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STUDY OF BULK MODULUS OF COMPRESSIBILITY OF BIODIESEL AND THEIR IMPACT ON EXHAUST EMISSIONS

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ABSTRACT:

Physical properties of vegetable oils and their biodiesels (esters) play a vital role in the combustion performance and exhaust emissions. Experiments were conducted to evaluate the bulk modulus of compressibility of biodiesel and their blends with diesel in varying proportions by volume. Biodiesel considered were the biodiesel obtained from non-edible vegetable oil of Pongamia Pinnata (Karanja oil). The study revealed that for a given pressure and temperature, the bulk modulus of compressibility of biodiesel and their blends with diesel were higher than that of diesel oil. However, increase in the temperature lowers the value of bulk modulus of biodiesel and their blends at all pressures.

The study also revealed that high value of bulk modulus of biodiesel and their blends with diesel lead to advanced injection timing compared to neat diesel operation in the diesel engine. It is due to faster transfer of pressure waves from fuel injection pump of the engine to the nozzle, therefore the needle valve lifted in advance. As a result, at the same crank angle, the injection of biodiesel or its blend in the combustion chamber start earlier compared to diesel with increased pressure resulting in delivery of greater volume of biodiesel or its blends than diesel due to increased density. The increased amount of fuel delivery into the combustion chamber causes short time period for the combustion and probably lesser time for cooling of the engine resulting in high temperature inside the cylinder compared to diesel. This high temperature facilitate in the oxidation of inactive nitrogen present in the air to form more NO_X due to inherent free oxygen present in the biodiesel or its blend resulting in increased formation and emissions of NO_X (5%).

Key words:

Biodiesel; bulk modulus; injection timing; exhaust emission.

INTRODUCTION:

In recent years, increased environmental awareness and energy shortage have encouraged researchers to investigate the possibility of using alternate fuels such as vegetable oils or animal fats instead of fossil fuels. Vegetable oils have considerable potential to be considered as appropriate alternative as they possess fuel properties similar to that of diesel oil. The major problem associated with direct use of vegetable oil is their high viscosity and gum content. One possible method to overcome the problem of high viscosity is the transesterification of potential vegetable oils to produce biodiesel (esters) of respective oils. This interest is because biodiesel is bio-degradable, sulphur free, oxygenated and renewable alternative diesel fuel derived from vegetable oils or animal fats. Many researchers have reported that with the use of biodiesel as a fuel in diesel engines, a comparable engine performance was achieved with a marked reduction in many harmful exhaust emissions in the existing diesel engine without significant modifications (1,2). However differences in physico-chemical properties between the biodiesel and diesel fuel may change the fuel injection timing and combustion characteristics. These altered physical and chemical properties may also cause exhaust emissions to differ from the optimized settings of the engine chosen by the manufacturer. In particular the physical properties like density, viscosity and bulk modulus of compressibility of the fuel used have a significant effect on fuel injection timing, combustion performance and harmful exhaust emissions (3,4).

It is well established that biodiesel can be used in conventional diesel engines as blended forms without any modifications of the engine hardware. Many researchers had reported that engine performance was unaffected for the blend B_{20} i.e 20 % biodiesel and 80% diesel by volume (5). They also carried out wear assessment and long duration tests between diesel and biodiesel and confirmed that biodiesel reduce the extent of damage, coefficient of friction and wear and keeps the engine in a better health thus improving the life of its vital moving components (6).

Biodiesel is a highly oxygenated fuel that can be used in diesel engines to improve combustion efficiency. Many studies have focused on the emissions of particulate matter, NO_X, CO, smoke density and HC from diesel engine fueled with biodiesel or its blends. The research indicated that HC, CO and smoke was reduced roughly by 90, 40 and 40 % on using biodiesel where as NO_X increased by 4-8% (7).

Despite these efforts, the study of the effect of bulk modulus of compressibility of biodiesel and its impact on exhaust emissions quality and fuel injection timings for different blends of biodiesel fuel samples have not been fully investigated. In this paper, a comparative study of the bulk modulus of compressibility of diesel and biodiesel obtained from non-edible Karanja oil and their blends with diesel in varying proportions have been made and its impact on delay periods and exhaust emissions have been investigated.

EXPERIMENTAL:

1. Synthesis of Biodiesel

In the present work, samples of biodiesel were prepared in small scale through the process of transesterification from non-edible Karanja oil. These samples were prepared using alkali catalyzed method. Methanol (1:3 molar oil:alcohol) was mixed with KOH (1 wt% of oil) and added to the reactor containing vegetable oil slowly along with stirring. The reaction temperature was maintained at 66^0 C. The reaction mixture was refluxed for 2-3 hours. After completion of the reaction the material was transferred to separating funnel and both the phases were separated. Upper phase was biodiesel while lower phase was glycerin. Biodiesel so obtained was purified by washing with distilled water one or more times to remove unreacted oil, catalyst or soap. After washing, the biodiesel was heated to 100^0 C to get rid of residual mixture.

2. Blending of Biodiesel with High Speed Diesel and Sample Preparation

The synthesized biodiesel from Karanja oil namely Karanja oil biodiesel (KB_{100}) were tested for physic-chemical properties as per ASTM D-6751 in the Diesel Shed Laboratory of Indian Railways, Jamalpur. After testing of biodiesel KB_{100}, their blends with diesel oil was prepared in varying proportions (i.e KB_{20}, KB_{40}, KB_{60} and KB_{80}) by volume and their physical and chemical properties were also determined as listed in Table 1.

Table 1: Properties of Biodiesel, Diesel and blended biodiesel

S.No.	Biodiesel blend	Density (Kg/m^3) at 25^{o}C	Calorific value (MJ/kg)	Viscosity (CSt)at 40^{o}C	Flash point (^{o}C)	Pour point (^{o}C)	Cloud point (^{o}C)
1	KB_{20}	851	43.6	3.04	96	3.1	8.9
2	KB_{40}	854	43.1	3.51	99	3.6	10.9
3	KB_{60}	859	42.9	3.81	123	4.3	11.6
4	KB_{80}	871	42.3	4.01	149	4.9	12.3
5	KB_{100}	883	42.1	4.37	163	5.1	14.6
6	Diesel	840	44.0	2.87	76	3.1	6.5

3. Determination of Sonic Velocity of Diesel, Biodiesel and its Blends

In order to measure the acoustic properties of diesel oil, biodiesel and their blends, an ultrasonic interferometer was used. The propagation of small amplitudes of ultrasonic waves through liquid or mixtures (blends) at a resonant frequency of transducer and agreement of the corresponding frequency and wavelength provides an accurate method for measurement of sonic velocities in liquids or mixtures. The sonic velocity C is related with the wavelength λ and frequency f by the following equation

$$C = \lambda \times f$$

where f is the transducer frequency.

The temperature of the liquid sample was maintained by selecting the thermostat of the water bath which was circulated in the outer column around the liquid sample in the cell. The sonic velocity of the liquid samples was measured at atmospheric pressure and at 297 K.

The isentropic bulk modulus of compressibility (β) of liquid samples were calculated at 297 K using the following equation

$$\beta = C^2 \times \rho$$

where β is the isentropic bulk modulus in Pascals (Pa), C is the speed of sound in the liquid sample in m/s and ρ is the density of the sample in kg/m^3.

The specific gravity of the sample of biodiesel and their blends were determined using hydrometers of different ranges as per ASTM D-445. The calculated values of sonic velocity and bulk modulus of biodiesel and their blends are shown in Fig.1.and Fig.2.

4. Performance study and Exhaust Emissions from Diesel Engine

The biodiesel KB_{100} and its blends KB_{80}, KB_{60}, KB_{40} and KB_{20} obtained from Karanja oil were used in a single cylinder diesel engine (specifications listed in Table 2) to study the their emission quality at different engine loads (20, 40, 60, 80 and 100 % of the load corresponding to the load at rated engine power) at a constant engine speed of 1500 rpm. After the engine reached the steady state working condition, various engine performance parameters and exhausts emission like CO_2, CO, and NO_X were measured using exhaust gas analyzer at different engine loads.

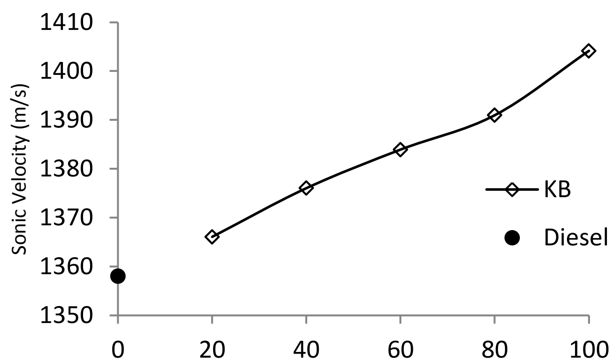

Fig.1: % composition of blends of biodiesel with diesel

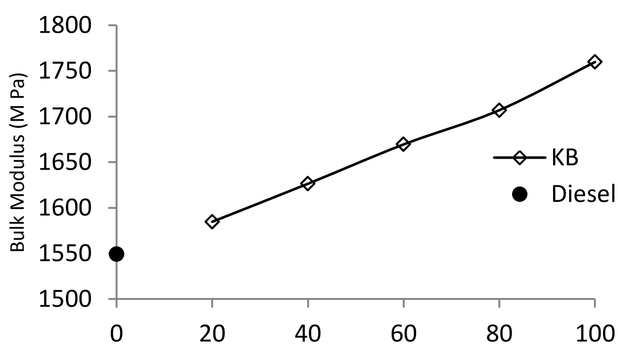

Fig.2: % composition of blends of biodiesel with diesel

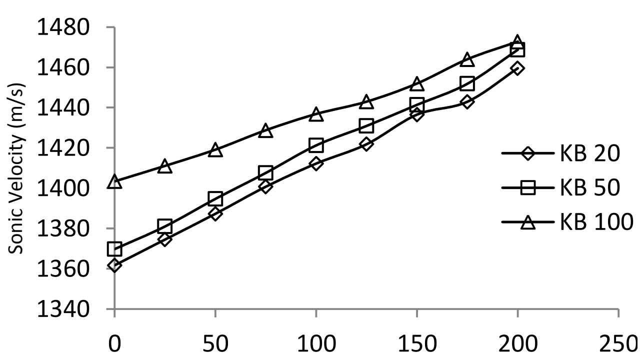

Fig.3: Pressure (bar)

Table 2: Specifications of Kirloskar single cylinder diesel engine

S.No.	Particulars	Specification
1.	Make	Kirloskar Oil Engines Ltd. India
2.	Model	DAE8
3.	Rated brake Power	6 KW
4.	Rated speed	1500 rpm
5.	No. of cylinder	01
6.	Bore x stroke (mm)	95x110
7.	Displacement volume (cc)	779.704
8.	Compression ratio	17.5:1
9.	Cooling system	Air cooled
10.	Lubrication system	Forced Feed
11.	Cylinder arrangement	Vertical
12.	Cubic capacity	0.78 litres
13.	Inlet valve open	4.5^o BTDC
14.	Inlet valve closed	35.5^o ABDC
15.	Exhaust valve open	35.5^o BBDC
16.	Exhaust valve closed	4.5^o ATDC
17.	Fuel injection timing	26^o BTDC
18.	Injector opening pressure	200 Bar

Specifications of alternator coupled with single cylinder diesel engine:

S. No.	Particulars	Specification
1.	Make	Kirloskar Electric Co. Ltd., India
2.	Alternator type	Three phase, 50 Hz, AC
3.	Rated output	5 KVA at 1500 rpm
4.	Rated rpm	1500
5.	Rated voltage	415V
6.	Power Factor	0.8

Results and Discussion

1. Sonic Velocity and Bulk Modulus of Biodiesel and their Blends

The variations in sonic velocity with percentage composition of blends of Karanja biodiesel are shown in Fig.1. The sonic velocity in diesel oil and its blends with Karanja biodiesel were measured as per the procedure mentioned earlier at 297 K and at atmospheric pressure. The sonic velocity in diesel oil was found to be 1358 m/s. The sonic velocity was observed to increase with increasing concentration of biodiesel in the blend and was found maximum for KB_{100} having a value of 1416 m/s. Thus sonic velocity of neat biodiesel was found 4.25% higher than diesel oil.

Similar trends were observed in the variation of bulk modulus of compressibility as shown in Fig.2. As evident, the bulk modulus of compressibility of diesel oil was calculated to be 1549 MPa. The bulk modulus was also found to increase with increasing concentration of biodiesel in the mixture and was found maximum for KB_{100} with a value of 1770 MPa which is 25% higher in comparison to diesel oil.

Fig. 3 depicts the effect of pressure on the sonic velocity of biodiesel and its blends. One can see that by increasing the pressure and biodiesel content, the sonic velocity also increases. Since the properties of tested fuel samples differ significantly, this means that biodiesel content in the fuel sample will have a significant influence on the combustion process and consequently on engine emissions.

2. Study of Engine Test Results

In fig.4. a slight drop in brake thermal efficiency was found with biodiesels when compared with diesel. This drop in thermal efficiency may be attributed due to poor spray characteristic which is due to higher viscosity and lower calorific value of biodiesels compared to that of diesel. The poor spray pattern effect the homogeneity of air fuel mixture which in turn lower the heat release rate their by reducing brake thermal efficiency. It was observed that the brake thermal efficiency of KB_{20} and KB_{40} are comparable with brake thermal efficiency of diesel. With increase in load on the engine and increasing biodiesel concentration in the blend increases the brake thermal efficiency. Thus, the blends of esterified karanja oil with diesel up to 40% by volume could effectively replace diesel for running the diesel engine with efficiency comparable with diesel.

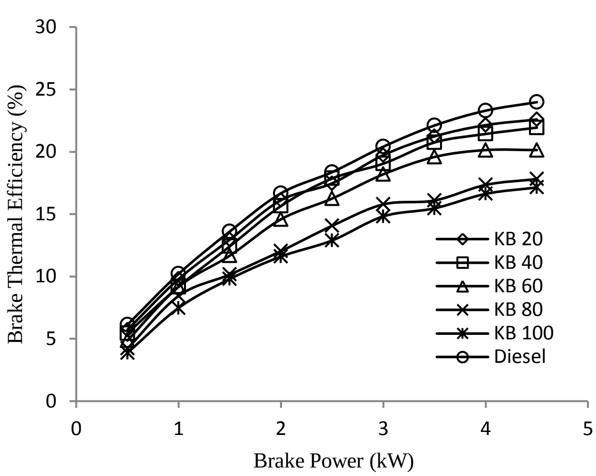

Fig.4. Brake Thermal Efficiency VS Brake Power

3. Study of NO_x Emissions

The exhaust gas temperature increased with increasing concentration of biodiesel in the diesel however the variation in exhaust gas temperature was less at lower loads but more pronounced at higher loads. This may be attributed due to advance in injection timing by the use of biodiesel compared to neat diesel operation. As a result the injection of biodiesel fuel in the combustion chamber start earlier compared to diesel. With delivery of greater volume of fuel into combustion chamber causing short time period for the combustion and probably lesser time for cooling of the engine resulting in high temperature inside the cylinder compared to diesel. This high temperature facilitate in the oxidation of inactive nitrogen present in the air to form more NOx due to inherent free oxygen present in the biodiesel resulting in increased formation and emission of NOx (by 4%) as shown in fig.5.

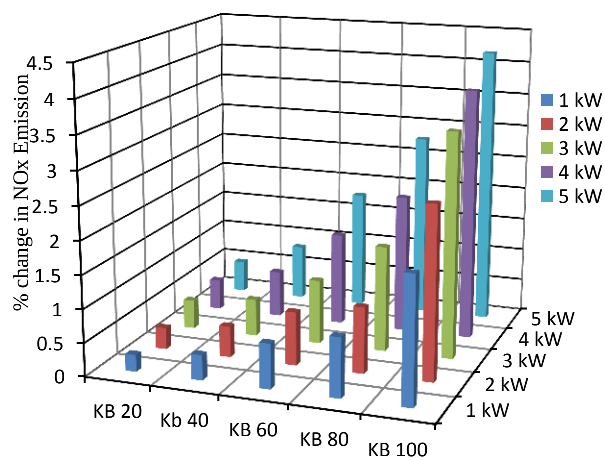

Fig.5. % Change in NOx Emission vs Brake Power and % Composition of Blends

4. Study of Smoke Density, CO and HC Emissions

Smoke density was calculated by opacity test for various blends of biodiesel and diesel. Biodiesel gives less smoke density (35% low) from no load to full load and for all the blends tested compared to diesel as shown in fig.6. This could be due to inherent oxygen molecule present in the biodiesel chain which enhanced its burning compared to diesel. When percentage of blends of biodiesel increases, smoke density decreases. It also decreases with increasing load. Similar trends were observed with CO (15% decrease) and HC (24% decrease) as shown in fig.7 and fig.8 respectively, which may be attributed due to enhanced burning and proper combustion of biodiesel due to inherent oxygen present in the chain.

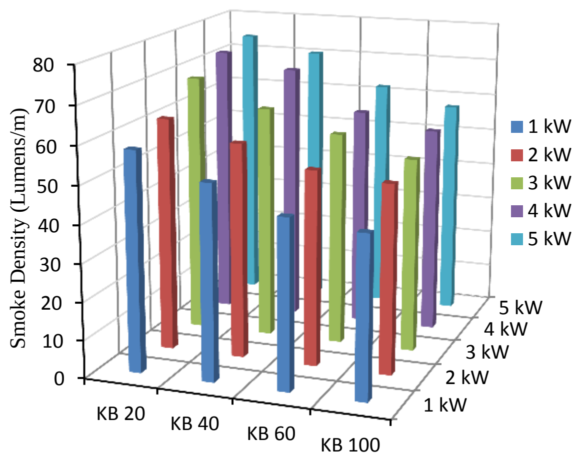

Fig.6: Smoke Density VS Brake Power and % Composition of Blends

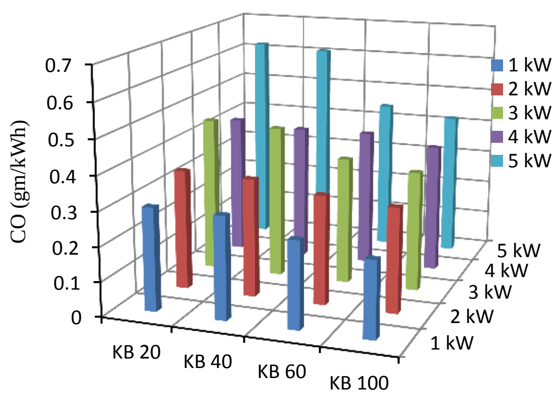

Fig. 7: CO Emission VS Brake Power and % Composition of Blends

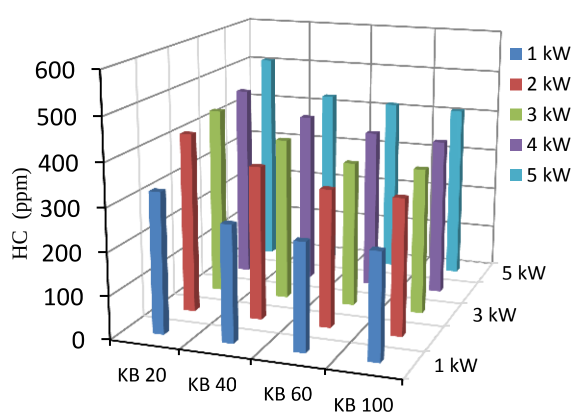

Fig. 8: HC Emission VS Brake Power and % Composition of Blends

5. Combustion analysis

The significant features related to combustion aspects are tabulated in Table 2. The peak pressure achieved using Diesel, Karanja biodiesel and their blends are shown in fig.9 full load conditions. The peak pressure and heat release rate at no load and half load are also analyzed which gives very important information on the ignition delay in case of biodiesel, diesel and their blends.

Table 3: Comparative data on the combustion parameters of the different test fuels at peak load.

Fuel sample	Start of Injection (Degree BTDC	Start of combustion (Degree) BTDC	Ignition delay (Degree)	Peak Pressure (Bar)	Peak Heat Release Rate (HRR) Joule/CA
Diesel	23	14.5	8.5	78.7	90.96
KB20	23	14.9	8.1	80.4	85.49
KB50	23	16.6	6.4	83.3	81.52
KB100	23	19	4	84.2	70.93

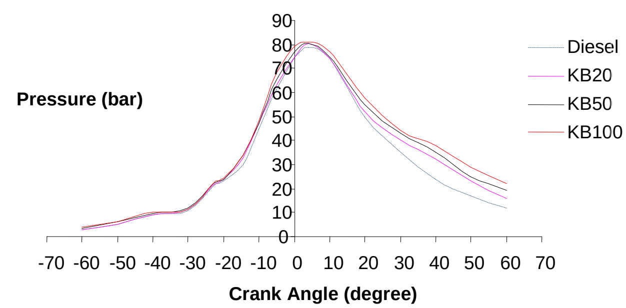

Fig.9: Pressure vs Crank Angle diagrams for Diesel, Karanja biodiesel and blends at full load

From the Figure 9 it is clear that the peak pressure for KB20, KB50 and, KB100 are 80.4 bar occurring at 5.3 degree CA after TDC, 83.3 bar occurring at 5.2 CA after TDC, 84.2 bar occurring at 4.9 degree CA after TDC. The early peaking characteristics and shortening of ignition delay for biodiesel may be attributed due to high bulk modulus of biodiesel compared to diesel.

It can be seen from the Table 3 that the maximum heat release rate of biodiesel and their blends are lower than diesel. This is as a consequence of the shorter ignition delay and the premix combustion phase for biodiesel and their blends are less intense. On the other hand, while running with diesel, increased accumulation of fuel during the relatively longer delay period resulted in higher rate of heat release. Because of the shorter delay, maximum heat release occurs earlier for biodiesel and their blends in comparison with diesel. However, the heat release during late combustion phase for biodiesel and their blends are marginally lower than that of diesel. This is because the constituents with higher oxygen content are adequate to ensure complete combustion of left over fuel during the main combustion phase and continues to burn in the late combustion phase.

Conclusions

Based on the exhaustive experimental investigations with special reference to transesterification process, the following conclusion can be drawn:
Biodiesel is an attractive option for the replacement of petro-diesel because of their desirable properties. It can be produced from locally available vegetable oils through a chemical reaction known as tranesterification. Tansesterification is a low cost process which brings about a change in the molecular structure of the vegetable oil molecules, thus bringing down the levels of viscosity, density and unsaturation of vegetable oil. The density and viscosity of vegetable oil gets drastically reduced after esterification and are very close to petroleum diesel oil. The flash point of biodiesel is greater than that of diesel and calorific value is slightly lower than that diesel. The addition of biodiesel to diesel fuel changes the physico-chemical properties of the blends. With the increase of biodiesel concentration in diesel-biodiesel blends, the kinematic viscosity, bulk modulus of compressibility, cetane number, flash point and fire point of the blends increase.

The experimental results of various engine tests concluded on bio-diesel fueled single cylinder diesel engine lead to the following important conclusions:

A diesel engine can perform satisfactorily on bio-diesel fuel without any engine hardware modifications. Short term endurance test using bio-diesel proved that biodiesel can be used for substituting diesel oil. The appropriate blend necessary to ensure optimum performance and low emission characteristics depend upon the particular feed stock and the subsequent biodiesel formulation.The brake thermal efficiency of the engine running on KB_{20} and KB_{40} blends are better than KB_{100} but still inferior to neat diesel operation. The blends of karanja oil biodiesel yielded the best result in terms of brake thermal efficiency of the engine followed by jatropha, polanga and waste cooked oil biodiesel. The reduction in brake thermal efficiency compared to diesel operation was noticed with increasing load and increasing biodiesel concentration in the blends. The smoke emissions reduced appreciably as a result of bio-diesel utilization in the engine. The higher the concentration of bio-diesel in the blend, the higher was the reduction in smoke levels. Similar trends were observed for CO and HC emissions. The exhaust temperature increased as a function of the concentration of the biodiesel blend, i.e., higher the percentage of bio-diesel, higher was the temperature with the increasing load. Increase in the exhaust temperature of a biodiesel fueled diesel engine led to approximately 4% increase in NOx emissions for KB_{100} blends. This is because NOx formation is a highly temperature dependent phenomenon. The pressure-crank angle diagrams suggested that the peak pressures and rates of pressure rise were marginally higher in case of bio-diesel operated engines than the diesel operated at all loads. No undesirable combustion feature was observed throughout the entire range of experiments. The heat release rate (HRR) were found to be marginally lower in case of biodiesel than diesel operation and were found to decrease with increasing concentration of bio-diesel in the blend.

From the above observations it could be concluded that Bulk Modulus of Compressibility of biodiesel and its blends is an important physical property that influences the exhaust emission characteristics of a biodiesel fueled C.I engine. High value of bulk modulus causes reduction in delay period, increased peak pressure and higher exhaust temperature responsible for increased emission of NO_X

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