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TESTING OF THREE-FUEL MIXTURE IN A FOUR-STROKE SINGLE CYLINDER DIRECT INJECTION DIESEL ENGINE

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Summary

This paper deals with non-petroleum renewable and non-polluting fuels. The performance study has been carried out for three-fuel mixture in an Internal Combustion engine. The three-fuel mixture consist of diesel, turpentine blend and acetylene gas. Acetylene gas is produced from lime stone ($CaCO_3$) and turpentine oil is obtained from pine trees. The performance of the three-fuel mixture has been analyzed experimentally in a single cylinder direct injection and compression ignition engine with diesel and turpentine blend as primary fuel and acetylene as secondary gaseous fuel i.e., diesel and turpentine blend (40% turpentine(40T) and 60% diesel) were considered for the study. The results have shown that the blend and the acetylene gas flow rate of 3 liters per minute (through a gas flow meter) offer higher brake thermal efficiency by between 1% and 3% than the fuel of the baseline diesel operation.

Key words: *Three-fuel mixture, turpentine, acetylene, brake thermal efficiency, combustion engine.*

1. Introduction

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to a reduction in underground-based carbon resources. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis. Gasoline and diesel-driven automobiles are the major sources of greenhouse gases (GHG) emissions. The present energy scenario has stimulated active research interest in non-petroleum, renewable, and non-polluting fuels. The world reserves of primary energy and raw materials are, obviously, limited. According to an estimate, the reserves will last for 213 years for coal, 36 years for oil, and 58 years for natural gas, under a business-as-usual scenario [1-3].Scientists around the world have explored several alternative energy resources, which have the potential for quenching the ever-increasing energy thirst of today's population. Various bio-fuel energy resources explored include biomass, biogas, primary alcohols, vegetable oils, biodiesel, etc. These alternative energy resources are largely environmentally-friendly but they need to be evaluated on case-by-case basis for their advantages, disadvantages and specific applications. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties closer to conventional fuels. In the present scenario due to the lack of knowledge and awareness of alternate fuels the petroleum fuel is commonly used in various sectors.

However, diesel engines can be made to use a considerable amount of gaseous fuels in the dual fuel mode without incorporating any major changes in the engine construction. It is possible to trace the origin of the dual fuel engines to Rudolf Diesel, who patented an engine running on essentially the dual-fuel principle. Here gaseous fuel called primary fuel is either supplied with the air intake, or injected directly into the cylinder and compressed, but does not self-ignite due to its very high self-ignition temperature. Ignition of homogeneous mixture of air and gas is achieved by the timed injection of a small quantity of diesel called pilot fuel near the end of the compression stroke. The pilot diesel fuel self-ignites first and acts as a deliberate source of ignition for the primary fuel air mixture. The combustion of gaseous fuel occurs by flame propagation similar to the SI engine combustion. Thus, the dual fuel engine combines the features of both the SI and the CI engine in a complex manner. The dual fuel mode of operation leads to a smoother operation; lower smoke emissions and thermal efficiency are almost comparable to the diesel version at medium and at high loads. However, major drawback with these engines are higher NOx emissions, poor part load performance, and higher ignition delay with certain gases like biogas, and rough engine operation near full load due to the high rate of combustion [4]. Most of the alternative bio-fuels identified today are proved to be a partial substitute for the existing biofuel due to its few undesirable fuel characteristics [5]. However, the various admission techniques experimented earlier are giving a good solution to apply a larger fraction of replacing fuel in the existing engine. The biologically based alternative fuels called bio-fuels were identified well before the exploration of other promising alternative fuels Robert et al [16]. The primary advantage of this fuel is that it is renewable and eco-friendly. Generally, plants yield two types of oils namely triglyceride oil (TG oils) and turpene oil (light oil) of which, triglyceride oil is obtained from the plant seeds but turpene oil is obtained from all parts of the plant [6]. TG oils have higher viscosity than terpene oils. But, terpene oils exhibit lower viscosity and favourable fuel properties than TG oils. In addition, their availability from natural sources is estimated to be greater than the availability of TG oil. Terpene oils are largely available in some plant species namely eucalyptus, pine tree etc. Jorge [7] conducted a performance and emission test on a dual fuel engine using propane and diesel fuel. It is reported that, up to 90% of the diesel fuel energy input was replaced with propane gas without any loss of thermal efficiency. He also reported that this engine emits more CO and less NOx at all load conditions than that of the standard diesel operation. Senthil Kumar et al [8] examined the performance and emission characteristics of the dual fuel engine fuelled with jatropha oil and orange oil. Their results showed that the utilisation of orange oil reduces smoke and NO emission and improves thermal efficiency with all pilot fuels.

The paper of Karim [4] on the utilization of gaseous fuels such as methane, propane, acetylene, ethylene and hydrogen in diesel engines reveals that the maximum amount of gas consumption is limited due to the onset of knock. Karim reported that in dual fuel engines, at low load, when gaseous fuel concentration is low,the ignition delay period of the pilot fuel increases and some of the homogeneously dispersed gaseous fuel remains unburned which results in poor performance. Pilot fuel quality, quantity, injection timing and intake temperature are important variables affecting the performance of the dual fuel engine. Gunea et al. [5] conducted experiments on a four-stroke, single cylinder, direct injection (DI) diesel engine, fuelled with natural gas. The tests were conducted with diesel as the pilot fuel having different cetane numbers in order to study the effect of pilot fuel quality on ignition delay. They authors concluded that the ignition delay of a dual fuel engine mainly depends on pilot fuel quantity and quality. High cetane number pilot fuels can be used to improve the performance of low cetane number gaseous fuel engines. Liu and Karim [6] studied the effect of admission of gaseous fuels and diluents into the dual fuel diesel engine. They reported that gaseous fuels and diluents would change physical and chemical processes of the ignition delay period. The extent of the extension of the ignition delay period depends strongly on the type of gaseous fuel used and its concentration.

Rao et al [10] investigated the performance of diesel engines in the dual fuel mode by supplying a small quantity of hydrogen to the inlet manifold. At higher loads, the efficiencies attained were closer to diesel with a notable reduction in smoke and exhaust gas temperature. NOx emissions increased with the increase in peak pressure. Tomita et al. [17] investigated the supply of hydrogen in the intake port of the diesel engine. They found that NOx emission decreased because the combustion was lean and premixed. HC, CO, CO_2 and smoke emission also decreased with a marginal sacrifice in thermal efficiency. Das [9] suggested that hydrogen could be used in SI engine as well as in CI engine without any major modification in the existing system. He studied different modes of hydrogen supply by carburetion, continuous manifold injection, timed manifold injection, low-pressure direct injection and high-pressure direct injection and suggested to use manifold injection method for the supply of gases to avoid the undesirable combustion phenomenon (back fire) and the rapid rate of pressure rise.

Table 1 Physical and chemical properties of turpentine & acetylene

Properties	Gasoline	Diesel	Turpentine	Hydrogen	Acetylene
Formula	C_4 to C_{12}	C_8 to C_{25}	$C_{10}H_{16}$	H_2	C_2H_2
Molecular weight in kg/kmol	105	200	136	2	26.04
Density kg/m^3	780	830	860-900	0.08	1.092
Specific gravity	0.78	0.83	0.86-0.9	0.07	0.920
Boiling point ^{o}C	32-220	180-340	150-180	- 252.8	-84.44
Latent heat of vaporization kJ/kg	350	230	305	0.904	801.9
Lower heating value kJ/kg	43,890	42,700	44,000	1,20,000	48,225
Flash point ^{o}C	-43	74	38	-	32
Auto ignition temperature ^{o}C	300-450	250	300-330	572	305
Flammability limit % volume	1.4	1	0.8	4	2.3

Saravanan et al. [11] carried out an experimental study on a single cylinder water cooled direct injection diesel engine using hydrogen in the dual fuel mode. It was reported that the brake thermal efficiency increases from 23.59% to 29% with an optimized start of injection and duration. The peak pressure increases rapidly when hydrogen is used in the dual fuel mode. The emissions such as NOx, CO, CO_2 and HC are reduced drastically. Ashok et al. [12] studied the suitability of acetylene in a spark-ignited engine along with an exhaust gas recirculation and reported that emissions drastically reduced on par with the hydrogen engine with a marginal increase in thermal efficiency. Swami Nathan et al. [13] conducted experiments in a CI engine by using acetylene as a fuel in the homogeneous charge compression-ignited mode along with preheated intake air. The efficiency achieved was very near to diesel. The NOx and smoke level reduced considerably. However, the HC level increased. Karthikeyan et al [15] was conducted an experiment on hot air assisted turpentine in DI diesel engine to study BTE, NOx emission and smoke emission. Tesfa et al [18] reported the effects of physiochemical properties on fuel supply system such as fuel pump, fuel filter and air-fuel mixing cylinder.

The present study used one such type of oil called turpentine in a regular DI diesel engine along with blends (60% diesel 40% turpentine) and acetylene gas of fixed quantity supplied to the inlet manifold at a point closer to the intake valve. The properties of turpentine fall in between the properties of petrol and diesel and few of them are also closer to those of diesel oil and the same way acetylene exhibits the properties of hydrogen gas. However the method used in the present investigation helped to use the both turpentine and acetylene in the DI diesel engine.

2. Material and methods

A single cylinder four-stroke air cooled naturally aspirated direct injection diesel engine developing power of 4.4 kW at 1500 rpm, fuelled with a diesel and turpentine fuel blend, was utilized with acetylene for the three-fuel mixture operation. A schematic of the experimental setup is shown in Fig. 1. Acetylene was supplied to the intake manifold at a point closer to the intake valve by a non-return valve arrangement through a flame trap. The flow of acetylene was controlled by a needle valve and was measured by a calibrated gas flow meter. Air flow was determined by measuring the pressure drop accurately across a sharp edge orifice of the air surge chamber with the help of a manometer. The diesel and turpentine blend fuel flow was measured by noting the time of a fixed volume of the diesel blends consumed by the engine. A water-cooled piezoelectric pressure transducer was fixed on the cylinder head to record the pressure variation on the screen of a cathode–ray oscilloscope along a crank angle encoder. A thermocouple was used for exhaust gas temperature measurement. The exhaust gas constituents CO, CO_2, HC, NOx, and smoke were measured by a gas analyzer, and a Bosch smoke meter was used for the measurement of smoke.

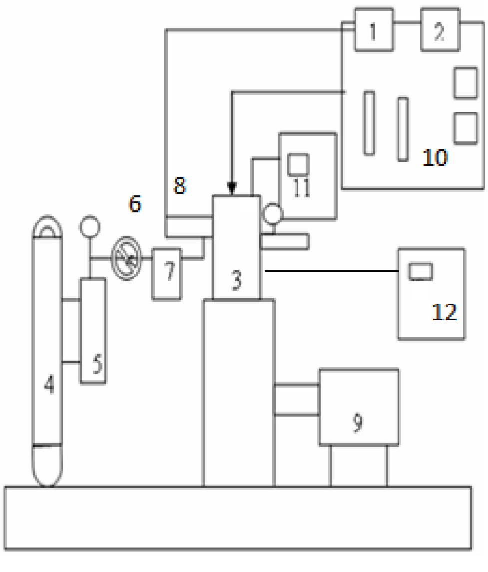

Fig.1 Schematic of the experimental setup
1. Air flow meter 2. Diesel and turpentine blend fuel tank 3. Diesel engine 4.Acetylene generator 5. Flame trap 6. Flow control valve 7. Gas flow meter 8. Intake manifold 9. Dynamometer 10. Control panel 11. Oscilloscope 12. Gas analyzer.

Initially, the engine was started with the diesel and turpentine fuel blend and allowed to warm up. Acetylene fuel was then supplied to the intake manifold at the fixed flow rate of 3lpm through a gas flow meter, which was at equivalence ratio of 0.13. The load on the engine was increased. The quantity of the injected diesel fuel was automatically varied by the governor attached to it, which maintained the constant engine speed at 1500 rpm throughout the experiment. Table 2 shows the engine specifications.

Table 2 Engine specification

Make and model	Kirloskar, TAF 1
Type	4 Stroke, Air Cooled
General details	Four-stroke, Compression Ignition,Direct Ignition
Bore/stroke	87.5 Mm/110mm
Compression ratio	17.5:1
Type of combustion chamber	Hemispherical Open Combustion Chamber
Rated output	4.4 Kw At 1500 Rpm
Injection timing and injection pressure	23`C btdc and 200 bar

3. Error Analysis

Errors and uncertainties in experiments may result from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is needed to prove the accuracy of experiments. An uncertainty analysis was performed by using the method described by J. B. Holman [14]. Percentage uncertainties of various parameters such as total fuel consumption, brake power; specific fuel consumption, and brake thermal efficiency were calculated by using the percentage uncertainties of various instruments given in Figure 2. Total percentage of uncertainty in this experiment is calculated from Equation 1.

$$\sqrt{(X_1)^2+(X_2)^2+(X_3)^2+(X_4)^2+(X_5)^2+(X_6)^2+(X_7)^2+(X_8)^2+(X_9)^2+(X_{10})^2+(X_{11})^2} \qquad (1)$$

Where,

X_1 = Uncertainity of TFC
X_2 = Uncertinity of brake power
X_3 = Uncertainity of specific fuel consumption
X_4 = Uncertainity of brake thermal efficiency
X_5 = Uncertainity of CO
X_6 = Uncertainity of CO_2
X_7 = Uncertainity of unburned hydrocarbon
X_8 = Uncertainity of NO_X
X_9 = Uncertainity of smoke number
X_{10} = Uncertainity of exhaust gas temperature
X_{11} = Uncertainity of pressure pickup.

Using the calculation procedure, the total uncertainty for the whole experiment is obtained to be ± 4%

4. Results and discussion

The three-fuel mixture has been analyzed in a single cylinder four-stroke air cooled naturally aspirated direct injection diesel engine. The performance study has been made for brake thermal efficiency, CO emissions, HC emissions, NO_X emissions, ignition delay and heat release rate of the three-fuel mixture and compared with those for standard fuel (Diesel).

In general, it is noted that in the dual fuel engines, thermal efficiency decreases at low loads and increases above the base line at fuel load operation with the addition of supplied fuels like LPG and CNG etc. In the present three-fuel mixture analysis, thermal efficiency is not lower than in the pure diesel fuel operation due to wide flammability limit, high combustion rate of acetylene and the release of lighter HC fractions by the turpentine blend.

Table 3 shows that the brake thermal efficiency of the three-fuel mixture is higher than in the standard fuel. The maximum brake thermal efficiency obtained in the three-fuel mixture concept is 33 % and it is by 3% higher than that of the standard fuel operation. Table 4 shows that the amount of CO emissions of the three-fuel mixture is lower than in the case of standard fuel.

Table 3 Brake thermal efficiency of standard fuel and three-fuel mixture

S.No.	Load in %	Break thermal efficiency in %	
		Standard fuel	Three-fuel mixture
1	0	0	0
2	25	18	19.5
3	50	26	26.5
4	75	28	29
5	100	30	33

Table 4 CO emission of Standard fuel and Three-fuel mixture

S.No.	Load in %	CO emissions in %	
		Standard fuel	Three-fuel mixture
1	0	35	25
2	25	30	2
3	50	35	25
4	75	40	30
5	100	70	65

Fig. 2 shows the variation of brake thermal efficiency of three-fuel mixture concept in the fully loading condition. It shows comparatively higher brake thermal efficiency than that of standard fuel (Diesel) at all loads. This is due to the presence of high volatile turpentine in the blend. Basically, turpentine is a cyclic compound of terpene (basic element of turpentine). It decomposes easily at low temperatures and releases more intermediate compounds (lighter HC fractions) immediately after injection. The presence of turpentine in the blend causes a longer ignition delay and rapid combustion. During the longer ignition delay the engine accumulates more fuel before the commencement of combustion and releases a higher fraction of heat during the premixed phase of combustion. This leads to the higher cylinder pressure. The improved volatility, increased heat content and improved air entrainment could be other reasons for higher thermal efficiency. These may be also the reasons for higher brake thermal efficiency.

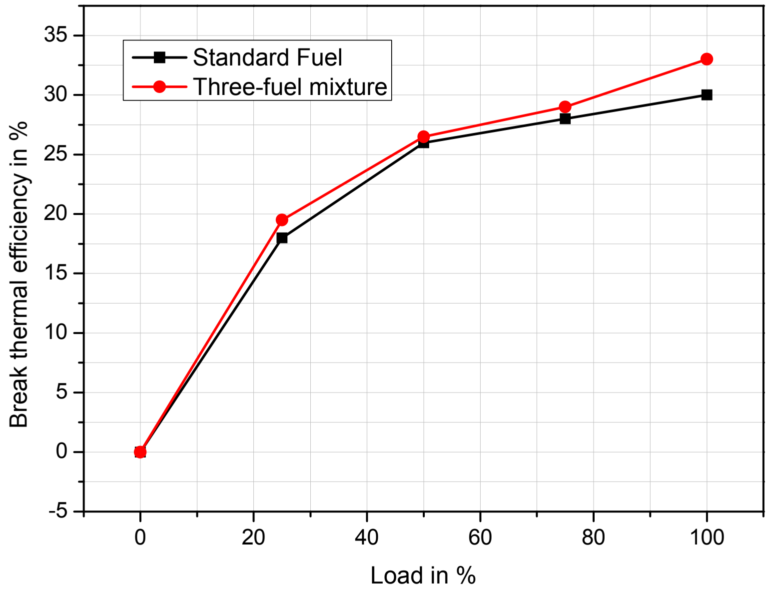

Fig. 2 Load vs brake thermal efficiency

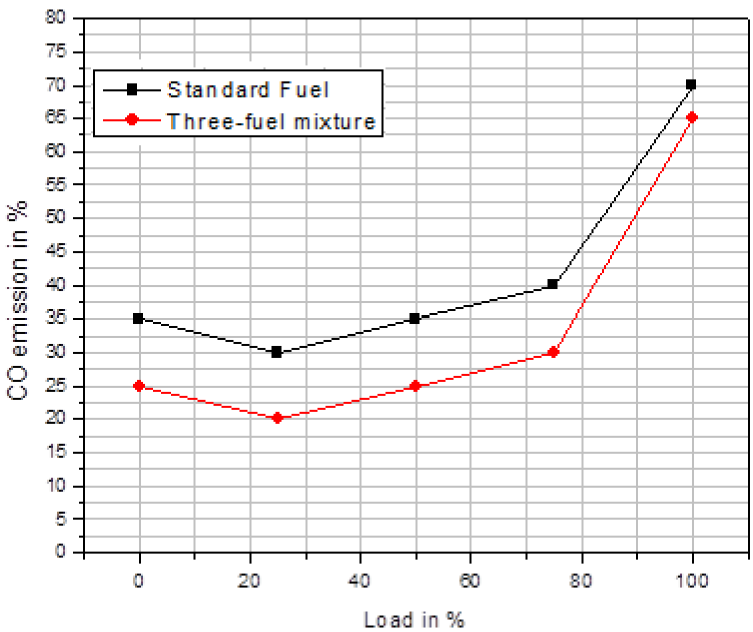

Fig. 3 Load vs CO emission of standard fuel and three-fuel mixture

Fig. 3, compares CO emissions of three-fuel mixture concept with the standard fuel operation. It shows that the amount of CO emissions of the three-fuel is lower than that of standard fuel at all loads. This is due to the complete burning of the fuel and reduction in overall C/H ratio of the total supplied fuel. The correct fuel admission and effective fuel utilization are other reasons for low CO emissions at all loads. The amount of CO emission of three-fuel at all loads is by 0.1% lower than in the case of standard fuel.

Table 5 HC emissions of standard fuel and three-fuel mixture

S.No.	Load in %	HC emissions in (ppm)	
		Standard fuel	Three-fuel mixture
1	0	75	65
2	25	70	60
3	50	100	70
4	75	145	110
5	100	240	215

Table 5 shows that the amount of HC emissions of the three-fuel mixture is lower than in the case of standard fuel. Fig. 4 shows that the amount of HC emissions for the three-fuel mixture is lower than that of the reference fuel at all loads. This is due to the higher burning velocity of acetylene which enhances the burning rate. Simple molecular structure, higher volatility and the unstable nature of turpentine combustion result in higher temperature and better air entrainment which are considered as probable reasons for lower HC emissions. The HC emissions of the three-fuel mixture at full load amount to 200 ppm, which is 25 ppm lower in comparison with the reference fuel.

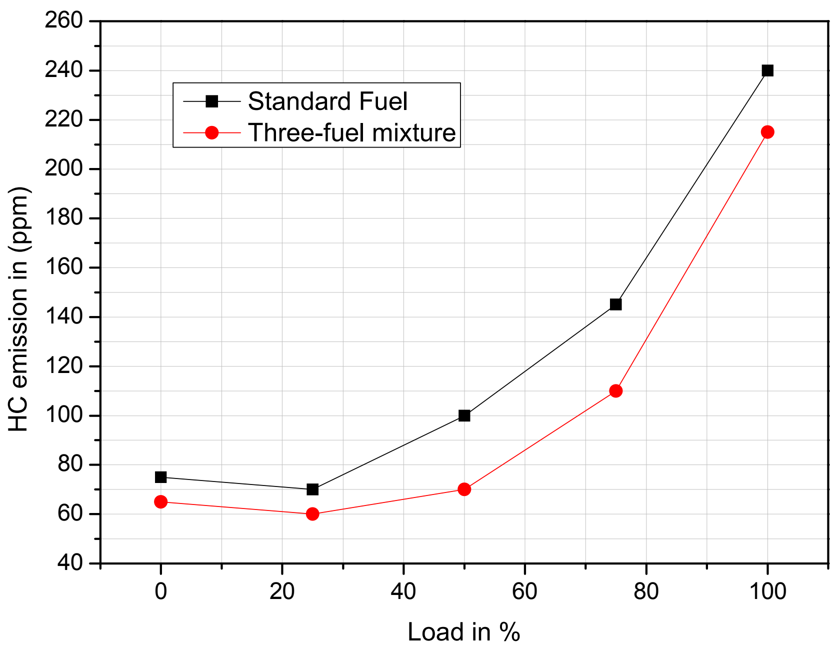

Fig. 4 Load vs HC emissions of standard fuel and three-fuel mixture

Table 6 shows that the amount of NO_x emission of the three-fuel mixture is lower than in the case of standard fuel. From the Figure 5 shows NO_X emissions of the three fuels with standard fuel operation at various engine tools. It is observed that the three-fuel mixture shows higher reduction in NO_X at all loads because the combustion of the acetylene-diesel fuel is faster, contributing to the complete combustion and is also due to triple bond in acetylene which is unstable. More specifically, at full load, the three fuel mixture offers

210 ppm lower NO_X than the standard diesel operation. This is due to the production of a higher combustion temperature and rapid release of intermediate compounds It is observed that the three-fuel mixture shows a higher reduction in smoke at all loads because the combustion of acetylene-Diesel fuel is faster, contributing to the complete combustion and is also due to the triple bond in acetylene which is unstable. More specifically, at full load, three fuel mixture offers 40% less smoke than that of the standard diesel operation. This is due to the production of a higher combustion temperature and a rapid release of intermediate compounds.

Table 6 NO_x emissions of standard fuel and three-fuel mixture

S.No.	Load in %	NO_X emissions in (ppm)	
		Standard fuel	Three-fuel mixture
1	0	350	250
2	25	600	500
3	50	925	825
4	75	1190	1090
5	100	1400	1190

Fig. 6, shows that the combustion of the three-fuel mixture occurs approximately 3 degrees later than in the standard diesel operation and produces peak pressure 5 degrees after TDC and an increase of 3 bar peak pressure inside the cylinder. Table 7 shows that the ignition delay of the three-fuel mixture is higher than in the case of the standard fuel determined from the indicated curves on the cathode-tube screen.

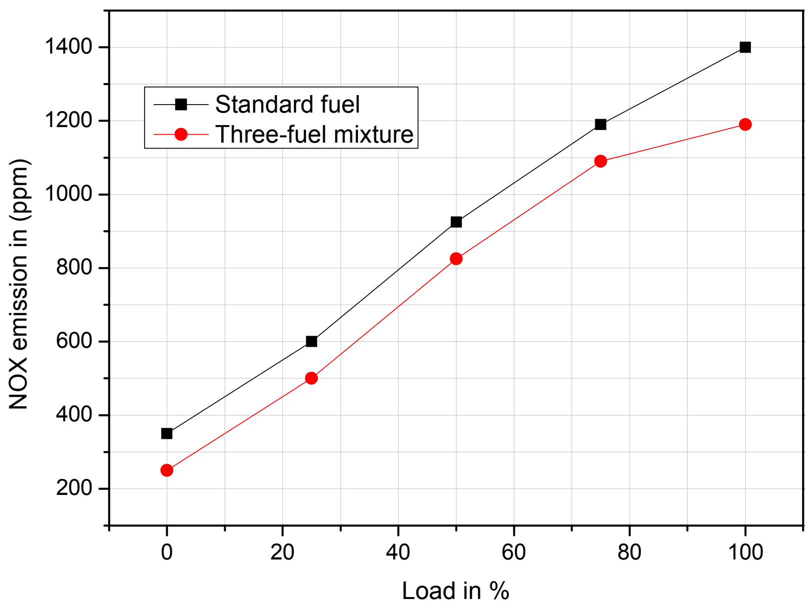

Fig. 5 Load vs NO_x emission of standard fuel and three-fuel mixture

The heat release rate of the three-fuel mixture with respect to the crank angle is compared with the standard fuel operation at full loading. From figure 7 it can be seen that the two phase of combustion are clearly visible and distinguishable. The first phase of combustion of the three fuel mixture is slightly lower than that of the standard diesel operation. Acetylene aspiration shows distinct characteristics of the explosive, premixed type of combustion and turpentine has a low cetane number and offers a longer ignition delay. This is the main reason for higher brake thermal efficiency, shorter burn duration and higher peak pressure of the three-fuel mixture. Table 8 shows that the heat release rate of the three-fuel mixture is lower than in the standard fuel.

Table 7 Ignition delay of standard fuel and three-fuel mixture

S.No.	Load in %	Ignition delay in degree	
		Standard fuel	Three-fuel mixture
1	25	12	12
2	50	11	11,5
3	75	10	11
4	100	9	12

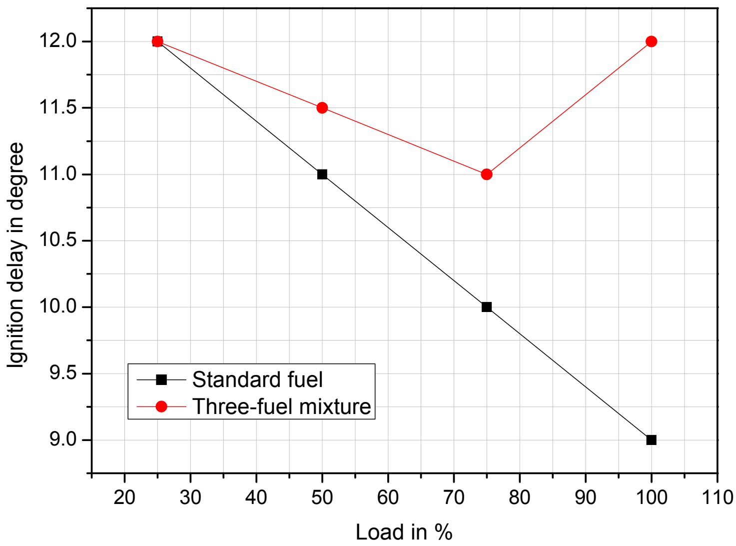

Fig. 6 Load vs ignition delay of standard fuel and three-fuel mixture

Table 8 Heat release rate of standard fuel and three- fuel mixture

S.No.	Crank angle in degree	Heat release rate (J/ Degree)	
		Standard fuel	Three-fuel mixture
1	340	0	0
2	360	180	140
3	380	20	27
4	390	15	20
5	440	0	0

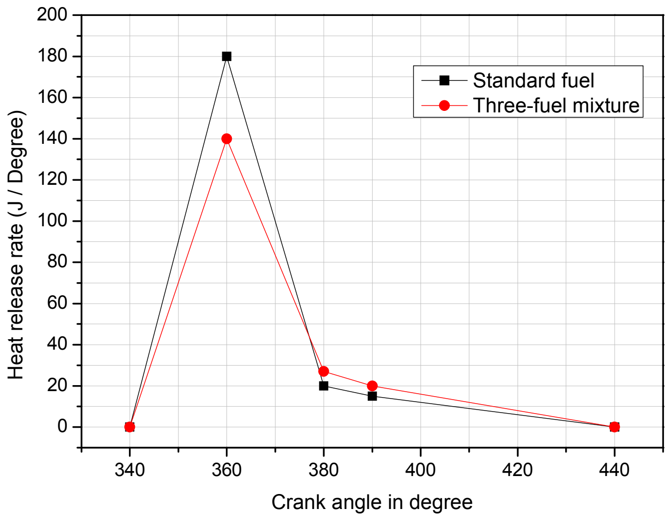

Fig. 7 Crank angle vs ignition delay of standard fuel and three-fuel mixture

5. Conclusion

The three-fuel mixture concept (acetylene aspiration in the inlet manifold up to 3 lpm and mixing of turpentine with diesel fuel upto 40%) results in the brake thermal efficiency increased by 1 to 3 % in the standard diesel fuel. It also exhibits a lower exhaust gas temperature compared with the diesel operation. Comparatively a slighter increase in NOx emissions was found and approximately 40% of smoke reduction is achieved with the three-fuel mixture concept operation. An appreciable reduction in HC, CO and CO_2 emissions was observed in the three-fuel mixture concept with an increase in engine performance without much worsening its emissions. There is an increase in the peak cylinder pressure and a rise in the rate of pressure, when gas is supplied.

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