Experiment on the Performance and Emission Characteristics of the Blend B25 of Papaya Oil Methyl Ester on a Diesel Engine with Standard and Magnesium Stabilised Zirconia Coated Piston

V. Dinesh Kumar, K. M. Mrityunjayaswamy, M. Chinnapandian

Abstract:-The long term ongoing research in the field of automobile is to increase the efficiency of the engine and to reduce its harmful exhaust emissions. It is well known that only the one third of the thermal energy produced during the combustion of fuel is converted into useful mechanical work. Thermal barrier coating reduces the rate of heat transfer and utilizes the maximum rate of heat developed for the complete combustion of fuel. In this paper a comparison is made on the performance and emission characteristics of the blend B25 of papaya oil methyl ester on a single cylinder diesel engine with standard and magnesium stabilised zirconia coated piston under variable loading condition from no load to full load in the incremental of 20% and its thermal analysis using ANSYS. The blend B25 is selected because it is found optimum when compared with its other blends in earlier investigation.

Keywords: thermal barrier coating, heat transfer, papaya oil methyl ester (POME), magnesium stabilised zirconia.

I. INTRODUCTION

Due to the rapid depletion of fossil fuels, the search for alternate and renewable fuels has become pertinent. The demand of energy and the harmful environmental pollution because of automobile exhaust have promoted to adopt one of the concepts of adiabatic engine with catalyst coated combustion chamber of internal combustion engine. (J.B. Heywood 1998). The selection of suitable thermal barrier coating material is the requirement that the thermal barrier coating material should have high melting point, no phase transformation should take place at the room and at the operating temperature, low thermal conductivity, chemical inertness, good adherence to the metallic substrate and low sintering rate of the porous microstructure (K. Thiruselvam, 2015). The thermal efficiency engine varies from 38% to 42%, and as nearly as 58% to 62% of energy is lost in the form of waste heat. In order to save the energy that is being lost the hot parts especially the combustion chamber or its components are insulated.

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* Correspondence Author

V. Dinesh Kumar*, Ph.D scholar, Department of Mechanical Engineering, Dayananda Sagar University, Bangalore,India.

K.M. Mrityunjayaswamy, Associate Professor, Department of Mechanical Engineering, School of Engineering, Dayananda Sagar University, Bangalore,India.

M. Chinnapandian, Professor and Head, Department of Aeronautical Engineering, St. Peter's College of Engineering and Technology, Avadi, Chennai,India.

This will lead to reduction in heat transfer through the engine, resulting in an increased efficiency (Prof. Parvez et al November 2015) (59). The coatings can be applied either to the entire combustion chamber or to the selected surfaces of combustion chamber such as piston crown, valves and cylinder head. Ceramic materials find its extensive application in thermal barrier coatings due to its effective properties such as high thermal shock, tendency to operate under high temperature, high thermal expansion coefficients, less rate of wear, high rate of fracture toughness and its low cost. Some of the commonly used coating materials are zirconates, mullite, alumina, spinel, forsterite, yttria, magnesia and garnets. During the process of fuel combustion the piston especially its crown is exposed to relatively high temperature. The coating on the piston enables it to work at high temperature and it is also found from several experimental investigations and analysis that the heat lost through the piston will be minimum under its coated condition.

II. LITERATURE REVIEW

The performance of an externally scavenged engine is found to be increased with Ni-Cr-Ce thermal barrier coating as compared to normal piston and Ni-Cr coating (Mr. Shailesh Dhomne et al2014). The polycrystalline garnets such as YAG ($Y_3Al_5O_{12}$) because of its high temperature property and its phase stability up to 1970^{0}C melting point are a good choice particularly for high temperature applications. The other advantages are their comparatively low thermal conductivity and oxygen diffusivity. The thermal conductivity value of YAG ($Y_3Al_5O_{12}$) is almost same as zirconia with lower thermal expansion coefficient than the zirconia (Shubham Barnwal et al September 2015) (46). The zirconium oxide (ZrO_2) stabilized with yttrium (Y_2O_3) as the top layer ceramic coat over NiCrAlY bond coat layer as a coating material gives good results for aluminium alloyed pistons. The zirconia in pure form undergoes phase transformation if the operating temperature exceeds 500^{0}C and hence zirconia is used as thermal barrier coating material only in its stabilized form like Yittria stabilized zirconia (7-8 wt % Y_2O_3-ZrO_2) or magnesium stabilized zirconia (MgO- ZrO_2), Millite ($3Al_2O_3$-$2SiO_2$) etc. It is evident from the experimental investigation that the brake thermal and mechanical efficiency of zirconia coated piston is increased by 9% and 25% respectively, the total fuel consumption is reduced by 7%, the specific fuel consumption is reduced by 6%, reduction in the emission of carbon monoxide (CO) by 48%, reduction in the emission of nitrous oxide (NO_X) by 14% and reduction in the emission of unburned hydrocarbon (HC) by 23% were recorded (K. Thiruselvam, 2015). The zirconia based ceramic coatings are used as thermal barrier coatings due to their low thermal conductivity and relatively high coefficients of thermal expansions, which reduce the detrimental interfacial stress. (Ekrem Buyukkaya et al November 2007). The experimental analysis of the redesigned piston using Pro-E software and analysed by ANSYS software in which the piston is coated by magnesium oxide (MGO) and zirconium oxide (ZiO) over existing aluminium alloy piston resulted that the coated section of the piston cause an increase in the temperature. It is therefore concluded that this temperature increase leads to an increase in the temperature of air fuel mixture and thus unburnt charge oxidation near the entrance of the clearance increases. Due to the increase in temperature the emission of carbon monoxide decreases since the carbon monoxide (Co) oxidation reactions strongly depend on temperature (R. Silambarasan et al April 2015).

III. PAPAYA OIL EXTRACTION FROM ITS SEED

The seeds of papaya are collected from the local market and fruit shops. The collected seeds are winnowed, washed well with water and shade dried for a period of three days. Oil is extracted from the seeds with the help of rotary oil extractor available in the local market. The oil in its pure form is subjected to transesterification in presence of alcohol (methanol) and catalyst (NaOH). The oil to methanol ratio is maintained as 1:6 and the reaction temperature maintained as 60^0C. Papaya oil methyl ester (POME) and glycerol are the end products of the process. The papaya oil methyl ester thus formed is separated from the glycerol by gravity separation process.

IV. PREPARATION OF COATING MATERIAL

As ceramics find its extensive application as coating material, magnesium stabilized zirconia is selected as the piston coating material. The zirconia in pure form undergoes phase transformation if the operating temperature exceeds 500^0C and hence zirconia is used as thermal barrier coating material only in its stabilized form. The weighed magnesium and zirconia is ball milled and the resulting slurry is dried in an oven at a temperature of 175^0 for 10 hours separately. The powders of magnesium and zirconia in suitable proportion is dried completely and is mixed with the required quantity of binder and compacted into a square pellet using hydraulic/pneumatic pressing machine. Polyvinyl alcohol is used as binder in this research work. The square pellets after sintering at a temperature of 1650^0C were powdered by wet ball milling method and the process of coating is achieved by plasma spray coating technique.

V. EXPERIMENTAL PROCEDURE

The experiment is carried on a single cylinder water cooled diesel engine equipped with data acquisition system, exhaust gas analyzer and smoke meter.

- After checking the level of engine oil in the oil sump and water circulation, the engine is allowed to run for 10 minutes for initial warm-up.
- Initially the performance and emission characteristics of the test engine with standard piston is determined under variable load conditions using the conventional diesel and the blend B25 of papaya oil methyl ester as fuel.
- later the performance and emission characteristics of the test engine with magnesium stabilized zirconia piston is determined under variable load conditions using the blend B25 of papaya oil methyl ester as fuel.
- The results are compared and the optimum is suggested

VI. RESULT AND DISCUSSION

The performance and emission characteristics of the blend B25 of papaya oil methyl ester on conventional and coated piston is shown in the figure 1-5.

A. BRAKE SPECIFIC FUEL CONSUMPTION

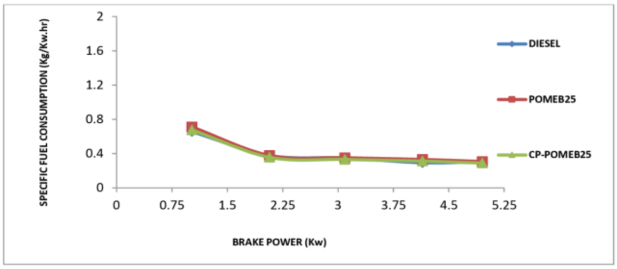

Figure 1.variation of specific fuel consumption with brake power

The specific fuel consumption of the blend B25 of papaya oil methyl ester (POME) on coated piston is found decreasing with increase in load. The specific fuel consumption of the blend B25 of papaya oil methyl ester on coated piston is found less when compared with the blend B25 of papaya oil methyl ester (POME) on the standard piston. The specific fuel consumption of the blend B25 of papaya oil methyl ester (POME) on coated piston at the load conditions 40%, 60% and 100% is found less than diesel. The specific fuel consumption of the blend B25 is found to decrease about 4-6% on a coated piston when compared with the standard piston.

B. BRAKE THERMAL EFFICIENCY

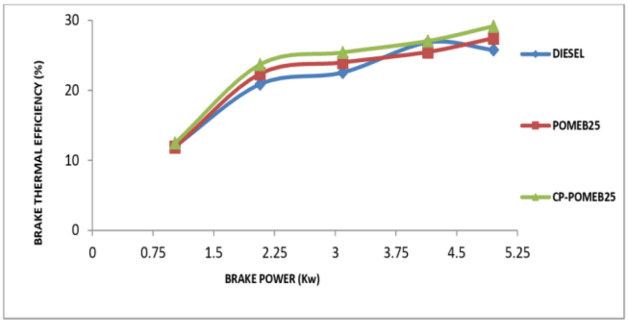

Figure 2.variation of brake thermal efficiency with brake power

The brake thermal efficiency of the blend B25 of papaya oil methyl ester (POME) on coated piston is found higher than the diesel and the blend B25 of papaya oil methyl ester (POME) on standard piston at all load condition. The brake thermal efficiency of the blend B25 is found to increase by 3-4% on a coated piston when compared with the standard piston.

C. EMISSION OF CARBON MONOXIDE

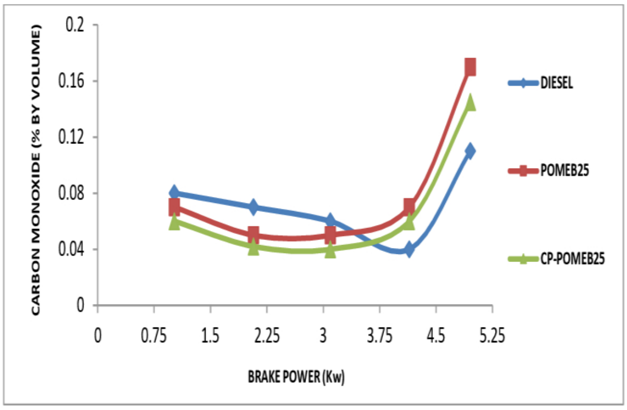

Figure 3.variation of carbon monoxide emission with brake power

The carbon monoxide emission of the blend B25 of papaya oil methyl ester (POME) on coated piston is found less than the blend B25 of papaya oil methyl ester (POME) on standard piston at all load condition. The carbon monoxide emission of the blend B25 of papaya oil methyl ester (POME) on coated piston is found increasing with increase in load. The emission of carbon monoxide of the blend B25 is found to decrease about 4% on a coated piston when compared with the standard piston.

D. EMISSION OF HYDROCARBON

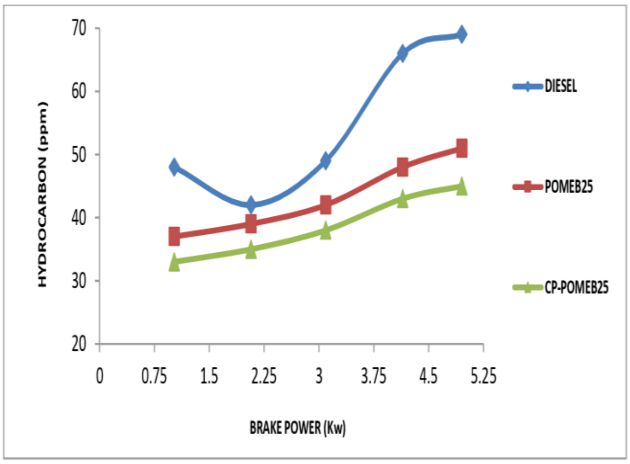

Figure 4.variation of hydrocarbon emission with brake power

The hydrocarbon emission of the blend B25 of papaya oil methyl ester (POME) on coated piston is found increasing with increase in load. The hydrocarbon emission of the blend B25 of papaya oil methyl ester (POME) on coated piston is found less than the diesel and the blend B25 of papaya oil methyl ester (POME) on standard piston at all load condition. The emission of hydrocarbon of the blend B25 is found to decrease about 5% on a coated piston when compared with the standard piston.

E. EMISSION OF NITROUS OXIDE

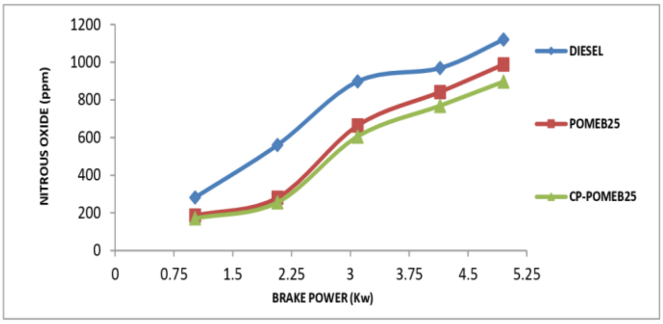

Figure 5.variation of nitrous oxide emission with brake power

The nitrous oxide emission of the blend B25 of papaya oil methyl ester (POME) on coated piston is found increasing with increase in load. The nitrous emission of the blend B25 of papaya oil methyl ester (POME) on coated piston is found less than the diesel and the blend B25 of papaya oil methyl ester (POME) with standard piston at all the respective load conditions. The emission of nitrous oxide is found to decrease about 2-3% in coated piston when compared with the standard piston.

VII. PISTON MODELLING

In this experimental analysis the piston of Kirloskar single cylinder diesel engine based on its technical specification is designed using the software SOLID WORKS. The same engine is used in determining the performance and emission characteristics of papaya oil methyl ester (POME) and its blends in the earlier work and the blend B25 of papaya oil methyl ester is found optimum. The designed piston is then imported into ANSYS using IGES (international graphics exchange specification).

VIII. THERMAL ANALYSIS

As the inner surface of piston resembles curved shape, the shape of piston is therefore irregular. In this analysis the method of automatic meshing is used in meshing the piston. The element used is 20 node tetrahedron solid 90 and the size of element is taken as 4. The number of elements and nodes found from the mesh models are 11050 and 17255 respectively. The maximum pressure acting at the top of piston surface is 8.1829MPa and the temperature at the top of the piston surface is 1007.6^{0}C respectively. The results of thermal analysis for standard and coated piston are shown in the figure 6 and 7.

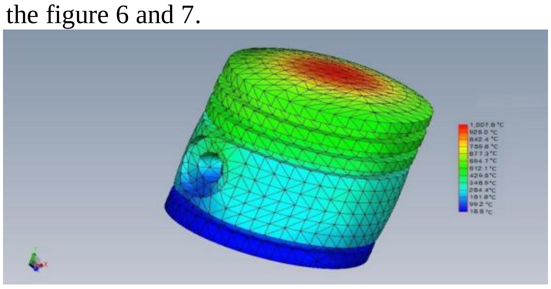

Figure 6.temperature distribution on a conventional piston made of cast aluminium alloy

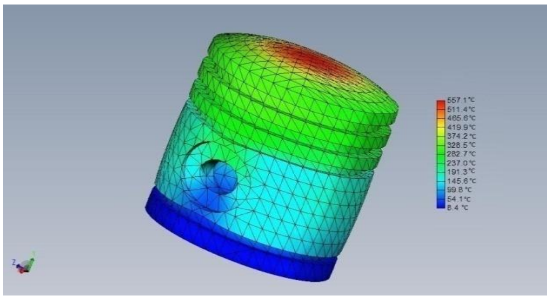

Figure 7.temperature distribution on a magnesium stabilized zirconia piston

IX. CONCLUSION

It is evident from the experimental investigation that the magnesium stabilized zirconia coated piston revealed better performance and emission when compared with the standard piston for the optimum blend B25 of papaya oil methyl ester. The results of thermal analysis using ANSYS also reflected the same. The specific fuel consumption is found to decrease about 4-6%, the brake thermal efficiency is found to increase by 3-4%, the emission of carbon monoxide is found to decrease about 4%, the emission of hydrocarbon is found to decrease about 5% and the emission of nitrous oxide is found to decrease about 2-3% in coated piston when compared with the standard piston.

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