Performance, Exhaust Emission & Combustion Characteristics of Titanium Oxide Coated Variable Compression Ratio Diesel Engine Fuelled with Mixed Milk Scum and Safflower Oil as Biodiesel

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Abstract:
The work carried out deals with effect of variation in compression ratio (VCR) on engine performance and emission by applying thermal barrier coating on to engine parts for improving engine performance when biodiesel (mixed milk scum and safflower) is used as alternative fuel and the layer of thermal coating was made of Alumina-Titaniuim oxide (Al2O3/TiO2) plasma coated on to the base of NiCrAl. The work also deal with experimental analysis of performance and exhaust emission characteristics of diesel-biodiesel blends use in single cylinder 4-stroke with varying compression ratio (VCR) i.e. 14:1, 16:1& 18:1 using biodiesel blends i.e. B20, B40,B60,B80 and B100 with load variation from a load to full load and compare with base. The result showed a reduction in specific fuel consumption .CO and HC emissions are slightly more than the conventional coated diesel engine at low and medium loads but lesser at higher load where NOx is reduced.

1. INTRODUCTION
Energy conservation and efficiency have always been the quest of engineers concerned with internal combustion engines. The diesel engine generally offers better fuel economy than its counterpart petrol engine. Even the diesel engine rejects about two thirds of the heat energy of the fuel, one-third to the coolant, and one third to the exhaust, leaving only about one-third as useful power output. Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved, at least up to the limit
set by the second law of thermodynamics. Low Heat Rejection engines aim to do this by reducing the heat lost to the coolant. Thermal Barrier Coatings (TBCs) in diesel engines lead to advantages including higher power density, fuel efficiency, and multi fuel capacity due to higher combustion chamber temperature (900°C vs. 650°C)\cite{2,3}. Using TBC can increase engine power by 8%, decrease the specific fuel consumption by 15-20% and increase the exhaust gas temperature 200K\cite{1}. In internal combustion engines, the energy cycle occurs within the combustion chamber. The components of the combustion chamber are defined as the cylinder bore, piston, piston head, piston rings and valves. These components are subject to a number of mechanisms of wear, including acids that occur after combustion, high temperature, high pressure, sulphur, relative humidity in air and gas atmosphere, and particles vacuumed through inlet valves. The cylinder bore and piston rings are subjected to particularly high levels of friction, high thermal pressure, and corrosive media. Because of these conditions, wear seems on these surfaces relatively. Abrasion occurs on the sliding surfaces due to friction between compression segment and cylinder bore. High loads on the cylinder surface lead to wear lines and micro cracks. The deformation movement then continues until the particles break away from the surface \cite{4}. Many different technologies and coating processes, including plasma spraying, have been used in combustion engine applications, to improve the surface deflection, increase the surface quality and increase performance after burning. In plasma spray processes, the artificial plasma is formed by achieving high temperatures. Plasma is formed inside the plasma gun by generating a high voltage arc between the water-cooled copper anode and thorium cathode. During this event, the plasma gases such as Ar, H, N\textsubscript{2} and He are passed through the high voltage arc. The neutral positions of the plasma gases in the electrical arc degenerate as a result of dissociation, ionization and recombination there occurs a high temperature of up to 20,000 K. The gases having gone so high temperatures expand as radially and axially. The supersonic expansion is reached by the gases passed through the narrow way of nozzle. Coating powders are fed by the Ar carrier gas which has been passed from the plasma beam. The powders melted in ionize gas sprayed on the substrate which is prepared before. The powders hit to the surface which are melted or half melted flatten, or turn into the shape of lamellar and hardens because of the sudden cooling. (10-^\circ\textdegree C/s) \cite{5,6}. Figure 1 shows cross section of plasma spray gun and formation of plasma. Due to their physical and chemical properties, the use of ceramic-based composites in this plasma spray process produces a coating on the material surface that is highly wear resistant and acts as a thermal barrier. Engines that have a thermal barrier coating applied are called low heat rejection (LHR). The low heat rejection (LHR) engine concept is based on minimizing heat transfer to the coolant system and recovering the energy in the form of useful work. Insulating the combustion chamber parts reduces heat transfer between the gas within the cylinder and the cylinder line \cite{8-13}.

![Cross Section of Plasma Spray Gun](image)

2. LITERATURE REVIEW

Y. Miyairi \cite{1} has investigated the performance and exhaust emission characteristics of a thermally insulated single cylinder diesel engine. The cylinder head and piston crown are thermally insulated with sintered silicon nitride (SSN) whereas the upper part of the cylinder liner with Partially Stabilized Zirconia (PSZ). He has shown that volumetric efficiency of engine with insulated cylinder head and liner is higher in comparison with the engine which has an insulated piston cavity. It is also examined that the gas
temperature in the cylinder with insulated piston crown, cylinder head and cylinder liner is much higher than that of other types of engines such as baseline engine, engine insulated with piston crown, engine with insulated cylinder head and cylinder liner which is mainly due to formation of Nitrogen Oxide in large amount. Local insulation of combustion chamber walls with ceramics has resulted in improved engine performance with decreased volumetric efficiency. Insulation of the piston cavity, cylinder head and cylinder liner upper part together is found to reduce the emission of hydrocarbons under natural aspirated conditions at low speeds. On the other, a reduction in Brake Specific Fuel Consumption (BSFC) is reported under both naturally aspirated and turbo charged condition when the cylinder head and liner upper parts were thermally insulated with ceramics. Further insulation of the piston cavity has contributed the increased in BSFC partly due to the increase in the reciprocating mass.

K Osawa [2] has conducted tests on coatings made on small aluminum bore of an air cooled diesel engine. He has reported that coatings possessing high thermal insulation and low friction characteristics perform best albeit with a 10% reduction in fuel consumption.

Wong [3] has considered different combinations of coatings with different thermal characteristics and coating thicknesses to predict the pattern of fuel consumption in IC engines. The simulation model developed by him considers the influence of transient heat transfer into and out of the combustion chamber surface throughout the entire engine operating cycle. The simulation also included an advanced liner friction model which accounts for the effects of liner surface temperatures and lubricating oil viscosity. Results of the analysis showed that all thermal barrier coating materials provided a performance benefit that is strongly dependent on the coating thickness. Most coatings for the piston and head face surfaces provided a maximum benefit at a coating thickness of 0.1mm. The predicted maximum benefit in thermal performance is found to range from 1 to 2%. It is predicted that a coating thickness of 0.5 mm in the liner would provide an optimum oil viscosity and a reduced friction with a 5% increase in performance.

Dennis Assanis and Kevin Wiese [4] have carried out work on zirconia band TBC coated on to the piston of diesel engine with a coating thickness of thickness of 0.5 mm and 1mm. They have compared the performance and exhaust emission of coated piston engine with that of base line piston engine. They have found that 0.5mm thick ceramic coated piston engine has in comparison with that of the metal piston engine. On the other, the thermal efficiency of 1mm thick ceramic coated piston was only 4% higher than that of base line engine piston. Due to more complete combustion in the insulated configuration, exhaust CO levels are found to be 30 to 60% lower than that of base line engines. Similarly unburned hydrocarbon levels were 35 to 40% lower than that of baseline engine. The NOx concentration is also found to 10 to 30% lower than that of baseline engine due to the changes in the nature of combustion. The variation in thermal efficiency and BSFC as a function of engine speed is shown in Fig. 2.1.

![Fig. 2.1 Thermal Efficiency and BSFC as a Function of Speed for Baseline and Ceramic Coated Engines](image)

Hideo Kawamura [5] has worked on Si₃N₄ monolithic ceramic coatings which are applied to combustion chamber walls. A combustion chamber with thermos structure made of sintered Si₃N₄ was used for this purpose. He has reported that the pre-combustion chamber exhibits a good potential for LHR (Low Heat Rejection) engine due to capability of combustion chamber wall temperature resulting in improved fuel consumption and controlling of exhaust emission. The NOx emissions are also found to be low due the presence of rich mixture in the pre-chamber in spite of the prevalent high temperature. It is mainly due to the diffusion of air and fuel mixture near the cylinder wall which reduces the temperature of the combustion gas. The fuel consumption in case of new type of energy recovery system is found to be 180 g/kWh or less for 2 liters cylinder light duty diesel engine with the proposed new combustion chamber. The LHR engine
consisting of a thermos structure having good heat insulation layer is found to eliminate the need for cooling system, and found to improve the heat insulation ratio up to 75% or more.

Roy Kamo [6] had carried out work on TBC for improving the engine performance considering three engine configurations such as Metal baseline builds, coated cylinder liner builds and fully insulated builds wherein the cylinder liner, piston top and cylinder head faces were coated with thin layers of thermal barrier ceramic composite materials. He has used Zirconia slurry and chrome oxide for piston and head face coatings, Zirconia for cylinder liner post densified with chrome oxide using plasma spraying technique with the thickness of coatings as 0.127 mm and 0.508 mm for piston and liner respectively. He has reported that the coated liner build exhibits about 1% improvement in performance over that of the metal base line while the fully insulated configuration would produce about 2% loss in fuel consumption. Heat rejection results indicate that the coated liner did not produce any significant reductions while the fully insulated configuration produced a full load reduction of 10% at 1400 rpm and no reduction at all with the increase in engine speed.

T Hejwowski [7] has suggested that TBC with NiCrAl bond coat and Alumina – Titania or yttria partially stabilized ZrO2 can be used to constitute a durable and efficient thermal barrier coating on gasoline and diesel engine piston crowns. An optimum thickness for TBC is slightly below 0.5 mm according to him. Further, he has also found that, that the Specific Fuel Consumption (SFC) is lowered by 15 to 20% with the use of coated piston crown with 8% increase in power (Fig. 2.9). TBC with alumina–titania shows good resistance to conditions prevailing in a gasoline engine combustion chamber. The fuel consumption of a modified engine is found to reduce by 4.2% at a speed of 1100 rpm, 11.7% at 4000 rpm and 20.7% at 2500 rpm. Temperatures of cooling water and oil are slightly higher in a modified engine.

Hem Chandra Joshi et. al [8] explained about biodiesel, which is defined as a mono alkyl esters of long chain fatty acids derived from alcoholysis of triacylglycerides (TAG), is a biodegradable nontoxic fuel with cleaner emissions, better lubrication properties and may be blended in any proportion with petroleum diesel. Ethanol in the presence of potassium hydroxide (KOH) was used to transesterify cottonseed oil to provide fatty acid ethyl esters (FAEE), since the alcohol does not fully solubilize the pigments present in the oil. Cottonseed oil has a red–brown colour because of the presence of pigments, the most important being gossypol. Gossypol is known to have antioxidant properties that may potentially increase the shelf life of the oil and biodiesel.

Mustafa Canakci et. al [9] diesel-fuel blends with biodiesel have superior lubricity, which reduces wear and tear on the diesel engine and makes the engine components last longer. Biodiesel mixes well with diesel fuel and stays blended. The fuel properties of biodiesel such as cetane number, heat of combustion, specific gravity, and kinematic viscosity influence the combustion and so the engine performance and emission characteristics because it has different physical and chemical properties than petroleum-based diesel fuel.

J-T Song et. at [10] discussed the optimization of the biodiesel for diesel engines, the emissions, fuel economies, and power performances of diesel, soybean oil methyl ester, and its blends with diesel from 10 to 80 wt% were compared and analysed by bench tests of a supercharged direct injection (DI) diesel engine. The exhaust emissions (smoke density, NOx, CO, and HC), the brake specific fuel consumption rate, the specific energy consumption rate, and the brake power and torque were investigated under different engine loads and speeds.
Orchidea Rachmaniah et al. [11] investigated the use of alkalis in base catalyzed alcoholysis is NaOH, KOH, carbonates and corresponding sodium and potassium alcoxides and found that the Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is used in the commercial production of biodiesel. Even at ambient temperature, the alkali-catalyzed reaction proceeds rapidly usually reaching 95% conversion in 1~2 h. On the other hand, the acid-catalyzed reaction commonly requires temperatures above 100°C, and reaction times of 3-48 h have been reported, except when reactions were conducted under high temperature and pressure. However, for alkali-catalyzed Transesterification, the starting materials (oil or fats) must be dry and free of FFA. The presence of minor amount of FFA and moisture in the reaction mixture produces soap, which lowers the yield of esters and renders the separation of ester and glycerol as well as the water washing difficult. Moreover, FFA consumes the catalyst and reduced catalyst efficiency. It has been reported that acid-catalyzed Transesterification can be used when the starting materials are low-grade fats or have a high FFA content. Thus, acid-catalyzed transesterification is more suitable to produce biodiesel from crude rice bran oil.

Samaga B.S. [12] Investigated the use of refined sunflower oil and unrefined groundnut oil as fuels in an AVI single cylinder water-cooled DI diesel engine. He did the experiments by varying the oil inlet temperature (Preheating), injection timing and fuel injection pressure to optimize these parameters. In order to optimize the parameters he concentrated only at 80% of rated load. Selection of parameters was as follows.
- Fuel Injection Pressure: 160, 180 and 210 bar
- Fuel Injection Timing: 24º, 29º and 34º BTDC
- Oil Preheating Temperature: 34º C, 55º C and 65º C

He observed that performance of the engine with test fuels to be comparable with diesel fuel operation without any combustion knock and objectionable smoke at the following conditions: 160 bar, 65º C and 29º BTDC.

3. COATING MATERIAL AND THEIR PROPERTIES

(Al2O3/TiO2) composite coatings consist of a matrix of Al2O3 and a second Al2O3/TiO2 phase called reinforcement. The function of the matrix is to distribute the stresses homogeneously inside the composite material. The function of the second phase in the coating is mostly to provide mechanical reinforcement. It is well known that the adhesion strength of alumina–titania composite coatings increases with increased Titania content.

Thermal barrier coatings are duplex systems, consisting of a ceramic topcoat and a metallic intermediate bond coat. The topcoat consists of ceramic material whose function is to reduce the temperature of the underlying, less heat resistant metal part. The bond coat is designed to protect the metallic substrate from oxidation and corrosion and promote the ceramic topcoat adherence. A thermal barrier application is shown in figure 3.1.

![Fig.3.1 Thermal barrier coating consisting of metallic bond coat on the substrate and ceramic top coat on the bond coat](image)

4. PROPERTIES OF COATING MATERIAL

- **Low Thermal Conductivity**: The coated material should resist almost or complete heat transfer to the substrate.
- **High thermal stability**: The coated material should be able sustain very high temperature having very high melting point. There by base or substrate material is protected from high temperature corrosion.
High wear resistance: The coated material should have oxidation and corrosion resistance properties. This can be obtained by proper heat treatment of the coated material.

Hardness: The coated material should possess optimum range of both micro and macro hardness.

Good adhesive properties: The coated material should be well adhered to the substrate, so that bonding strength will be excellent.

4.1. ALTERNATIVE MATERIALS FOR THERMAL BARRIER COATING

The selection of thermal barrier coating materials is restricted by some basic requirements. They are high melting point, no phase transformation between room temperature and operation temperature, low thermal conductivity, chemical inertness, thermal expansion match with the metallic substrate, good adherence to the metallic substrate and low sintering rate of the porous microstructure. So far, only a few materials have been found to basically satisfy these requirements. There is a great thermal expansion coefficient match between YSZ, bond coat and substrate (10.7x10^{-6} k^{-1} vs. 17.5x10^{-6} k^{-1} for NiCoCrAlY and 16x10^{-6} K^{-1} for IN737) [18]. Good thermo-mechanical performance and fair oxidation resistance are other properties of YSZ as a TBC.

4.1.1. Zirconates:

Zirconates materials with a pyrochlore structure have a fair thermal expansion coefficient in the range of 9E-6 k^{-1} to 10E-6 k^{-1}. The main advantages of zirconates are their low sintering activity, low thermal conductivity, high thermal expansion coefficient and good thermal cycling resistance. The main problem is the high thermal expansion coefficient which results in residual stress in the coating, and this can cause coating delamination [32]. Some materials in this category; e.g. BaO·ZrO_2, SrO·ZrO_2, and La_2O_3·2ZrO_2, undergo phase transformation or become non-stoichiometric during heating.

4.1.2. Garnets:

Polycrystalline garnet ceramics are used in different applications due to their unique properties. Particularly YAG (Y_3Al_5O_12) is a good choice for many high-temperature applications, due to its excellent high temperature properties and phase stability up to its melting point (1970°C) [28]. Other advantages which make YAG a candidate as a TBC are their low thermal conductivity, high thermal expansion coefficient and its low oxygen diffusivity [27]. Although the thermal conductivity value is almost the same as zirconia, the thermal expansion coefficient is lower. 2.3. Yttria Stabilized Zirconia: 7-8% yttria stabilized zirconia has high thermal expansion coefficient, low thermal conductivity and high thermal shock resistance. Disadvantages of yttria stabilized zirconia are sintering above 1473 K, phase transformation at 1443 K, corrosion and oxygen transparent.

4.1.3. Al_2O_3.SiO_2.MgO system:

Most traditional, high temperature refractory ceramic materials are found in the Al_2O_3.SiO_2.MgO phase diagram. (Fig). Among these oxides, some have been considered as alternatives to YSZ in TBCs.

4.1.4. Cordierite:

Cordierite (2MgO.2Al_2O_3.5SiO_2) has a very low TEC (1.67x10^{-6} k^{-1} [15]) but, for certain applications, could be an alternative for TBCs. However, after plasma spraying, the cordierite deposition is amorphous. While heating, two phase transformation occur, at 830°C and 1000°C, which produce a...
volume change and cause cracking [29]. To deposit crystalline cordierite, the addition of 6 wt% TiO2 has been reported to be effective [30].

4.1.5. Forsterite:
The high thermal expansion coefficient of forsterite permits a good match with the substrate. At thicknesses of some hundred microns, it shows a very good thermal shock resistance [32].

4.1.6. Spinel:
Although spinel has very good high temperature and chemical properties, its thermal expansion coefficient prevents its usage as a reliable choice for thermal barrier coatings [32].

4.1.7. Mullite:
Mullite is applied on SiC as an oxidation resistant layer to form an environmental barrier coating (EBC). Its low oxygen diffusivity, low creep rate at high temperatures, high thermo-mechanical fatigue resistance and close TEC match with SiC (4-5x10-6 K-1 vs. 5-6x10-6 K-1 [35]) makes it the ideal choice for this application. In thin coatings (up to some hundred microns) on top of a metallic substrate, the durability of mullite has been reported to be better than that of zirconia.

4.1.8. Alumina:
It has very high hardness and chemical inertness. Alumina has relatively high thermal conductivity and low thermal expansion coefficient compared with yttria stabilized zirconia. Even though alumina alone is not a good thermal barrier coating candidate, its addition to yttria stabilized zirconia can increase the hardness of the coating and improve the oxidation resistance of the substrate. The disadvantages of alumina are phase transformation at 1273K, high thermal conductivity and very low thermal expansion coefficient.

4.2. Advantages of Thermal Barrier Coatings for Diesel Engines

Some advantages of thermal barrier coatings on diesel engines are below.

- Low cetane fuels can be burnt.
- Improvements occurs at emissions except NOx.
- Increased effective efficiency and thermal efficiency.
- Using lower-quality fuels within a wider distillation range.
- The ignition delay of the fuel is considerably reduced.
- The faster vaporization and the better mixing of the fuel.
- Reduced specific fuel consumption.
- Multi-Fuel capability.
- Improved reliability.
- Increased life time of engine parts and combustion temperature.
- Reduces the transient stress and thermal stress in the parts.
- High surface emissivity.

5. INTRODUCTION TO OILS

5.1. Safflower Oil
Safflower, Carthamus tinctorius, L., is an oilseed crop that belongs to the family Asteraceae, a diverse group of flowering plants that grow in many parts of the world. Safflower originated in the eastern Mediterranean, and spread to Egypt, Ethiopia, southern Europe, south Asia and the Far East early in its evolution. India is the primary centers of origin of safflower. Currently, it is grown as an oilseed crop in over 60 countries worldwide and India as the largest producer of safflower. Safflower is mainly cultivated for its seed, which is used primarily for edible oil. In the past, the crop is grown for its flowers used for coloring and flavoring foods, making dyes and medicine. However, due to an increasing demand for vegetable oil in human diet, its production as an oil seed crop has received a great deal of attention. It is well known for its quality edible oil in view of higher proportion of linoleic and oleic acid content compared to other vegetable oils. The oil is semi-dry in nature
and is used in paints, textile and leather industries. In Ethiopia, boiled and finely pounded safflower kernels are mixed with water and the supernatants is used to prepare the so called ‘fitfit’, which is used as fasting-food. Also the supernatant is used as a drink mixed with sugar during fasting seasons. Roasted seeds, generally mixed with roasted chickpeas, barley or wheat, are eaten as a snack food in Ethiopia and Safflower has some agronomic advantages such as drought resistance and adaptation to arid and semiarid climatic conditions).

Ethiopian safflower is very much neglected and it is cultivated only as a minor oil crop with very limited information available on its genetic resources. In Ethiopia, safflower cultivation is mostly done by small farmers in well fertile and drained field, usually around homesteads. Nevertheless, seed can be harvested from the plant for oil extraction, roasted seed and other traditional uses. Despite all these local uses and industrial applications of safflower plants, it remains as low acreage crop compared to other oilseed crops. Moreover, limited attention has been given to conserve, add value and improve the productivity of safflower in Ethiopia.

5.2. MILK SCUM OIL

This scum is collected from the scum removing area of the effluent treatment plant in a fresh condition and processed immediately to avoid increase in free fatty acid further by biological action. Scum is turbid white in color and semi solid in texture. Annual production of milk in India is 150 million tons per year. Thousands of large dairies are engaged in handling this milk across the country. Raw chilled milk of cows and buffalos are standardized into market milk and milk products such as Butter, Ghee, Cream, Peda, Panner, Cheese, Yoghurt, Ice cream and other products. Large dairies are handling number of equipments for processing, handling, storage, packing and transportation of milk and milk products. Enormous quantities of water are used for housekeeping, sterilizing and washing equipments, during this process residual butter and related fat which are washed and get collected in effluent treatment plant as a scum. Scum is a less dense floating solid mass usually formed by a mixture fat, lipids, proteins, packing materials etc. A large dairy, which processes 5 lakh liters of milk per day, will produce approximately 200–350 kgs of effluent scum per day, which makes it difficult to dispose. Most of the dairies dispose this scum in solid waste disposal site or by incinerating. By doing so, it is economically wasteful and generates pollutants. Further, scum causes direct as well as indirect operational difficulties for effluent treatment.

SAFFLOWER

Fig.5.1 Flower stage  Fig.5.2 Maturity stage  Fig.5.3 Safflower seeds  Fig.5.4 Safflower Oil
DAIRY MILK SCUM

Fig. 5.5 Dairy Waste Milk Scum

Fig. 5.6 Dairy Waste Milk Scum Oil

6. PRODUCTION OF BIODIESEL

Fig. 6.1 Reactor with condenser

SAFFLOWER

DAIRY MILK SCUM
7. PROPERTIES OF BIODIESEL

Fig.7.1  Flash Point

Fig.7.2  Fire Point
8. WORKING METHODOLOGY

In this work of a diesel engine, the piston outside surface, exhaust and inlet valves were coated with Al₂O₃ ceramic material using an atmospheric plasma spray process. The plasma spray parameters used in the study are given in Table 1. The effects of this applied thermal barrier on the coated samples were examined.

The tests were performed on the single cylinder, four-stroke, direct applied to combustion chamber components. Technical specifications of the engine are given in Table 2. Switch on the mains of the control panel and set the supply voltage from servo stabilizer to 220 volts. The main gate valve is opened and the pump is switched ON and the water flow rate to the engine cylinder jacket (300 liters/hour), calorimeter (50 liters/hour), dynamometer and sensors are set. Engine is started by hand cranking and allowed to run for a 20 minutes to reach steady state conditions. The engine soft version 3.0 is run to go on ONLINE mode. The varying engine compression ratio of 14, 16 and 18 and a normal speed of 1500 rpm controlled by the governor. An injection pressure of 200 bar is used for the best performance as specified by the
manufacturer. The engine is first run with neat diesel at loading conditions such as 20%, 40% and 60% and

- Injection, air-cooled diesel engines; one engine was standard and the other had thermal coating 80%.
  Between two load trials the engine is allowed to become stable by running it for 3 min before taking the readings. At each loading conditions, performance parameters namely speed, exhaust gas temperature, brake power, peak pressure are measured under steady state conditions.

- The experiments are conducted with diesel, mix of SO + MSO and blends of diesel – SO+MSO. With the above test conditions, the parameters such as total fuel consumption, brake specific fuel consumption, brake thermal efficiency are presented with respect to load.

9. RESULTS

9.1. PERFORMANCE CHARACTERISTICS

9.2. EMISSION CHARACTERISTICS

Fig 9.1: Variation of BTE with BP

Fig 9.2: Variation of BSFC with BP

Fig 9.3: Variation Exhaust Gas Temperature with BP
Fig 9.4: Variation of Oxides Of Nitrogen With BP

Fig.9.5: Variation of CO with BP

Fig.9.6: Variation of CO2 with BP

Fig.9.7: Variation of HC with BP
The performance characteristics, brake thermal efficiency, brake specific fuel, Exhaust gas temperature consumption, and emission characteristics, HC, CO, CO₂ and NOₓ of single cylinder 4-stroke CI at compression ratio of 17.5:1 and injection pressure of 200 bar using mixture So and MSO biodiesels with their blends as fuels were experimentally investigated. The following general results are made based on the experimental results.

- BTE biodiesel and its blends were found to be less than diesel fuel. The decrease in brake thermal efficiency for higher blends may be due to the combined effect of its lower heating value and increase in fuel consumption and BTE for diesel 34.51 % and for B20 blend 33.03 % which is 4.28 % lower than the diesel. Hence B20 blend is more preparable alternative fuel for CI engine.

- The BSFC and EGT increases with the increase of biodiesel in the blends, due to the lower heating value of biodiesel and presence of additional content of oxygen in the biodiesel which leads complete combustion respectively.

- The maximum BSFC at full load is 0.2438 kg/kWh for diesel and for B20 it is 0.2596 kg/kWh which is 6.08 % higher than the diesel and The maximum EGT at full load is 255°C for petrodiesel for B20 it is 265°C which is 10% higher than the diesel. Lesser values of BSFC and EGT are apparently desirable.

- The NOₓ emission for biodiesel and its blends is higher than that of diesel. This could due to increase in exhaust gas temperature. and NOₓ for diesel 730ppm and for B20 blend 755ppm which is 3.31 % higher than the diesel. Lesser values of NOₓ are apparently desirable.

- CO and CO₂ emissions were found to be less than that of neat diesel fuel. CO is one of the compounds formed during the intermediate combustion stages of hydrocarbon fuels. As combustion proceeds to completion, oxidation of CO to CO₂ occurs through recombination reaction between CO and the different oxidants. If these recombination reactions are incomplete due to lack of oxidants or due low gas temperature, CO will exist. CO and CO₂ values for B20 as compared to pure diesel are decrease by 16.66% and 2.74 % respectively.

- The HC emission for biodiesel and its blends is lower than that of diesel. Unburnt hydrocarbons emission is the direct result of incomplete combustion. At full load condition emission of HC is 10% lower than the diesel.

**CONCLUSIONS**

1. When the operating conditions and the surface characteristics of combustion chamber components of diesel engines and are considered, atmospheric plasma spray is the most appropriate technique for applying protective surface coatings.
2. The application of a metal oxide coating to the surface of combustion chamber components provides increased surface resistance and a high performance thermal barrier.
3. The coated engines are optimum for low and medium load conditions and more suitable for high load conditions when compared to standard engine.
4. The mechanical lifespan of the base materials were successfully increased by the application of ceramic coatings.
5. Bond layer components provide effective adhesion durability over the substrate layer.
6. The coating process contributes to reducing many undesired phenomena such as wear, operational delays, renewal of equipment, delays caused by servicing and repairs.
7. Varying compression ratio follows almost similar results on engine running with diesel, blend of diesel and biodiesel & biodiesel. Increasing compression ratio until certain limits increases break thermal efficiency decreasing brake specific fuel consumption & smoke-CO emissions. However, the results can vary with change in other parameters like injection pressure and injection timings also. Exhaust gas temperature increases with increase in compression ratio.
8. Calorific value of Biodiesel is less as compare to diesel. Decrease in calorific value results in higher consumption of fuel for biodiesel-diesel blend and pure biodiesel as compare to diesel. Biodiesel is more...
viscous as compared to diesel. For higher blends of biodiesel, the modification in injection system of engine may be required due to increase in viscosity of fuel.

9. From performance and emission test analysis, it is found that when compression ratio increases brake thermal efficiency (BTHE) increases and brake specific fuel consumption (BSFC) decreases. The results of brake power remains unaffected by changing compression ratio.

10. In emission parameters with the increment in compression ratio emission of carbon monoxide (CO), unburned hydrocarbons (HC) and carbon dioxide (CO2) was found to be decrease. Emission of nitrogen oxide (NOx) was increases considerably with the compression ratio increases. This was due to better combustion characteristics with increase in compression ratio.

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