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Effect of thermal Barrier coating in CI engines fueled with Citrus Medica (Citron) peel oil biodiesel dosed with cerium oxide nanoparticle

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ABSTRACT

In modern days, due to the increase in the automobile pollution and energy crisis has been major concern that world is facing. So, discovering a alternate source of fuel that can partially replace the conventional fuel sources is certainly necessary. Biodiesel is one such alternate fuel source that can fractionally meet the energy requirement. Additionally, control of Green House Gases (GHG) also plays a vital role in conserving the environment. In the present research article, the emission and performance characteristics of Citrus Medica Peel Oil bio diesel dosed with Cerium Oxide (CeO_2) nano particle additive was studied. As well the engine cylinder liner and piston head were coated with Thermal Barrier Coating (TBC) of thickness 300 μm and 150 μm respectively to furthermore improve the performance characteristics. TBC was done with Zirconia Stabilized with Yttria and Ceria (Zirconia 85%, Yttria 10%, and Ceria 5%). Air Plasma Spray Technique (APS) was employed to carry out the coating. Finally, the emission and performance analysis were carrier out with DCO, B15, B20, B25 blends in single cylinder compression ignition engine with TBC and with and without TBC under same testing conditions. It was found that Brake Thermal Efficiency (BTE) of B20 + 15 ppm was marginally higher and with TBC the Specific Fuel Consumption is reduced by 10.59% and there was rise in frictional power loss. The Exhaust Gas Temperature (EGT) escalated by 8-15^{o}C. Regarding the emissions, there was accountable decline in Carbon monoxide (CO), Carbon dioxide (CO_2) and oxides of Nitrogen (NOx). The morphology of coating remained undifferentiated after 20 h of uninterrupted operation of engine but with only excess carbon deposits on the surface.

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1. Introduction

With respect to the rapid exhaustion of the conventional fossil fuels and tremendous demand for it, the use of alternate fuel has become more prominent to meet the energy requirements of the current situation. Numerous explorations have been carried out to find the pertinent and efficient bio oil that can be blended with diesel and can be used for combustion of IC engines. Additionally, stern norms have been imposed for control emissions globally. Considering the former and latter immense research has been carried out to control emission and increase efficiency. Some research deals with the minor modifications in engine so that former men-

Abbreviations: ASTM, American Society of Testing and Materials; CMPO, Citrus Medica Peel Oil; TBC, Thermal Barrier Coating; CI, Compression Ignition; CeO_2, Cerium Oxide (Ceria); B15, Diesel + 15% of Citrus Medica Peel Oil + 15 ppm of CeO_2; B20, Diesel + 20% of Citrus Medica Peel Oil + 15 ppm of CeO_2; B25, Diesel + 25% of Citrus Medica Peel Oil + 15 ppm of CeO_2; BSFC, Brake Specific Fuel Consumption; EGT, Exhaust Gas Temperature; BTE, Brake Thermal Efficiency; GHG, Green House Gases; YSZ, Yttria Stabilized Zirconia; IC, Internal Combustion; APS, Air Plasma Spraying; SFC, Specific Fuel consumption; HC, Hydrocarbons; IDI, Indirect Diesel Injection; EB-PVD, Electron Beam – Physical Vapor Deposition; NO_x, Oxides of Nitrogen; PM, Particulate Matters; CO, Carbon Monoxide.

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tioned goal can he achieved while quite few new alterations in compositions of mineral diesel so that emission control can be intrinsically achieved.

1.1. Biodiesel

For the global complications such as environmental degradation, energy security, restricting imports, rural employment and agricultural economy, these biofuels are acquiring global compliance as a solution. The most promising biofuel, and closest to being competitive in current markets without subsidy, are ethanol, methanol, vegetable oils and biodiesel. Ethanol is used as fuel or as oxygenate to gasoline. Biodiesel is a is obtained from vegetable oils and is made from virgin or used edible and non-edible vegetable oils and animal fats through a chemical process named *trans*-esterification. Biodiesel can be blended in any ratio with diesel fuel [1-6].

[7] has investigated possibility of nano-emulsion of orange peel oil ad biodiesel. 82.3% yield was achieved from the solvent extraction of orange peel oil. The tests were carried out in pure orange oil methyl ester, orange oil methyl ester with 50 ppm of titanium oxide, orange oil methyl ester with 100 ppm of titanium oxide. Reduction in smoke, CO, HC, NO_x was observed in orange oil methyl ester with 100 ppm of titanium oxide. Upon adding additives, the total heat release spiked up. [8] examined orange oil in direct injection engine and found that Brake Thermal efficiency increased for orange oil compared to mineral diesel. Also, Peak pressure and rejection of heat rate found to increase considerably for orange oil. Regarding emission Carbon dioxide, Carbon monoxide reduced but Oxides of nitrogen marginally increased compared to mineral diesel. Momordica charantia seed oil with CeO_2 nano particle was investigated in four proportions B10, B20, B30, B40 with CeO_2. It was observed that there was increase in viscosity which leads to the additional lubrication on the moving parts. B30 blend was performing good in terms of both characteristics and emissions [9].

A multi cylinder IDI engine was experimented with Jatropa and Karanja oils. The BSFC increased 3% and also the CO_2 and NO_x emission increased 7% and 8% respectively as that of diesel. Preheating technique was employed to heat the fuel before entering into the combustion chamber. 3% excess cylinder pressure was noted at full load for both plant oil [10]. [11] considered emulsified Lemon Peel Oil as alternative fuel with novel ionic surfactant methyldihydroxy propyl imidazolium chloride due to its much higher hydrophilic-lipophilic balance value which facilitates to prepare stable water in oil emulsion. It was observed that CO emissions increased by 25–53% compared to pure Lemon Peel Oil.

1.2. Additives for biodiesel

Dosing of cerium oxide nano particle additive to diesel recorded decrease in number weighted size distributions and light-off temperature and the rate of oxidation was increased considerably. Cerium oxide has exceptional catalytic activity because of its oxygen buffering capability principally in nano size. Therefore, using it with diesel had drastic decrease in the NO_x and HC. It has also been shown that cerium oxide decreases the pressure in the combustion chamber, which reduces the production of NO_x [12-14]. It also has the potential to catalyse combustion reactions, by contributing oxygen atoms from its lattice structure. This catalytic activity is dependent on surface area, so using nanoparticles can offer distinct advantages over bulk material or larger particles [15] Table 1.

Cerium oxide nano particles additive can also be used as a momentary treatment for particulate filters in CI engines. The nanoparticles help to clear soot which chokes up the filters, contribution to the improved performance of the filters and the cleanliness of the exhaust emissions [16]. When diesel engines are powered using biodiesels of different origins, it was observed that engine performance was lower than with pure diesel. Also, NOx emissions increase with the use of biodiesel [17,18]. Hence, in order to improve engine performance and reduce the emissions, Nano particles of metal and metal oxides were used as additives to biodiesel by different researchers. It was observed that addition of nanoparticles improves engine performance and has a strong influence on engine emissions. Most engine emissions (CO, HC and smoke) were reduced [19-22]. However, comprehensive experimental research is needed to study the influence of nanoparticles on diesel/biodiesel engine combustion under different operating conditions. Detailed investigation is needed considering the type of the biodiesel, injection characteristics, nanoparticle size and its type. On addressing these issues, nanoparticle addition to base fuels like diesel/biodiesel may be considered a viable option for improving the thermal performance of the diesel engine and to reduce the major emissions from the engine. This will certainly aid fossil fuel conservation and decrease air pollution [23,24].

Table 1
Properties of cerium oxide nano particle additive.

Molecular formula	CeO_2
Molar mass	172.115 g/mole
Appearance	White or pale yellow solid, Slightly Hygroscopic
Density	7.215 g/cm^3
Melting point	2,400 °C (4,350 °F; 2,670 K)
Boiling point	3,500 °C (6,330 °F; 3,770 K)
Solubility in water	Insoluble
Crystal structure	Cubic (fluorite)

1.3. Thermal Barrier coatings in engines

TBC are most novel ceramic materials that is applied on metallic substrates, such as aircraft engines, turbines etc that operate at elevated temperature [25]. These coatings are usually used to serve extended insulation of the component and prolong the heat loads. The thermal efficiency also drops due to loss of heat through cylinder walls of engine. On employing these coatings, it can allow elevated operating temperatures while limiting the thermal vulnerability of structural components, there by increasing part life by reducing oxidation and thermal fatigue failure. Other factors like wear resistance, thermal efficiency was also improved compared to that of a conventional liner [26,27]. Implementing TBC in diesel engines lowered SFC by 15–10% and increased the performance of engine by 8% at high speeds. There was also a significant rise of EGT about 200 K [28].

It has been noted that mostly ceramic coatings possess such a combination of favourable characteristics at high temperatures, which is evident in their resistance to oxidation, corrosion, erosion and wear. However, the critical requirement of a TBC is its heat insulating capability of the material that is low thermal conductivity of ceramics, but a majority of them are poor in adhesion to the metal substrate material on which they are to be coated. The high thermal expansion and low thermo-mechanical stability of ceramics at elevated temperature also pose critical problems and these limitations are overcome to a significant extent by the use of bond coats [29,30].

2. Materials and methods

2.1. Preparation of bio diesel

The CMPO is produced by pyrolysis process of the peel, which is a solid bio waste. Preferably, the most economical process of pro-

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ducing biodiesel is using base catalysed transesterification as it is the requiring only low operational temperatures and pressures but achieving 98% conversion yield [31]. The raw CMPO is subjected to transesterification process. Methanol is added to the raw oil with Potassium Hydroxide as catalyst. The chemical break down of raw oil into ester and glycerol is achieved. In the end glycerol is separated which is a by-product of this process.

For extraction of bio diesel, 1000 ml of citrus medica oil is taken in a container. 18 g of Potassium hydroxide alkaline catalyst is weighed. 250 ml of methanol is taken is beaker. Potassium Hydroxide is mixed with the alcohol and it is stirred until proper dispersion takes place. Raw CMPO is taken in a container and is stirred with a mechanical stirrer and concomitantly heated with the help of a heating coil. The speed of the stirrer should be as low as possible and when the temperature of the raw CMPO reaches 60 °C the Potassium Hydroxide-alcohol solution is poured into the raw oil container and the container is closed with a air tightly. Now the mixture is stirred at high speeds about 720 rpm. Care should be taken to maintain the temperature below 60 °C as methanol evaporates at temperatures higher than 60 °C. Also, after adding Potassium Hydroxide-alcohol solution to the raw oil only heat is generated. After stirring the oil- Potassium Hydroxide - alcohol solution at 60 °C for two hour the solution is transferred to a glass container [36-39] Fig. 1.

Following that separation of mixture takes place and biodiesel gets collected in the upper portion of the glass container whereas glycerin gets collected in the bottom portion. This glycerin is separated from the container. Then the biodiesel is washed with water [40-45]. Again, glycerin gets separated from the biodiesel and is removed. The biodiesel is washed with water repeatedly till no glycerin is there in the biodiesel. Now this biodiesel is heated to 100 °C to vaporize the moisture content in it. The resulting product is the biodiesel which is ready for use or even it can be mixed with alcohol for better combustion [46-50]. The properties of the fuel which was found using ASTM standards was found to be almost equal to that of diesel with marginal increase in the viscosity [51,52].

2.2. Thermal barrier coating of engine liner and piston head

The TBC thickness depends on the application for which it is used. If maximum insulation is required, then coating can be done up to thickness of 1000 μm in CI engines. Since this in a cylinder liner complete insulation cannot be done which leads to the engine cease due to temperature increase. So partial conduction is required. In this research work the cylinder liner and piston head is coated to thickness of 300 μm and 150 μm respectively.

In manufacturing process, primarily an undercut done is a special type of recess in the inner diameter. It is similar to the internal grinding process. Here the undercut is done for a depth of 300 μm in the internal surface of the cylinder liner. This increases the diameter and creates a rough surface so that the coat can strongly adhere to the substrate. In the APS powder application method, the ceramic material is in the form of a flowable powder that is fed into a plasma torch and sprayed molten onto the surface of the metallic substrate. Droplets of molten material form "splats" on the metallic substrate. Sprayed coatings have half the thermal conductivity of the EB-PVD coatings and are therefore better isolators Fig. 2.

The ceramic layer is usually deposited by means of the atmospheric plasma spraying (APS). The thermal diffusivity of APS is comparatively low [32-34]. The main goal in the research field of the TBCs is the development of systems for higher application temperatures and with a longer lifetime an APS top coat, the orientation of the cracks and pores are normal to the flow of heat, which reduces the thermal conductivity from 2.3 W/(m*K) to about 0.8–1.7 W/(m*K). However, because of the orientation of

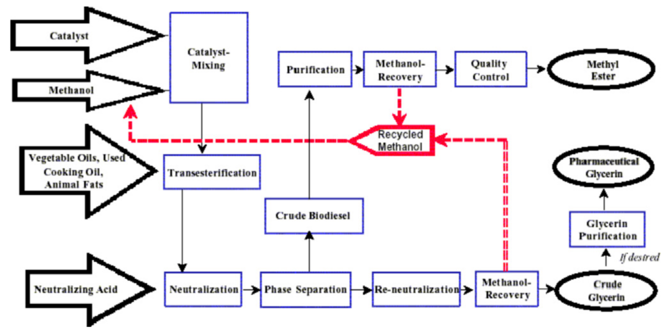

Fig. 1. Schematic flow chart of bio-diesel production.

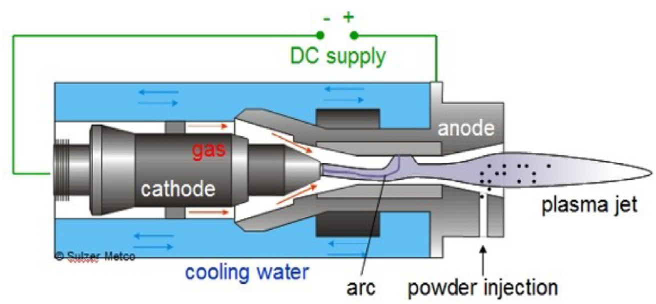

Fig. 2. Air plasma spaying technique.

the microstructure and the roughness of the interface, this method generally produces a shorter thermal cycle compared to other methods. The sparing is done to approximate thickness of 500 μm Table 2.

Finally, the process of Horning is carried out. Now using a grinding wheel 500 μm is reduced to 300 μm. Horning zirconia ceramic is eventually little hard due to its hardness. Care should be taken to maintain the standard internal diameter of cylinder 87.5 mm. If the clearance increases better compression cannon be achieved. So, the tolerance value should be as negligible as possible.

There are several ceramic materials with which coating can be done. Zirconia is chosen ceramic for coating. This is hardest material. The Mohr's hardness scale value is 8.5 as that of diamond is 10. But phase transition takes place at the temperature of 1170^{0}C and 2370^{0}C. Since heat is retained there is a chance of failure of the material. Considering the safety aspects, a stabilising material should be added in order to overcome the phase transformation. Yttria and ceria is chosen as stabilising material. As far as the literature studies maximum of 20% stabilising material would be efficient. If the composition stabilisers increase coating strength, wear and tear decreases. This leads to the failure of the coating. Some the following composition is selected and tested Table 3.

2.3. Test fuel preparation:

The Fuel for experiment is prepared in three different ratios- B15, B20 and B30. B15, B20, B25 comprises 15%, 20%, 25% of CMPO by volume and rest mineral diesel respectively as represented in Table 4. The fine cerium oxide nano particle is blended to the biodiesel using Ultrasonicator. The Ultrasonicator procedure is the most appropriate technique to scatter the nano particles in base fuel (CMPO), as it encourages conceivable agglomerate nanoparticles back to nanometer go. Nano particles are for the most part having higher surface territory and henceforth surface vitality will be high and it will in general agglomerate to frame a smaller scale atom and begins to silt. So as to make nano molecule to be steady

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Table 2
Plasma spraying parameters.

Parameters	Values
Plasma spray gun	3 MB
Current I (Ampere)	500
Voltage V (Volts)	65–70
Maximum power	40
Primary gas flow -Ar (SCfh)	80
Secondary gas flow $-H_2$(SCfh)	15
Spray distance	2

Table 3
Composition of TBC coating.

Material	Composition
Zirconia	85%
Yttria	10%
Cerium	5%

Table 4
Blending composition.

Blend	Diesel (ml)	CMPO (ml)	CeO_2 Additive (ppm)
Diesel	1000	0	15
B15	850	150	15
B20	800	200	15
B25	750	250	15

in a base liquid, it ought to be developed to surface adjustment. Consequently, the molecule sedimentation was controlled. So as to scatter the nano molecule to base liquid ultra-sonication system was followed. A known amount of 15 mg of CeO_2 was gauged and mixed into in the biodiesel blends and mineral diesel. This is constantly ultrasonicated for 60 min. Then it forms a stable nano fluid.

3. Experimental test setup

A single cylinder, 4 S, water cooled diesel engine (TV-1 model Kirloskar, India) with power 5.2 kW at 1500 rpm was used for experimentation and coupled to eddy current dynamometer for loading. The air box fitted with orifice meter and manometer was used to measure flowing rate air with a percentage of uncertainty ± 1. Detailed engine specifications are summarized in Table 5, and the schematic arrangement of the experimental setup is depicted. The fuel consumption was calculated manually by a calibrated glass tube by measuring the time required for the consumption of 10 cc of fuel. The eddy current type dynamometer was coupled to the engine output shaft. A piezoelectric pressure transducer (AVL Indimicra 602- T10602A) used for observing the pressure in the cylinder, while the magnetic pickup was used to record the crank angle. AVL 365C Angle Encoder Indi Advanced was mounted on at the front-end of the crankshaft for measuring the engine speed. Recorded cylinder pressure readings for 50 cycles were averaged for every steady state. Cylinder pressure and heat release rate were observed and reported in the computer, and the corresponding graphs were obtained for comparing for each and every test blend with standard diesel fuel. CO, CO_2, HC, NOx and O_2 emissions were measured by five gas analyser (AVL Digas 444). Smoke was measured by an AVL437 smoke meter and chromyl alumel (k-type) thermocouple was used for measuring the exhaust gas temperature. All the experimental tests were carried out under standard steady-state laboratory conditions with a constant speed of 1500 rpm. All the tests were recurred thrice, and the outcomes were cumulated. A computerized data acquirement system was engaged to record, report and analyze the experimental

Table 5
Engine specification.

Parameters	Values
Model	Kirloskar TV-1
Cylinder orientation	Vertical
Rated power	5.2 kW
Maximum rated Speed	1500 rpm
Number of cylinders	Single
Number of Stroke	4
Compression ratio	17.5: 1
Combustion chamber	Piston with hemispherical bowl
Bore diameter	87.5 mm
Stroke length	110 mm
Ignition type	Compression ignition
Cooling type	Water

data. The required emission parameters were measured and recorded after allowing sufficient time for the engine to reach its steady state condition Fig. 3 Table 6.

The experiments were conducted in two stages. In the first stage the conventional engine liner and piston head which is made of cast iron was directly used in the engine setup without TBC coating and the responses Diesel with Cerium oxide, B15, B20, B25 blends were noted. Following that the liner and piston head which is TBC coated is used to replace the conventional ones and again corresponding responses for all blends were recorded. Both outputs were compared and discussed in detail to find out the performance, emission and surface morphology advancements that is achieved using TBC.

4. Results and discussion

4.1. Performance analysis

For the different blends B15, B20, B25 the performance and emission characteristics is examined. It is done at two stages i.e. with and without TBC coating and following observations were made.

4.1.1. Brake power

The useful power developed in the engine cylinder refers to brake power after a fraction of power being lost in the engine cylinder to overcome the internal friction. The net power available at the shaft is known as brake power. The test was conducted for pure diesel fuel which was base line fuel and then for different blends B15, B20, B25 both with and without TBC coating. It was observed that brake power increases when the load was increased for all operations of diesel and emulsion oil that is evident from Fig. 4. Generally, the brake power was approximately similar at any load for diesel and blends of emulsion oil and diesel.

4.1.2. Indicated power

The performance of Citrus Medica Peel biodiesel blends for various loads with respect to three blending ratios indicated power with cerium oxide as additive are shown below in the Fig. 5.

As it is evident that, the indicated power increases with TBC coating. This is because heat is retained within the cylinder. So that this acts as pre heat for incoming fuel mixture and ignition occurs easily. This also reduces the fuel consumption.

4.1.3. Friction power

The performance of citrus medica biodiesel blends on the friction power for various loads with respect to three blending ratios with cerium oxide as additive both with and without TBC coating are shown below in the Fig. 6.

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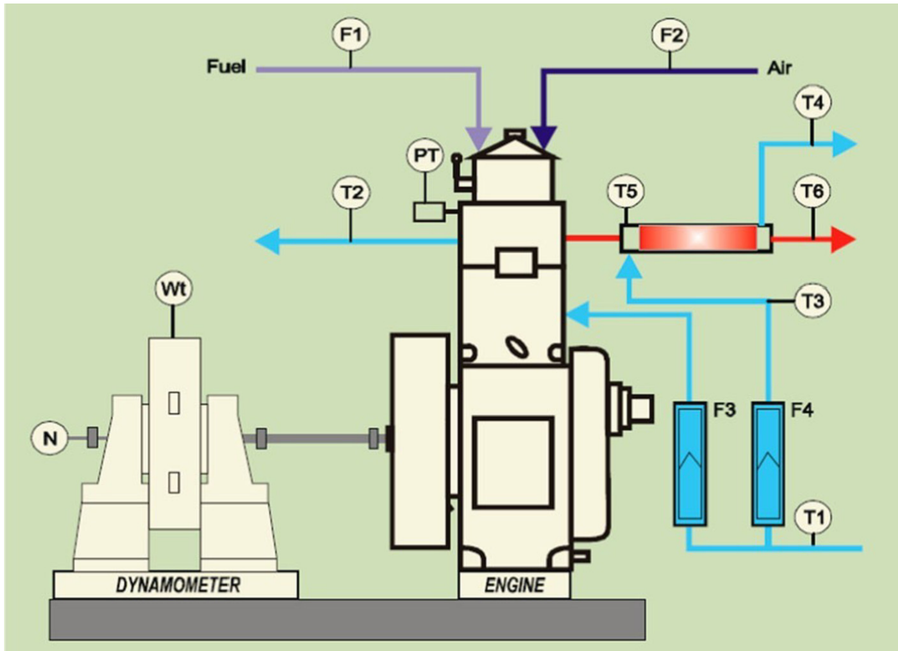

Fig. 3. Experimental test setup.

Table 6
Engine component description.

Parameters	
Engine cooling water inlet	T1
Engine cooling water outlet	T2
Calorimeter water inlet	T3
Calorimeter water outlet	T4
Calorimeter exhaust gas in	T5
Calorimeter exhaust gas out	T6
Fuel line	F1
Air inlet	F2
Engine cooling water	F3
Calorimeter water	F4
Pressure Transmitter	PT
Crank angle encoder	N

4.1.4. Brake thermal efficiency

The performance of citrus medica biodiesel blends on the brake thermal efficiency with cerium oxide as additive both with and without TBC coating are shown below in the Fig. 7. The higher viscosity of the blended fuel reduced the brake thermal efficiency and the blended fuel was similar to that of the diesel performance. It is observed that, at maximum load condition and it was only 2% variation from that of the pure diesel performance.

4.1.5. Indicated thermal efficiency

The performance of citrus medica biodiesel blends on the Indicated thermal efficiency for various loads both with and without TBC coating respect to three blending ratios with cerium oxide as additive are shown below in the Fig. 8.

Inferring the above graph, it is clear that there is not much changes in the Indicated thermal efficiency.

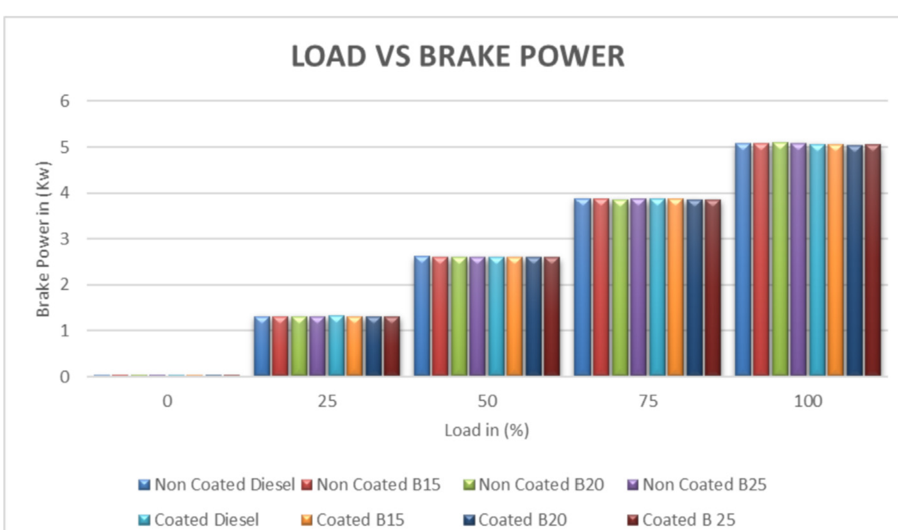

Fig. 4. Variation of brake power with load for CMPO blends with and without TBC coating.

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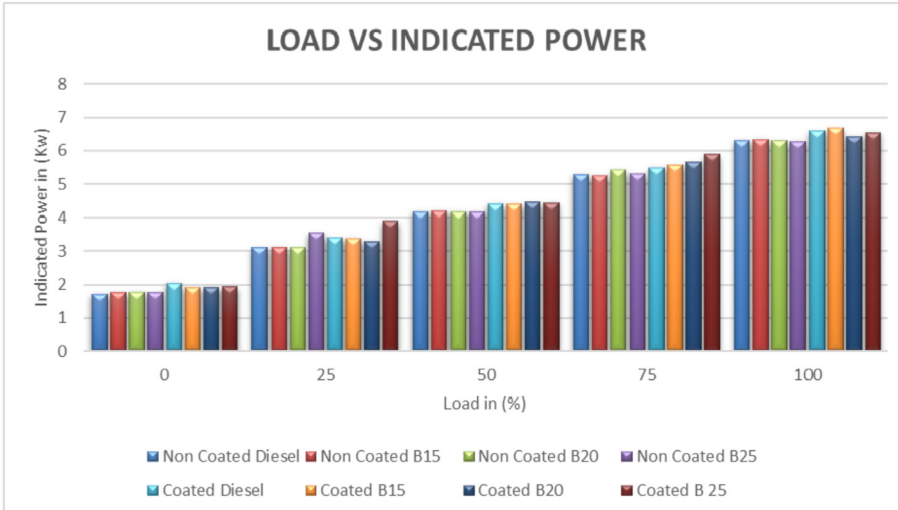

Fig. 5. Variation of indicated power with load for CMPO blends with and without TBC coating.

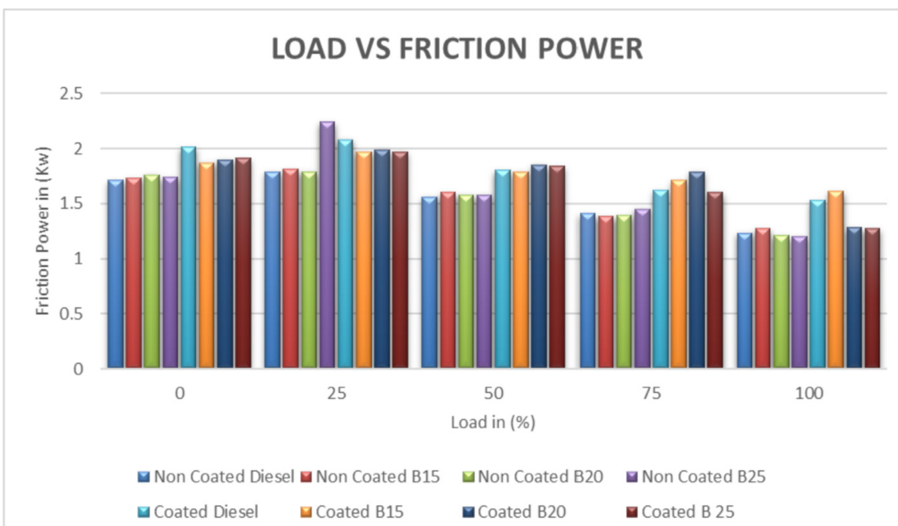

Fig. 6. Variation of friction power with load for CMPO blends with and without TBC coating.

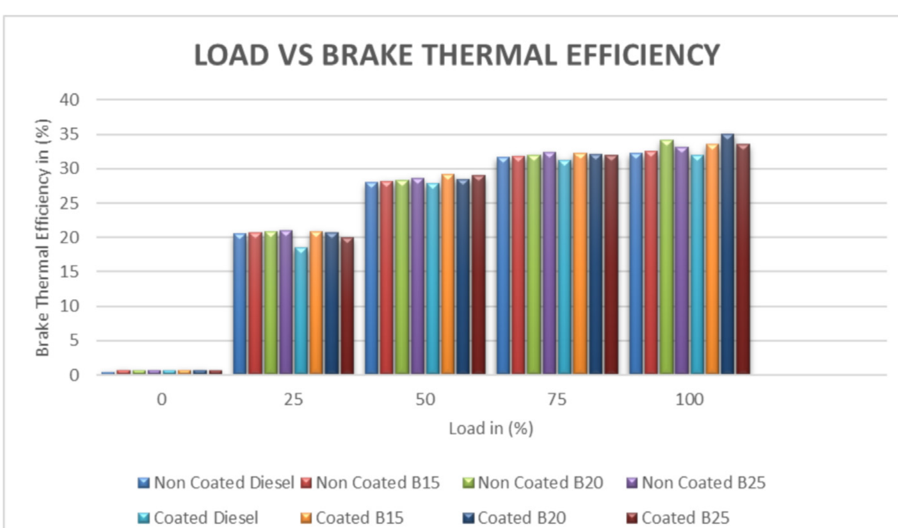

Fig. 7. Variation of BTE with load for CMPO blends with and without TBC coating.

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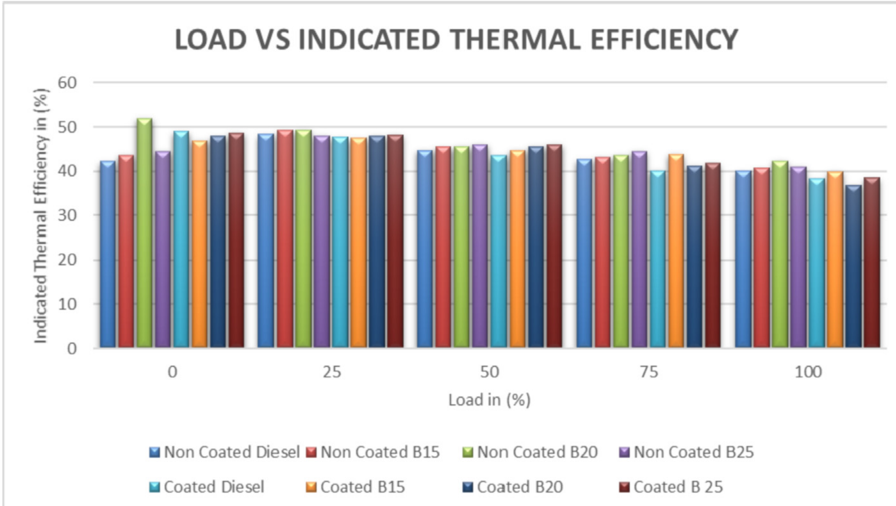

Fig. 8. Variation of ITE with load for CMPO blends with and without TBC coating.

4.1.6. Volumetric efficiency

The volumetric efficiency of the fuel mixtures is plotted in Fig. 9**.** It can be seen that the volumetric efficiency for B20 is better than diesel fuel at lower load conditions. It is found that with TBC coating at high temperatures on the combustion chamber wall surface due to insulation cause a drop in volumetric efficiency although increased boost pressure from the turbocharger can be used to overcome this problem.

4.1.7. Fuel flow

The tests were performed for pure diesel fuel and then for different blends of B15, B20, B25 with and without TBC coating. Experimentally, it was observed that the fuel consumption increases when the load was increased for all operations of diesel and emulsion blends as shown in Fig. 10.

It was also observed that fuel consumption decreases when nanoparticle volume fraction in the emulsion blend was increased for any given load. Also, for B15 blend, the increase in fuel consumption was more than that of other blends and diesel operations at higher load conditions. This was due to the higher viscosity and lower calorific value of B15 as compared to other blends and conventional Diesel fuel. At full load operation maximum power of the engine was produced that needs higher amount of fuel energy and due to lower energy content of B15 as compared to conventional diesel and other blends, fuel consumption increases for B25 as compared to diesel and the other blends at higher loads. Nanoparticle blended emulsion were found to be improve with the increase in their calorific value due to presence of cerium oxide nanoparticle which acts as oxygen buffer, thereby making the engine to consume less fuel compared to B15 to overcome identical load.

4.1.8. Air flow

This below graph shows the amount of air intake during each load for combustion. It is found that without coating at high load the air intake is comparatively high from Fig. 11. But with coating it reduces because the amount of oxygen required for combustion is additionally supplied by the ceria in coating surface and nano additive. This layer consists of elements in the form of oxides.

4.1.9. Specific fuel consumption (SFC)

The performance of citrus medica biodiesel blends Specific Fuel Consumption with cerium oxide as additive are shown below in the Fig. 12.

The Specific fuel oil consumption of blended oil is slightly higher than diesel oil. From the Fig. 12, it is derived that the diesel has a lower Specific fuel oil consumption because of high calorific value, with blended fuel B15 the equivalent SFC was very closer but higher than that for the pure diesel fuel. This was observed due to the slightly lower calorific value and higher viscosity of the biofuel. Compared to the SFC without coating is little higher than SFC with TBC coating

4.2. Emission analysis

The various emission characteristics such as carbon dioxide, carbon monoxide, hydrocarbon, oxygen. Oxides of nitrogen and smoke opacity is discussed below:

4.2.1. Carbon monoxide (CO)

The emission characteristics was carried out for different blends of biofuels with the pure diesel fuel. The emissions characteristics of CO analysed with and without cerium oxide additives are shown in Fig. 13.

The various Carbon Monoxide emissions for varying blends were shown in Fig. 13. The Carbon Monoxide emissions from blended fuel are a bit more than the normal diesel fuel at all loads. Diesel engines produce little amount of CO when compared to NO_x and particulate emission as the engine was not loaded.

4.2.2. Carbon dioxide (CO_2)

The emission test was carried out for different proportions of biofuel blended with the pure diesel fuel. The emissions characteristics of CO_2 analysed with and without TBC coating are shown in Fig. 14.

The various Carbon Dioxide levels for varying blends were shown in Fig. 14. From the readings, it is inferred that emission of Caron dioxide is slightly higher than pure diesel. The CO emission can be reduced by providing surplus oxygen into the combustion chamber [35]. There by converting CO into CO_2 this is possible by complete combustion.

4.2.3. Hydrocarbons (HC)

The test was carried out for different proportions of biofuel blended with the pure diesel fuel. The emissions characteristics of HC analysed with and without nano additives are shown in Fig. 15.

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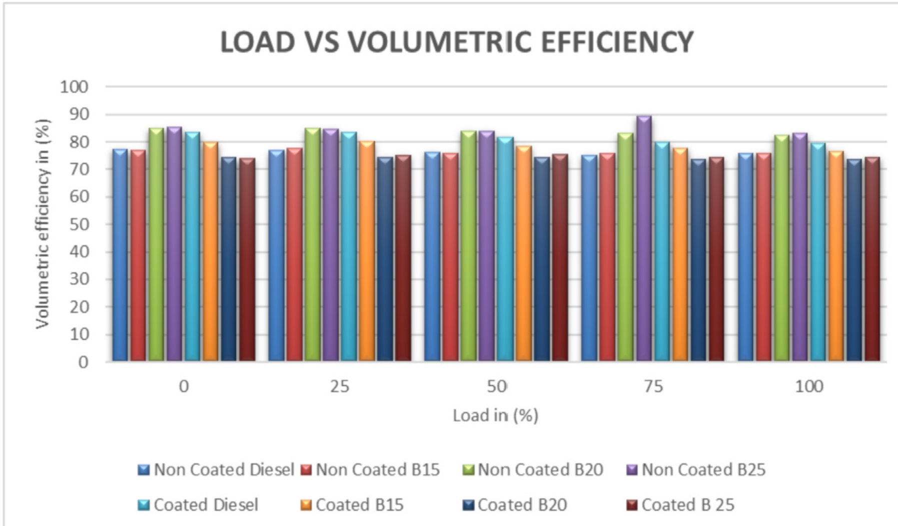

Fig. 9. Variation of volumetric efficiency with load for CMPO blends with and without TBC coating.

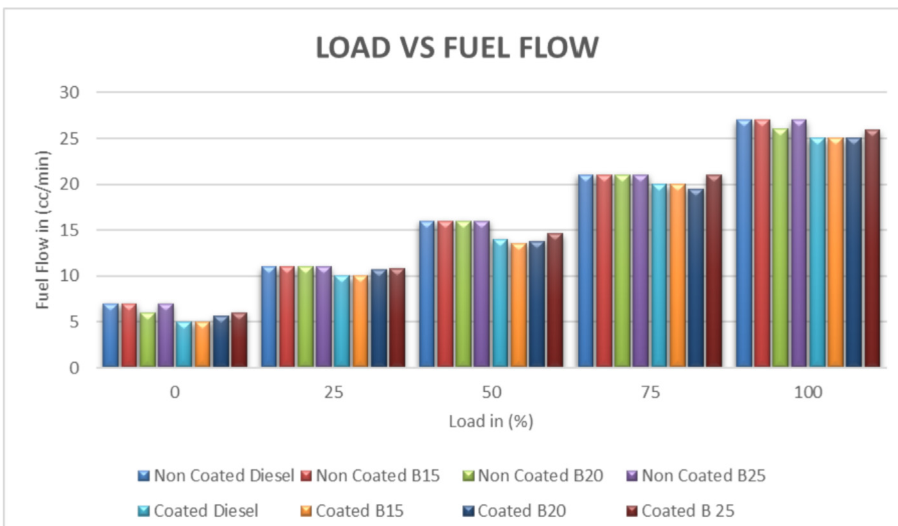

Fig. 10. Variation of fuel flow with load for CMPO blends with and without TBC coating.

At different load conditions, the unburned hydrocarbon emission was lower for the diesel fuel with respect to the blends of CMPO as shown in Fig. 15. This is because of the higher calorific value of diesel and due to which less amount of fuel was injected when compared to biofuel. Because of oxygen enrich environment, combustion is complete. Hence lower unburned hydrocarbon emission was observed with diesel fuel.

4.2.4. Oxygen (O_2)

The emission test was carried out for different proportions of biofuel blended with the pure diesel fuel with and without TBC coating. The emissions characteristics of oxygen analysed with and without nano additives are shown in Fig. 16.

This is the unburnt oxygen content that is released with emission. From the above figure we find that as load increases the oxygen output content decreases as combustion takes place in the faster rate. Moreover, as the temperature increases the free oxygen combines with the free nitrogen to form oxides of nitrogen.

4.2.5. Oxides of nitrogen (NO_x)

The emission test was carried out for different proportions of biofuel blended with the pure diesel fuel with and without TBC coating. The emissions characteristics of NO_X analysed with and without Nano additives are shown in Fig. 17.

The study of nitrogen oxide emission from diesel, CMPO blends are slightly lower than the pure diesel fuel performance at maximum loads. Because of more air action, much elevated than stoichiometric values, diesel engines produce more NOx at part load conditions and at higher loads. Diesel has higher calorific value than that of CMPO, so a lesser amount of diesel was injected into the combustion chamber.

4.2.6. Smoke opacity

The Smoke opacity for different blends of fuel and that of conventional diesel at different load is reported in figure 6.35. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of B15, B20, B25 with and without TBC coating. It was observed that smoke opacity increases for all blends as the load increased evident from Fig. 18. Diesel fuel show the

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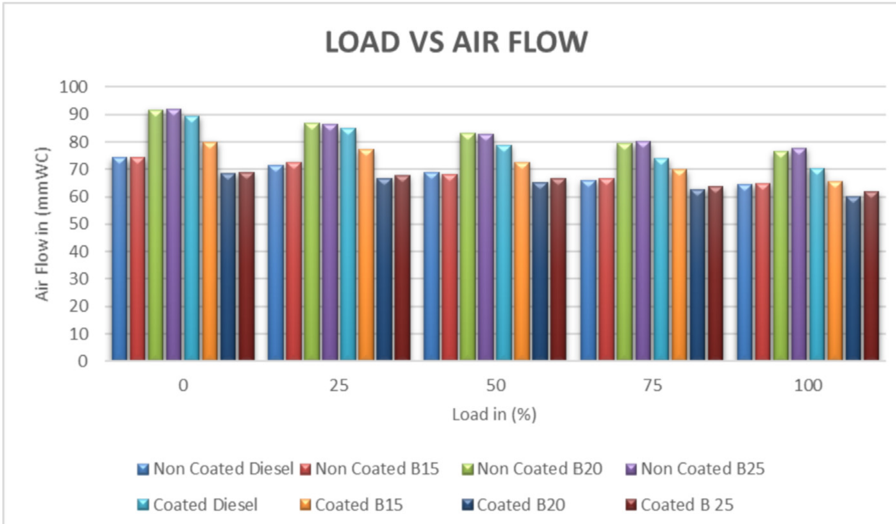

Fig.11. Variation of air flow with load for CMPO blends with and without TBC coating.

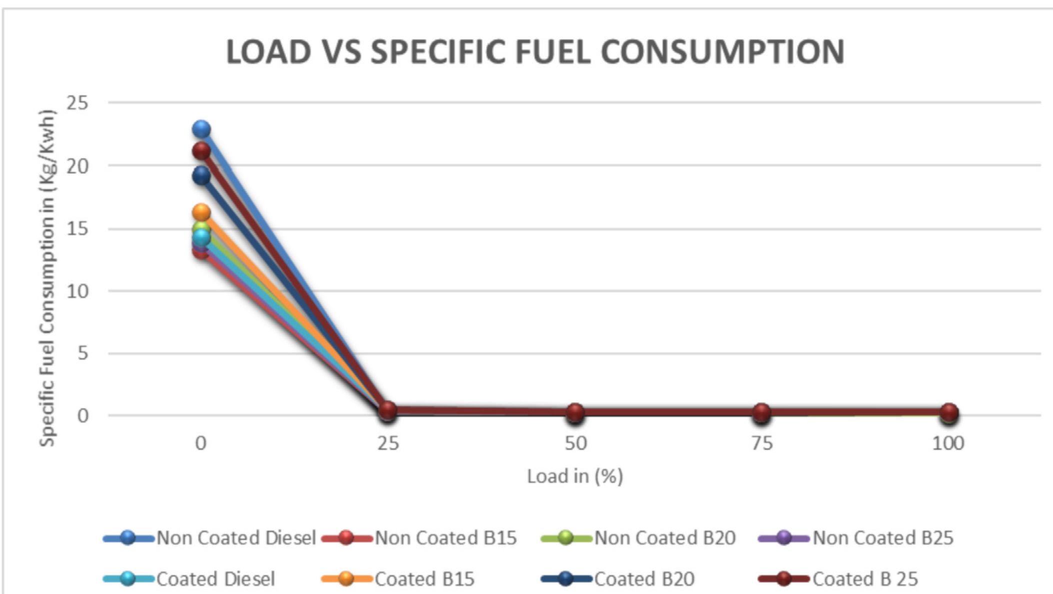

Fig. 12. Variation of SFC with load for CMPO blends with and without TBC coating.

higher magnitude of smoke opacity over the entire load range. But the smoke opacity in case of B15 was found to reduce due to micro-explosion of emulsion fuel improving the evaporation of fuel which results in an improvement in mixing with air.

4.2.7. Exhaust gas temperature (EGT)

The exhaust gas temperature of an engine is an indication of the conversion of heat into work**.** Fig. 19 shows the variation of the exhaust gas temperature with load for the fuel blends. Exhaust gas temperature for Diesel with TBC coating is the highest. For the diesel fuel, the exhaust gas temperature is the lowest among all the tested fuels. The exhaust gas temperature rises from 95 °C at no load to 267 °C at full load for Diesel, while for B20 the exhaust gas temperature rises from 110 °C at no load to 249 °C at full load.

In the case of CMPO-diesel fuel blends, the heat release may occur in the later part of the power stroke. So, this may result in lower time for heat dissipation and higher exhaust gas temperatures.

4.3. Economic analysis

4.3.1. Fuel consumption

Fuel consumption without coating for B20 blend = 17 cc/min.
Fuel consumption with TBC coating for B20 blend = 15.2 cc/min.
Percentage reduction in the fuel = 100 – [(15.2/17) × 100]
= 100 – 89.41
= **10.59%**

The overall consumption of the fuel is reduced by 10.59% when TBC is employed. This proves that a vehicle whose liner is coated with TBC can ride 10.5% additional distance with same amount of fuel that is used without TBC coating.

Suppose for a year if a user with one vehicle consumes 365 L of fuel (Assuming one liter consumed per day)

Total fuel saved per year = 0.1059 × 365
= 38.65 L
Total fuel consumed with TBC coating per year = **326.35 L**

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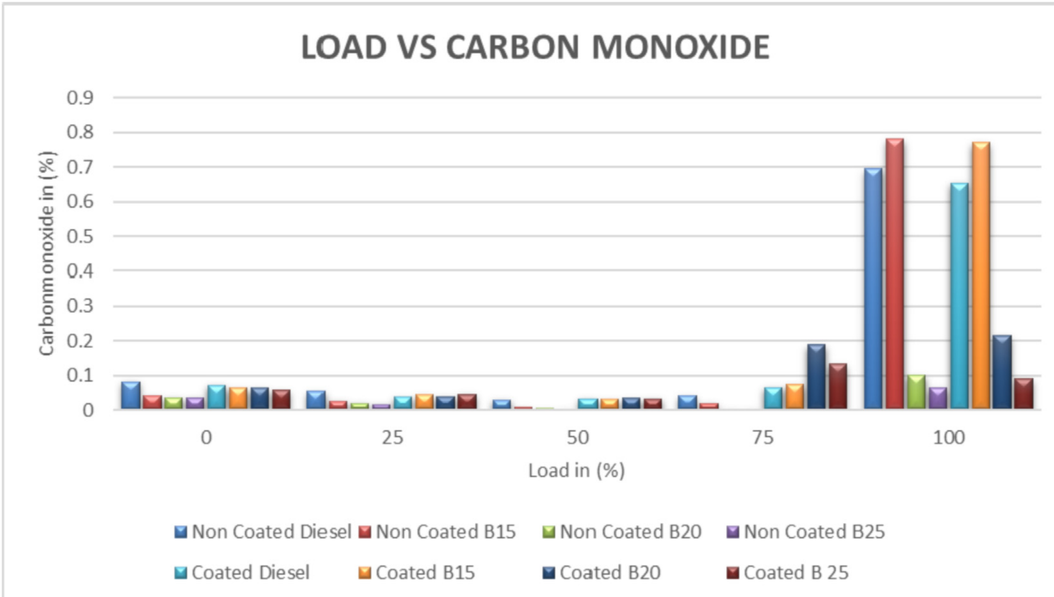

Fig. 13. Variation of CO emission with load for CMPO blends with and without TBC coating.

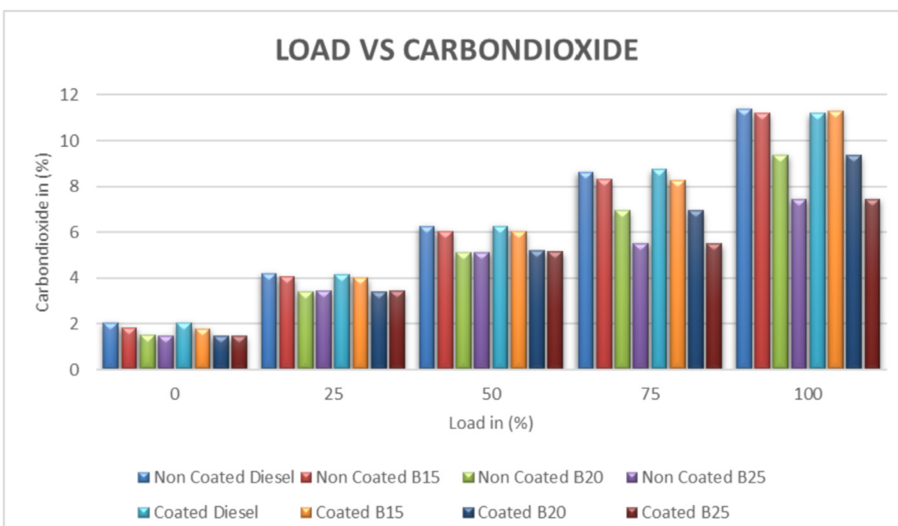

Fig. 14. Variation of CO_2 emission with load for CMPO blends with and without TBC coating.

4.3.2. Cost analysis

Cost of one liter of citrus medica = □ 700 = $ 9.25[1] (approx.)

Cost of one liter of Diesel is = □ 76.77 = $ 1.01[2]

If it is blended in 20% ratio then,

Total Cost spent for fuel without TBC coating = 365 × [(0.20 × 700) + (0.80 × 76.77)]

= 365 [201.42]

= □ 73,516.84

= $ 971.28 (approx.)

Total Cost spent for fuel with TBC coating = 365 × [(0.20 × 700) + (0.80 × 76.77)]

= 326.35 [201.42]

= □ 65,733.42

= $ 868.44 (approx.)

Cost Saved Per year = □ 73,516.84 – □ 65,733.42

= □ 7,783.42

= $ 102.83 (approx.)

Cost invested for TBC coating = □ **12,500**

= $ 165.15

Considering life of a Vehicle to be 5 years

Total Cost spent for fuel without TBC coating = 365 × 5 × [(0.20 × 700) + (0.80 × 76.77)]

= 1825 [201.42]

= □ 3,67,591.50

= $ 4856.48 (approx.)

Total Cost spent for fuel with TBC coating = 326.35 × 5 × [(0.20 × 700) + (0.80 × 76.77)]

= 1631.75 [201.42]

= □ 3,28,667.09

= $ 4342.22 (approx.)

Total Cost inclusive of TBC coating = □ 3,28,667.09 + □ 12,500

[1] *All conversions from Indian Rupee (INR) to United States Dollar (USD) are. approximate (taking □1 = 0.031$) and may vary everyday accordingly.*

[2] *Price of diesel in Chennai, India on the day when the test was carried out it may vary.*

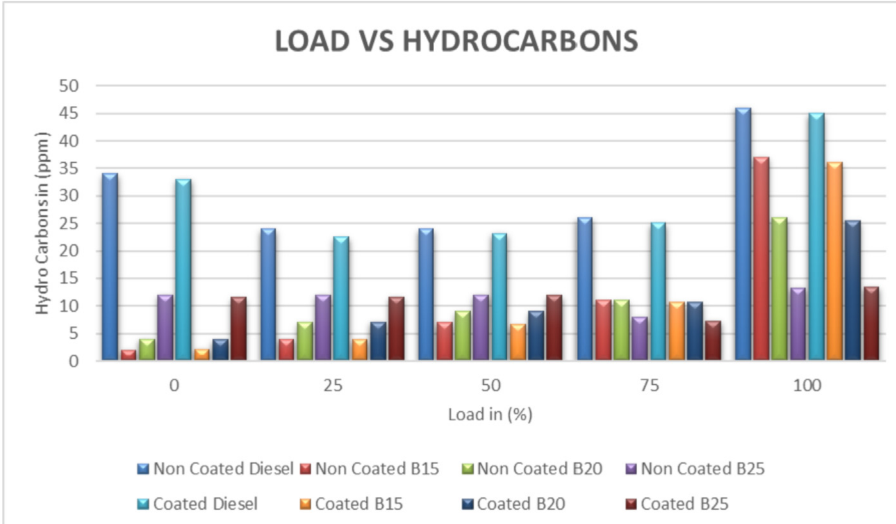

Fig. 15. Variation of HC emission with load for CMPO blends with and without TBC coating.

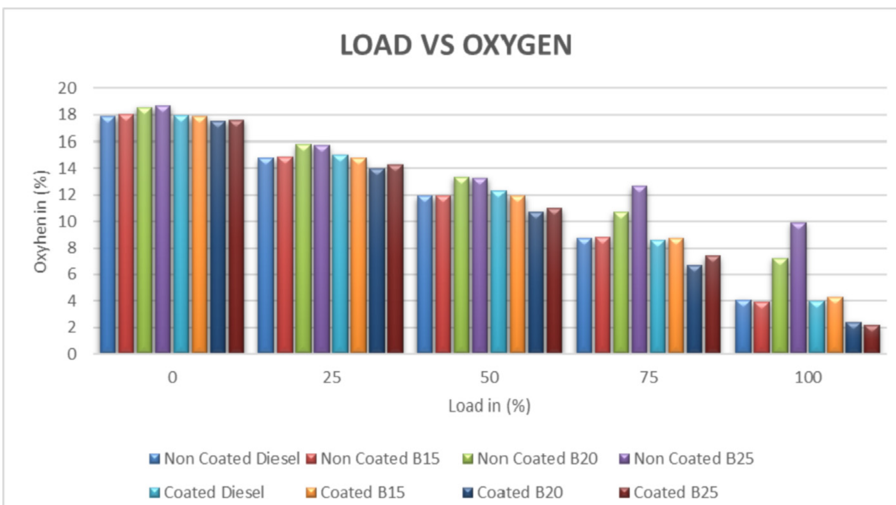

Fig. 16. Variation of O_2 emission with load for CMPO blends with and without TBC coating.

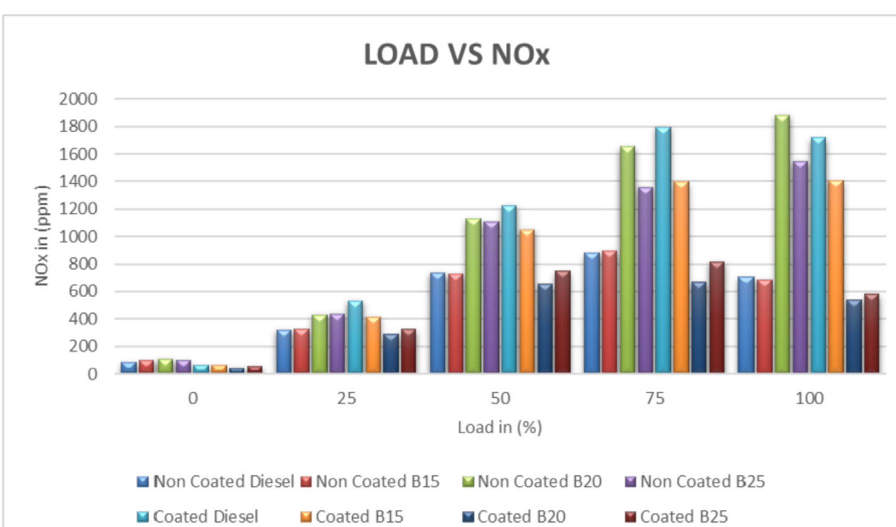

Fig. 17. Variation of NO_X emission with load for CMPO blends with and without TBC coating.

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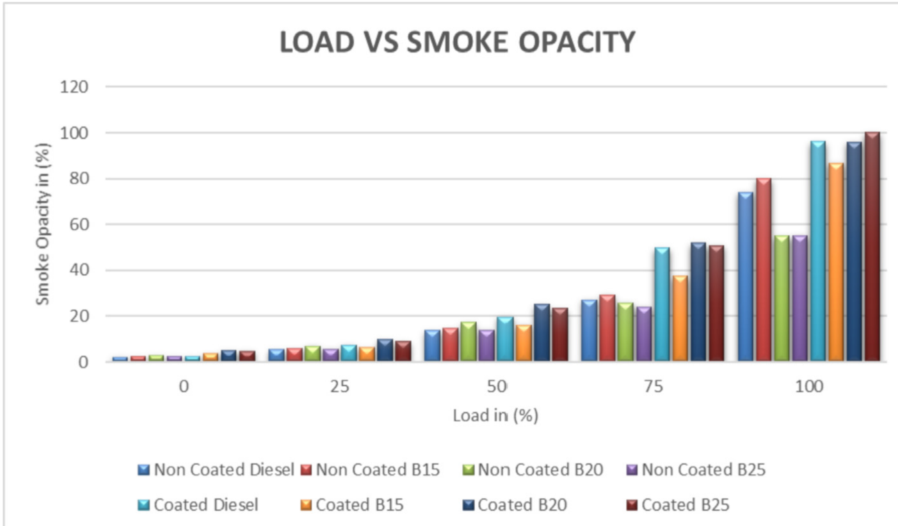

Fig. 18. Variation of smoke opacity with load for CMPO blends with and without TBC coating.

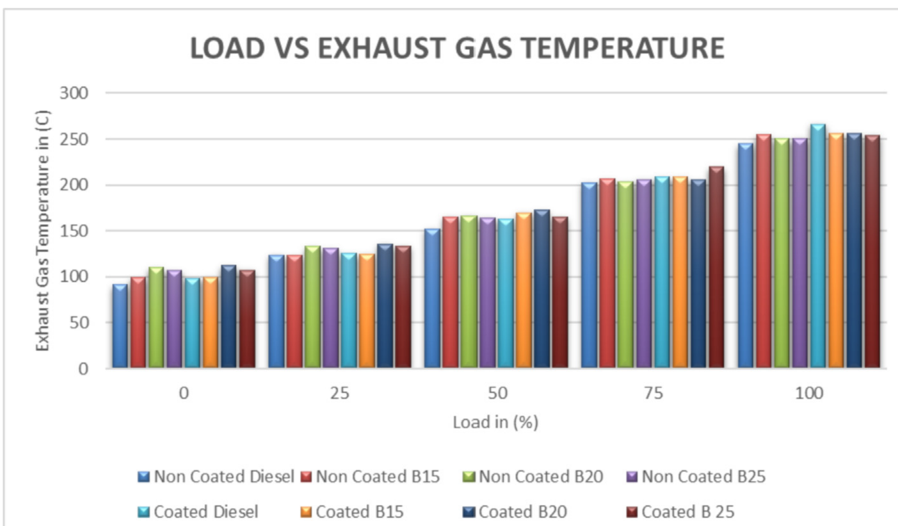

Fig. 19. Variation of EGT with load for CMPO blends with and without TBC coating.

= □ 3,41,167.09
= $ 4507.37 (approx.)
Total Cost Saved on a vehicle = □3,67,591.50 – □3,41,167.09
= □ 26,424.42
= $ 349.11 (approx.)

Percentage reduction in the cost for running a vehicle throughout its lifetime
= [100 - (341167.09/367591.50)100]
= 100 – 92.811
= 7.189%

5. Conclusion

CMPO with cerium oxide seems to have a better potential to use as alternative fuel in diesel engines. Blending CMPO with diesel decreases the viscosity of raw bio oil considerably. Using the above composition with TBC coating also increases the performance and emission characteristics. Adding to that, it is economical efficient, and emission was controlled remarkably. The following results are made from the experimental study-

- The brake thermal efficiency of the engine with TBC coating and B20 blend of CMPO with cerium oxide Nano particle was marginally better than another blend and with mineral diesel.
- The friction power increases with the TBC coating. This is due to the frictional loss since the surface finish is little rough. This can be improved by the use of appropriately sized particle for coating.
- SFC is reduced by 10.59% with TBC coating and this constitutes increase in the efficiency of the engine
- With the TBC coating, the exhaust gas temperature is found to increase 8^0C-15^0C.
- The mechanical efficiency achieved with B20 + 1 CeO_2 is higher than diesel at lower loading conditions. At higher loads, the mechanical efficiency of certain blends is almost equal to that of diesel.
- The emission such as CO, CO_2, NO_X, are reduced for biodiesel when compared to mineral diesel. This is due to the addition of cerium oxide Nano particle as additive which acts as oxidizing agent.

- The smoke opacity increases as the load increases. It is difficult to control this, but necessary research can be carried out reduce this considerably,
- B20 + CeO_2 along with TBC coating can be accepted as a suitable fuel for use in standard diesel engines and further studies can be done with certain additives to improve the emission characteristics.
- Implementing TBC coating can cut down the cost up to $ 349.11 which is almost 7.189% reduction in cost for a vehicle, that is invested for its fuel during its lifetime.
- The morphology of coating remained unchanged after 20 h of continuous operation other than few traces of carbon deposits on the surface.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] F. Ma, M.A. Hanna, Biodiesel production: a review, Bioresour. Technol. 70 (1) (1999) 1–15.
[2] H.M. Mahmudul, F.Y. Hagos, R. Mamat, A.A. Adam, W.F.W. Ishak, R. Alenezi, Production, characterization and performance of biodiesel as an alternative fuel in diesel engines – A review, Renew. Sustain. Energy Rev. 72 (2017) 497–509.
[3] M.M. Hasan, M.M. Rahman, Performance and emission characteristics of biodiesel–diesel blend and environmental and economic impacts of biodiesel production: A review, Renew. Sustain. Energy Rev. 74 (2017) 938–948.
[4] C.W. Mohd Noor, M.M. Noor, R. Mamat, Biodiesel as alternative fuel for marine diesel engine applications: A review, Renew. Sustain. Energy Rev. 94 (2018) 127–142.
[5] R.K. Saluja, V. Kumar, R. Sham, Stability of biodiesel – A review, Renew. Sustain. Energy Rev. 62 (2016) 866–881.
[6] E. Jiaqiang, M. Pham, D. Zhao, Y. Deng, D. Le, W. Zuo, Z. Zhang, Effect of different technologies on combustion and emissions of the diesel engine fueled with biodiesel: A review, Renew. Sustain. Energy Rev. 80 (2017) 620–647.
[7] AR.M. Kumar, M. Kannan, G. Nataraj, A study on performance, emission and combustion characteristics of diesel engine powered by nano-emulsion of waste orange peel oil biodiesel, Renew. Energy 146 (2020) 1781–1795.
[8] K. Purushothaman, G. Nagarajan, Performance, emission and combustion characteristics of a compression ignition engine operating on neat orange oil, Renew. Energy 34 (1) (2009) 242–245.
[9] V.S. Shaisundaram, M. Chandrasekaran, M. Shanmugam, S. Padmanabhan, R. Muraliraja, L. Karikalan, (2019). Investigation of Momordica charantia seed biodiesel with cerium oxide nanoparticle on CI engine. Int. J. Ambient Energy, 1-5.
[10] A.K. Hossain, P.A. Davies, Performance, emission and combustion characteristics of an indirect injection (IDI) multi-cylinder compression ignition (CI) engine operating on neat jatropha and karanj oils preheated by jacket water, Biomass Bioenergy 46 (2012) 332–342.
[11] A. Bragadeshwaran, N. Kasianantham, S. Balusamy, SenthilKumar Muniappan, D.M.S. Reddy, R.V. Subhash, N.A. Pravin, R. Subbarao, Mitigation of NOx and smoke emissions in a diesel engine using novel emulsified lemon peel oil biofuel, Environ. Sci. Pollut. Res. 25 (25) (2018) 25098–25114.
[12] L.F. Nascimento, J.F. Lima, P.C. de Sousa Filho, O.A. Serra, Control of diesel particulate emission based on Ag/CeOx/FeOy catalysts supported on cordierite, Chem. Eng. J. 290 (2016) 454–464.
[13] P.R. Shah, A. Ganesh, A comparative study on influence of fuel additives with edible and non-edible vegetable oil based on fuel characterization and engine characteristics of diesel engine, Appl. Therm. Eng. 102 (2016) 800–812.
[14] S. Abdalla, R. AL-Wafi, A. Pizzi, Stability and combustion of metal nanoparticles and their additive impact with diesel and biodiesel on engine efficiency: A comprehensive study, J. Renew. Sustain. Energy 9 (2) (2017) 022701, https://doi.org/10.1063/1.4979962.
[15] S. Tajudeen, R. Velraj, Nanoadditives: enhancement of combustion and performance characteristics of a CI diesel engine, Int. J. Appl. Environ. Sci. 9 (4) (2014) 1727–1741.
[16] S. Shahnazar, S. Bagheri, S.B. Abd Hamid, Enhancing lubricant properties by nanoparticle additives, Int. J. Hydrogen Energy 41 (4) (2016) 3153–3170.
[17] S. Kumar, P. Dinesha, I. Bran, Experimental investigation of the effects of nanoparticles as an additive in diesel and biodiesel fuelled engines: a review, Biofuels 10 (5) (2019) 615–622.
[18] H.K. Rashedul, H.H. Masjuki, M.A. Kalam, A.M. Ashraful, S.M. Ashrafur Rahman, S.A. Shahir, The effect of additives on properties, performance and emission of biodiesel fuelled compression ignition engine, Energy Convers. Manage. 88 (2014) 348–364.
[19] A. Prabu, R.B. Anand, Emission control strategy by adding alumina and cerium oxide nano particle in biodiesel, J. Energy Inst. 89 (3) (2016) 366–372.
[20] M.V. Kumar, A.V. Babu, P.R. Kumar, Influence of metal-based cerium oxide nanoparticle additive on performance, combustion, and emissions with biodiesel in diesel engine, Environ. Sci. Pollut. Res. 26 (8) (2019) 7651–7664.
[21] V.S. Shaisundaram, L. Karikalan, M. Chandrasekaran, (2019). Experimental investigation on the effect of cerium oxide nanoparticle fuel additives on pumpkin seed oil in CI engine. Int. J. Vehicle Struct. Syst. (IJVSS), 11(3).
[22] S. Padmanabhan, S. Ganesan, A. Masen Venkata Anvesh, B. Pradeep, Influence of cerium oxide additive and aloe vera biodiesel on a CI engine, Int. J. Ambient Energy 39 (5) (2018) 516–520.
[23] S. Kumar, P. Dinesha, C.M. Ajay, P. Kabbur, Combined effect of oxygenated liquid and metal oxide nanoparticle fuel additives on the combustion characteristics of a biodiesel engine operated with higher blend percentages, Energy 197 (2020) 117194, https://doi.org/10.1016/j.energy.2020.117194.
[24] V.S. Shaisundaram, M. Chandrasekaran, S. Mohan Raj, R. Muraliraja, Investigation on the effect of thermal barrier coating at different dosing levels of cerium oxide nanoparticle fuel on diesel in a CI engine, Int. J. Ambient Energy 41 (1) (2020) 98–104.
[25] R.A. Miller, Current status of thermal barrier coatings — An overview, Surf. Coat. Technol. 30 (1) (1987) 1–11.
[26] A. Rohini, S. Prema, A review on thermal barrier coating for diesel engine and its characteristics studies, J. Phys. Conf. Ser. 1473 (2020) 012039, https://doi.org/10.1088/1742-6596/1473/1/012039.
[27] M. Andrie, S. Kokjohn, S. Paliwal, L.S. Kamo, A. Kamo, D. Procknow, (2019). Low heat capacitance thermal barrier coatings for internal combustion engines (No. 2019-01-0228). SAE Technical Paper.
[28] T. Hejwowski, A. Weroński, The effect of thermal barrier coatings on diesel engine performance, Vacuum 65 (3-4) (2002) 427–432.
[29] D. Assanis, K. Wiese, E. Schwarz, W. Bryzik, The effects of ceramic coatings on diesel engine performance and exhaust emissions, SAE Trans. (1991) 657–665.
[30] A. Thibblin, S. Kianzad, S. Jonsson, U. Olofsson, Running-in behaviour of thermal barrier coatings in the combustion chamber of a diesel engine, Proc. Inst. Mech. Eng. Part D: J. Automobile Eng. 234 (1) (2020) 172–182.
[31] B. Ashok, R. Thundil Karuppa Raj, K. Nanthagopal, R. Krishnan, R. Subbarao, Lemon peel oil – A novel renewable alternative energy source for diesel engine, Energy Convers. Manage. 139 (2017) 110–121.
[32] A. Thibblin, S. Jonsson, U. Olofsson, Influence of microstructure on thermal cycling lifetime and thermal insulation properties of yttria-stabilized zirconia thermal barrier coatings for diesel engine applications, Surf. Coat. Technol. 350 (2018) 1–11.
[33] W.U. de Goes, N. Markocsan, M. Gupta, R. Vaßen, T. Matsushita, K. Illkova, Thermal barrier coatings with novel architectures for diesel engine applications, Surf. Coat. Technol. 125950 (2020).
[34] R. Muraliraja, J. Sudagar, R. Elansezhian, A.V. Raviprakash, R. Dhinakaran, V.S. Shaisundaram, M. Chandrasekaran, Estimation of zwitterionic surfactant response in electroless composite coating and properties of Ni–P–CuO (Nano) coating, Arab. J. Sci. Eng. 44 (2) (2019) 821–828.
[35] V.S. Shaisundaram, M. Chandrasekaran, S. Mohan Raj, R. Muraliraja, T. Vinodkumar, Control of carbon dioxide emission in automobile vehicles using CO 2 scrubber, Int. J. Ambient Energy 40 (7) (2019) 699–703.
[36] R. Akash, R. Muraliraja, R. Suthan, V.S. Shaisundaram, Synthesis and testing of aluminium composite using industrial waste as reinforcement, Mater. Today Proc. (2020).
[37] E. Devandiran, V.S. Shaisundaram, P.S. Ganesh, S. Vivek, Influence of feed water heaters on the performance of coal fired power plants, Int. J. Latest Technol. Eng. Manage. Appl. Sci 5 (2016) 115–119.
[38] R. Muraliraja, D. Sendilkumar, D.R. Elansezhian, Prediction and supplementation of reducing agent to improve the coating efficiency and wear behavior of electroless Ni-P plating, Int. J. Electrochem. Sci. 10 (2015) 5536–5547.
[39] R. Muraliraja, R. Elansezhian, Influence of nickel recovery efficiency on crystallinity and microhardness of electroless Ni–P coatings and optimisation using Taguchi technique, Trans. IMF 93 (3) (2015) 126–132.
[40] S. Baskar, V. Vijayan, S. Saravanan, A.V. Balan, A. Godwin Antony, Effect of Al2O3, aluminium alloy and fly ash for making engine component, Int. J. Mech. Eng. Technol. (IJMET) 9 (12) (2018) 91–96.
[41] A. Godwin Antony, V. Vijayan, S. Saravanan, S. Baskar, M. Loganathan, Analysis of wear behaviour of aluminium composite with silicon carbide and titanium reinforcement, Int. J. Mech. Eng. Technol. 9 (2018) 681–691.
[42] S. Saravanan, A. Godwin Antony, V. Vijayan, M. Loganathan, S. Baskar, Synthesis of SiO2 nano particles by using sol-gel route, Int. J. Mech. Eng. Technol. 1 (2019) 785–790.
[43] S. Dinesh, A. Godwin Antony, K. Rajaguru, V. Vijayan, Experimental investigation and optimization of material removal rate and surface roughness in centerless grinding of magnesium alloy using grey relational analysis, Mech. Mech. Eng. 21 (2017) 17–28.
[44] S. Dinesh, K. Rajaguru, V. Vijayan, A. Godwin Antony, Investigation and prediction of material removal rate and surface roughness in CNC turning of EN24 alloy steel, Mech. Mech. Eng., 20(2016), pp. 451-466.
[45] B. Suresh Kumar, V. Vijayan, N. Baskar, Burr dimension analysis on various materials for convenantionally and CNC drilled holes, Mech. Mech. Eng. 20 (2016) 347–354.

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[46] Jishuchandran, K. Manikandan, R. Ganesh, S. Baskar, ''Effect of nano-material on the performance patterns of waste cooking biodiesel fuelled diesel engine'' Int. J. Ambient Energy, pages 1-16.
[47] D. Arunkumar, M. Ramu, R. Murugan, S. Kannan, S. Arun, Sanjeevi Baskar, ''Investigation of heat transfer of wall with and without using phase change material'' Mater. Today Proc., Pages 1-5.
[48] A. Prabhakaran, K. Sridhivya Krishnan, R. Dhinakaran,S. Baskar, V.S. Shaisundaram, ''Analysis of the efficiency of an automotive alternator by replacing mild steel into aluminum as a material for Rotor'', Mater. Today Proc.
[49] S. Ramasubramanian, M. Chandrasekaran, S. Baskar, A. Dowhithamaran, Ravin, Design and development of pneumatic compressed air vehicle, Mater. Today Proc. (2020), https://doi.org/10.1016/j.matpr.2020.05.637.
[50] S. Ramasubramanian, M. Chandrasekaran, S. Baskar, A. Dowhithamaran, Ravin, ''Design and development of material behavior of line follower automated vehicle'', Mater. Today Proc., Available online 20 June 2020.
[51] S. Baskar, V. Vijayan, I.J. Isaac Premkumar, D. Arunkumar, D. Thamaran, Design and material characteristics of hybrid electric vehicle, Mater. Today Proc. (2020), https://doi.org/10.1016/j.matpr.2020.05.352.
[52] D. Arunkumar, M. Ramu, R. Murugan, S. Kannan, S. Arun, S. Baskar, Investigation of heat transfer of wall with and without using phase change material, Mater. Today Proc. (2020), https://doi.org/10.1016/j.matpr.2020.01.220.