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EFFECT OF HIGHER BLENDS OF CASHEW NUT SHELL OIL WITH DIESEL FUEL BY THERMAL BARRIER COATED PISTON IN A DIESEL ENGINE

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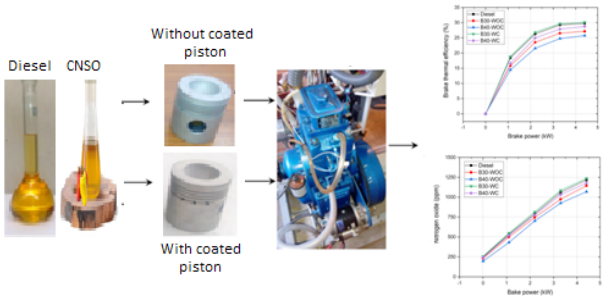
ABSTRACT

Swiftly developing industrialization, growing population, environmental threat, energy demands, have directed research towards alternative fuels. This experimental investigation aims to determine the temperature distributions by coating on piston crown to analyze the effect of higher blends (B30 & B40) of Cashew nut shell oil (CNSO) diesel blends and studied the combustion behavior. The thickness of the coating layer on the piston crown of the test engine are 500 ìm. Prior to coating, the surface of the crown area was grinded upto 500 µm so that the compression ratio of the existing engine continue to be the same. Then the mentioned parts were coated with 150 µm NiCrAl as a bond coat and thereafter same parts were coated with 85% of $ZrO_2$and 15% Magnesium of 350 µm by plasma spray method. In this experimental work, single-cylinder 4-stroke compression ignition engine are used. The influence of coating thickness and distribution of temperature was investigated using the finite element method. Effect of combustion analysis, performance-and emissions parameter are evaluated on the coated piston and compared with the uncoated piston. It was observed that BTE improved and CO, HC and smoke emission reduced significantly at maximum load, with increased NO_x emissions.

KEY WORDS : Cashew nutshell oil, Zirconium oxide, Low heat rejection diesel engine, Thermal barrier ceramic coating.

GRAPHICAL ABSTRUCT



INTRODUCTION

The emerging challenge for the automotive, power plant and industrial sectors are the present emission requirements, which require a high-performance and low-emission engine for a green environment. Biodiesel has been validated and assimilated as an alternative fuel in diesel engines and used to reduce pollution (Cetinkaya *et al.*, 2004). In contrast to fossil fuels, biodiesel such as edible oil and non-edible oil has higher viscous nature and lower volatility properties (Cheng *et al.*, 2004). Considering the commercialization of biodiesel, producing biodiesel from edible oil is expensive than petroleum products. The researcher has redefined feedstock selection for processing to resolve such circumstances. Non-edible oils will be cheaper and not have an unenthusiastic effect on the food chain. The fringe benefit of non-edible oils is that they can be produced from waste products and grow in the wasteland, which is inexpensively feasible. It has

been targeted recently to utilize non-edible oils to produce biodiesel (Darnoko *et al*., 2000).

The literature and general studies proclaim that waste products such as plastic oil, tyre oil, engine lubricating oil, Cashew nut shell liquid, waste vegetable and fried oil can be customized and used in the diesel engine. Cashew nut shell is a waste part of the Cashew nut processing industry. Many researchers emphasized the production of CNSO from Cashew nut shells (CNS), which are the economic resources in the cashew industry.The primary importance of reducing viscosity in CNSO is a good replacement fuel for diesel. The viscosity of CNSO can be reduced by the methods of preheating the oils, mixing or diluting with other fuels, transesterification and the process of pyrolysis (Mashad *et al*., 2006). In the polymer-based industries, CNSO has many applications, such as friction linings, paints, varnishes, laminating resins, rubber compounding resins, cashew cement, polyurethane-based polymers, foundry chemicals, diesel engine biofuel, and chemical industry intermediates (Encinar *et al*., 2005)

CSNO is a non-edible and one of the cheapest options that has been regarded as a possible substitute fuel for the compression ignition (CI) engine. CNSO is a by-product of the cashew field. The nut has a shell of about 3 cm thickness inside which is a soft honeycomb structure containing a dark reddish brown viscous liquid. It is often considered the better material for unsaturated phenols. The total production of raw cashew shell oil in the Asian country could be as much as 9 lakh tonnes per year. Higher blends of bio fuel and biodiesel can be used in applications of thermal barrier piston coating (TBPC).

TBPC helps predict the essential combustion properties and improves the diesel engine efficiency and emissions with a reasonably large substitution of conventional fuels and precise results. Typical piston materials are used in TBPC, such as alloyed steels, light alloy and cast iron. TBPC has good properties such as high melting point, no phase transformation between room temperature and operation temperature, low thermal conductivity, low sintering rate of the porous microstructure, thermal expansion match with the metallic substrate, good adherence to the metallic substrate, chemical inertness.

Generally, the in-combustion temperature of the piston of the coated engine is considerably higher than that of an uncoated engine piston. Due to piston coating, the ignition delay decreases in the low heat rejection diesel engines (Encinar *et al*., 2007). The combustion rate can be improved by coating on the piston crown of the engine piston for higher biofuel blends. coated piston scales reduce the heat rejection rate in the combustion chamber (Felizardo *et al.,* 2006). The atomization of CNSO higher blend with diesel is increased due to reduced crank angle (CA) to achieve finer burning of the mixture at fuel injection. Low cetane fuel burned with the help of thermal barrier coating (TBC) expedience. The life span of engine valves increases by 25%, the total cost decreases by 20%, and the oil consumption reduction is about 15% (Bennett, 1986).

Hazar *et al.,* (2010) and Sivakumar *et al.,* (2014). Investigated the ZrO2 coated piston in a diesel engine for pure vegetable oil. His results showed that the engine efficiency parameters such as power, torque, mean effective pressure and BSFC were improved for vegetable oil blends. The emission level of CO, HC, and smoke was significantly reduced with increases in NOx emissions. It is possible to run the conventional engine that originates from the internal combustion engine 10 percent faster than the conventional engine. Owing to its vicious life cycle in different applications, the ceaseless use of fossil fuel increases the global temperature and the mere number of motor-based applications makes it more disturbing than ever before (Van Gelder, 2017). As the primary cause of greenhouse effects is higher air pollution, its explosive and exponential release has been of great concern to researchers since the beginning of this century (Aydin *et al.,* 2015) .The higher the operational temperature, the performance of the device would be greater. Much higher temperatures, however, require the use of improved temperature-resistant materials.

Coated diesel engine piston, cylinder head and valve with ceramic content of Al2O3-TiO2 (87 percent -13 percent) was experimented. They reported that increasing the BTE and decreasing the BSFC and also CO, HC and smoke level with increasing the NOx emission in comparison to the standard engine (Haþimoðlu *et al*., 2010; Taymaz *et al.,* 2015). The cylinder head, valves and pistons of the engine were protected by a 0.15 mm thick nickel-chromium-aluminum (NiCrAl) interconnecting element with the atmospheric plasma spray process and then the 0.35 mm thick yttria-stabilized zirconia (YSZ-ZrO2) material was coated with the same

method on the primer sheet (Muhammetcerit, 2014). A turbo diesel engine coated combustion chamber components with 0.15 mm Muhammetcerit binders material and 0.35 mm thick ceramic material. As a result, 5-25 percent of the cooling water energy is decreased, while an increase in exhaust energy of 5-20 percent has been reported to have occurred (Huseyin Aydin, 2013). Molybdenum (Mo) ceramic material covered the cylinder head, piston, and valves of the diesel engine using the plasma spray process. In the TBC engine, to determine the efficiency of the diesel engine, evaluate the temperature and thermal stress distribution in plasma-sprayed magnesia stabilized zirconia coated in aluminum piston crown and includes the result using the method of finite elements (Manikam *et al*., 2015).

From the above-mentioned earlier research studies, it is concluded that the CI engine run by biodiesel and biofuel performance has rarely been studied, so far. The objective of the current experimental investigation is to compare the performance, combustion and emission levels of the B30 and B40 CNSO diesel blends in the with coated (WC) and without-coated (WOC) $MgZrO_2$ conventional and semi-LHR diesel engines under different load conditions. In addition, 3-D aluminium alloy finite element modeling and $MgZrO_2$ coated diesel engine piston were studied to visualize the piston temperature distribution (Buyukkaya *et al.,* 2007).

MATERIALS AND METHODS

Cashew Nut Shell Oil

CNSO is a non-edible and one of the cheapest resources that have been regarded as a possible substitute fuel for the compression ignition engine. CSNO is considered the better and most affordable material for unsaturated phenols. Various methods are used to extract the CNSO from Cashew Nut Shell, including open pan roasting, drum roasting, hot oil roasting, cold extrusion and solvent extraction, etc. Vacuum pyrolysis is an efficient CNSO extraction process with lower viscosity and high energy content. This method works in the absence of oxygen. CNSO mainly consists of ancardic, cardanol and cardol in various proportions depending upon the type of extraction. Pyrolysis is generally used for the production of biogas or biofuel from biomass. The extraction through vacuum pyrolysis is the effective method of extraction CNSO with less viscosity and high energy content. It is a thermo chemical treatment, which can be applied to any organic (carbon-based) product. It can be done on pure products as well as mixtures. In this treatment, material is exposed to high temperature, and in the absence of oxygen goes through chemical and physical separation into different molecules. The reaction conditions are maintained at, initial reactor vacuum pressure of 5 kPa. The pyrolysis oil has found to have a very high calorific value which is closer to diesel fuel and therefore it can be considered to be promising bio oil with a potential as a fuel for diesel engine. The tested properties of CNSO, diesel, and CNSODB (B30 and B40) are shown in Table 1.

In the present experimental work, the Zirconium oxide (ZrO2) and magnesium (Mg) are deposited using the Plasma Spraying technique. The powder content is pumped into a plasma flame at a very high temperature (1300 to 1600 °C), where it is quickly heated and accelerated to a high velocity. The mixture of argon (Ar) and nitrogen (N_2) are used as plasma gas in the Plasma Spraying technique. The TBPC protects a weaker or less resistant material by isolating it from the environment. Zirconia based ceramic coatings improve the thermal conductivity and the relatively high coefficients of thermal expansion and eliminate detrimental interfacial stresses of TBPC. Table 2 shows the properties of $MgZrO_2$, NiCrAl and the

Table 1. Properties of diesel, CNSO and CNSODB

Properties	Test method	Diesel	CNSO	CNSODB (B30)	CNSODB (B40)
Density (gm/cc) at 30 °C	EN ISO 3675	0.850	0.944	0.868	0.893
Kinematic viscosity (cSt) at 40 °C	EN ISO 3105	3.13	30.26	6.2	7.8
Flash point (°C)	EN ISO 2719	63.0	198.0	158	142
Fire point (°C)	EN 23015	61.0	193.0	153	141
Calorific value, MJ/kg	EN ISO 1928	44.20	39.23	41.2	39.5
Cetane number	EN ISO 5165	51	35	38	36

Table 2. Material properties of piston alloy and coatings

Material	Density (kg/m^3)	Thermal conductivity (W/mK)	Specific heat (J/kgK)	Thermal expansion 10^{-6} (1/K)	Young's modulus (GPa)	Poisson's ratio
Aluminium	2700	155	960	21	80	0.28
NiCrAl	7870	16.1	764	12	90	0.27
$MgZrO_2$	5600	0.8	650	8	46	0.2

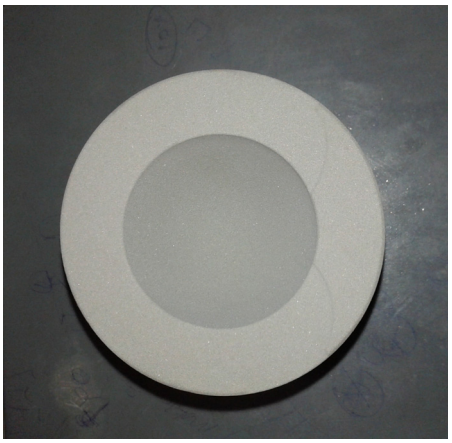


Fig. 1. Ceramic coated piston

piston material made from AlSi alloy. The piston is coated with a thickness of $MgZrO_2$ of 350 ìm over a bond coat thickness of 150 ìm NiCrAl. The coated piston of the present experimental study is shown in Fig. 1.

EXPERIMENTAL SETUP AND METHODOLOGY

The experimental tests were carried out on a single-cylinder vertical, air cooled, four-stroke direct injection diesel engine with a constant speed and nominal power of 1500 rpm and 4.4 kW, respectively, under various operating conditions. The bore and stroke length of the engine are 87.5 mm and 110 mm, respectively. The engine is equipped with a conventional fuel injection system with a 0.2 mm three-hole nozzle divided by 120°, inclined to the cylinder axis at an angle of 60°. The normal nozzle opening pressure was 200 bar during the experiment, and the engine's injection timing was 23° bTDC. According to the manufacturer's recommendation, the engine injection system is frequently cleaned and tuned. The engine is coupled with a swinging field electrical dynamometer, and separate fuel tanks for the diesel fuel and CNSO blends are installed. The fuel consumption is calculated by flow time into the engine for a fixed fuel volume. A flue gas exhaust analyzer (AVL 444 DIGAS) is used to measure the emissions of exhaust gases such as CO, HC, and NOx emissions. The exhaust gas analyzer specification shown in Table 3. The exhaust smoke level is assessed using a standard BOSCH smoke measurement apparatus. The experimental configuration of the engine is shown in Fig. 3.

Experiments are conducted at various engine loads by utilizing coated piston with biofuel. A piezoelectric pressure transducer (GH1D/AHO1) is mounted on the engine cylinder head. The pressure transducer has a sensitivity of 18.99 pC/bar. A high-speed data acquisition system collects the in-cylinder pressures relating to the crank angle. During experiments, data are collected for 50 cycles and used to measure the combustion parameters such as torque brake power and brake specific fuel consumption. The exhaust gas temperature is measured using K-Type thermocouples.

Fig. 3. Experimental setup diagram

The overall error or uncertainty,

$$\partial z = \left[\sum_{i=1}^{n} \left(\frac{\partial z}{\partial x_i} \delta x_i \right)^2 \right]^{1/2} \quad .. (1)$$

$$\frac{\partial z}{z} = \left[\left(\frac{\frac{\partial z}{\partial x_1} \delta x_1}{z} \right)^2 + \left(\frac{\frac{\partial z}{\partial x_2} \delta x_2}{z} \right)^2 \right]^{1/2}$$

Table 3. Specifications of the Exhaust Gas Analyzer

Measured quantity	Measuring range	Accuracy
CO	0-10% vol/0.01% vol	±0.03% volume
CO_2	0-20% vol /0.1% vol	±0.4% volume
HC	0-20000 PPM/10 PPM	+10PPM
O_2	0-22%vol /0.01%vol	±0.1%vol
NO_x	0-5000PPM/1PP	+50PPM

The overall error or uncertainties of the experimental data are determined, using the Schultz and Cole method shown in Table 4.

The relative error or relative uncertainty, $\frac{\partial Z}{Z}$ .. (2)

$$\frac{\partial BP}{BP} = \left[\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta I}{I}\right)^2\right]^{1/2} \quad . (3)$$

$$\frac{\partial TFC}{TFC} = \left[\frac{\left(\frac{\delta \nu}{\nu}\right)^2 + \left(\frac{\delta \rho}{\rho}\right)^2}{\left(\frac{\delta t}{t}\right)^2}\right]^{1/2} \quad .. (4)$$

$$\frac{\partial \eta_{bth}}{\eta_{bth}} = \left[\frac{\left(\frac{\delta BP}{BP}\right)^2}{\left(\frac{\delta TFC}{TFC}\right)^2 + \left(\frac{\delta CV}{CV}\right)^2}\right]^{1/2} \quad .. (5)$$

The highest relative error or relative uncertainty of the measured experimental data are ± 0.58%, ± 4.19% and ± 2.54% for the brake power (BP), total fuel consumption (TFC) and brake thermal efficiency (ς_{bth}) of the diesel engine, respectively.

RESULTS AND DISCUSSION

Combustion Analysis

Over multiple periods, direct experimental data is acquired from the diesel engine with coated piston and biofuel. A top dead centre location is taken as the first in the voltage signal due to the top dead centre indicator. The computer obtains about 370-380 pressure-voltage readings for each crankshaft rotation at the affixed clock frequency of the data acquisition card of 100 kHz. The pressure voltage readings are arranged at a distance of 1° cranke angle by interpolation.

Cylinder Pressure

The variation in the in-cylinder pressure with a crank angle for diesel, B30-WC, B40-WC, B30-WOC and B40-WOC at full load conditions are shown in Fig. 4. Peak cylinder pressure is directly influenced by test fuel's combustion temperature and combustion rate. The engine operates with varying biofuel blends at peak pressure when the peak pressure decreases as the fuel blends increase, viscosity increases as blends increase. Piston coating is an excellent method to overcome the higher blends. The cylinder pressure of diesel, B30-WOC,

Table 4. Uncertainty analysis

Parameter	Measuring technique	Accuracy	Errors (±)
Load	Strain gauge type load cell	±10 N	±0.2
Speed	Magnetic pickup principle	±10 rpm	±0.1
Fuel flow measurement	Volumetric measurement	±0.1 cc	±0.1cc
time	Stopwatch (Manual)	±1 sec	±0.1sec
Crank angle encoder	Magnetic pickup principle	±1 deg	±1 deg
pressure	Magnetic pickup principle	±0.1 kg	±0.1 kg
temperature	Thermocouple	±1ºC	±1ºC
Soundmeter	Frequency or pitch	±1.4 dB	±0.1
Manometer deflection	Balancing of a column of liquid	±1 mm	±1 mm
CO	NDIR technique	±0.02 volume	±0.2
HC	NDIR technique	±10 ppm	±0.1
NO_X	NDIR technique	±12 ppm	±0.2
Smoke opacity	Opacimeter	±1 FSN	±1

B40-WOC, B30-WC and B40-WC are 69.543, 66.743, 62.741, 70.744 and 68.641 bar, respectively. It is observed that the engine's performance increases in coated B30-WC and B40-WC and near the diesel fuel due to reducing the value of viscosity and improving the atomization.

Heat Release Rate (HRR)

The variation of HRR with respect to crank angle (CA) for diesel, B30-WC, B40-WC, B30-WOC and B40-WOC at full load conditions are shown in Fig. 5. The combustion duration and intensity are essential to understand the combustion technique in diesel engines; these parameters are calculated from HRR

The HRR diagram is provided for the important information during the premixed and diffusion phase of combustion. This also helps to understand the formation of most of the emissions like NO, HC during the initial stage of combustion. HRR of diesel, B30-WOC, B40-WOC, B30-WC and B40-WC is 68.262, 65.191, 62.734, 69.592 and 67.343 j/° CA respectively. It is observed that coated B30-WC is increases and B40-WC is near to the diesel fuel. This is due to the viscosity reduces and atomization improves for higher blends. For deciding HRR, the first law of thermodynamics was used. To analyze HRR for all fuels, crank angle rotation was used and 100 cycle data was averaged to find from the equation of the heat release rate.

$$\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma - 1} p \left(\frac{dV}{d\theta} \right) + v \frac{dp}{d\theta} \left(\frac{1}{\gamma - 1} \right) \quad .. (6)$$

Where,
p- in-cylinder pressure
V- Cylinder volume in m^3
q- Crank angle in degree,
g= (C_P/C_V) ratio of specific volume.

Performance Analysis

For the higher blends, B30 and B40 performance characteristicsare examined. It is done in two stages without coated engine piston with coated engine piston and following observation were furnished.

Brake Thermal Efficiency (BTE)

Figure 6 for uncoated and coated piston engines demonstrates the difference of BTE with engine brake power for all test fuel samples at engine part load and maximum load. From the tested result, it is observed that for B30-WC BTE is significantly higher and B40-WC is closer to the diesel fuel. BTE of B30-WC, diesel and B40-WC is 30.12, 29.75 and 28.74% respectively. The findings show that the thermal barrier coating in the piston crown increases the thermal performance compared to the uncoated engine.This is because the ceramic coating has a low thermal conductivity that raises the engine's higher operating temperature to become more favorable for combustion conditions, resulting in a decrease in ignition delay time in the coated engine piston.

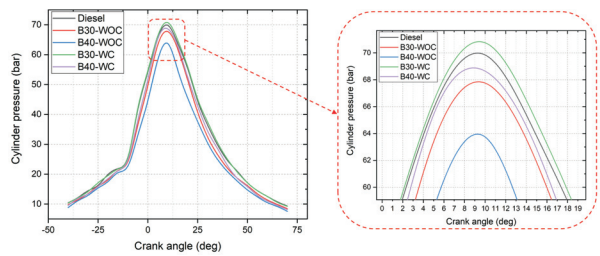


Fig. 4. Variation of cylinder pressure

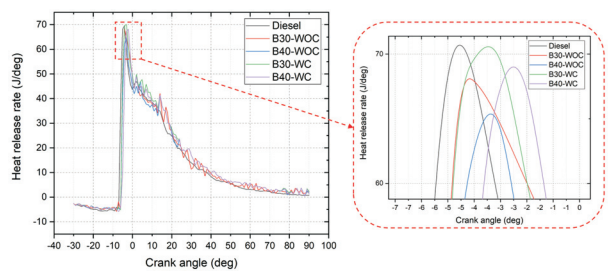


Fig. 5. Heat release rate

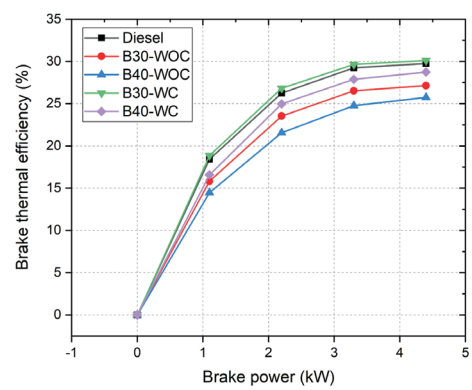


Fig. 6. Variation of BTE with brake power

Brake Specific Fuel Consumption (BSFC)

For uncoated and coated piston engines, the difference of BSFC with engine brake power for all test fuel samples at engine part load and maximum load is shown in figure 7. BSFC of B30-WC, diesel and B40-WC at full load are 0.204, 0.219 and 0.253 kg/kW-hr respectively It can be seen from the findings that, relative to an uncoated engine, the

thermal barrier coated in the piston crown decreases BSFC. This may be due to the elevated piston crown temperature, which raises the cylinder wall and gas temperature, allowing the combustion chamber to have a higher temperature.

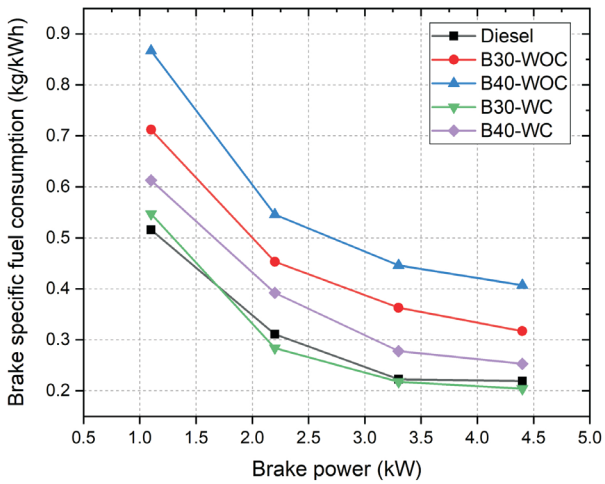


Fig. 7. Variation of BSFC with brake power

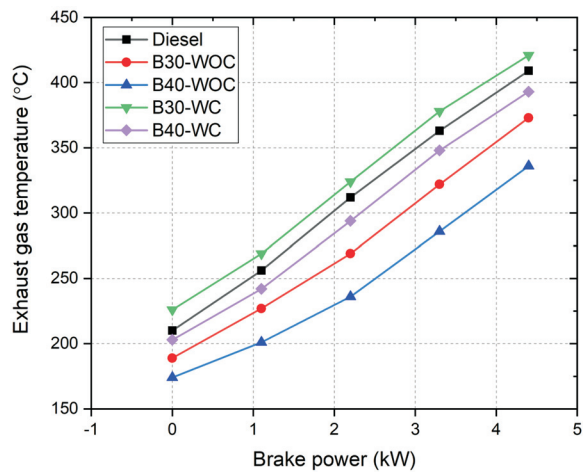


Fig. 8. Variation of EGT with brake power

Exhaust Gas Temperature (EGT)

For the higher blends of with and without coated piston results, the variance of EGT is shown in Fig. 8. EGT for diesel, B30-WOC, B40-WOC, B30-WC and B40-WC engine are 409 °C, 373 °C, 336 °C, 421°C and 393 °C respectively at maximum load. It is observed that EGT for the B30-WC engine, increased by 2.93 % in comparison to diesel fuel at maximum load. EGT is an important parameter as it gives the comprehension to estimate the combustion chamber temperature. The increase in EGT could be due to a decrease in the loss of heat to the coolant and trapped heat that the fuel uses.

Emission Analyses

Various emission properties are discussed below, such as carbon monoxide, hydrocarbons, oxides of nitrogen, and smoke opacity.

Carbon Monoxide (CO)

The Variation of CO emission for the higher blends of with and without coated piston results are shown in Fig.9. A indicator of combustion inefficiency is carbon monoxide, which occurs primarily due to incomplete combustion. The CO emission for diesel, B30-WOC, B40-WOC, B30-WC and B40-WC engine piston are 0.23, 0.22, 0.25, 0.21 and 0.24% respectively at full load conditions. It is observed that CO emissions decreased by 8.7% for B30-WC as compared to the diesel at maximum load. Carbon can easily combine with oxygen at high temperatures and decrease CO emissions, This may be due to the complete combustion of CNSO diesel blend, which is insulated from the coolant jacket in the combustion chamber.

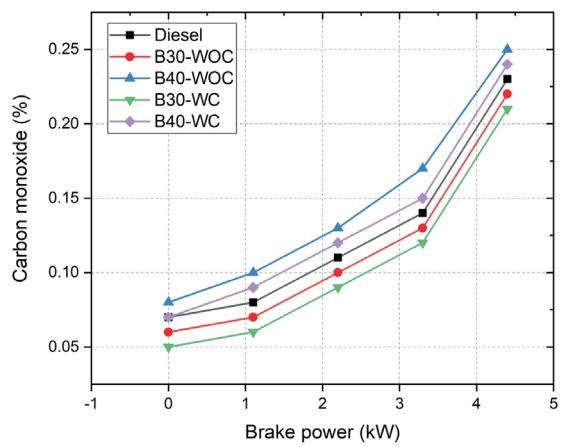


Fig. 9. Variation of CO with brake power

Hydrocarbon (HC)

The difference of HC emissions for the WOC and WC engine piston for all load conditions is shown in Fig. 10. HC emissions are 47, 45, 69, 43 and 51 ppm for diesel, B30-WOC, B40-WOC, B30-WC and B40-WOC engine pistons at full load conditions, respectively. It is observed that for B30-WC, HC emissions decreased by 8.51% compared to diesel at full load. It is observed that for B30-WC, HC emissions decreased by 8.51% compared to diesel at full load. When the engine has a B40-WC coating, the unburned HC emissions are marginally higher.The main reason for this decrease in the unburned HC is that the engine would have a

sufficient amount of oxygen that mixes with the HC emissions at high temperatures. As a result, the HC that mixes with O_2 will be split into H and C, thus reducing HC emissions.

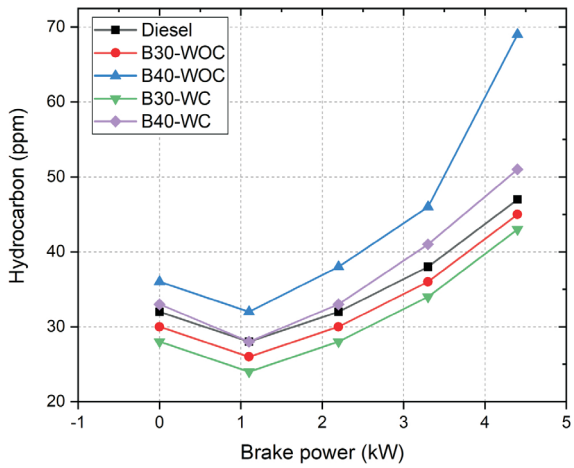


Fig. 10. Variation of HC with brake power

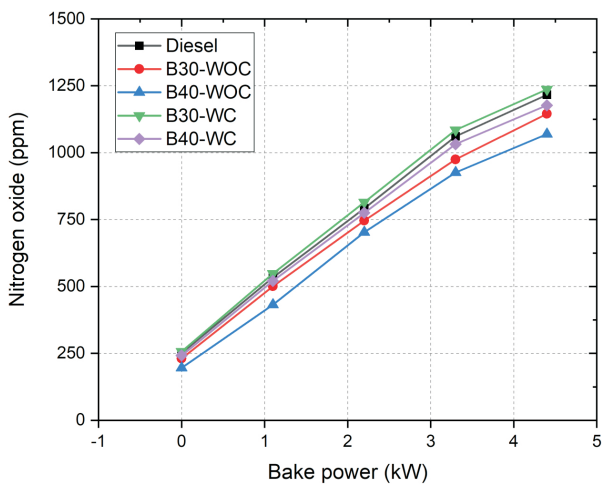


Fig. 11. Variation of NO_X with brake power

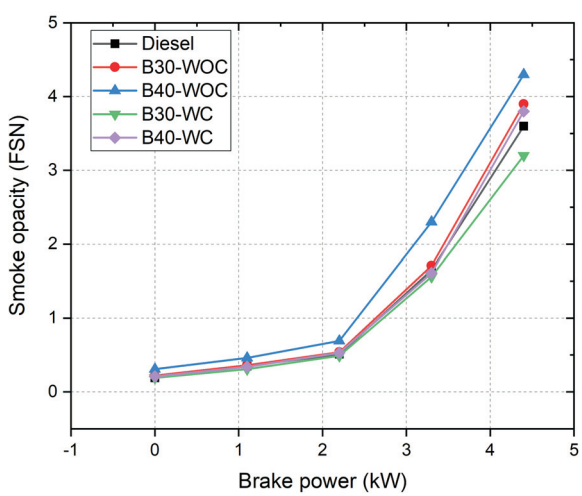


Fig. 12. Variation of Smoke opacity with brake power

Oxide of Nitrogen (NO_X)

The variation of NO_X emissions with all load conditions for the higher blends of WOC and WC engine piston is shown in Fig. 11. NOx is directly influenced by the cylinder combustion temperature, engine exhaust and oxygen present in the test fuel. At low-temperature atmospheric nitrogen exits as a stable diatomic molecule (N_2). So a very small amount of NO_X can be traced at low temperatures. Whereas at high temperatures, more NO_X can be traced in the combustion chamber of an engine.This is because some diatomic molecule (N_2) breaks down into monatomic nitrogen (N), which is very reactive and NO_X will be formed. The NO_X emission for the standard diesel, B30-WOC, B40-WOC, B30-WC and B40-WC is 1216, 1145, 1069, 1237 and 1177 ppm respectively at full load conditions. The NOx emissions are shown to be 1.73 percent higher for B30-WC compared to diesel fuel at full load. Higher combustion temperatures and the intrinsic oxygen in the CDB during combustion may be responsible for the rise in NOx emissions. .

Smoke Opacity

Fig. 12 indicates the smoke opacity difference for all load conditions for pure CDB with and without coated engine piston coating.The smoke opacity for the standard diesel fuel B30-WOC, B40-WOC, B30-WC and B40-WC is 3.6, 3.9, 4.3, 3.2 and 3.8 FSN, respectively at full load conditions. It is seen that smoke level decreases when engine operates with coated piston also B40-WC shows closer smoke opacity to diesel fuel. This may be due to the higher temperature of combustion and the proper rate of combustion. Generally, biofuel contains more oxygen molecules

Numerical results

To test the temperature gradients in the diesel engine pistons, numerical analysis was performed, made of AlSi alloy, without and with thermally coated zirconia using the ANSYS work bench. The diameter and height of the piston were 85mm and 104mm respectively. The computational domain and the corresponding mesh of the diesel engine piston used in the present numerical analysis are shown in Figure 13. Table 5 lists the material properties of the piston coated material used in the analysis. In the thermal analysis, a total of 277417 elements and 556579 nodes are used. Thermal boundary conditions were determined in this analysis by analyzing related literary.

Numerical analyses were performed to evaluate the temperature gradients of the conventional and the thermal barrier coating piston. The temperature distributions on conventional and ceramic coating piston with AlSi alloy are shown in Fig. 14 and 15 respectively. For traditional piston the maximum temperature of 433.73 °C was attained at the piston bowl lip. Whereas, for AlSi ceramic coated piston the maximum temperature of 496.89 °C attained at the edge of the piston bowl.

The maximum temperature value is determined as 433.73 °C at the lip of a conventional piston bowl. The maximum temperature value of the ceramic coating piston is determined as 496.89 °C at the top verge of the piston bowl.

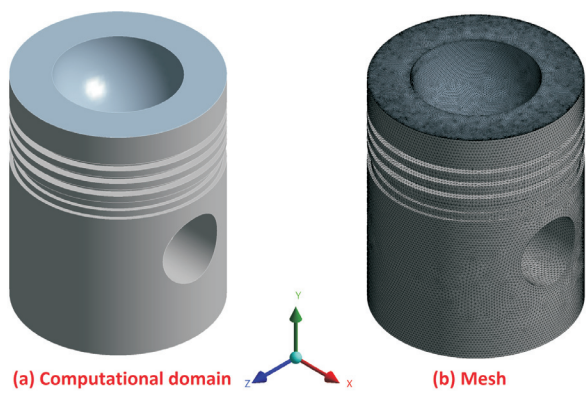
Table 5. Boundary conditions

Location	Temperature (°C)	Convection coefficient (W/m^2K)
Piston top	650	800
Upper ring land	300	230
Lower ring land	110	200
Piston skirt	85	60
Piston inside surface	85	60
Piston pin	85	60

The migration of the highest temperature from the lip of the piston to the sharp edge of the piston has been due to the fact that the heat transfer region of the lip is comparatively greater than that of the sharp edge. Since the surface of the lip was circumferentially coated with a material with a relatively very low conduction coefficient, the heat transfer was greatly reduced. Therefore, instead of the lip surface, the highest temperature was observed on the sharp-edged surface. The piston temperature for both uncoated and coated pistons was plotted against the piston radius at the highlighted edge as shown in Fig. 16 and 17 respectively.

The maximum temperature of 433.73 °C was attained at the piston lipof the uncoated piston at the radius of 0.0353 m from the center of the piston. In the bowl middle, the temperature was found to be 423.93 °C. The maximum difference in temperature on the piston top surface was found to be 15.23 °C. Similarly, the maximum temperature of 496.89 °C was attained at the sharp edge of the piston bowl of the coated piston at the radius of 0.0268 m from the center of the piston. In the bowl middle, the temperature was found to be 441.43 °C. The maximum difference in temperature on the piston top surface was found to be 59.47°C. It indicates an improvement in the engine's combustion chamber temperature. Less thermal load is involved in the base metal. In addition, the system'scooling load is reduced. The ceramic coated piston prevents the heat transer into the pison and since the temperature was noted to be higher than at the metallic surface of the coated piston. From Fig. 15 and it was observed the inside surface temperature of the coated piston was increased by 14.56% compared against the uncoated piston.

It is therefore very certain that the increase in thermal efficiency observed and the decrease in fuel consumption observed in the experimental sample could be well associated with the results of the simulation study, as there is strong evidence of a decrease in piston temperature.



Computational domain Fig 13 (a) and 13 (b)

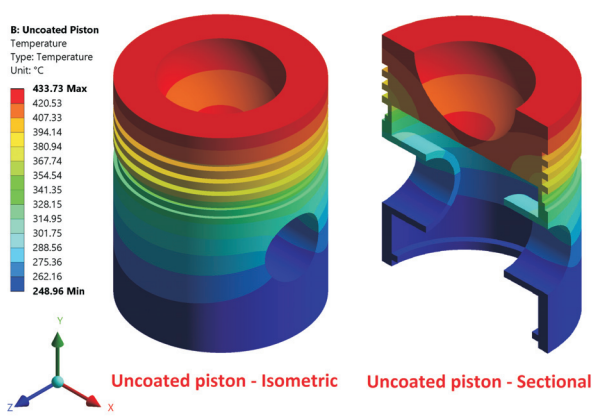


Fig. 14. Conventional uncoated piston

CONCLUSION

To utilize the higher blends like B30, B40 blends and studied the combustion, thermal efficiency and exhaust emissions of the internal combustion

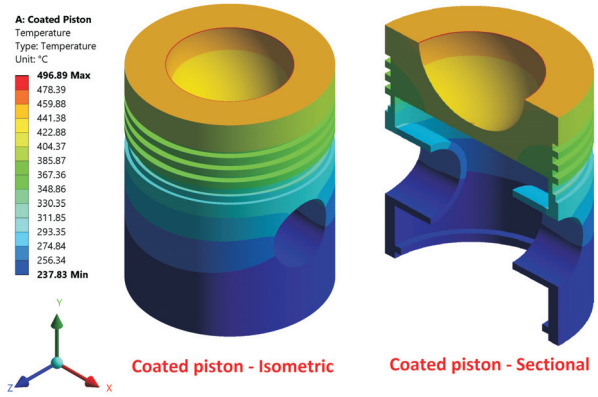


Fig. 15. Thermal barrier coated piston

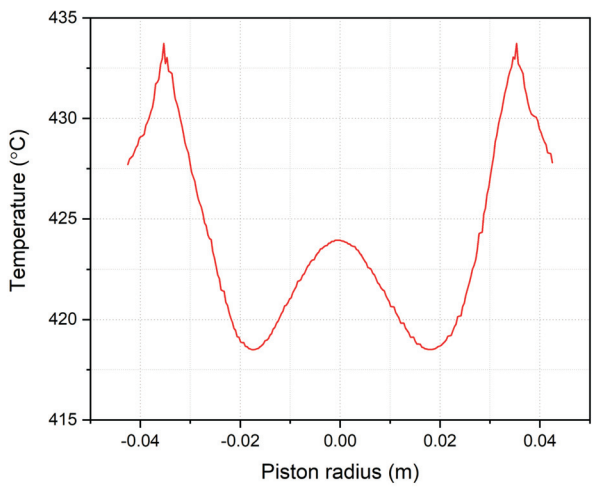


Fig. 16. Temperature variation at the highlighted location along the radius of the uncoated piston

engines, thermal barrier coatings are applied. In this research work, the engine piston crown has been coated to achieve the semi adiabatic engine feature. The following conclusions have been drawn from the present experimental study. For B30, B40 blends in with coated engine the peak pressure and heat release rate for B30-WC increases and B40-WC it is closer to the conventional diesel. In the coated engine, it is seen that BTE and EGT for B30-WC marginally increase and for B40-WC it closer to the neat diesel fuel. The CO, HC and smoke emission decreased and NO_X emissions are increased for B30-WC compared with the pure diesel of the base engine. Finally, a coupled field (thermal-stress) analysis was performed using FEA to help substantiate this increase the performance. The coated and uncoated piston finite element model, performed using the ANSYS work bench, shows a decrease in the average temperature, thermal stress and heat flux for the coated piston compared to the uncoated piston. The capacity of the PSZ coated

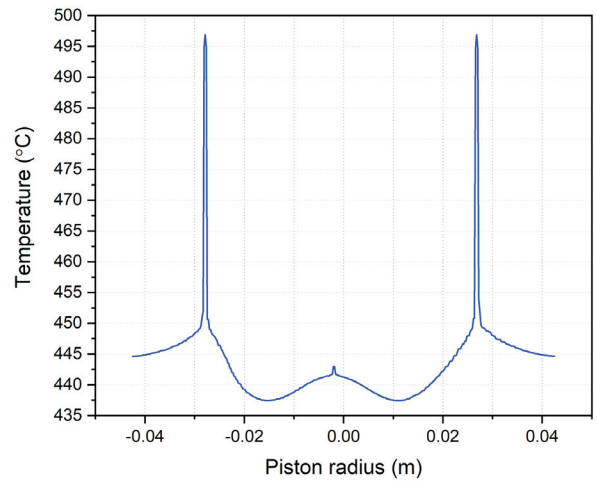


Fig. 17. Temperature variation at the highlighted location along the radius of the coated piston

piston to withstand stress and lower mean temperature is significant evidence of the conversion of heat energy to useful piston function, confirming an increase in thermal performance.

In our experimental tests, the overall surface temperature of the coated piston with low thermal conductivity content is enhanced by about 48 percent for the AlSi alloy and 35 percent for the steel. These findings indicate that the reduction of the system's cooling load is also achievable.

Thus we concluded that higher blends (B30) can be utilized to replace the sizeable amount of diesel fuel.

Nomenclature

BTE	-	Brake thermal efficiency
B30	-	Diesel 70% & CNSO 30%
BSFC	-	Brake specific fuel consumption
bTDC	-	Before the top dead centre
CNSO	-	Cashew nut shell oil
CO_2	-	Carbon dioxide
CI	-	Compression ignition
CO	-	Carbon monoxide
DI	-	Direct injection
HC	-	Hydrocarbon
kW	-	Kilowatt
ppm	-	Part per million (by volume)
TBC	-	Thermal barrier coating
WC	-	With coated
WOC	-	Without coated
PSZ	-	Partially Stabilized Zirconium

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