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# Simultaneous Reduction of Smoke and NO Emission Using Lower Order Alcohols in a Jatropha Methyl Ester Fuelled Compression Ignition Engine

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## ABSTRACT

The objective of this work is to experimentally study the consequence of blending lower order alcohol (methanol and ethanol) with jatropha oil methyl ester (JOME) in a single cylinder, four stroke and water-cooled CI engine. 70% JOME blended with 30% methanol (J70M30) and 70% JOME blended with 30% ethanol (J70E30) are the two blends prepared to operate the engine. Experiments were conducted from 0 to 100% load at a fixed engine speed of 1500 rpm and the results were compared with base fuels. Due to the inferior physical properties of JOME, brake thermal efficiency (BTE) decreases compared to diesel at maximum load. Also, NO emissions increased by 4% and smoke opacity decreases by 10% while operating the engine with JOME compared to diesel. Simultaneous reduction of NO and smoke is achieved by blending lower order alcohol with JOME and a slight improvement in BTE is observed.

## INTRODUCTION

Diesel engines operating with higher compression ratio and lean air-fuel ratio will deliver higher thermal efficiency and thus play a major role in transportation and agriculture sector. Also, diesel engines can slow down the increase in atmospheric carbon concentrations compared to gasoline engines (Sun et al. 2010). Although diesel engines produce less carbon monoxide, carbon dioxide and hydrocarbons, they emit more $NO_x$ and smoke compared to SI engines. In addition, due to rapid depletion and increasing cost of petroleum-based fuels, biodiesel is considered to be a potential alternate fuel for the future. Prakash et al. (2018) studied the effect of operating high viscous neat castor oil (NCO) and its biodiesel (COME) in a single cylinder CI engine and observed an increase in brake thermal efficiency from 23.5% (NCO) to 29.7% (COME) and a marginal decrease in smoke opacity for COME in comparison with NCO. Thiyagarajan et al. (2016) attempted an experimental study on combustion, performance and emission behaviour of a karanja biodiesel (KO) fuelled CI engine and compared the outcome with the base fuel (diesel). They concluded that both KO and diesel have similar brake thermal efficiency under all the loads, and NO emission rises from 9.06 g/kWh (diesel) to 10.25 g/kWh (KOME) at 100% capacity.

*Jatropha curcas* is a large plant that belongs to the biological group of Euphorbiaceae and grows widely in most parts of India, in particular in semi-wild conditions near villages. Jatropha plant can grow rapidly almost anywhere even on gravelly, sandy and saline soils. It has hardly any special requirement with regard to soil and climate. Cetane number of Jatropha oil is high compared to diesel which makes jatropha oil as an alternative fuel for CI engine compared to other biofuels. Kumar et al. (2003) analysed the effect of using jatropha oil methyl ester in a diesel engine on performance, combustion and emission parameters. The outcome of the experiment is a small reduction in BTE due to low heating value of biodiesel and a significant reduction in CO, HC and smoke emissions. Dubey et al. (2017) operated the CI engine in dual fuel mode with jatropha oil methyl ester and turpentine oil in different ratios without any engine modification. They concluded that with BT 50, the engine parameters such as BTE, CO, HC, NO and smoke get reduced by 2.9%, 42.5%, 4.56%, 4.72% and 29.16% respectively, while $CO_2$ emissions increased by 10.7%, at full load. Already exhaustive research work has been carried out with jatropha oil biodiesel and reports suggest that this oil can be used directly in diesel engines without any engine modification. However, the engine performance characteristics are slightly inferior than diesel.

Alcohols have the ability to blend directly with vegetable oils and without any change in the engine setup these blends can be used directly in the existing diesel engines (Agarwal 2007). Lower order alcohol has a low viscosity, low flash point, low boiling point and high heat of vaporization compared to neat diesel but its low cetane number makes it unsuitable as a single fuel for diesel engine operation. However, physical properties improve significantly by blending vegetable oil with alcohol in minor proportion. Primarily, a considerable reduction in density and viscosity is observed with the improvement in volatility. Yilmaz & Sanchez (2012) have tested standard diesel (D), neat biodiesel (B), biodiesel (85%)-methanol (15%) and biodiesel (85%)-ethanol (15%) in a twin cylinder CI engine and observed a reduction in NO emissions with all the tested biodiesel-alcohol blends. However, they observed a maximum reduction in NO emission with biodiesel methanol blend.

In India, ethanol is manufactured from molasses, which is a byproduct of sugar industry. It can be used in diesel engine since it is a low cost oxygenate and its use will help the rural farmers. Chelladorai et al. (2019) investigated various blends of grapeseed biodiesel and ethanol blends at full load operation to evaluate the performance and emission characteristics of a single cylinder CI engine. They concluded that blending of 10% volume of ethanol with grapeseed biodiesel increases the BTE from 26.54% to 30.04% and reduces CO, $NO_x$ and smoke level from 0.037% to 0.03%, 945 ppm to 813 ppm and 51% to 41% opacity, respectively. Huang et al. (2009) in their work investigated the solubility of ethanol in diesel with and without the addition of n-butanol and further investigated the performance and emission parameters in a CI engine. Engine tests with diesel-ethanol blend with butanol in the following ratio Z5E10D85, Z5E20D75. Of all the combinations, Z5E25D70 blend is found to have a maximum brake thermal efficiency of 37% compared to all other blends. Subbaiah et al. (2010) have evaluated experimentally the performance and emission characteristics of rice bran oil biodiesel-ethanol blend in a CI engine with a blending ratio of 2.5 %, 5% and 7.5 %. They observed a maximum BTE with 2.5% ethanol blended with rice bran biodiesel and the BTE obtained is reported to have been 6.98% and 3.93% higher than neat diesel and biodiesel, respectively, at full load operation of the engine. Smoke emission of the biodiesel was reduced by 20% when blended with 7.5% of ethanol while a reduction in smoke of 27.47% has been recorded with 2.5% blend.

A number of research studies have shown that high isentropic bulk modulus of biodiesel causes artificial advance in injection timing, lower stoichiometric air-fuel ratio, high adiabatic flame temperature, fuel bound oxygen and radiative heat transfer as the possible reasons for the $NO_x$ increase with biodiesel. Several techniques were proposed by numerous research studies to reduce $NO_X$ emission in CI engine like use of oxygenates (Kasiraman et al. 2016), antioxidant additives (Varatharajan et al. 2011), emulsion (Yoshimoto et al. 1999), EGR (Mahalingam et al. 2018) and SCR (Anderson et al. 2018). Kathirvelu et al. (2017) studied the impact of operating a single cylinder CI engine with 100% JOME and blending diesel with 20% JOME. They noticed a significant increase in NO emission and lower soot emission with JOME compared to diesel. Sayin (2010) in his experiments on a single cylinder CI engine, has studied the effects of diesel-methanol and diesel-ethanol blends, respectively on the performance and exhaust emissions. Readings were observed for speeds in the range of 1000 to 1800 rpm with the engine torque at 30 Nm. They observed a decrease in brake thermal efficiency, smoke opacity, CO and HC emissions for the fuel blends in comparison to diesel.

Many research works based on biodiesel-alcohol blends have been investigated as indicated above. However, not much work has been reported on the use of jatropha oil biodiesel lower order alcohol blends as it is expected to improve the BTE with the simultaneous reduction of NO and smoke emission. Therefore, the main objective of this work is to study the effect of blending lower order alcohols (methanol and ethanol) with jatropha oil methyl ester in a CI engine on the performance, combustion and emission characteristics.

## TEST FUELS

Experiments were carried out with diesel, jatropha oil methyl ester (JOME), jatropha oil methyl ester 70% + methanol 30% (J70M30), jatropha oil methyl ester 70% + ethanol 30% (J70E30). Tables 1 and 2 show the specifications of the test engine and properties of the test fuels respectively, and Fig.1 shows the schematic diagram of the experimental setup on which experiments were conducted.

Table 1: Engine specifications.

| Parameter | Value |
|---|---|
| Make and Model | Kirloskar, TV1 |
| No. of Cylinder | 1 |
| Cycle | 4 Strokes |
| Bore | 87.5 mm |
| Stroke | 110 mm |
| Displacement volume | 661 $cm^3$ |
| Compression ratio | 17.5:1 |
| Combustion chamber | Hemispherical |
| Rated power | 5.2 kW @ 1500 rpm |
| Injection timing | 23° BTDC |

## RESULTS AND DISCUSSION

### NO Emission

Fig. 2 shows the variation of nitric oxide emission with

Table 2: Properties of test fuel.

| Property | Diesel | JOME | J70M30 | J70E30 |
|---|---|---|---|---|
| Density @ $15^{o}$ C (g/cc) | 0.840 | 0.880 | 0.843 | 0.852 |
| Kinematic Viscosity @ $40^{o}$C cSt | 2.95 | 4.57 | 3.37 | 3.53 |
| Lower Heating value (kJ/kg) | 42500 | 38450 | 32188 | 35615 |
| Cetane index | 45 | 52 | 38 | 40 |

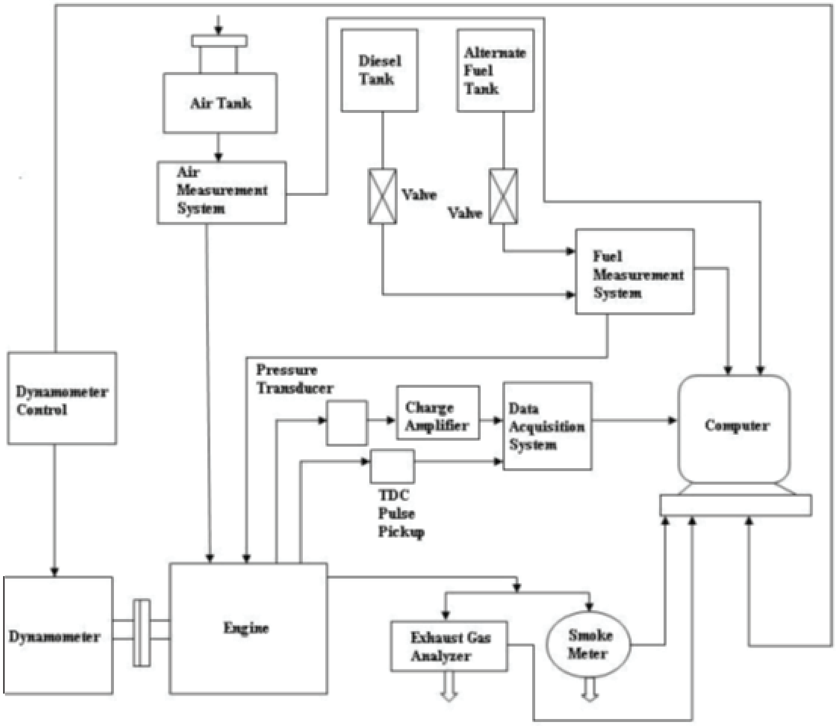

Fig. 1: Schematic diagram of the experimental setup.

respect to brake power. High in-cylinder temperature, oxygen availability, time available for reaction, presence of free radical in the hydrocarbon flame and fuel bound oxygen are the important reasons for the $NO_x$ emission in compression ignition engines. NO emissions are slightly higher in pure biodiesel operation at all loads compared to diesel due to the oxygen content in the biodiesel. It is evident that addition of alcohol to biodiesel decreases the NO emissions significantly. At 100% load, NO emission of J70M30 and J70E30 are lower by 31.1% and 28.9%, respectively compared to JOME. High latent heat of vaporization and low heating value of methanol and ethanol reduces the in-cylinder temperature during combustion thus lowering the NO emission.

## Smoke Opacity

Fig. 3 shows the variation of smoke opacity with respect to brake power. Incomplete combustion in fuel rich zone is responsible for smoke formation (Dale et al. 2007). When the engine was operated at rated load, smoke opacity of diesel and JOME are 50.7 and 45.2% respectively. JOME has lower smoke opacity due to the presence of fuel bound oxygen. Blending alcohol with JOME will further increase the oxygen concentration in the mixture. Smoke opacity of J70M30 and J70E30 are 42.8% and 43.9% respectively. Lower smoke opacity of methanol blend is due to high oxygen content of methanol (0.5% by weight) compared to ethanol (0.35% by weight).

## CO Emission

Fig. 4 shows the variation of CO emission with respect to brake power. Diffusion combustion phase is responsible for more CO formation as oxidation of CO is more during pre-

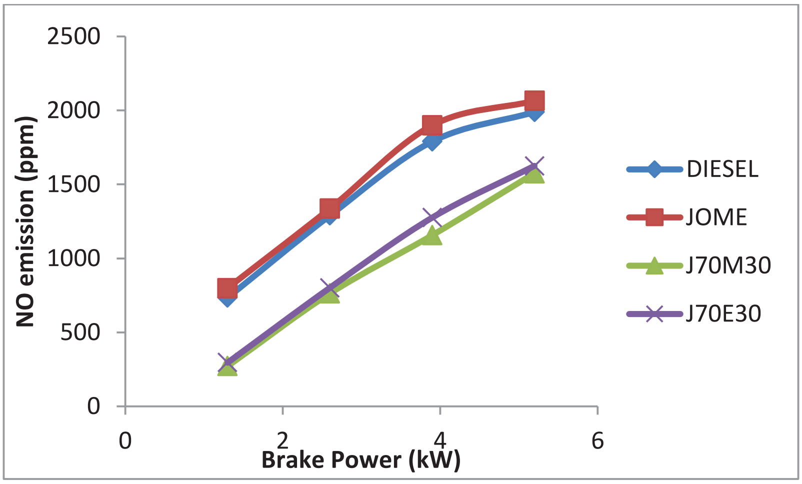

Fig. 2: Variation of NO emission at different load conditions.

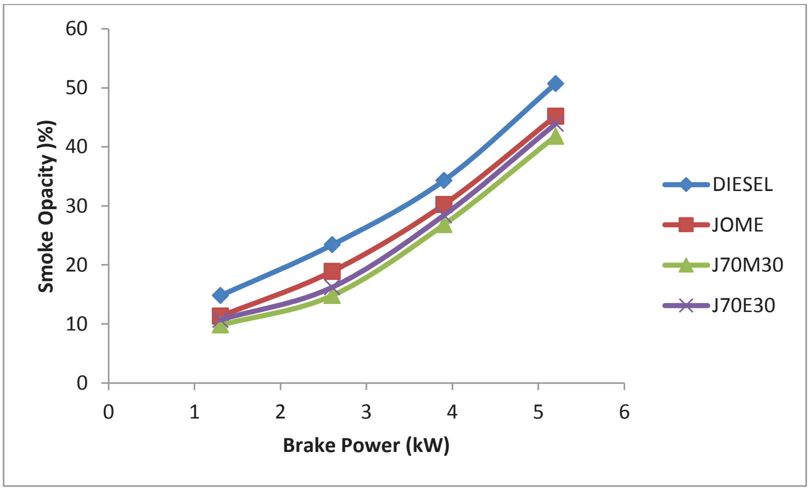

Fig. 3: Variation of smoke opacity at different load conditions.

mixed combustion phase due to high temperature. At maximum load, CO emission for diesel and JOME is 0.073 % and 0.096 % as shown in the figure. JOME emits more CO due to higher carbon content in fuel structure and poor physical properties like high viscosity and density in comparison to diesel. However, at low and part load operation, carbon monoxide emission for JOME is lower than diesel. Carbon monoxide emission is reduced to 0.072 % and 0.074 % for J70M30 and J70E30 respectively. Lower carbon monoxide emission for J70M30 and J70E30 is due to oxygen enrichment in the blend that leads to oxidation of CO.

## HC Emission

Fig. 5 shows the HC emission as a function of brake power. Hydrocarbon emissions are due to incomplete combustion of hydrocarbon fuel and is a useful measure of combustion inefficiency. The figure depicts the hydrocarbon emission for J70M30 and J70E30 compared to diesel and JOME at various load operation. HC emission for diesel and JOME is 52 ppm and 61 ppm respectively at maximum load. Higher HC emission with JOME is attributed to higher C-H ratio and poor combustion leading to less combustion temperature. Hence, JOME emits higher HC emission in spite of its fuel borne oxygen atoms. J70M30 emits more HC compared to J70E30 at all loads. HC emission for J70M30 and J70E30 is 76 ppm and 71 ppm respectively at full load. Alcohol blending with biodiesel increases HC emission because of the cooling effect produced due to high latent heat of vapor-

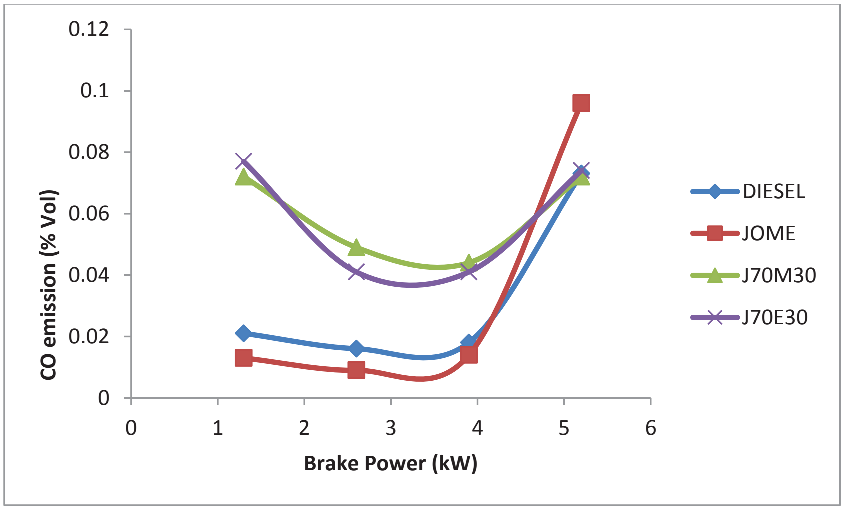

Fig. 4: Variation of CO emission at different load condition.

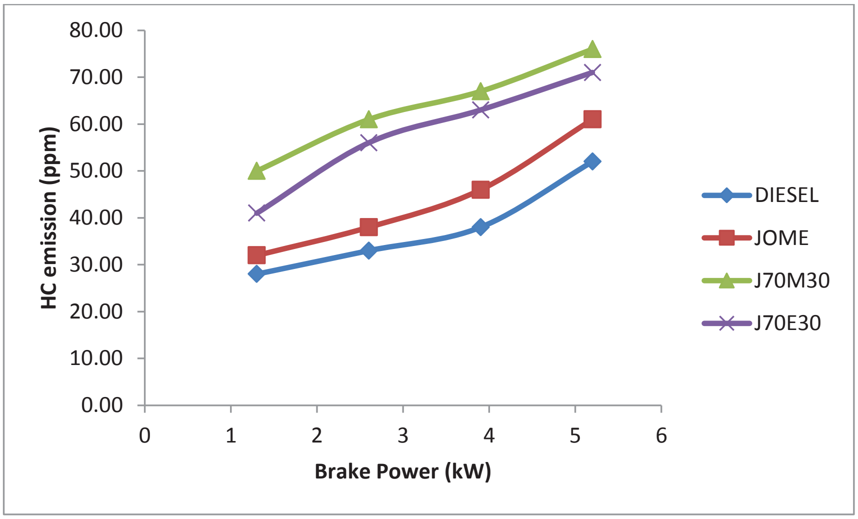

Fig. 5: Variation of HC emission at different load conditions.

ization of methanol and ethanol (Yilmaz & Sanchez 2012).

### Brake Thermal Efficiency

Fig. 6 illustrates the variation of BTE with brake power. BTE indicates the quantity of power delivered for the given quantity of heat supplied. Brake thermal efficiency of diesel and JOME was found to be 34.34% and 32.24% respectively at full load. Lower brake thermal efficiency of JOME is due to high viscosity and low calorific value of the fuel compared to diesel. Methanol and ethanol addition to JOME slightly improves the brake thermal efficiency compared to diesel. The possible reason may be due to low viscosity, improved volatility and oxygen enrichment of the blend which enhances the quality of combustion.

### Exhaust Gas Temperature

Fig. 7 portrays the variation of exhaust gas temperature (EGT) with brake power. It can be observed that EGT increases with increase in load since the quantity of fuel supply increases with load. At full load, exhaust gas temperature of JOME (356°C) is slightly higher than diesel (351°C). High viscosity of JOME leads to slow atomization and vaporization of air-fuel mixture and hence the exhaust gas temperature of JOME is more than diesel. Alcohol ad-

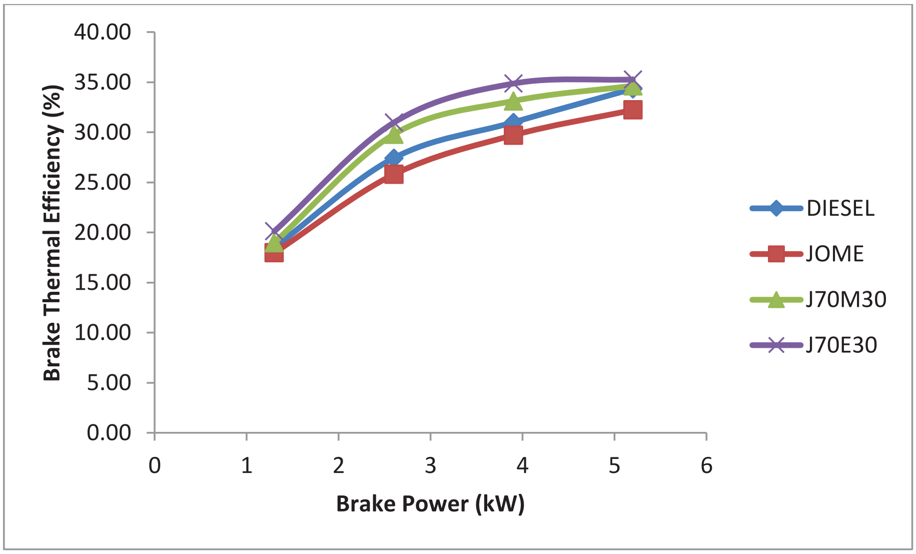

Fig. 6: Variation of BTE at different load conditions.

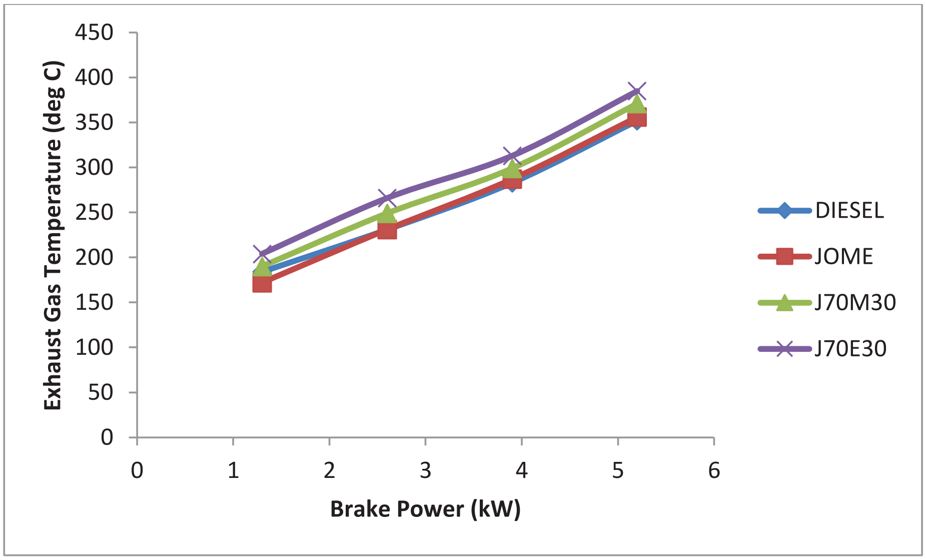

Fig. 7: Variation of exhaust gas temperature at different load conditions.

dition increases the EGT at all loads. EGT of J70M30 and J70E30 is 371°C and 385°C respectively at full load.

### Net Heat Release

Fig. 8 shows the variation of heat release with crank angle for diesel, JOME, J70M30 and J70E30 at full load. Peak heat release for diesel and JOME is 47.5 J/°CA and 44.3J/°-CA, respectively. Maximum heat release is lower for JOME due to its high viscosity and low heating value. Due to high cetane number of JOME the peak heat release occurs early compared to diesel. With alcohol addition, the cetane number decreases and ignition delay period slightly increases leading to fuel accumulation in the cylinder which in turn delays the start of combustion and increases the maximum heat release. The peak heat release for J70M30 and J70E30 is 46.9 J/°CA and 51.4 J/°CA respectively.

## CONCLUSION

The present work investigates the effect of lower order

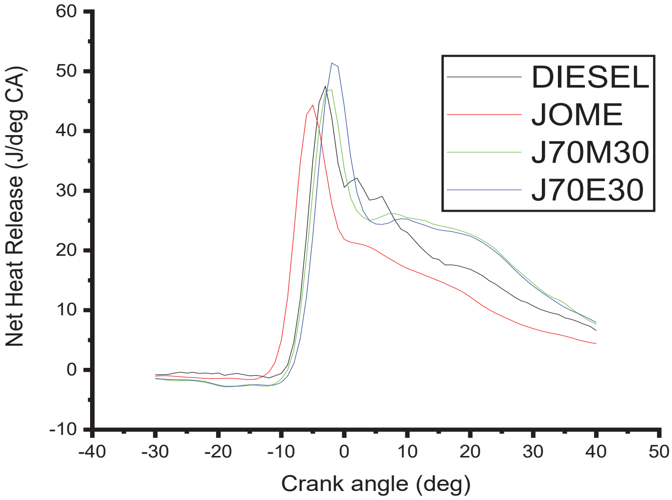

Fig. 8: Rate of heat release at 100% load.

alcohol addition with jatropha oil methyl ester to achieve simultaneous reduction of NO and smoke emission in a single cylinder CI engine. Lower order alcohols namely methanol and ethanol were blended 30% by volume with 70% JOME and tested at different load conditions.

- Blending 30% lower order alcohol with JOME reduces NO emissions significantly. NO emissions reduced by 31.1% and 28.9% for J70M30 and J70E30 respectively, compared to JOME at full load.
- JOME contains oxygen in its molecular structure and hence JOME emits less smoke compared to diesel. Smoke emission is least for J70M30 blend which is 5.3% lower than JOME and 15.6% lower than diesel, at full load.
- JOME emits slightly higher CO and HC emissions compared to diesel. Blending lower alcohols with JOME, CO and HC emissions increases further.
- BTE of JOME is slightly lower than diesel due to inferior combustion. However, addition of methanol and ethanol with JOME, enriches the blend with oxygen and improves combustion to get higher brake thermal efficiency. Maximum heat release improved with alcohol blending with JOME due to low cetane number of alcohol that delays the start of combustion.

It is concluded that J70M30 is optimum for achieving simultaneous reduction of NO and smoke without any compromise in performance of a jatropha biodiesel fuelled CI engine.

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