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Influence of TBC Coating and Honge Biodiesel on Diesel Engine Exhaust Emission Control

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Abstract

Now a days vehicular air pollution becomes a serious threat causing environmental damage. Generally diesel engines produce more pollutants than gasoline engines. In this research work, the emission behaviour of a single cylinder four stroke constant speed diesel engine fuelled with honge biodiesel blends are examined. The combustion chamber components are coated with Yttria Stabilized Zirconia material over bond coat with a total thickness of 200 μm approximately. The pollutants from diesel engine exhaust gases are measured and compared with standard engine. Drastic reduction in CO emission levels of about 20% for diesel and 29 % for B15 are recorded in coated engine than that of uncoated engine at full load. Unburnt HC and smoke emissions values are found less in coated engine of about 9% and 11% for diesel and B15. High in-cylinder temperature in coated engine increases combustion gas temperature which tends to increase NO_x emission for biodiesel blends. B15 exhibits slightly higher NO_x emission of 7.8% than other blends in coated engine. CO_2 emission values remains higher for biodiesel blends in all loading conditions.

Keywords: TBC, honge biodiesel, pollution control, CO, HC, smoke, NO_x, CO_2

1. INTRODUCTION

Bio-diesel fuel obtained from vegetable oils, animal fats or recycled greases appears to be the most suitable alternate fuel for diesel engines since it reduces the emission values of particulates, carbon monoxide, hydrocarbons from diesel powered vehicles and has the potential to meet global energy demand and controls environmental pollution.

The species mainly available for the production of biodiesel in India are Jatropha Curcas, Pongamia pinnata, Madhuca Indica, Shorea Robusta, Pongamia Glabra, Mesua ferra (Linn), Mallotus Philippines and Garcinia Indica. High cultivation cost of Jatropha oil subject to the replacement of Pongamia and castor oils in India. Milletia pinnata is a non-edible species of tree in the pea family, native to tropical and temperate Asia including India. It is often known by name Pongamia pinnata and some other common names include Indian bleech, Pongam oil tree, Karanja oil and Honge oil. Oil content in pongamia seed is around 27-39% as specified by Murugesan et al (2009).

The bulky saturated, mono unsaturated and polyunsaturated fatty acid constituents comprised in plant oils caused more engine problems which necessitate bio-fuels subjecting to various processing methods. Usually the vegetable oil is subjected to chemical treatment called alcoholysis or transesterification which is determined as the most common technique and cost effective process for the biodiesel production. The use of alkali catalysts are more preferred compared to acid catalysts in continuous transesterification reaction for high yielding of biodiesel as described by Ma and Hanna (1999), Haas (2005), Meher et al (2006 a).

The processed bio-fuel and its blends with diesel shows unique properties compared with diesel fuel and can be used as an alternate fuel for diesel engines. The processed bio-fuel possess lower viscosity, less flash and fire point and improved fuel properties compared with unprocessed vegetable oil. The processed Bio-fuel was blended with diesel in various proportions to determine the suitability of biodiesel blend on engine performance and emission. Muralidharan and Govindarajan (2011) studied the effect of injection timing on performance and emission and revealed that injection retard causes reduced NOx and CO2 emissions for lower blends of biodiesel over the entire range of engine operation. Many researchers determined that a blend of 20% of biodiesel along with 80% of diesel appears to be an optimal blend resulted in improved engine performance, emission and combustion characteristics and is ideally suited as alternate fuel for diesel engines as described by Raheman and ghadge (2007), Sureshkumar et al (2008), Murugesan et al (2009), Godiganur et al (2009).

Muralidharan and Govindarajan (2011), Mahalingam et al (2013), Mahalingam et al (2014), Muralidharan (2015) in their experimental work confirmed that higher injection pressure causes better fuel atomization with improved heat release rate and emission characteristics for diesel and biodiesel fuels at all engine loads. Mahalingam, et al (2012), Mahalingam et al.(2016) investigated diesel engine fuelled with dual fuel blend at increased injection pressure from the designed pressure and observed that SFC, CO, UHC and NOx were lowered and the BTE and CO2 increased for the blend B20 at all load conditions.

Taymaz et al (2003) coated engine combustion components with low conductivity ceramic materials where cylinder head and valves are coated with $CaZrO_3$ and piston crown coated with $MgZrO_3$ over bond coat for about 0.5 mm thickness by plasma spray coating technique. Experimental results revealed significant reduction in heat loss of about 25% in coated engine compared to uncoated engine. The increased in-cylinder temperature resulted in increase of exhaust gas energy which thereby improves brake thermal efficiency in coated engine. Mahalingam et al (2015) investigated Zirconia stabilized with the yttrium oxide (Zirconia 80% wt and Yttia 20 % by weight) applied on the piston crown and observed reduced exhaust emission level of CO, UHC and NOx. Muralidharan and Senthilkumar (2016) investigated the influence of YSZ ceramic coating for a thickness of 300μm and revealed lesser bsfc with significant reduction in emissions of CO, HC, smoke with slight increase of NOx and CO2 for diesel and biodiesel fuels.

2. MATERIALS AND METHODS

2.1 Transesterification

Biodiesel was produced in lab practice by base catalysed transesterification process where methanol was used as alcohol and NaOH was used as alkyl catalyst. Honge oil seed were collected from local farmers in Tamilnadu and the raw Honge oil was extracted mechanically with a crushing machine from which a maximum of 31% oil was extracted.

2.2 Test fuel properties

Biodiesel poses high viscosity and it causes lot of problems for engine, in comparison of diesel (2.87 cSt) the viscosity of biodiesel (38 cSt) is much higher, in raw oil it is found to be 58.54 cSt which is reduced to 38 cSt by esterification process by virtue of removal of fats in the form of glycerol. The Honge methyl ester produced was blended with diesel in various proportions from 0 to 30% by volume (B5, B10, B15, B20) with the help of a magnetic stirrer. The blends were stirred continuously to achieve stable property values. The properties of various fuels tested are analysed as per ASTM standards in Table.2.1.

Table 2.1 Properties of Tested Fuels

S. No.	Fuel Blend	Density (kg/m^3)	Calorific value (kJ/kg)	Viscosity cSt at 30° C	Flash Point ° C	Fire Point °C	Cloud Point °C	Pour Point °C
1	Diesel	836	43,415	2.87	46	52	4	2
2	B5	839	43,192	4.12	55	61	4.6	2.3
3	B10	842	42,969	5.34	62	73	4.8	2.5
4	B15	845	42,740	6.56	70	85	5	2.8
5	B20	848	42,511	7.78	78	98	5.3	3.1

[B5=5% biodiesel+95% diesel; B10=10% biodiesel+90% diesel; B15=15% biodiesel+85% diesel; B20=20% biodiesel+80% diesel]

2.3 Error Analysis

Errors and uncertainties in the experiments may end from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments. An uncertainty analysis was performed using the method described by Holman (2001). Using the calculation procedure, the total uncertainty for the whole experiment is obtained to be ± 3 %

2.4 Thermal barrier coating

Thermal barrier coating is usually laid by means of plasma spray technique using plasma gun Metco 3 MB in presence of atmosphere. In this experimental work, the combustion chamber components involving piston crown, cylinder head, inlet and exhaust valves are coated with a low conductivity material YSZ ($Y_2O_3ZrO_2$) for a thickness of 150 μm over NiCrAl alloy bond coating of 50 μm thickness.

2.5 Engine operating conditions

The engine was set run at a constant speed of 1500 rpm with fuel injection timing of 23 CA BTDC, compression ratio of 17:1 and a nominal injection pressure of 210 bar. The engine was coupled to an eddy current dynamometer and the output shaft is fixed to a strain gauge type load cell for measuring engine load. Engine cooling water inlet, outlet temperature and exhaust gas temperature were measured using K type thermocouples. Air flow rate to engine is measured by mass air flow sensor and two optical slot sensors are located in engine to measure fuel supply. A Piezo electric pressure transducer is mounted on engine head to measure combustion pressure. Engine exhaust emissions are measured with a portable digital multi gas analyser (NETEL) and smoke opacity by NETEL smoke meter. The performance and emission tests were measured for diesel and blends at various loads 0%, 25%, 50%, 75% and 100%. The tests were repeated for coated and uncoated engine for the same set of operations. Every reading taken for graph is the average of three measured readings.

3. RESULTS AND DISCUSSION

3.1 Carbon monoxide Emission (CO):

The formation of CO depends upon the oxygen quantity and fuel viscosity in turn atomization. At low loads up to 50% the air fuel mixture was lean since the availability of oxygen is more and hence the formation of CO is also low due to more complete oxidation of biodiesel as compared to diesel as agreed by authors Raheman and Ghadge (2007), Ramadhas et al (2005), Godiganur et al (2009). Above 50% load, fuel air mixture was rich since the presence of fuel is more in mixture causing incomplete combustion resulting in increase of CO at high loads for all fuels Nabi et al (2009) and (2009a), Ramadhas et al (2005).

The coated engine (CE) produced lesser CO emission at this injection timing in percentage of 20, 21, 26.67, 28.57 and 22.22 for fuels D, B5, B10, B15 and B20 compared with uncoated engine (UCE) as shown in Fig.1. The high cylinder wall temperature in the coated engine increases the combustion temperature which enhances combustion process as reported by Hazar (2009) and (2010). It was observed that blend B15 showed lesser values of CO emission at all loads than other fuels since the presence of oxygen in biodiesel blend itself in addition to air fuel mixture along with the high operating temperature makes the combustion process complete.

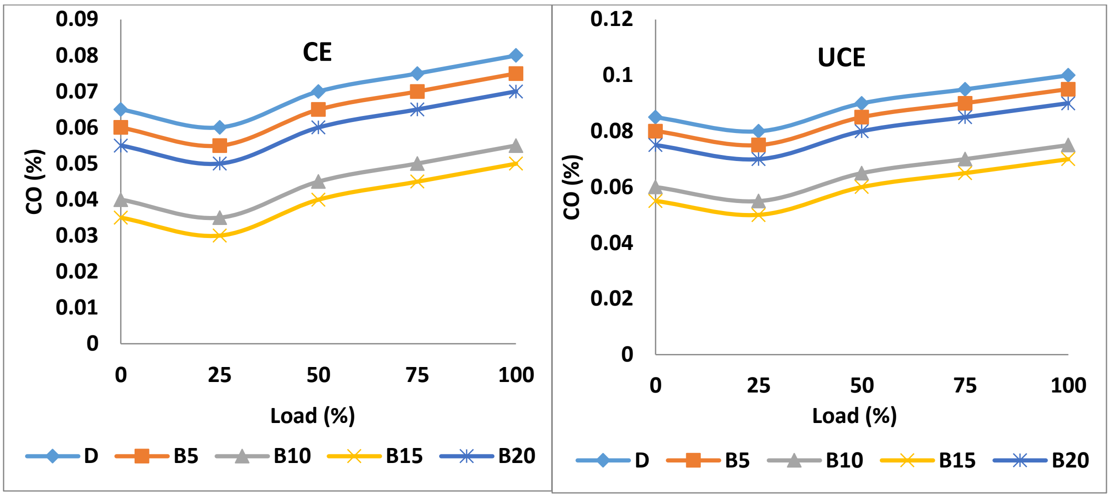

Fig.1. CO emission variation in coated engine (CE) and uncoated engine (UCE)

3.2 Unburnt Hydrocarbon Emission (HC):

Hydrocarbon emission is an important parameter for determining the emission behaviour of diesel engine and it consists of fuel that is incompletely burned. Coated engine exhibits lesser HC emission than uncoated engine since the high operating temperature in engine cylinder improves combustion process for diesel and biodiesel blends. Blends showed relatively lesser HC level than diesel at all loads due to the presence of oxygen in fuel in addition to air fuel mixture aids for complete combustion.

Blend B15 emits lesser HC emission than other fuels tested at all loads since the oxygen availability and high cylinder temperature improves combustion and making it complete. The coated engine produced significant reduction of HC emission level in percentage of 8.89, 9.09, 10.53, 11.43 and 9.76 for fuels D, B5, B10, B15 and B20 at full load and is shown in Fig.2. The high working temperature in coated engine ignites the combustible mixture rapidly and giving rise to maximum heat release well before the power stroke and causes the peak cylinder pressure to occur after TDC for safe engine operation.

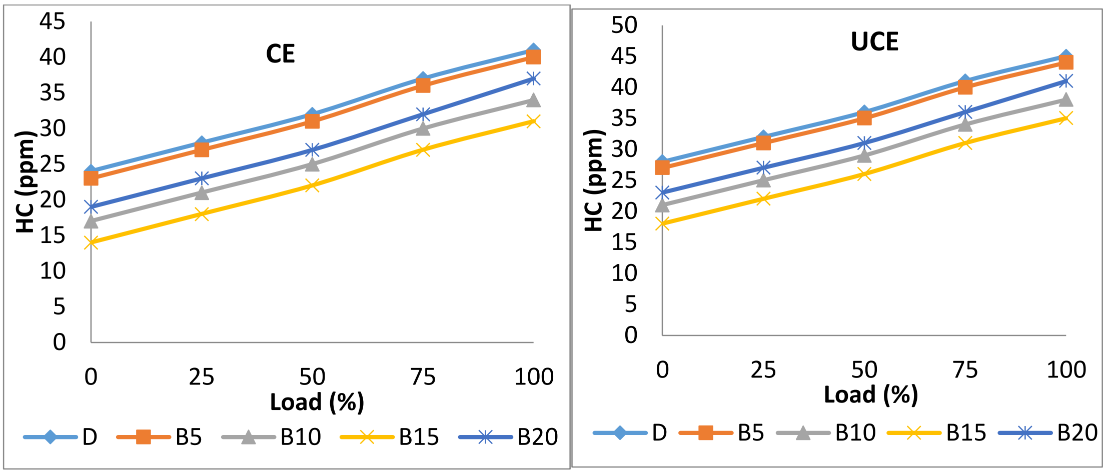

Fig. 2. Unburnt HC emission variation in coated engine (CE) and uncoated engine (UCE)

3.3 Carbon dioxide Emission (CO_2):

The coated engine produces increased amount of CO_2 than uncoated engine in percentage of 8.16, 8, 7.55, 7.41 and 7.55 for fuels D, B5, B10, B15 and B20 at full load as mentioned in Fig.3. Increase of blends percentage in diesel increased CO_2 emission up to blend B15 and decreases slightly for blend B20. This is may be due to high viscosity of biodiesel blends which tend to affect atomization and combustion. Blend B15 showed higher values of CO_2 emission at all loads than other fuels due to its inherent oxygen availability and slightly higher viscosity which may enhances combustion process.

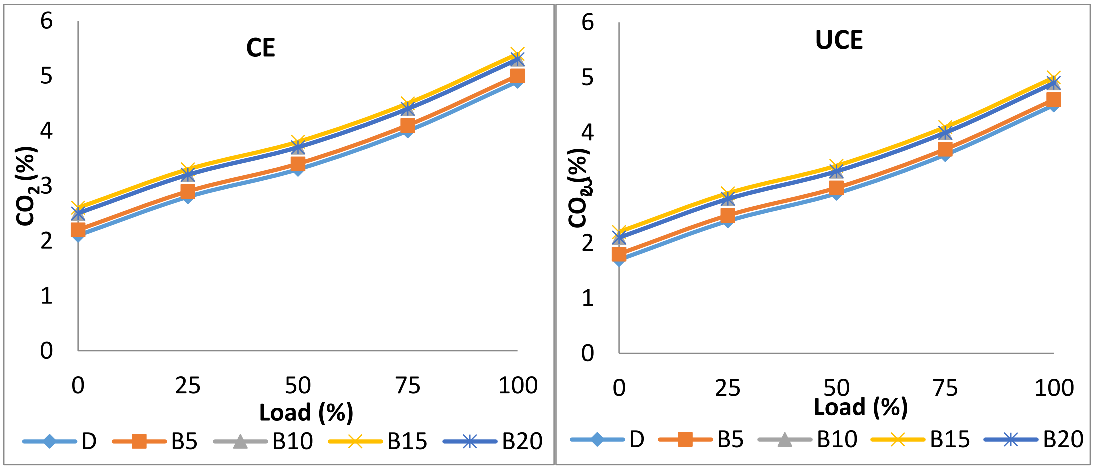

Fig. 3. CO_2 emission variation in coated engine (CE) and uncoated engine (UCE)

3.4 Smoke Emission:

Factors such as shorter ignition delay and poor air fuel mixing are responsible for the smoke formation. Smoke emission increases with load and decreases with the increase of blend percentage in diesel since it depends on the oxygen availability of the air fuel mixture to promote complete combustion as prescribed by Raheman and Ghadge (2007), Nabi et al (2008). The Coated engine shown in Fig.4 indicates lesser smoke emission than uncoated engine in percentage of 8.57, 8.82, 10, 10.34 and 9.09 for fuels diesel and biodiesel blends B5, B10, B15 and B20. This occurs due to high working temperature prevailed in coated engine which aids to utilize the energy of biodiesel blends effectively and making the combustion merely complete compared with limited temperature condition in uncoated engine. Diesel exhibits higher smoke emission than biodiesel blends due to the presence of oxygen in biodiesel blends in addition to air fuel mixture improves combustion process and forming comparatively lesser emission. Biodiesel blend B15 showed lower values of smoke at all loads than other blends because the slightly higher viscosity, density and its oxygen content in fuel aids for better atomization and improved combustion.

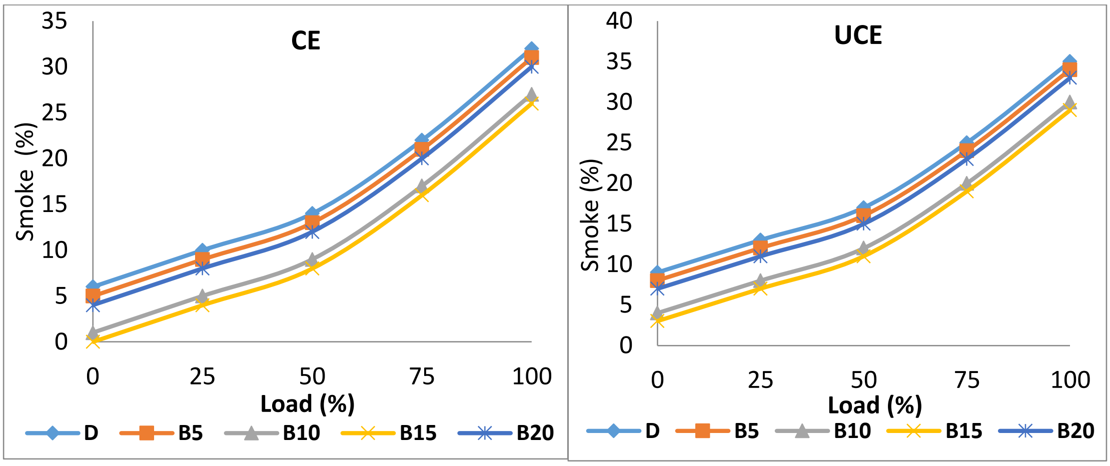

Fig. 4. Smoke emission variation in coated engine (CE) and uncoated engine (UCE)

3.5 Exhaust Gas Temperature (EGT):

Exhaust gas temperature indicates the combustion quality in the combustion chamber. It was observed that increase of engine loads increase the amount of fuel injection in order to retain the power output resulting in more heat release rate which increases exhaust gas temperature as agreed by Godiganur et al (2009). Increase of blend percentage in diesel increases the presence of oxygen in bio-diesel blends enhances combustion resulting in increase of exhaust gas temperature which is also agreed by authors Raheman and Ghadge (2007), Ramadhas et al (2005), Godiganur et al (2009) and (2009a).

The high in-cylinder temperature in coated engine causes the occurrence of maximum heat release rate slightly earlier around 2 degree crank angle for diesel and blends when compared with standard engine as depicted by Qi et al (2009). Coated engine produces higher exhaust gas temperature in percentage of 3.08, 2.62, 2.58, 2.54 and 2.51for the fuels D, B5, B10, B15 and B20 than uncoated engine as shown in Fig.5. Compared with diesel, biodiesel blends exhibits higher exhaust gas temperatures due to the enrichment of oxygen in biodiesel blends along with high working temperature in coated engine as proposed by Hazar (2009) and (2010).

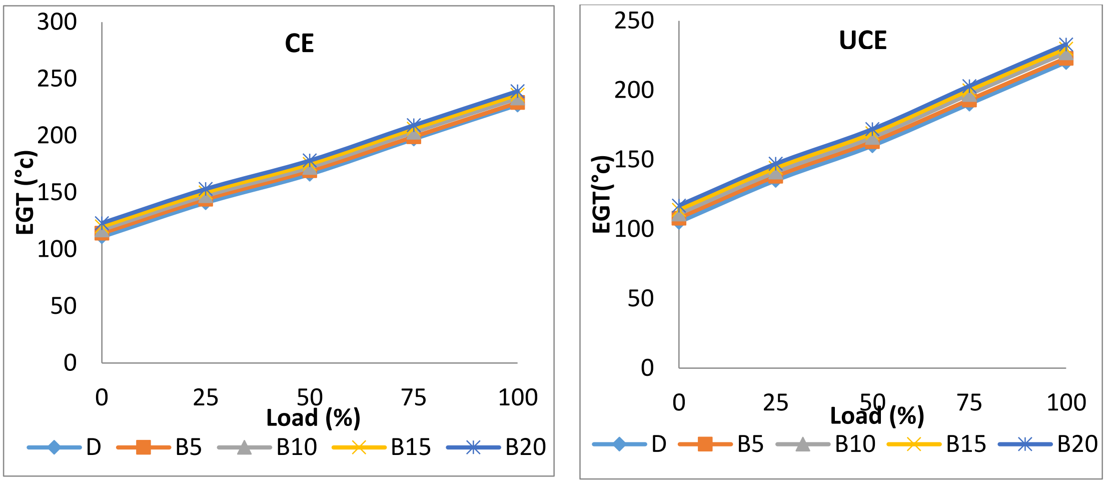

Fig. 5. EGT variation in coated engine (CE) and uncoated engine (UCE)

3.6 Oxides of Nitrogen Emission (NO_x) :

The formation of NO_x depends upon the oxygen concentration, combustion gas temperature and retention time. Nitric oxide (NO) and nitrogen di oxide (NO_2) are usually grouped together as NO_x emissions. NO_x forms by the oxidation of atmospheric nitrogen at sufficiently high temperatures. An increase in combustion gas temperature tends to form NO_x emission. This causes an increase of combustion gas temperature which tends to increase NO_x emission. The coated engine exhibits higher NO_x emission in percentage of 7.07, 6.05, 6.5, 7.8 and 6.64 for fuels D, B5, B10, B15 and B20 compared with uncoated engine since it rejects less amount of heat to the cooling water thereby raising the in-cylinder temperature. The high cylinder temperature thereby improves the combustion process resulting in higher NO_x emission in all biodiesel fuels. Diesel exhibits lower NO_x emission than other fuels in both the engines and is shown in Fig.6.

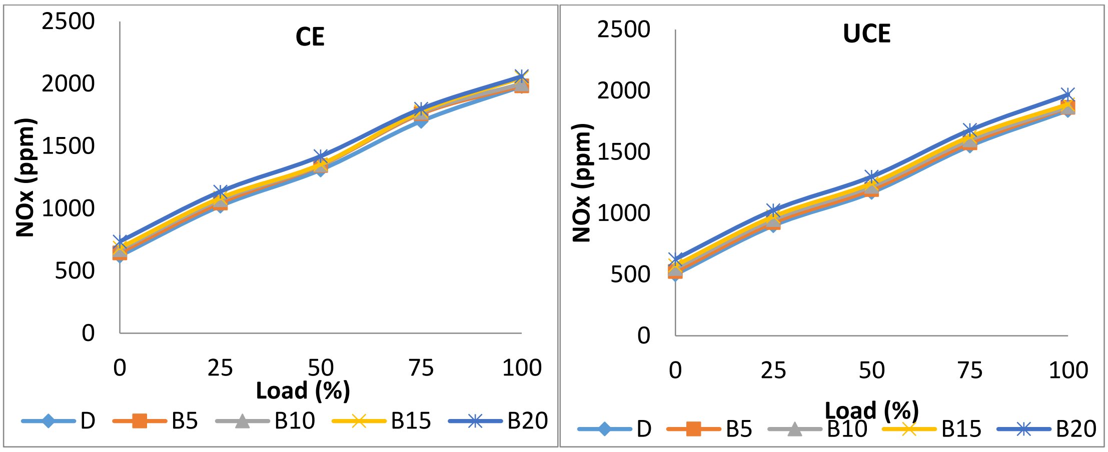

Fig. 6. NO_x emission variation in coated engine (CE) and uncoated engine (UCE)

4. CONCLUSION:

The single cylinder four stroke diesel engine combustion chamber components were coated with 150 µm thickness of ceramic material to avail the engine heat loss. The engine is set to run at a constant speed of 1500 rpm with a fuel injection timing of 23 CA BTDC and 210 bar pressure. The fuels tested were diesel and lower blends of Honge methyl ester in varying engine loads and the results are compared with uncoated diesel engine and following observations are made:

- Drastic reduction in CO emission levels of about 20% for diesel and 29 % for B15 are recorded in coated engine than that of uncoated engine at full load.
- Unburnt HC and smoke emissions values are found less in coated engine of about 9% and 11% for diesel and B15.
- High in-cylinder temperature in coated engine increases combustion gas temperature which tends to increase NO_x emission for biodiesel blends. B15 exhibits slightly higher NO_x emission of 7.8% than other blends in coated engine.
- CO_2 emission values remains higher for biodiesel blends in all loading conditions.
- Biodiesel blend B15 emits comparatively lesser pollutants to atmosphere than other fuels tested and can be recommended as a suitable alternate fuel for diesel in conventional and coated engines.

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