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EFFECT OF ISOAMYL NITARATE ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF C.I ENGINE OPERATED WITH CARDANOL ETHYL ESTER BLENDS

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ABSTRACT

This work aimed to investigate the effects of different proportions of cardanol ethyl ester (CEE) with diesel in a single cylinder diesel engine on the performance, emissions and combustion parameters. Results show improved performance for blends up to 50% of CEE (B50) content with increase in NOx emissions compared to neat diesel. B25 blends recorded a maximum brake thermal efficiency of 30.71% against 29.13% for the neat diesel at high load. Addition of 2% of isoamyl nitrate with diesel-CEE blends favour higher proportion of CEE to be employed in diesel engine with reduced emissions.

Indexing terms/Keywords

Diesel engine, Performance, Emission, Cardanol Ethyl Ester and Additive

Academic Discipline And Sub-Disciplines

Mechanical Engineering and Chemical Engineering

SUBJECT CLASSIFICATION

Fuel and Additives, Biofuel, combustion

TYPE (METHOD/APPROACH)

Experimental Investigation

INTRODUCTION

In today's world, majority of automotive vehicles are powered by the compression ignition engines using diesel fuel due to the fact that it is having high efficiency lower emission of CO and HC compared with gasoline. Pollution being the major criteria for today's extensive research work which has proved that the exhaust emissions causes considerable environmental pollution, low level of air quality, and acidic precipitation. Fossil fuels are not evenly distributed on the globe, which means that they must be transported over greater distances from one place to another place. This increases potential for soil and water contamination in storage and supply. Self-reliance in energy is vital for the economic development of one nation [1]. The needs to search for alternative energy sources which are renewable and eco-friendly is top priority in view of the uncertain supplies , because the supplies depends on the weather condition , transport in sea and frequent price hikes of fossil fuels in the international market. Bio fuels are fuels produced by a number of chemical and biological processes from biological materials like plants, etc. Being sourced from trees already existing and to be further extended, bio-fuel is a main source of renewable energy. Biodiesel can be used as a pure fuel or transesterified into methyl/ethyl ester and blended with neat diesel depending on the emissions. In India, the country has a well-established collection and marketing network for non-edible oils [2, 3]. Among hundreds of oil bearing crops that have been identified, Jetropha, sunflower, soyabean, cottonseed, mango seed, rapeseed, and peanut oils are considered as potential alternative fuels for diesel engines. Apart from renewability, the oxygen molecules present in the molecular structure of biodiesel, higher flash point and higher lubricity make complete combustion of the fuel than the diesel fuel[4]. Though the long chain hydrocarbon structure of vegetable oils has good ignition characteristics, the other properties like poor durability, high density, high viscosity, lower heat value, and more molecular weight makes the combustion poor and reduces thermal efficiency, while using vegetable oil in the engine. Literature says that these problems can be rectified by reducing the viscosity of vegetable oils by transesterification, dilution or cracking method [4]. It was found that the transesterified vegetable oils called biodiesel performing better than straight vegetable oil [5]. Last decade research reveals that, use of biodiesel instead of the conventional diesel fuel significantly reduces exhaust emissions such as carbon dioxide, particulate matter, carbon monoxide, sulphur oxides, and unburned hydrocarbons [6,7]. However, there is a major drawback in the use of biodiesel such as low heating value and NOx tends to be higher [8]. Also, its relatively poor low-temperature flow properties limiting its application to blends of 20% or less. These problems could be circumvented by using additives and hence, fuel additives plays indispensable role not only to decrease these drawbacks but also to produce specified products that meet the standards.

Many types of additives have been tried by different researchers for improving the performance and also reducing emissions from diesel engines. The selection of additives for the biodiesel fuel depends on economic feasibility, toxicity, fuel blending property, additive solubility, flash point of the blend, viscosity of the blend, solubility of water in the resultant blend, and water partitioning of the additive. Ali et al reviewed the application of additives for biodiesel and reported that addition of short-chain alcohols such as ethanol, isopropanol and butanol resulted in a moderate improvement in the low-temperature operability of biodiesels. Additives used to improve the properties of biodiesel may further improve combustion performance of biodiesel engine, thus it will promote economy, and meanwhile this will also improve engine power. Oxygenates additives can improve PM emissions of biodiesel, but it would not be useful for power recovery. Metallic additives, oxide additives, emulsifier, etc. seem to be useful to improve NOx emissions of biodiesel[9]. Guru et al. and Caynak et al investigated the effect of metal based additives on biodiesel and reported that the catalytic cracking effect of the additive results in smaller chains of hydrocarbons resulted in lower viscosity and flash point [10,11].

With a trend in the search for alternative fuels to replace conventional diesel totally or partially, Cashew nut shell biomass represents a new ample renewable energy source in India, as cashew cultivation covers a total area of about 0 .77 million hectares of land, with annual production of over 0.5 million metric tons of raw cashew nuts against the world production of 907,000 metric tons from which 15to20% by weight of shell can be obtained with 20% oil content [12]. Cardanol, a bio-fuel derived from cashew nut shell oil is investigated in this study. The influence of small addition of a new additive isoamyl nitrate, with the biodiesel on the performance and emission characteristics of a diesel engine was also studied and the results were compared with that of neat diesel

MATERIALS AND METHODS

Fuel Preparation and characterization

Cardanol ethyl ester (CEE) was prepared by the regular trasesterification process using unhydrous ethyl alcohol (99% grade laboratory reagent type) and sodium hydroxide as catalyst. 100% CEE named as B100 and three fuel blends with diesel namely B25 (75D: 25CEE), B50 (50D: 50CEE) and B75 (25D: 75CEE) without additive and B25A, B50A, B75A and B100A with isoamyl nitrate as additive were used in this investigation. The properties of test fuels were determined at ita lab, Chennai, as per the methods approved by Bureau of Indian Standards and are shown in table 1.

Table 1. Properties of test fuels

Fuel Properties	Diesel	Raw Cardanol Oil	B25	B25A	B50	B50A	B75	B75A	B100	B100A
Specific gravity @ 30^0 C	0.835	0.9216	0.8450	0.8430	0.8648	0.8692	0.8855	0.8955	0.8979	0.8980
Density @30^0C	0.85	0.9209	0.8443	0.8428	0.8640	0.8690	0.8848	0.8952	0.8971	0.8972
Flash Point (^{0}C)	80	200	70	65	52	50	50	48	48	46
Viscosity (cst)	2.8	25.77	3.40	3.36	4.57	4.50	7.16	6.52	10.94	8.95
Fire Point (^{0}C)	88	210	80	81	62	62	60	59.5	58	58
Calorific value(KJ/Kg)	42000	42007	41876	41848	39465	39438	39222	39195	38192	38166
Cetane Number	50	57	55	55	52	52	47	47	46	46

Parameter tested and experimental procedure

Experiments were conducted on a 5.2 kW single-cylinder, water-cooled diesel engine connected with an eddy current dynamometer. The engine was set at 1500 rpm with a standard injection pressure of 216 bar. The detailed specification of the engine is given in tab. 2. K-type thermocouple and a digital display were employed to note the exhaust gas temperature. The fuel flow rate was measured on volume basis using a burette and a stop watch. Smoke level was measured using a standard AVL437C smoke meter. Exhaust emissions of unburned HC, CO, CO_2, O_2, and NOx were measured on dry basis. A non-dispersive infrared (NDIR-AVL-444 digas) analyzer was used. HC and NOx were measured in ppm and CO, CO_2, and O_2 emissions were measured in terms of vol. %. AVL combustion analyzer with 619 Indi meter hardware and indwin software version 2.2 is used to measure in cylinder pressure, heat release rate (HRR), indicated mean effective pressure, etc. Data from 100 consecutive cycles can be recorded.The schematic experimental set-up is shown in Fig. 1.

Base data was generated with standard diesel fuel. Subsequently, four fuel blends ranging from 25 to 100% of cardanol ethyl ester by volume were prepared and tested. The experiments were repeated by adding 2% and 3% of isoamyl nitrate with all the blends. Fuel flow rate, NOx and smoke were recorded to study the engine performance and emission characteristics. The performance of the engine was evaluated in terms of brake specific fuel consumption and brake thermal efficiency. The cylinder pressure and heat release rate were recorded for different blends to study the combustion characteristics.

Table 2. Test engine and measuring instrumentation details

Make	Vertical,Watercooled,Fourstroke,KIRLOSKARAV-1
Number of cylinders	One
Bore	87.5mm
Stroke	110mm
Displacement Volume	661CC
Compression ratio	17.5:1
Maximum power	5.2 BHP
Speed	1500rpm
Load	Eddy current dynamometer
Injection opening angle	23^0 bTDC
Emission measuring instrument	AVL 444 DI gas Analyser & AVL Smoke meter
In cylinder data aquisation	AVL Combustion Analyser

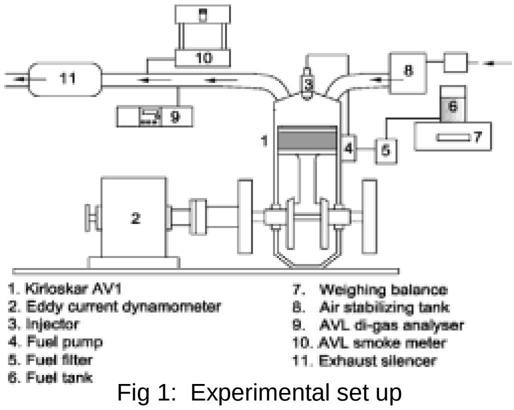

Fig 1: Experimental set up

RESULTS AND DISCUSSIONS

Since CEE contains oxygen in its structure, the stoichiometric air requirement for the combustion of CEE is lower, hence larger amount of fuel can be burnt in a given amount of air and hence the brake specific fuel consumption (BSFC) to decrease for the blends compared with neat diesel. But, CEE has lower heat value than diesel fuel that makes the heat value of the blends to decrease. In order to maintain the same power, more fuels are consumed. As a result, BSFC will increase as the blended fuels with high CEE concentration are used as indicated by Subramanian et al [13]. B25 recorded a minimum BSFC of 0.279 kg/kw-hr against 0.359 and 0.294 kg/kw-hr for B100 and neat diesel respectively at high load. Fig. 2 illustrates the variation of BSFC for diesel and different blends without additive and with 2% and 3% additives at different loading conditions. The fuel and 2% additive result lower BSFC than Fuel and3% additive thus the addition of 2% additive is optimum.

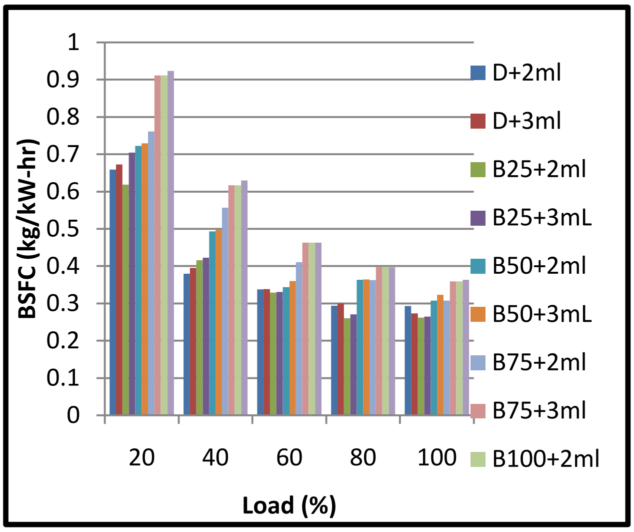

Fig 2: Variation of BSFC for all test fuels with Load

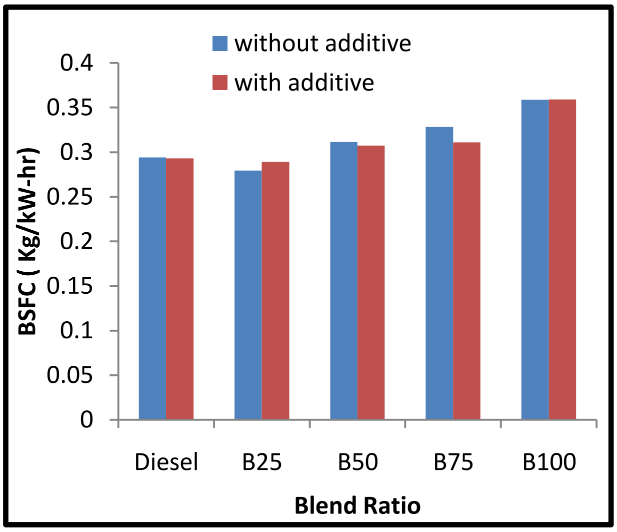

Fig 3: Variation of BSFC at maximum load

The addition of 2% Isoamyl nitrate influence the viscosity, heat value and specific gravity of CEE and its blends due to catalytic cracking effect of the additive [10]. The reduction in viscosity improved the spray characteristics of CEE and thereby decreases the BSFC for blends depending on the CEE concentration. B25 blends with additive show higher BSFC than B25 but for higher blends it is in reverse order. The variation of BSFC at maximum load for diesel, CEE blends without and with 2% additive is shown in Fig. 3.

Fig. 4 depicts variation of brake thermal efficiency obtained for single cylinder at full load for diesel and CEE volumetric blends with and without additive. The presence of oxygen due to CEE improves the combustion, especially diffusion combustion and hence increases the brake thermal efficiency (BTE). B25 blend shows a maximum of 30.7% BTE which is better than neat diesel. However, the higher density and viscosity of higher blends reduces the BTE for higher blends. Additive improved the viscosity of CEE and hence higher blends with additives shows improved efficiency than CEE blends without additive.

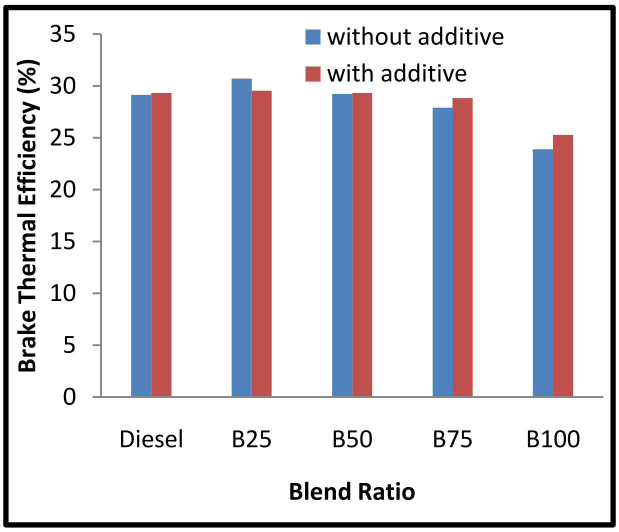

Fig 4: Variation of BTE at maximum load

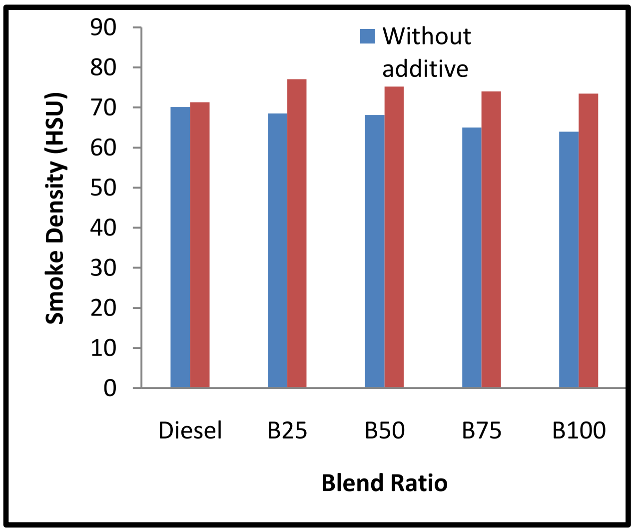

Fig 5: Smoke density variations at maximum load

Fig. 5 shows the variation of smoke density at maximum load for diesel, CEE biodiesel and its blends. Smoke is mainly produced in the diffusive combustion phase; the oxygenated fuel blends lead to an improvement in diffusive combustion for biodiesel and its blends. It is observed from the figure that the smoke density of CEE-diesel fuel blends is significantly lower than that for the corresponding neat diesel fuel case, with the reduction being higher the higher the percentage of CEE in the blend, as the combustion being assisted by the presence of the fuel-bound oxygen of the CEE that may attribute the engine to run with overall "leaner" mixture. It is also evident that the heat release rate of oxygenated fuels is high due to improved injection spray quality and causes less smoke [14, 15]. The results reveal that the tendency to generate soot from the fuel-rich regions inside diesel diffusion flame is decreased by CEE in the blends. Another reason of smoke reduction, when using biodiesel is due to the lower C/H ratio and the absence of aromatic compounds as compared to diesel. The carbon content in biodiesel is lower than diesel fuel. The more carbon a fuel molecule contains, the more likely is to produce soot. Conversely, oxygen within a fuel decreases the tendency of a fuel to produce soot [16]. The catalytic cracking effect of additive results in smaller chains of hydrocarbons and favor higher smoke for isoamyl nitrate doped CEE blends.

The variation of NOx at maximum load for diesel, CEE biodiesel and its blends is shown in Fig.6. NOx emissions of CEE and its blends are slightly higher than those of diesel fuel. The higher temperature of combustion and the presence of oxygen with CEE cause higher NOx emissions. NOx emissions were found to increase due to the presence of extra oxygen in the molecules of biodiesel blends [17]. It is also found that the NOx concentration decreases with additive blended fuel. The presence of additive reduces the combustion temperature and that reason for the reduced NOx emission, Moreover the flame temperature also reduced dramatically which cause complete fuel combustion. Another reason is, the blended fuel with additive reduces friction between the cylinder wall and piston thus the heat loose is controlled in the cylinder and result in considerable reduction in NOx as observed several researchers who conducted some studies in terms of flame and combustion stability of oxygenated and renewable fuels[18,19].

Fig.7 shows HC emissions for all the fuels. It is found that CEE with additive produces lower level of HC emission. The maximum level of HC was produced by neat diesel fuel. It can be seen that isoamyl nitrate doped CEE fuel produces 40 t0 50% lower level of HC as compared to other fuel blends mainly due to complete combustion in the combustion process.

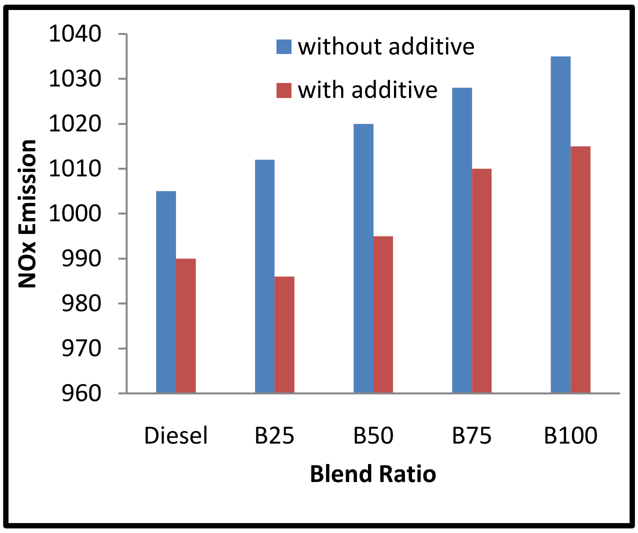

Fig 6: NOx Variations at maximum load

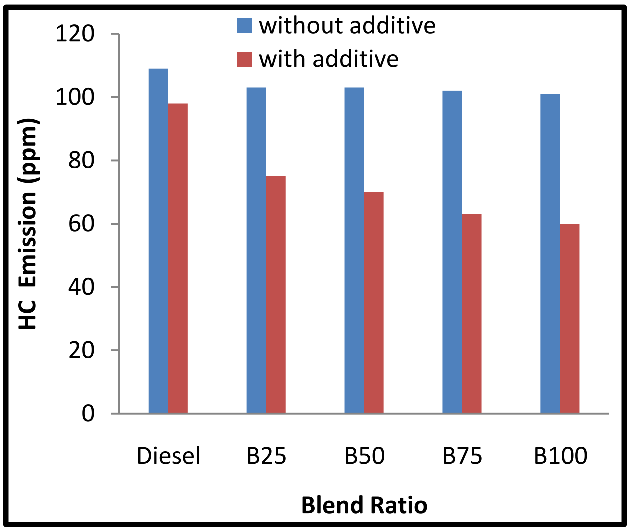

Fig 7: Variations of HC emissions at maximum load

Fig. 8 shows the traces of maximum cylinder pressure (Pmax) of diesel fuel and CEE fuel with or without addition of isoamyl nitrate at maximum loading conditions for 100 cycles. It is found that the peak combustion pressure of CEE fuel blend was increased more than that of diesel as the ignition delay for the CEE blends are higher than that for the neat diesel fuel.

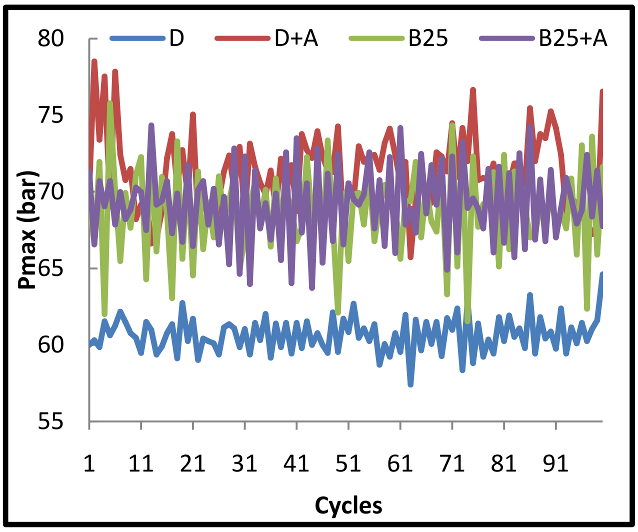

Fig 8: Traces of maximum cylinder pressure for 100 cycles

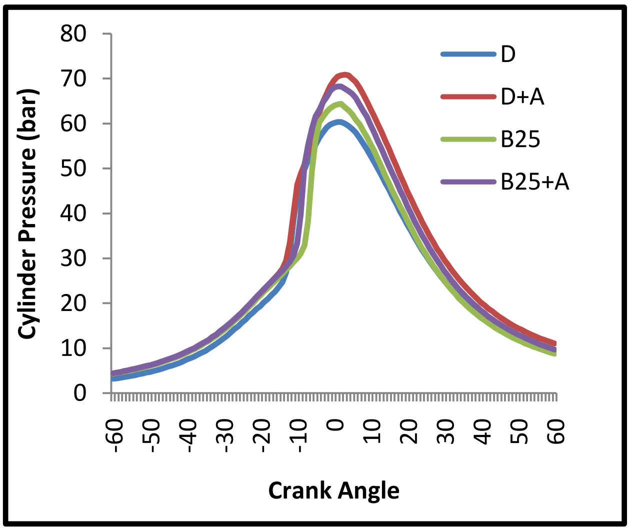

Fig 9: Cylinder pressure profile for optimum blends with and without additive and neat diesel

Fig.9 illustrates that, doping of isoamyl nitrate reduces friction between the cylinder wall and piston and hence the heat loss in the cylinder similar to thermal barrier coating and decreases the ignition delay due to the increasing gas temperature and hence the cylinder pressure.The oxygen in the CEE accelerates the combustion, though the heating value of the biodiesel was lower than that of diesel.

It is observed from Fig.10 that the ignition delay for the CEE blend is higher than that for the neat diesel and its pre mixed combustion peak is high and sharp. It is the lower cetane number of CEE that causes the increase of ignition delay and so the increased amount of “prepared” fuel for combustion after the start of ignition and results in cylinder pressure increase. The heat release rate curves of the CEE fuel blends and neat diesel fuel shows similar curve pattern although the rate of heat release for the B25 shows higher heat release than neat diesel fuel. The reason is the rate of diffusion combustion of the CEE fuel due to the presence of oxygen increasing the heat release rate consequently to have controlled rate of pre-mixed combustion. The heat release rate is further increased for additive added CEE blends due to increased pre-mixed combustion.

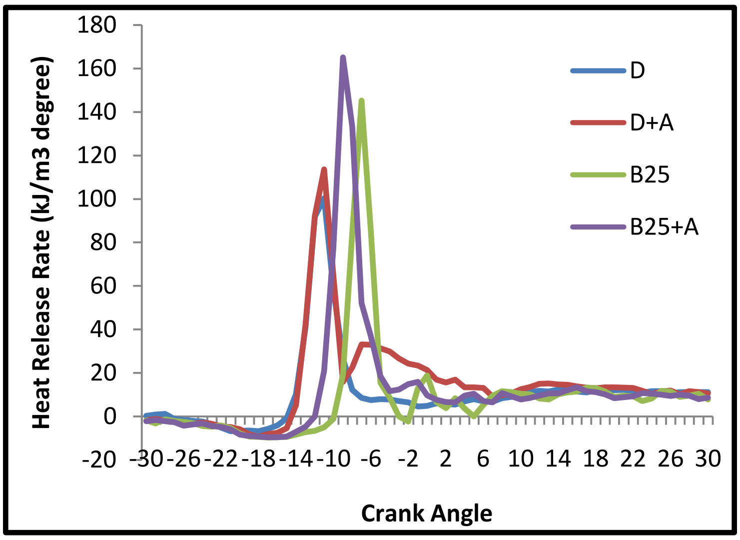

Fig 10: Heat release rate for optimum blends with and without additive and neat diesel

CONCLUSIONS

The major conclusions arrived in this experimental investigation is

- B25 blends (25% CEE) with diesel performs better than neat diesel fuel with less smoke and increased NOx emission
- The increase in NOx emission can be controlled by doping the blends with 2% isoamyl nitrate as the additive reduces friction between the cylinder wall and piston to control the heat loss
- Higher blends with additive also behave like neat diesel fuel with reduced NOx and HC emissions and slight increase in smoke
- B50 with additive performs with efficiency equal to that of neat diesel with 11% and 36% decrease in NOx and HC respectively.

Therefore, use of isoamyl nitrate as additive with CEE blends is a better technique to improve the combustion qualities and emission characteristics of cardanol bio diesel (CEE) for the application of higher blends in diesel engine.

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