International Journal of Advancements in Mechanical and Aeronautical Engineering – IJAMAE
Volume 1 : Issue 4 [ISSN 2372 –4153]
Publication Date : 27 December, 2014

Studies on Performance, Combustion and Exhaust Emission Characteristics of Copper Coated Two Stroke Spark Ignition Engine with Alcohol Blended Gasoline

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Abstract— **Investigations were carried out to evaluate the performance of two-stroke, single cylinder spark ignition (SI) engine with alcohol blended (80% gasoline, 10% ethanol and 10% methanol by volume) having copper coated combustion chamber [copper-(thickness, 300 μ) coated on piston crown, and inner side of cylinder head]. Performance parameters [brake thermal efficiency, exhaust gas temperature and volumetric efficiency] and Exhaust emissions of CO and UBHC were determined at various values of brake mean effective pressure of the engine, combustion characteristics [peak pressure, maximum rate of pressure rise, time of occurrence of peak pressure and maximum heat release] and aldehydes were measured by wet chemical method at full load operation of the engine. A microprocessor-based analyzer was used for the measurement of CO/UBHC in the exhaust of the engine. Comparative studies were made on performance parameters, combustion characteristics and exhaust emissions with conventional and copper coated SI engine with pure gasoline operation. Copper-coated combustion chamber (CCCC) showed improved performance, combustion parameters and reduced pollutants when compared with conventional engine (CE) with both test fuels. Catalytic converter with air injection significantly reduced pollutants with test fuels on both configurations of the engine. The catalyst, sponge reduced the pollutants effectively with both test fuels in both versions of the engine**.

Keywords— S.I .Engine, Copper coating, Performance, combustion characteristics

I Introduction

The large amount of pollutants emitting out from the exhaust of the automotive vehicles run on fossil fuels are increasing and these pollutants are proportional to number of vehicles. The civilization of any country is measured on the basis of number of vehicles. Hence the Government has to spend huge foreign currency for importing crude petroleum to meet the fuel needs of the automotive vehicles, in the context of fast depletion of fossil fuels. In view of heavy consumption of gasoline due to individual transport, the search for alternate fuels has become pertinent apart from effective fuel utilization which has been the concern of the engine manufacturers, users and researchers involved in combustion & alternate fuel research.

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Alcohols are suitable substitutes as alternate fuels for use in SI engines, as they have properties compatible to gasoline fuels, that too their octane rating is more than 100. If alcohols are blended in small quantities with gasoline, no engine modification is necessary. Engine modification and change in fuel composition are two methods to improve the performance of the engine and reducing pollution levels.

II. Literature

This section deals need and necessity of alternate fuels for SI engine, experimental investigations taken up by different researchers connected to this work, methods to improve the performance of SI engine, modification of combustion chamber, change of fuel composition, research gaps and objectives of the experimentation.

Engine modification [1-4] with copper coating on piston crown, and inner side of cylinder head improves engine performance as copper is a good conductor of heat and combustion is improved with copper coating..

Nedunchezhian et al.[1] evaluated the performance of a two-stroke copper coated engine (copper coating of thickness 300 microns and binding material of thickness of 100 microns on piston crown and inside portion of cylinder) with pure gasoline and reported that CCCC improved the specific fuel consumption by 4% at full load operation of the engine .
Murali Krishna et al. [4] conducted experiments on four-stroke copper coated combustion chamber (CCCC) with gasohol (20% ethanol blended with gasoline by volume) and reported that CCCC increased efficiency of the engine by 20%. .
Murali Krishna et al. [5] employed four-stroke variable compression ratio (3-9) SI engine ranging from, variable speed (2200-3000 rpm) with methanol blended gasoline (20% by volume) and reported increase of thermal efficiency by 15% in comparison with pure gasoline operation on conventional engine.
Farayedhi et al. [6] investigated the efficiency of CE with oxygenated fuels of ethanol and methanol used as blends of 10, 15, and 20 % by volume with gasoline and it was reported that these blends improved brake thermal efficiency.
Ceviz *et al.* [7] reported the effects of ethanol-unleaded gasoline blends on cyclic variability in an SI engine. The results showed that the coefficient of variation in indicated mean effective pressure (IMEP), CO and UBHC emissions decreases by using ethanol-unleaded gasoline blends as a fuel, while CO_2 concentration increased with 10 % ethanol (by vol.) fuel blend.

Bahattin [8] conducted experiments on SI engines with blends of E25 (75% gasoline and 25% ethanol by vol.), E50, E75 and E100 fuels at a constant load and speed. The experimental results show that the most suitable fuel in terms of performance and emissions was E50.

Al-Baghdadi [9] carried out investigations on blends of ethanol with gasoline 30% by volume and reported that these blends increased engine power, thermal efficiency and reduces the nitrogen oxides, CO and HC emissions.

Investigations were carried out [10-12] conducted experiments on two-stroke copper coated (thickness of copper coating- 300 microns- coated on piston crown and inside portion of cylinder head) spark ignition engine with gasohol (80% gasoline and 20% ethanol by volume) employed with catalytic converter effectively decreased the pollution levels by 40% with catalyst and 60% with catalyst and air injection. However, in their investigations, combustion characteristics were not reported.

Carbon monoxide (CO) and un-burnt hydrocarbons (UBHC), major exhaust pollutants formed due to incomplete combustion of fuel, cause many human health disorders [13]. These pollutants cause asthma, bronchitis, emphysema, slowing down of reflexes, vomiting sensation, dizziness, drowsiness, etc. Such pollutants also cause detrimental effects [15] on animal and plant life, besides environmental disorders. Age and maintenance of the vehicle are some of the reasons [16] for the formation of pollutants. Aldehydes which are intermediate compounds [17] formed in combustion, are carcinogenic in nature and cause detrimental effects on human health and hence control of these pollutants is an immediate task. The present paper reported the control of exhaust emissions of CO, UBHC and aldehydes (formaldehydes and acetaldehydes) from two stroke SI engine with alcohol blended gasoline in different configurations of the combustion chamber with catalytic converter with sponge iron as catalyst and compared with gasoline operation on CE.

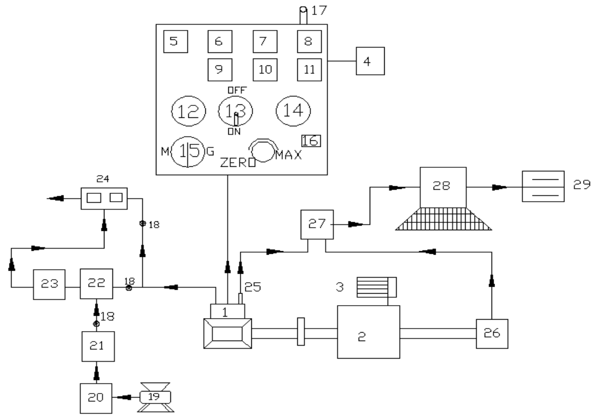
However, little work is done in evaluating the performance of two-stroke engine with alcohol blended gasoline (gasoline-80%, ethanol-10% and methanol-10%) on CCCC (copper coating of thickness 300 microns on piston crown and inside portion of cylinder head)-Copper coated combustion chamber.

III. Materials and Methods

This section deals with fabrication of copper coated combustion chamber, description of experimental set-up employed for the investigations, operating conditions and definitions of used values.

In catalytic coated combustion chamber, piston crown and inner surface of cylinder head are coated with copper by flame spray gun. The surface of the components to be coated are cleaned and subjected to sand blasting. A bond coating of nickel- cobalt- chromium of thickness 100 microns is sprayed over which copper (89.5%), aluminum (9.5%) and iron (1%) alloy of thickness 300 microns is coated with METCO (A trade name) flame spray gun.

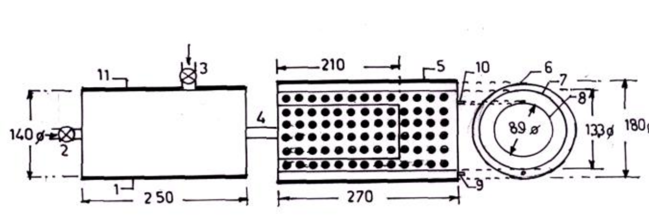
Fig.1 shows experimental set-up used for investigations. A two- stroke, single-cylinder, air- cooled SI engine is coupled to an eddy current dynamometer for measuring its brake power. The conventional engine has an aluminum alloy piston with a bore and stroke of 57 mm each. The rated output of the engine is 2.2 kW at a speed of 3000 rpm. Compression ratio of engine is 7.5:1.The recommended spark ignition timing is 25°aTDC (after top dead centre). Fuel consumption, speed, air flow rate, exhaust gas temperature are measured with electronic sensors.



1. Engine, 2.Electrical swinging field dynamometer, 3. Loading arrangement, 4.Fuel tank, 5.Torque indicator/controller sensor, 6. Fuel rate indicator sensor, 7. Hot wire gas flow indicator, 8. Multi channel temperature indicator, 9. Speed indicator, 10. Air flow indicator,11. Exhaust gas temperature indicator, 12. Mains ON, 13. Engine ON/OFF switch, 14. Mains OFF, 15. Motor/Generator option switch, 16. Heater controller, 17. Speed indicator, 18. Directional valve, 19. Air compressor, 20. Rotometer, 21. Heater, 22. Air chamber, 23. Catalytic chamber, 24. CO/HC analyzer, 25. Piezoelectric transducer, 26. TDC encoder, 27. Consol, 28. Pentium personal computer, 29. Printer.

Fig.1 Schematic Diagram of Experimental set up

The Piezo electric transducer, fitted on the cylinder head to measure pressure in the combustion chamber was connected to a console, which in turn was connected to Pentium personal computer. TDC encoder provided at the extended shaft of the dynamometer is connected to the console to measure the crank angle of the engine. Pressure-crank angle diagram was obtained on the screen of the personal computer. A special P-θ software package evaluated the combustion characteristics such as peak pressure (PP), time of occurrence of peak pressure (TOPP), maximum rate of pressure rise (MRPR) and maximum heat release from the signals of pressure and crank angle, at full load operation of the engine. The accuracy of the instrumentation was 0.1%.



1.Air chamber, 2.Inlet for air chamber from the engine, 3.Inlet for air chamber from compressor, 4.Outlet for air chamber, 5.Catalyst chamber, 6. Outer cylinder, 7. Intermediate cylinder, 8.Inner cylinder, 9. Outlet for exhaust gases, 10.Provision to deposit the catalyst and 11.Insulation

Fig.2. Details of Catalytic converter

Performance parameters of brake thermal efficiency (BTE), exhaust gas temperature (EGT) and volumetric efficiency (VE) are evaluated at different values of brake mean effective pressure (BMEP) of the engine. Brake specific energy consumption was determined at full load operation of the engine. Combustion characteristics were determined at full load operation of the engine. Experiments were carried out on CE and copper coated combustion chamber with different test fuels [pure gasoline and gasoline blended with alcohol (gasoline-80%, methanol-10% and ethanol-10% by volume].

A catalytic converter [11] (Fig.2) is fitted to exhaust pipe of engine. Provision is also made to inject a definite quantity of air into catalytic converter. Air quantity drawn from compressor and injected into converter is kept constant so that backpressure does not increase. Experiments are carried out on CE and copper coated combustion chamber with different test fuels under different operating conditions of catalytic converter like set-A, without catalytic converter and without air injection; set-B, with catalytic converter and without air injection; and set-C, with catalytic converter and with air injection. Air fuel ratio is varied so as to obtain different equivalence ratios.

For measuring aldehydes in the exhaust of the engine, a wet chemical method [6] is employed. The exhaust of the engine is bubbled through 2,4-dinitrophenyl hydrazine (DNPH) in hydrochloric acid solution and the hydrazones formed from aldehydes are extracted into chloroform and are analyzed by high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine.

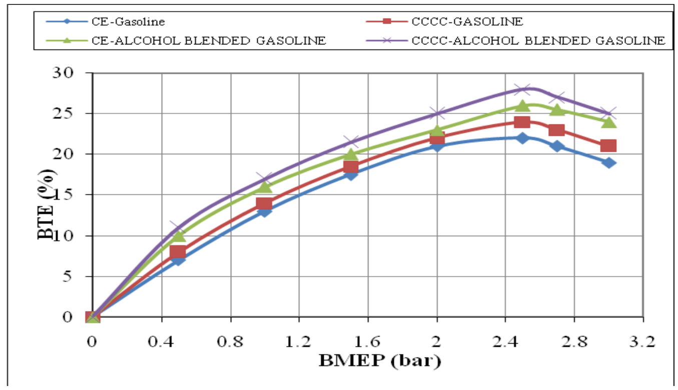
IV. Results and Discussion

This section is divided into i) Evaluating performance parameters ii) Determination of combustion characteristics iii) Determining the exhaust emissions

Performance parameters like brake thermal efficiency, exhaust gas temperature and volumetric efficiency were evaluated at different values of brake mean effective pressure. Brake specific energy consumption was determined at full load operation of the engine. Combustion characteristics include peak pressure, maximum rate of pressure rise and time of occurrence of peak pressure determined at full load operation.Exhaust emissions deals with variation of CO emissions and UBHC emissions with brake mean effective pressure (BMEP) of the engine, variation of CO emissions and UBHC emissions with equivalence ratio and control of these pollutions along with aldehydes with different operating conditions of the catalytic converter.

4.1 Performance Parameters

Figure.3 shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in different versions of the combustion chamber with test fuels of pure gasoline and alcohol blended gasoline. BTE increased up to 80% of the full load operation with an increase of BMEP in different versions of the combustion chamber, with different test fuels. Beyond 80% of the full load operation, BTE decreased with test fuels due to reduction of volumetric efficiency and air fuel ratio.



CE- conventional engine: CCCC-Copper coated combustion chamber.
BTE-brake thermal efficiency BMEP-Brake mean effective pressure

Fig.3. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in different versions of the engine with test fuels at a compression ratio of 7.5:1 and speed of 3000 rpm

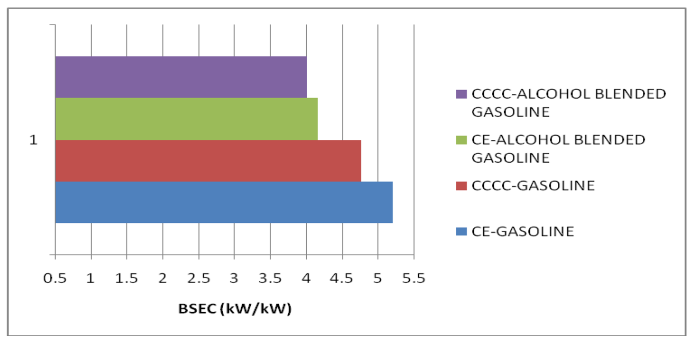
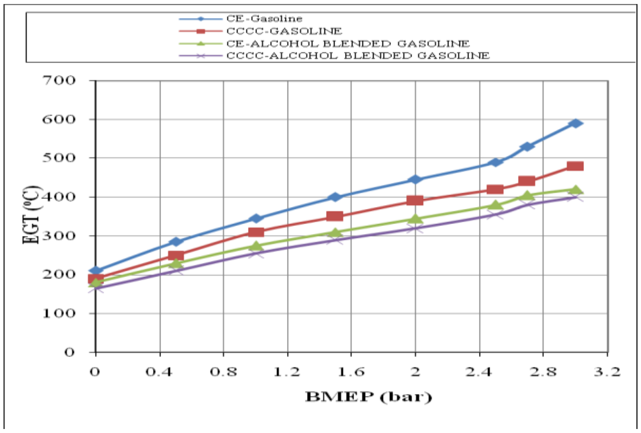


Fig.4 presents bar charts showing the variation of brake specific energy consumption (BSEC) at full load operation with different versions of the combustion chamber with test fuels

Figure.4 presents bar charts showing the variation of brake specific energy consumption at full load operation with different versions of the combustion chamber with test fuels. CCCC showed lower BSEC in comparison with CE with test fuels. This was due to improved combustion with increased catalytic activity with test fuels. Alcohol blended gasoline showed lower value of BSEC in comparison with pure gasoline operation on both versions of the combustion chamber.This was due to lower theoretical air fuel ratio requirement of alcohol blended gasoline.

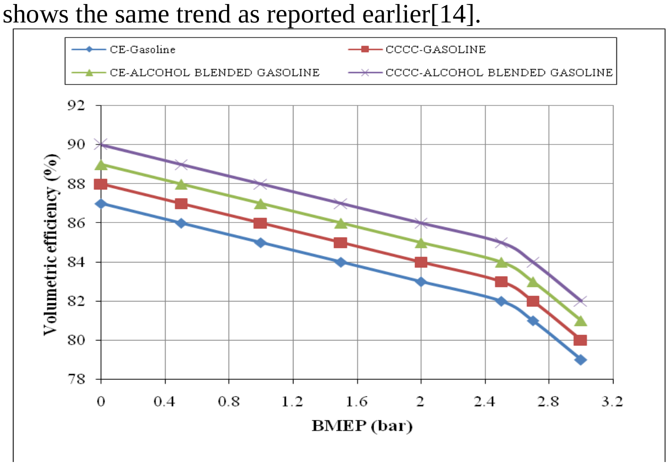
Figure.5 shows the variation of EGT with BMEP which indicated that EGT increased with an increase of BMEP. This was due to increase of fuel consumption with load. The value of EGT was lower with alcohol blended gasoline when compared to pure gasoline at all loads in CE and CCCC, because, with alcohol blended gasoline, work transfer from piston to gases in cylinder at the end of compression stroke was too large, leading to reduction in the value of EGT.



CE- conventional engine: CCCC-Copper coated combustion chamber. BTE- brake thermal efficiency
BMEP-Brake mean effective pressure

Figure.5. Variation of exhaust gas temperature (EGT) with brake mean effective pressure (BMEP) in different versions of the combustion chamber with test fuels at a compression ratio of 7.5:1 and speed of 3000 rpm

Figure 6 shows the variation of volumetric efficiency (VE) with BMEP with test fuels, which indicated that VE decreased with increase of BMEP. CCCC showed marginally higher VE at all loads in comparison with CE with different test fuels, due to reduction of residual charge and deposits in the combustion chamber of CCE when compared to CE, which shows the same trend as reported earlier[14].



CE- conventional engine: CCCC-Copper coated combustion chamber,
BMEP-Brake mean effective pressure

Figure.6 Variation of volumetric efficiency with BMEP in different versions of the combustion chamber with test fuels at a compression ratio of 7.5:1 and speed of 3000 rpm

4.2 Combustion characteristics

Figure.7 (a) presents bar charts showing the variation of peak pressure with test fuels with different versions of the combustion chamber. Peak pressures were observed to be higher with alcohol blended gasoline in comparison with pure gasoline in both versions of the combustion chamber. But an engine may not ingest its mixture with the fuel already evaporated. Under such conditions the number of moles of products should be examined on the basis of number of moles of air inducted since fuel occupies very little volume. Alcohol blended gasoline produced more number of moles of products on dry and wet basis

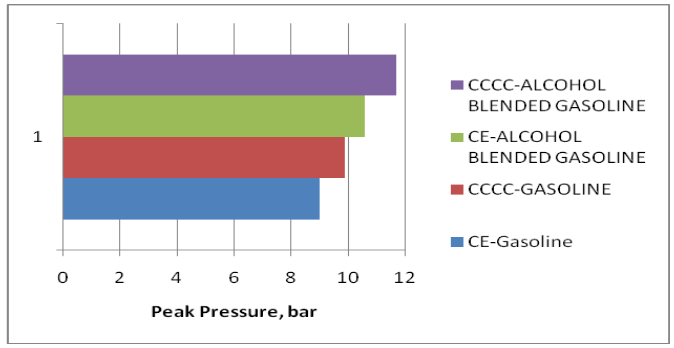


Fig.7 (a) Variation of PP for test fuels for different configurations of the engine

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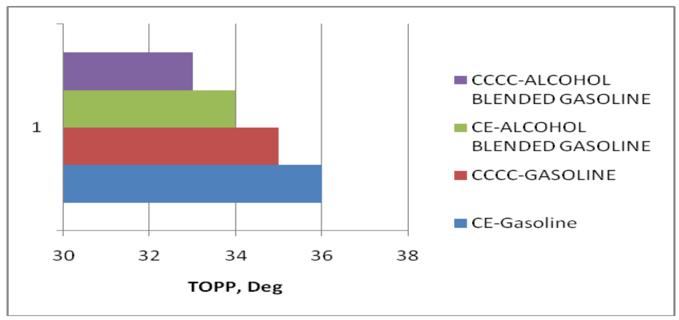


Fig.7 (b) Variation of TOPP for test fuels for different configurations of the engine

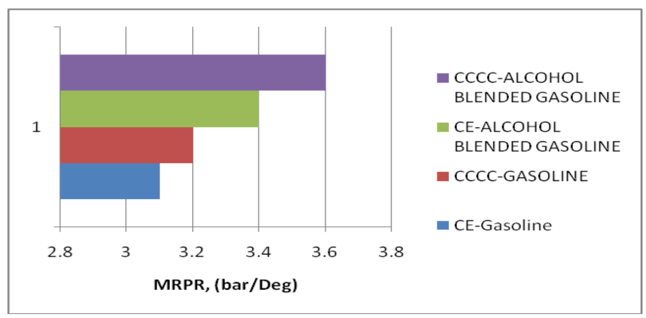


Fig.7(c)- Variation of MRPR for test fuels for different configurations of the engine

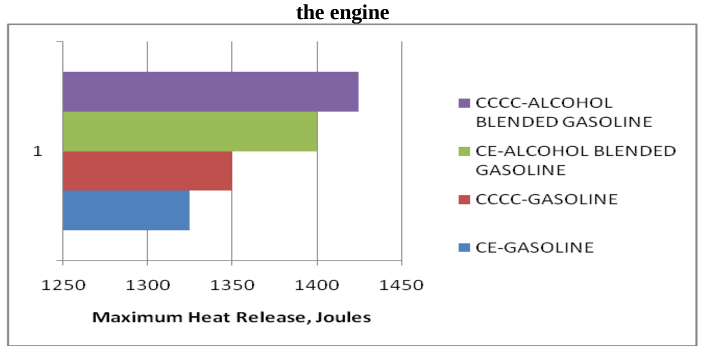


Fig7 (d) Variation of maximum heat release for test fuels for different configurations of the engine

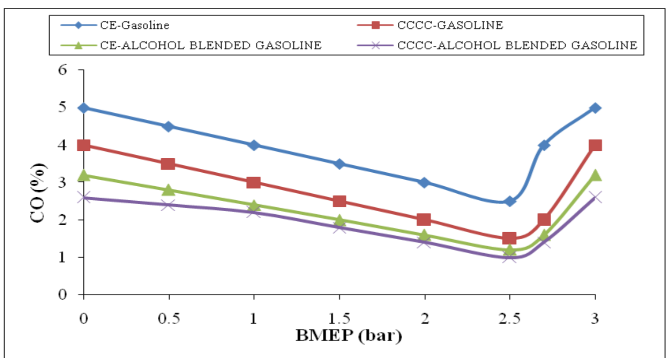
Figure.7 (b) presents the bar charts showing the variation of time of occurrecne of peak pressure (TOPP) in both versions of the combustion chamber with test fuels. TOPP was found to be lower (nearer to TDC) with CCE with alcohol blended gasoline compared with CE with pure gasoline, which confirms that performane was improved with CCE. Higher PP and lower TOPP confirmed that performance of the copper coated combustion chamber with alcohol bleded gasoline operaton improved causing efficient energy utilizaion.

Alcohol addiction improves the combustion process, reduces the crevices flow energy, reduces the cylinder temperature, reduces the ignition delay, speeds up the flame front propagation, and reduces the duration of combustion.

The trend followed by MRPR was similar to that of PP as indicated in Figure.7 The increase in maximum heat release (calculated from heat release diagram obtained from software package) indicates (Figure.7 (d)) that the combustion in the copper coated combustion chamber with alcohol blended gasoline was improved when compared with CE with gasoline due to the combustion of the relatively lean air- fuel mixtures, which shows that combustion was efficient with CCE with gasohol.

4.3 Exhaust Emissions:

This section deals with variation of CO emissions and UBHC emissions with brake mean effective pressure (BMEP) of the engine and with equivalence ratio.

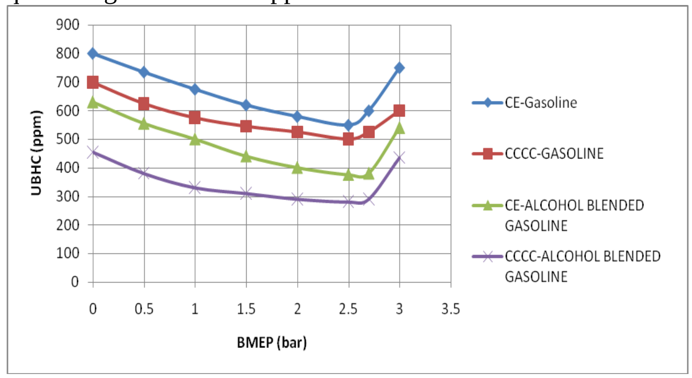


CE- conventional engine: CCCC-Copper coated combustion chamber, Carbon monoxide emissions: BMEP-Brake mean effective pressure

Fig.8 Variation of CO emissions with BMEP in different versions of the combustion chamber with pure gasoline and alcohol blended gasoline at a compression ratio of 7.5:1 and speed of 3000 rpm

Figure.8 shows the variation of CO emissions with BMEP ,CO emissions decreased with alcohol blended gasoline at all loads when compared to pure gasoline operation on CCCC and CE, as fuel-cracking reactions [13] were eliminated with alcohol. The combustion of methanol or ethanol produces more water vapor than free carbon atoms as methanol has lower C/H ratio of 0.25, while with ethanol 0.33, against 0.50 of gasoline. Methanol or ethanol has oxygen in its structure and hence its blends have lower stoichiometric air requirements compared to gasoline. Therefore more oxygen that is available for combustion with the blends of methanol and gasoline, leads to reduction of CO emissions.

Figure.9 shows the variation of un-burnt hydro carbon emissions (UBHC) with BMEP in different versions of the combustion chamber with both test fuels. UBHC emissions followed the similar trends as CO emissions in copper coated combustion chamber and CE with both test fuels, due to increase of flame speed with catalytic activity and reduction of quenching effect with copper coated combustion chamber.



CE- conventional engine: CCCC-Copper coated combustion chamber, UBHC- Un-burnt hydro carbons: BMEP-Brake mean effective pressure

Figure. 9 Variation of UBHC emissions with BMEP in different versions of the combustion chamber with pure gasoline and alcohol blended gasoline at a compression ratio of 7.5:1 and speed of 3000 rpm

The data of formaldehyde and acetaldehyde emissions is listed in Table-3 and Table-4 respectively at full load with different versions of the engine at different operating conditions of the catalytic converter with different test fuels of pure gasoline and alcohol blended gasoline repetitively. The formaldehyde emissions in the exhaust decreased considerably with the use of catalytic converter, which was more pronounced with an air injection into the converter. Copper coated combustion chamber decrease formaldehyde emissions when compared with CE. The trend exhibited by acetaldehyde emissions is same as that of formaldehyde emissions. The partial oxidation of alcohol blended specifically ethanol during combustion predominantly leads to formation of acetaldehyde. Copper (catalyst) coated engine decreased aldehydes emissions considerably by effective oxidation when compared to CE.

TABLE-3

DATA OF FORMALDEHYDE EMISSIONS (% CONCENTRATION) WITH DIFFERENT TEST FUELS WITH DIFFERENT CONFIGURATIONS OF THE COMBUSTION CHAMBER AT DIFFERENT OPERATING CONDITIONS OF THE CATALYTIC CONVERTER AT A COMPRESSION RATIO OF 7.5:1 AND SPEED OF 3000 RPM.

Set	Conventional Engine (CE)		Copper Coated Combustion Chamber (CCCC)	
	Pure Gasoline	Alcohol blended gasoline	Pure Gasoline	Alcohol blended gasoline
Set-A	9.1	18.1	6.8	11.1
Set-B	6.3	4.1	9.1	8.1
Set-C	3.5	3.2	6.5	3.5

Table-4

DATA OF ACETALDEHYDE EMISSIONS (% CONCENTRATION) WITH DIFFERENT TEST FUELS WITH DIFFERENT CONFIGURATIONS OF THE COMBUSTION CHAMBER AT DIFFERENT OPERATING CONDITIONS OF THE CATALYTIC CONVERTER

Set	Conventional Engine (CE)		Copper Coated Combustion Chamber (CCCC)	
	Pure Gasoline	Alcohol blended gasoline	Pure Gasoline	Alcohol blended gasoline
Set-A	7.7	14.1	4.9	11.1
Set-B	4.9	7.2	3.5	6.5
Set-C	2.1	5.0	1.4	3.5

V. Conclusions

With copper coated combustion chamber, in comparison with CE,

1. Thermal efficiency increased by 9% and EGT decreased by 19 %with gasoline operation, while with alcohol blended gasoline operation it increased by 8%.
2. Volumetric efficiencies were compatible with gasoline operation as well as alcohol blended gasoline operation.
3. Peak pressure and Maximum heat release rate increased by 11% and 2% with gasoline operation, while with alcohol blended gasoline it increased by 10%. And both MRPR and TOPP were compatible
4. CO and UBHC emissions at full load operation decreased by 20% with CCE when compared with CE with both test fuels.
5. With copper coated combustion chamber, formaldehyde and acetaldehyde emissions decreased by 25% and 36% in comparison with pure gasoline operation and formaldehyde and acetaldehyde emissions decreased by 39% and 21% in comparison with CE and alcohol blended gasoline operation.
6. Set-B operation decreased CO, UBHC and aldehyde emissions by 40%, while Set-C operation decreased these emissions by 60% with test fuels when compared with Set-A operation.
7. Sponge iron is proved to be more effective in reducing the pollutants.

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