure 3 Variation of brake thermal efficiency

3.3 Effect on emission parameters

Emissions like CO, HC and SD, Figures 4, 5 and 6 respectively, of HK reduced compared to ND and H20. The SD emission reduction for HK oil is mainly dependent on a decrease in the aromatic content of honne oil and the effect of oxygen in the honne oil also due to the presence of kerosene in the fuel[24].

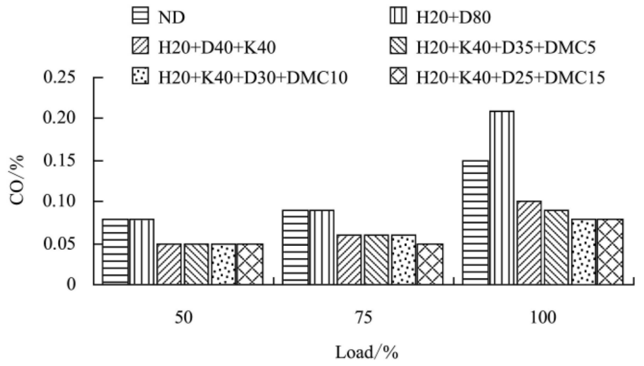


Figure 4 Variation of CO with load

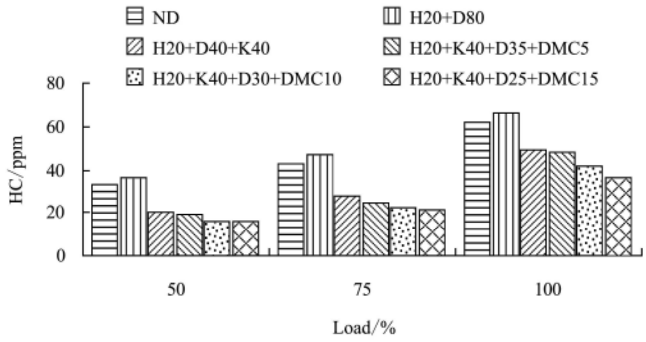


Figure 5 Variation of HC with load

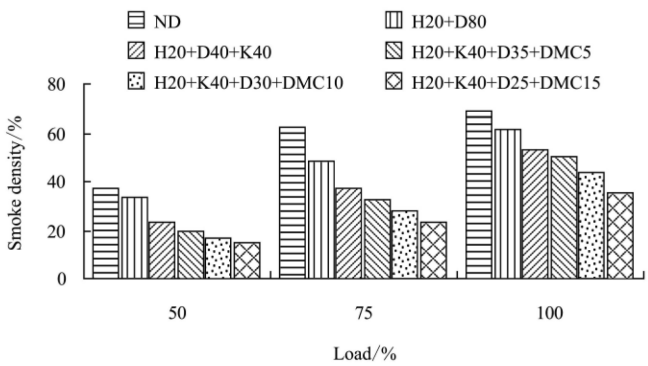


Figure 6 Variation of smoke density with load

Similar observations on SD emissions have been reported in the literature[19]. With an increase in DMC content, significant improvements, in CO, HC and SD are obtained compared to HK and ND, which is in agreement with the findings of other researchers[11-13,15,17,18,23], especially SD dropping significantly[10,14,16,19]. The reason might be due to the inherent oxygen present in honne oil[9] and kerosene improved atomisation, vaporisation and well mixed with air forming relatively lean condition where the spray consumed major portion of the air owing to the higher volatility and lower viscosity of the kerosene and DMC in the blend and improved premixed combustion phase. The engine fuelled with DMC emitted very low SD (compared to ND) because this oxygenated fuel has no C=C bonds in the molecule; C is oxidised easily and least aromatics. Wang et al.[10] reported that CO and HC emissions increased compared to ND.

With DMC, the reduction in CO is higher at higher load (100%) compared to medium load. In diesel engine combustion takes place normally at higher A/F ratio, therefore sufficient O_2 is available to burn all the carbon in the fuel fully to CO_2. The oxidation reaction is reversible and the process is limited due to the phenomena of dissociation of CO_2 into CO and O_2. The dissociation is more at high load due to high cylinder temperature[25]. Due to presence of extra oxygen (vegetable oil and DMC), additional oxidation reaction might have taken place between O_2 and CO releasing heat. This improves premixed combustion phase (Figure 10) increasing BTE (Figure 1). This oxidation reaction gives lower CO emission than ND and HK.

Figure 7 shows the NO_x emissions for all the fuels under consideration. The important factors that cause NO_x formation are high combustion temperatures and the availability of oxygen. The NO_x emissions increased with the increase of the engine load as expected. It is seen that the NO_x emissions increased for HK compared to ND and H20. The curves also show that the NO_x increases when the percentage of DMC increase in the fuel blend. Similar observations on NO_x emissions have been reported in the literature[13]. The increase in the NO_x with DMC added may be caused by the high temperature promoted by the improved premixed combustion phase (Figure 10) and oxygen enrichment. NO_x and CO_2 emissions of the blends are decreased compared to ND[10,16]. It was reported that there is no significant change in NOx emissions[11,12,14].

Figure 8 shows the trade off between SD and NO_x as DMC content changes. As DMC content increases, the percentage decrease of SD is much higher than the percentage NO_x increase, which implies better trade off between NO_x and SD.

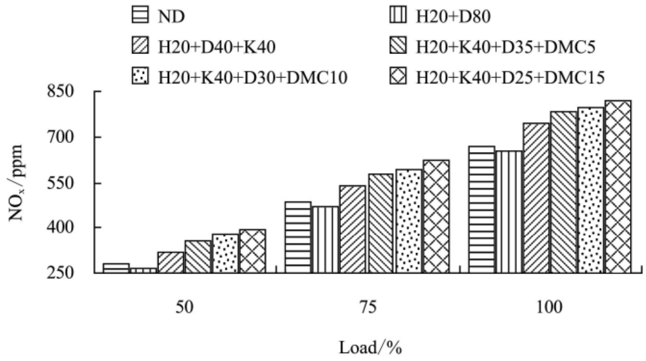


Figure 7 Variation of NO_x with load

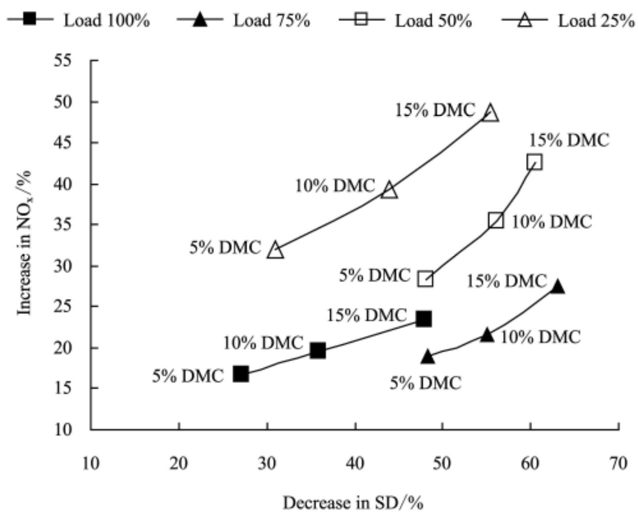


Figure 8 Trade off between SD and NO_x

3.4 Combustion characteristics

Figure 9 shows the cylinder pressure at 75% load. It can be seen that peak pressure of HK is higher compared to ND. The curves also show that the peak cylinder pressure increases as DMC content increase and it is higher than ND and HK. The occurrence of peak pressure shifted towards right as DMC content increase. Senthil et al.[23] reported that increase in peak pressure rise, almost same maximum rate of pressure rise in case of jatropha oil (85% by volume), and DMC (15% by volume) blend compared to ND.

Figure 10 shows the NHRR at 75% load. It can be seen that premixed combustion phase of HK is more than ND. Presence of kerosene (low boiling point and low auto ignition temperature), might improved atomisation, vaporisation and mixing with air, leading to better combustion. The addition of DMC did not cause any significant change in ignition delay, but premixed combustion phase increased as DMC content increased, which might explain the increase in NO_x formation. These characteristics make it possible to realise simultaneous improvements in BTE and emissions (CO, HC and SD). Improved premixed combustion phase of blend of DMC and kerosene might be due to its low boiling point, volatility, and additional oxygen; hence DMC evaporated quickly and better combusted. Senthil et al.[23] reported that ignition delay period and combustion duration increases in case of jatropha oil (85% by volume) and DMC (15% by volume) blend compared to ND.

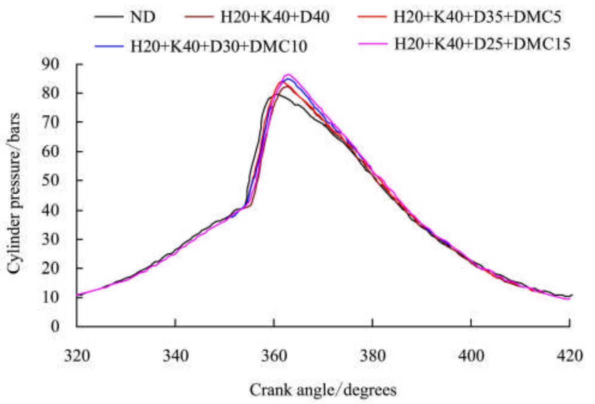


Figure 9 Cylinder pressure with crank angle

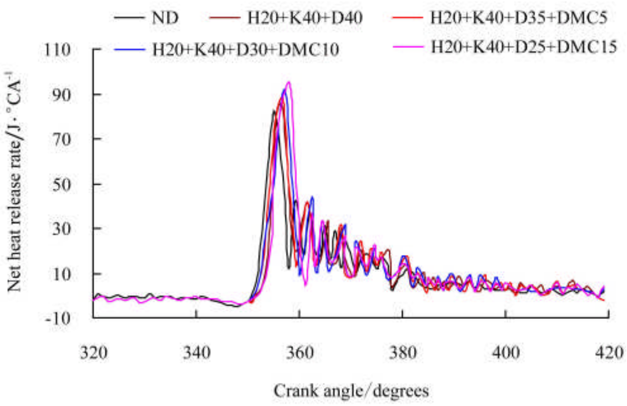


Figure 10 Net heat release rate with crank angle

Generally, a lower auto ignition temperature results in a lower delay period, the maximum value of pressure is least since most of the fuel burn in the controlled phase[25]. Owing to the low auto ignition temperature of kerosene and DMC, delay period should decrease leading to decrease in premixed combustion phase, but this did not happen. The delay period of HKD5 to HKD15 is almost same and equal to ND, DMC and kerosene helped to accelerate the combustion process, more heat is released during the premixed combustion phase.

Owing to the high latent heat of vaporisation of DMC, as its content increase, maximum NHRR should decrease and NO_x should also decrease, but this did not happen. This requires further investigation.

4 Conclusions

From the extensive experiments conducted on a DI diesel engine, the following concluding remarks can be made:

4.1 Comparing the honne oil and diesel fuel blend with ND resulted in:

1) Brake thermal efficiency and CO emission is almost same

2) HC emission is slightly increased

3) SD and NO_x emission is slightly decreased

4.2 Comparing honne oil / diesel fuel / kerosene blend with ND and H20

1) Brake thermal efficiency increased

2) Emissions (CO, HC and SD) reduced

3) NO_x emission increased

4.3 Comparing honne oil / kerosene / DMC blend with ND, H20 and HK

1) Brake thermal efficiency of HKD5 to HKD15 is almost same and it is higher as compared to ND, H20 and HK.

2) Emissions (CO, HC and SD) decreased as DMC content increased and it is lower compared to other fuels, especially SD decreased significantly.

3) NOx emission increased as DMC content increased and it is higher compared to other fuels.

4) There is good trade off between SD and NOx as DMC content increase

5) Peak cylinder pressure increased as DMC content increased.

6) Premixed combustion phase and maximum NHRR increased as DMC content increased.

On the whole it is concluded that honne oil / diesel fuel blend and honne oil / diesel fuel / kerosene blend can be used as DI diesel engine fuel for short term applications. The blend of honne oil / kerosene / diesel fuel / DMC can be used in DI diesel engine for long term applications. Further experimental work is required for 1) optimisation of fuel injection parameters (nozzle opening pressure and injection advance) based on performance and emissions, 2) estimation of durability and 3) assessment its effect as a carcinogen.

Notations

BTE	Brake thermal efficiency	H20	20%H + 80%D
C	Carbon	HK	20%H + 40%K + 40%D
CA	Crank angle	HKD10	20%H + 40%K + 30D + 10%DMC
Cp	Cylinder pressure	HKD15	20%H + 40%K + 25D + 15%DMC
D	Diesel fuel	HKD5	20%H + 40%K + 35D + 5%DMC
DI	Direct injection	K	Kerosene
DMC	Dimethyl carbonate	ND	Neat diesel
EGT	Exhaust gas temperature	NHRR	Net heat release rate
Fp	Fuel line pressure	PM	Particulate matter
H	Honne oil	SD	Smoke density

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