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Experimental Investigations on Performance Evaluation of Four Stroke Copper Coated SI Engine With Methanol Blended Gasoline With Catalytic Converter-A Review

B.Raja Narender[1] Dr.P.V.Krishana Murthy[2] Dr.Md.Yousuf Ali[3] Dr.M.V.S Murali Krishna[4]

[1]*Associate Professor, Department of Mechanical Engineering,Anurag Group of Institutions (CVSR) Venkatapur, Ghatkesar, Medchal.Dist,Telangana,India*
[2]*Principal, Annamacharya Institute of Technology &, Sciences, Batasingaram, R.R.Dist,Telangana, India*
[3]*Principal, Avanthi Institute of Engineering & Technology,Gunthapally,Hayathnagar,R.R Dist, Telangana,India*
[4]*Professor, Department of Mechanical Engineering,Chaitanya Bharathi Institute of Technology Gandipet, Hyderabad,Telangana, India*
Corresponding Author: B.Raja Narender[1]

Abstract: *The performance evaluation of four stroke spark ignition engine with gasoline and alcohol (methanol and ethanol) blended gasoline was reviewed and research gaps were identified. This paper reports performance evaluation of four–stroke, single–cylinder, water cooled, variable compression ratio (3–9), variable speed (2200–3000 rpm) spark ignition engine with brake power of 2.2 kW at a speed of 3000 rpm. The combustion chamber of the engine was coated with copper (Copper Coated Engine, CCE) [copper-(thickness, 300 μ) was coated on piston crown, inner side of liner and cylinder head]. The engine was fuelled with methanol blended gasoline [20% methanol with 80% gasoline with varied spark ignition timing. The engine was provided with catalytic converter with sponge iron as catalyst along with air injection. The performance of CCE with methanol blended gasoline was compared with engine with conventional combustion chamber (CE) with gasoline operation. Performance parameters of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature and volumetric efficiency were determined at different values of brake mean effective pressure of the engine. Exhaust emissions (carbon mono oxide {CO) emissions, un-burnt hydro carbon (UBHC) emissions and nitrogen oxide (NO_x) levels) were evaluated at full load operation of the engine. Aldehydes (formaldehyde and acetaldehyde) were measured by wet method of 2,4, dinitrophenyle method at full load operation of the engine. Combustion characteristics were measured at full load operation with Piezo electric pressure transducer, TDC (top dead center) encoder, console, and pressure-crank angle software package. NO_x emissions were controlled by employing selective catalytic reduction (SCR) technique with the use of modified zeolite and lanthanum zeolite infused with urea. Methanol blended gasoline operation improved performance, reduced CO, UBHC emissions and NO_x levels when compared with gasoline operation with both versions of the combustion chamber. At recommended and ignition timing, CCE with test fuels of gasoline and methanol blended gasoline improved performance and reduced pollution levels, when compared with CE. Catalytic converter with sponge iron as catalyst along with air injection significantly reduced pollutants with test fuels. Combustion characteristics improved with CCE in comparison with CE with both test fuels.*

Keywords: *Alcohols, copper coating, catalytic converter, fuel performance, exhaust emissions, SCR, combustion characteristics.*

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I. Introduction

In the context of i) fast depletion of fossil fuels, ii) increase of pollution levels with fossil fuels and iii) ever increase of fuel prices in International Market causing economic burden on developing countries like India, the search for alternative fuels has become pertinent. Alcohols (ethanol and methanol) are important substitutes for gasoline as they are renewable in nature and have high octane rating. Methanol can be produced from municipal solid wastes and waste or specifically grown biomass [1]. Though methanol can also be produced from natural gas, there is no point in it as the basic objective is to conserve petroleum gases or liquids. The municipal solid wastes can be converted to methanol. The wastes are first shredded and then passed under a magnet to remove ferrous materials. The iron free wastes are then gasified with oxygen. The product synthesis gas is cleaned by water scrubbing and other means to remove any particulates, entrained oils, H_2 S and CO_2.

CO-shift conversion for H_2 / CO / CO_2 ratio adjustment, methanol synthesis, and methanol purification are accomplished.

Ethanol is produced from organic materials such as grains, fruit, wood and even municipal solid wastes and waste or specifically grown biomass [1]. The municipal solid wastes can be converted to alcohol. The wastes are first shredded and then passed under a magnet to remove ferrous materials. The iron free wastes are then gasified with oxygen. The product synthesis gas is cleaned by water scrubbing and other means to remove any particulates, entrained oils, H_2 S and CO_2. CO-shift conversion for H_2 / CO / CO_2 ratio adjustment, alcohol synthesis, and ethanol purification are accomplished. Alcohols are renewable in nature. They have oxygen in their molecular composition. They have low C/H value. They have low stochiometric air fuel ratios. Their properties are suitable as blended fuel in spark ignition engine. They have oxygen in their molecular composition.

The civilization of a particular country has come to be measured on the basis of the number of automotive vehicles being used by its public. Gasoline engines employing Otto cycle are preferred in individual transport due to many reasons. It is concluded that SI engine is preferred over compression ignition (CI) engine as the cost of SI engine is less than that of CI engine for the same horse power [2]. It is lighter and cheaper in construction due to low compression ratio. The starting of the SI engine is very easy because the fuel will be homogeneously burnt, thus achieving very high speeds. The SI engine is also cheaper because of its greater mass production and less costly fuel system particularly in the automotive field. The maintenance cost of SI engine is low compared to CI engine. For individual transport SI engine is preferred to CI engine as it gives lower vibrations. CI engines are heavier and the fuel will be burnt heterogeneously, hence producing lower speeds.

Four–stroke engines are preferred over two–stroke engines as thermal efficiency and volumetric efficiency of four-stroke engines are higher than those of two–stroke engines. [3],The poor fuel economy and high emission rates of UBHC and CO of two–stroke engines are predominantly higher due to the scavenging losses; at wide open throttle even 30–40%of the air–fuel mixture may be short-circuited to the exhaust and hence escape burning in the cylinder. Alcohols were used in conventional four–stroke SI engines as blends. [4–20]. Fuel properties of ethanol–gasoline blended fuels were first examined by the standard ASTM methods. Results showed that with increasing the ethanol content, the heating value of the blended fuels is decreased, while the octane number of the blended fuels increases. It was also found that with increasing the ethanol content, the Reid vapor pressure of the blended fuels initially increased to a maximum at 10% ethanol addition, and then decreases. Results of the engine test indicated that using ethanol–gasoline blended fuels, torque output and fuel consumption of the engine slightly increased; CO and HC emissions decreased dramatically as a result of the leaning effect caused by the ethanol addition; and CO_2 emission decreased because of the improved combustion. Finally, it was noted that NO_x emissions depends on the engine operating condition rather than the ethanol content. As blends have high latent heat of evaporation, hence higher blend ratios cause reduction of combustion temperatures. Hence the maximum blend ratio was limited to 20% by volume. They reported that thermal efficiency increased by 6–8%, CO and UBHC levels decreased by 30% with 20% of alcohol blended with gasoline by volume in comparison with CE with gasoline operation. [21–24].

Engine modification with copper coating on crown of the piston and inner side of cylinder head improves the engine performance as the copper is a good conductor of heat, stabilizes flame, improve pre–flame reactions. Methanol was used as blend (20% of methanol blended with gasoline by volume) with variable compression ratio (3–9), variable speed (2200–3000 RPM) engine with 2.2 k W brake power at the speed of 3000 rpm, four–stroke copper coated engine consisted of copper coating of thickness 300 microns on crown of the piston and inner portion of cylinder head. [25–27]. They reported that four–stroke CCE with methanol blended gasoline improved thermal efficiency by 8–10%, CO and UBHC levels decreased by 35% when compared with CE with gasoline operation. However, in their investigations, combustion characteristics and nitrogen oxide levels were not evaluated. Copper coating was not provided on inside portion of liner. Similar investigations were extended with gasohol (ethanol blended with gasoline 20% by volume) on four stroke copper coated engine [28–30]. Gasohol operation improved peak BTE by 10–12% and reduced CO and UBHC emissions by 30% at full load operation in comparison with gasoline operation on CE. However, in their investigations, combustion characteristics and nitrogen oxide levels were not determined. Copper coating was limited to crown of the piston and inner surface of cylinder head. Experiments were carried out on copper coated spark ignition engine with alcohols (ethanol blended with 20% by volume with gasoline; methanol blended with 20% by volume with gasoline) and performance was compared with one over the other [31–32]. Ethanol blended gasoline operation showed improved performance, while methanol blended gasoline showed reduction of pollutants. In their studies, nitrogen oxide levels were not reported. Copper coating was confined to only piston crown and inner side of cylinder head. Researchers attempted different blend ratios of alcohol with copper coated SI engine. They used 10% methanol, 10% ethanol and 80% of gasoline by volume and evaluated performance and determined the pollution levels with these blend ratios. [33–36]. With copper coated combustion chamber with alcohol blended gasoline, peak thermal efficiency increased by 8% exhaust gas temperature at full load decreased by 5%, volumetric efficiencies at full load were comparable, peak pressure at full load increased by 11% and maximum heat release rate increased by 2% in comparison with CE with neat gasoline operation. However, in their investigations, nitrogen oxide levels were not measured. Copper coating was confined to only on crown of the piston and inner surface of cylinder head.

Carbon monoxide (CO) emissions and un burnt–hydro carbon (UBHC) emissions, major exhaust pollutants from spark ignition (SI) engine formed due to incomplete combustion of fuel cause many human health disorders such as asthma, bronchitis, emphysema, slowing down of reflexes, vomiting sensation, dizziness, drowsiness etc, [37–41]. Such pollutants also cause detrimental effects on animal and plant life, besides environmental disorders [41]. Hence control of pollutants is an immediate and an urgent task. When the engine is run with alcohol blended gasoline, aldehydes should be checked. These aldehydes are carcinogenic in nature and responsible for eye irritation, dizziness, vomiting sensation. [41]. One of the major pollutants emitted from petrol engines is NO_x levels. Inhaling of these pollutants causes health hazards like severe headache, tuberculosis, lung cancer, dizziness, nausea, respiratory problems, skin cancer, hemorrhage [40–41].The contaminated air containing carbon dioxide released from automobiles reaches ocean in the form of acid rain, there by polluting water. Hence control of these emissions is an immediate task and important. Hence globally, stringent regulations are made for permissible pollutants in the exhaust of the engines. Though Government legislation has not been pronounced regarding the control of aldehyde emissions, when more and more alcohol engines are coming to existence, severe measures the controlling of aldehydes emitted out through the exhaust of the alcohol run engines will have to be taken as serious view.

There are many methods to reduce CO and UBHC emissions like change of engine variables, operating variables, etc., out of which employing catalytic converter is simple technique to reduce emissions[42]. However, expensive and rarely available catalysts of tungsten, platinum and palladium were used in this process [42]. The pollution levels of CO, UBHC and aldehydes were controlled by providing a catalytic converter with four-stroke SI engine with gasoline as fuel with sponge iron and manganese ore as catalysts and with air injection. [43–47]. The void ratio (defined as ratio of volume occupied by catalyst to volume occupied by catalytic chamber) was maintained as 0.6 during the experiments. The catalytic chamber was operated in three different operating conditions like Set–A (without catalyst), Set–B (with catalyst and without air injection), and Set–C (with catalyst and with air injection). Pollution levels of CO, UBHC and aldehydes were reduced by 40% and 60% with Set–B and Set-C operations. The performance of sponge iron over manganese as catalyst was also evaluated. Sponge iron was proved to be efficient than manganese ore. However, in their experiments, ignition timing was maintained as constant. Combustion characteristics and NO_x levels were not determined. Experiments were extended to control CO and UBHC emissions from exhaust of four stroke SI engine with methanol blended gasoline operation provided with catalytic converter as specified in Ref 26–30. [48–49]. The parametric variations of catalytic converter were studied. The influence of mass of catalyst, void ratio, space velocity, temperature of injected air, air flow rate, temperature of catalyst etc was studied apart engine variables such as load, speed, compression ratio on reduction efficiency of pollutants. However, combustion characteristics and NO_x levels were not reported. Similar investigations were carried out with gasohol operation. [50–52]. Void ratio was found to be 0.6, while mass of catalyst of sponge iron was observed to be 2 kg, for maximum reduction of pollution levels of CO and UBHC levels during their experiments. The percentage of CO was found to be lower when air quantity was 60 litres/ min for CE, 100 litres/min for CCE with neat gasoline operation, while for methanol blended gasoline they were each 80 litres/ min. Oxidation of CO emissions with methanol blended gasoline might have lowered the air flow rate. CO emissions decreased with an increase of temperature of injected air with both versions of the engine. When CE and CCE were operated with neat gasoline, CO emissions were found to be less when temperature of catalyst was at 120^{o}C. However, when they were operated with methanol blended gasoline, reduction of CO emissions was observed at 180^{o}C. Decrease of exhaust gas temperatures with methanol blended gasoline might have increased optimum temperature for improved oxidation reaction. CO% remained unchanged beyond a particular air temperature. The pollution levels of CO and UBHC decreased from no load to 80% of the load of the engine and beyond that load, they increased again and reached peak value at full load operation. However, NO_x emissions were not studied during their experiment. These pollution levels decreased with an increase of speed of the engine. These pollution levels increased marginally with an increase of compression ratio.

Investigations were carried out to study CO, UBHC and aldehyde emissions (formaldehyde and acetaldehyde) with engine as specified in Ref 25–27, with improved design of catalytic converter with different catalysts of sponge iron and manganese ore fuelled with methanol blended gasoline (20% methanol blended with 80% gasoline by volume) and gasohol (20% ethanol blended with 80% gasoline by volume). [53–54; 55–56]. Dinitrophenyl hydrazine (DNPH) method was employed for measuring aldehydes. There was provision for injection of air into the catalytic converter. Pollution levels of CCE with alternative fuels of methanol blended gasoline and gasohol were compared with conventional engine (CE) with neat gasoline operation. The performance of the catalyst was compared with one over the other. The engine with copper coated combustion chamber decreased CO levels, UBHC emissions and aldehyde emissions effectively in comparison with engine with conventional combustion chamber. Catalytic converter with improved design reduced pollution levels effectively when compared with existing design. A catalytic converter was fitted to exhaust pipe of engine. Using mild steel, hollow cylinders were made and chemically cleaned with a solution of 10% sodium hydroxide and then with 5% nitric acid and finally dried. For the preparation of catalytically active coating, aluminium oxide was used as the oxidizing catalyst. Kaolinite is clay mineral with the composition of Al2SiO5(OH)4, high temperature RTV silicone, bentonite clay and gel solutions consisting of tetra ethyl ortho silane and ethanol were used as the binders. The finely powdered catalyst and chosen binder were intimately mixed and slurry was made by mixing with a suitable solvent. The hollow cylinders mentioned above were dip coated by dipping in the above slurry solution and then dried. In order to improve the adhesion of coating, an under coat of slurry of above mentioned binders in a suitable solvent was first applied on the cylinders, dried and then the catalytic coating was applied over the under coat. After drying, the adhesion of the catalytic coating was tested by manual abrasion of the coatings. Aluminium oxide of thickness 500 microns was coated on inside portion of catalytic converter. Holes of size 25 mm were provided on circumference of intermediate cylinder and inner cylinder. However, aluminum coating was not provided and holes of size 20 mm were provided on cylinders in previous studies [43–49]. Holes were made larger in order to ensure proper contact of exhaust gases with catalysts of sponge iron/manganese ore which were less expensive and easily available with low initial cost. The catalytic converter was operated in three different conditions, They were Set–A (without catalyst), Set–B (with catalyst only) and Set–C (with catalyst and air injection). Set–B operation of catalytic converter decreased pollution levels of CO, UBHC and aldehydes by 40%, while Set–C by 70% when compared with Set-A operation. Pollution levels of CO, UBHC and aldehyde emissions reduced further by 15% with Set–B operation and 20% with Set–C operation with improved design of catalytic converter when compared with existing design [43–49]. Sponge iron was found to be more suitable in reducing exhaust emission in comparison with manganese ore. However, in their investigations, study of NO_x emissions was not carried out.

High CO/UBHC/NO_x emissions are still the main obstacle in the development of next generation conventional petrol engines. There are many methods like employing improved exhaust gas after–treatment technologies, spark retardation, exhaust gas recirculation (EGR), intake air pressure boosting, variation of operating parameters, engine parameters, etc. are being applied to reduce NO_x levels in the exhaust of the spark ignition engine [42].The selective catalytic reduction technique is becoming increasingly popular and cost effective method in reduction of NO_x levels [57–60]. The catalyst was prepared by using zeolite and lanthanum salt. The ion exchange was done by stirring 500 grams of zeolite in a 2 N solution of lanthanum sulphate for 5-6 hours at 70-80^o C. The ion exchanged zeolite (catalyst–A) was recovered by filtration and activated by calcination in an oven at 400^o C for 3 hours and was furnace cooled to retain mechanical properties [57]. The prepared zeolite was placed in catalytic chamber which had cylindrical shape with a a diameter of 100 mm and length diameter of 250 mm. The urea infused lanthanum zeolite (Catalyst–B) was prepared by infusing urea by gravity feed dosing system. A nozzle was used to generate fine spray of urea solution into the exhaust gas before it enters into catalytic chamber containing lanthanum exchanged zeolite. They reported that NOx emissions reduced by 35-40% with catalyst-A, while they were decreased by 20–25% with catalyst–B, with neat diesel operation [57]. They reported that, catalyst–A reduced NO_x emissions by 40%, while catalyst–B decreased the same by 50% with conventional engine. However, little reports were available on reduction of NO_x levels in the exhaust of SI engine, particularly copper coated SI engines.

Setting the correct spark plug ignition timing is crucial in the performance and exhaust emissions of SI engine [61]. The performance of spark ignition engines is a function of many factors. One of the most important ones is ignition timing. Also it is one of the most important parameters for optimizing efficiency and emissions, permitting combustion engines to conform to future emission targets and standards [62].Engine tests were carried out with the spark timing adjusted to the maximum brake torque timing in various equivalence ratios and engine speeds for gasoline and natural gas operations [63]. They reported from their investigations brake specific fuel consumption at full load decreased by 6.2%, brake thermal efficiency increased by 2.3%, exhaust gas temperature at full load decreased by 6.8% and lubricating oil temperature at full load decreased by 19% when compared to gasoline operation. However in their investigations, NOx levels were not measured. Investigations were carried out four–stroke, variable compression ratio (3–9), variable speed (2200–3000 rpm), 2.2 kW brake power at a speed of 3000 rpm, copper coated SI engine of thickness 300 microns on piston crown, and inner side of cylinder head fuelled with neat gasoline and 20% methanol blended with gasoline as test fuels [64–65]. The timing of spark plug was varied by sensor method. They reported that performance of the engine improved with advanced ignition timing with reduction of pollution levels. The optimum ignition timing was obtained with CE was 28^o bTDC while it was 27^o bTDC with CCE with 20% methanol blended with gasoline. Engine with copper coated combustion chamber showed improved performance over CE with test fuels at recommended ignition timing and optimum ignition timing. Methanol blended gasoline improved performance over gasoline operation on both versions of the combustion chamber. However, NO_x levels and combustion characteristics were not reported in their investigations. Investigations were carried out on four–stroke, single–cylinder, water cooled, variable compression ratio (3–9), variable speed (2200–3000 rpm) spark ignition engine with brake power of 2.2 kW at a speed of 3000 rpm with copper coated combustion chamber (CCE) [copper-(thickness, 300 μ) was coated on piston crown, inner side of liner and cylinder head] with alcohol blended gasoline [20% methanol with 80% gasoline ; 20% of ethanol with 80% of gasoline by volume) with varied spark ignition timing provided with catalytic converter with sponge iron as catalyst along with air injection and compared with engine with conventional combustion chamber (CE) with gasoline operation.[66]. Performance parameters and exhaust emissions (CO and UBHC) were evaluated at full load operation of the engine. Aldehydes (formaldehyde and acetaldehyde) were measured by wet method of 2,4, dinitrophenyle method at full load operation of the engine. Combustion characteristics were evaluated at full load operation of the engine. Gasohol operation (20% ethanol blended with gasoline by volume) showed improved performance, while methanol blended gasoline showed reduction of pollutants with both versions of the combustion chamber. Increased ignition advance showed improved performance and reduction of exhaust emissions with both versions of the combustion chamber. Catalytic converter with sponge iron as catalyst along with air injection effectively reduced pollution levels with both versions of the combustion chamber with test fuels. However, in their studies, NO_x levels were not reported.

The investigations carried out by earlier researchers were confined to copper coating provided on crown of the piston and inner side of cylinder head at constant ignition timing. Little reports were available on four–stroke CCE with copper coating on crown of the piston, inside portion of liner and cylinder head with varied ignition timing with modified catalytic chamber. Little reports are available on NO_x levels with copper coated engines fuelled with alcohol blended gasoline. The authors made an attempt in this direction to evaluate the performance of four–stroke SI engine with simultaneous i) change of configuration of the combustion chamber (CE and CCE), ii) change of fuel (from gasoline to methanol bended gasoline), iii) with provision of modified catalytic converter and iv) with varied ignition timing in order to evaluate performance, pollution levels of CO, UBHC, NO_x and aldehydes and combustion characteristics.

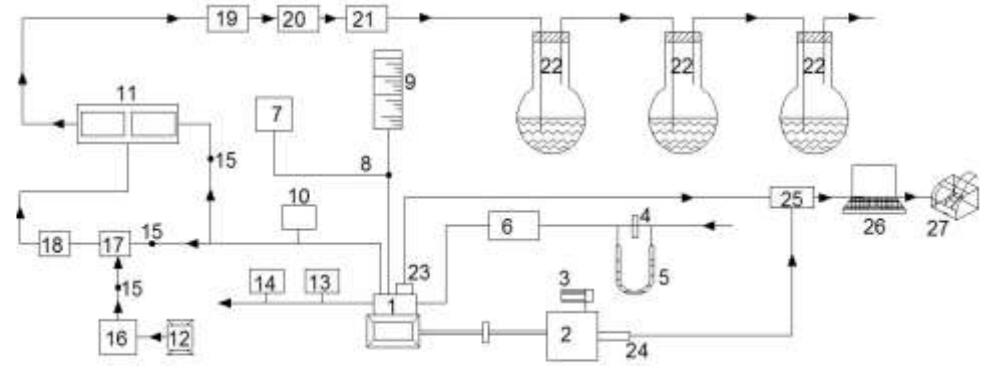
II. Material And Method

2.1. Fabrication Of Copper Coated Combustion Chamber.

In catalytic coated engine, piston crown and inner surface of cylinder head were coated with copper by flame spray gun. The surface of the components to be coated were cleaned and subjected to sand blasting. The material to be coated, which was either in the form of wire, rod or fine powder, was fed to a melting zone. The molten metal was further heated to a very high temperature leading to plasma stage. The hot plasma was accelerated along with carrier gas in the form of a jet towards the substrate. When the plasma impinged on the surface to be coated, the coating material flattens and sticks to the surface. It formed a hard surface when it was cooled and coalesced. The plasma coating consisted of a spray gun, feed hopper, carrier gas supply unit and power supply unit. The spray gun was used to coat the material of the surface. The coating was applied in layers until the desired thickness was obtained. A bond coating of nickel- cobalt- chromium of thickness 100 microns was sprayed over which copper (89.5%), aluminium (9.5%) and iron (1%) alloy of thickness 300 microns was coated with METCO (A trade name) flame spray gun. The coating has very high bond strength and does not wear off even after 50 h of operation [67].

2.2. Four Stroke Copper Coated Spark Ignition Engine:

Fig. 1 shows the schematic diagram of experimental set-up used for investigations. It is a four- stroke, variable speed (2200–3000 rpm), variable compression ratio (3:1–9:1), single-cylinder, water-cooled, SI engine (brake power 2.2 kW, at the speed 3000 rpm) was coupled to an eddy current dynamometer for measuring its brake power. Dynamometer was loaded by a loading rheostat. The accuracy of engine load was ±0.2kW. The bore of the engine was 70 mm while the stroke was 66 mm. Compression ratio of engine was varied with change of clearance volume by adjustment of cylinder head, threaded to cylinder of the engine. Brake power at different percentages of load was calculated by knowing the values of the output signals (voltmeter reading and ammeter reading) of dynamometer and speed of the engine. The accuracies obtained with measurement of output signals of dynamometer were within the limits. The speed of the engine was measured with digital tachometer with accuracy ±5 rpm. The manufacturer's recommended ignition timing was 25^{o} bTDC(before top dead center). Air-consumption of the engine was obtained with an aid of air box, orifice flow meter and U-tube water manometer assembly. By means of orifice flow meter and U-tube water manometer, discharge of air was calculated, from which mass flow rate of air was calculated. Air box with diaphragm was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. Coolant water jacket inlet temperature, outlet jacket temperature and exhaust gas temperature were measured by employing iron and iron-constantan thermocouples connected to analogue temperature indicators. The accuracies of analogue temperature indicators are ±5^o C. Ignition timing was varied by sensor method. The test fuels used in the experiment were neat gasoline and gasoline blended with 20% methanol by volume.



Details of components:

1.Engine, 2.Eddy current dynamometer, 3.Loading arrangement, 4.Orifice meter, 5.U-tube water monometer, 6. Air box,7.Fuel tank, 8. Three-way valve,9. Burette,10. Exhaust gas temperature indicator,11 CO analyzer, 12. Air compressor,13.Outlet jacket water temperature indicator,14. Outlet jacket water flow meter,15.Directional valve, 16. Rotometer, 17.Air chamber18.Catalytic chamber 19. Netel Chromatograph NO_x Analyzer provided with catalytic converter, 20. Rotameter provided with filter, 21. Heater provided 22.Round bottom flasks containing DNPH solution, 23. Pressure transducer, 24. TDC encoder,25.Console, 26.Personnel computer and 27. Printer

Fig.1 **Schematic Diagram of experimental set–up for four–stroke SI engine**

2.3. Measurement of Exhaust Emissions:

CO/ UBHC emissions and Nitrogen oxide (NO_x) levels in engine exhaust of different versions of the combustion chamber of four-stroke engine were measured with Netel Chromatograph analyzer at full load operation of the engine. The accuracy of measurement of emission is ±1% at full load operation.Table–1 shows the measurement principle, range, least count and repeatability of analyzers. Analyzer was allowed to adjust their zero point before each measurement. To ensure that accuracy of measured values was high, the gas analyzers were calibrated before each measurement using reference gases.

DNPH method (dinitrophenyl hydrazine) was employed for measuring aldehydes in the experiment. [68]. The exhaust of the engine was bubbled through 2,4 DNPH solution. The controlled flow rate of exhaust gas (2l/m) was maintained by rotometer and then it was purified by means of filer. The exhaust gas was heated to 140^o C with heater before sending it to DNPH solution. The hydrazones formed were extracted into chloroform and were analyzed by employing high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine. The advantage of this method over other methods is it can simultaneously measure formaldehydes and acetaldehydes.

Table.1

Specifications of the CO /UBHC Analyzer (Netel India ;NPM-MGA-1)

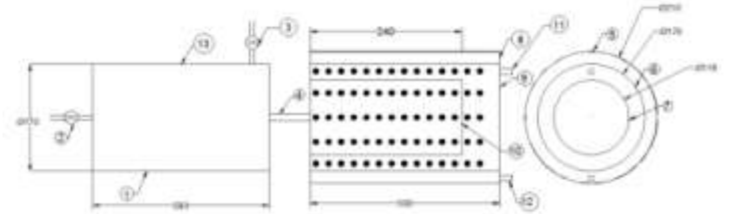
NO_x Analyzer (Netel India: 4000 VM)

Pollutant	Measuring Principle	Range	Least Count	Repeatability
CO	NDIR	1–10%	0.1% of Full Scale (FS)	0.1% for 30 minutes
UBHC	NDIR	1–1000 ppm	1 ppm	≤0.5% F.S
NO_x	Chemiluminiscence	1-1000	1 ppm	Better than ±1% range or±0.2 ppm whichever is the greater

2.4. Catalytic Converter for Control of CO and UBHC Emissions

Fig. 2 shows schematic diagram of catalytic converter [53–56]. It was fitted to exhaust pipe of engine. Hollow cylinders of mild steel were made and chemically cleaned with a solution of 10% sodium hydroxide and then with 5% nitric acid and finally dried. For the preparation of catalytically active coating, aluminium oxide was used as the oxidizing catalyst. Kaolinite is clay mineral with the composition of $Al_2SiO_5(OH)_4$, high temperature RTV silicone, bentonite clay and gel solutions consisting of tetra ethyl ortho silane and ethanol were used as the binders. The finely powdered catalyst and chosen binder were intimately mixed and slurry was made by mixing with a suitable solvent. The hollow cylinders mentioned above were dip coated by dipping in the above slurry solution and then dried. In order to improve the adhesion of coating, an under coat of slurry of above mentioned binders in a suitable solvent was first applied on the cylinders, dried and then the catalytic coating was applied over the under coat. After drying, the adhesion of the catalytic coating was tested by manual abrasion of the coatings. Aluminium oxide of thickness 500 microns was coated on inside portion of cylinders.

Holes of size 25 mm were provided on circumference of intermediate cylinder and inner cylinder. However, aluminum coating was not provided in previous studies [43–49]. Holes of size 20 mm were provided on cylinders in previous studies [43–49]. Holes were made larger in order to ensure proper contact of exhaust gases with catalyst of sponge iron which was less expensive and easily available. Discharge of the engine was calculated from which diameter of the opening through which exhaust gases enter into the catalytic chamber was determined assuming the velocity of exhaust gases (3–4 m/s). The length of the chamber was determined calculating the pressure drop. [69]. Provision was also made to inject a definite quantity of air (60 l/m) into catalytic converter. Air quantity drawn from compressor and injected into converter was kept constant so that backpressure does not increase. If necessary, provision was also made to heat injected air by means of heater (Part No.21 in experimental set–up). Void ratio (defined as ratio of volume occupied by catalyst to that of catalytic chamber) was maintained as 0.6:1. Mass of catalyst was maintained as 2.0 kg. Temperature of catalyst was at room temperature. Experiments were carried out 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 by operating direction valve (Part No.15 in experimental set–up).



(All dimensions are in mm)
1. Air chamber, 2. Inlet for air chamber from the engine, 3. Inlet for air chamber from the compressor, 4. Outlet for air chamber, 5. Catalytic chamber, 6. Intermediate-cylinder, 7. Inner-cylinder, 8.Outer sheet, 9.Intermediate sheet, 10. Inner sheet, 11. Outlet for exhaust gases, 12. Provision to deposit the catalyst, and 13. Insulation.
Fig.2. Details of catalytic converter

2.5 Catalytic Converter for Control of Nitrogen Oxide Levels

The catalytic converter was provided with Netel Chromatograph NO_x Analyzer with bypass valve arrangement so as to allow exhaust gas into catalytic converter or bypass the catalytic converter by means of arrangement of directional valves. The catalyst was prepared by using zeolite and lanthanum ion salt. [57]. Ion exchange was prepared by stirring 500 grams of zeolite in a 2N solution of lanthanum (III) salt for 5–6 hours at 70–80^{o} C. Ion exchanged zeolite was recovered by filtration and activated by calcinations in an oven at 400^{o} C for 3 hours and was furnace cooled to retain mechanical properties. Modified zeolite (Catalyst–A) so obtained was placed in catalytic chamber which had a cylindrical shape with a diameter of 120 mm and length 600 mm. These dimensions were calculated from the discharge of engine and assumed velocity of the exhaust gases [69]. Infusion of urea on lanthanum exchanged zeolite (catalyst–B) was made by gravity feed dosing system. A nozzle was used to generate fine spray of urea solution into exhaust gas before it entered into catalytic chamber containing lanthanum exchanged zeolite.

2.6. Combustion Characteristics

Combustion diagnosis was carried with miniature Piezo electric pressure transducer (AVL Austria: QC34D), TDC (top dead center) encoder (AVL Austria: 365x) and special pressure–crank angle software package at full load operation of the engine. The accuracy of measurement of pressure is ±1 bar, while it is ± 1^{o} for crank angle. Combustion parameters such as peak pressure (PP), time of occurrence of peak pressure (TOPP), maximum rate of pressure rise and maximum heat release at the full load operation of the engine were evaluated.

2.7. Methanol Blended Gasoline

As mentioned in earlier article, methanol can be produced from municipal solid wastes and waste or specifically grown biomass. It is renewable in nature. It has oxygen its molecular composition. It has low C/H value (c=Number of carbon atoms, H=Number of hydrogen atoms in fuel composition). Lesser the value of C/H, higher is the H value, which yields water vapor in the exhaust of the engine rather than CO_2 and CO. It has a low stochiometric air–fuel ratio. Its properties are suitable as blended fuel in spark ignition engine. It has higher octane rating than gasoline. The maximum content of methanol was limited to only 20% with gasoline. As methanol blend ratio is higher than 20% , combustion temperatures would be lowered due to higher latent heat of vaporization of methanol leading to reduce the rated speed of the engine. The properties of 20% methanol blended with gasoline by volume are given in Table–2.

Table:2

Properties of Test Fuels [7]

Property	Gasoline	(MB) M-20	ASTM Test Method
Low Calorific Value (MJ/kg)	44.13	38.23	ASTM D340
Reid vapor pressure (kPa)	35.00	66.58	ASTM D323
Research Octane Number	84.80	94.40	ASTM D2699
Density at 15.5^0 C(kg/l)	0.76	0.77	ASTM D 1298
Latent Heat of Evaporation(kJ/kg) at 15.5^{0}C	600	700	-

III. Results And Discussion

Performance evaluation consisted of three categories, like evaluating performance parameters, determining exhaust emissions and evaluating combustion characteristics. The variations in performance parameters, exhaust emissions and combustion characteristics were very small during part loads, hence these parameters were shown at full load operation of the engine by means of bar charts.

3.1 Performance Parameters

From fundamental principles of Thermodynamics, it is known that thermal efficiency of Otto cycle increased with an increase of speed and compression ratio. [42]. Increased turbulence and higher expansion ratios might have improved the performance of the engine. At a speed of 3000 rpm, and compression ratio of 9:1, peak BTE was obtained with both versions of the combustion chamber with test fuels. The optimum ignition timing was obtained at 28^o bTDC with CE with neat gasoline operation and methanol blended gasoline operation [66], while the optimum injection timing was obtained at 27^o bTDC with gasoline operation on CCE [66]. Optimum ignition timing is an ignition timing, at which maximum BTE is obtained at all loads in comparison with conventional engine with gasoline operation at recommended ignition timing of 25^o bTDC. Fig. 3 shows variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with varied ignition timing with CCE with gasoline blended with methanol operation at a speed of 3000 rpm and compression ratio of 9:1. BTE increased with advanced ignition timing with CCE. Increase of duration of combustion leading to complete participation of oxygen in combustion reaction with advanced ignition timing might have improved the performance of the engine. The optimum ignition timing was obtained at 27^o bTDC which was earlier than CE with gasoline operation. Since combustion chamber was hotter due to improved combustion reactions with the presence of copper coating, the optimum injection timing was obtained earlier with CCE than CE with both test fuels. Table.3 shows the optimum ignition timing with test fuels with different versions of the engine.

Table.3

Data of Optimum Ignition Timing

Manufacturer's Recommended Ignition Timing–25^o bTDC with gasoline as fuel

Engine Version	Fuel	Optimum Ignition Timing in degrees before Top Dead Center
CE	Gasoline	25
CCE	Gasoline	27
CE	MB	28
CCE	MB	27

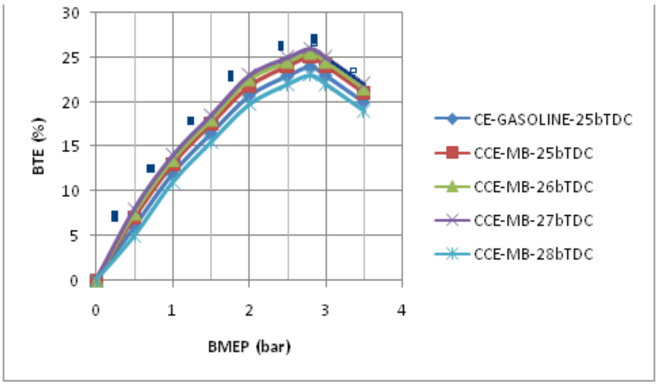


Fig.3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure copper coated engine (CCE) with methanol induction at a speed of 3000 rpm and compression ratio of 9:1

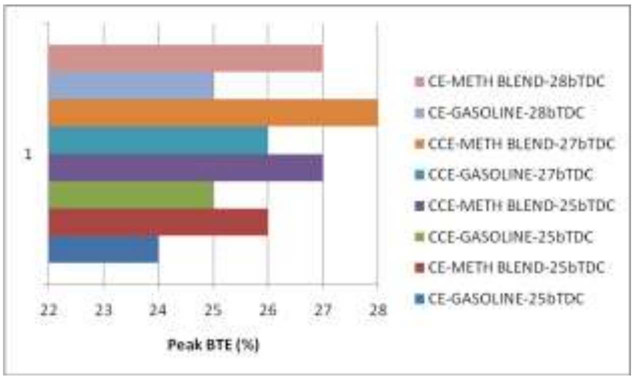


Fig.4. Bar charts showing variation of peak brake thermal efficiency (BTE)

Fig.4 presents bar charts showing the variation of peak BTE with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig.4, it is observed that peak BTE increased with methanol induction with both versions of the combustion chamber. This was because of improved homogeneity of the mixture with the presence of methanol, decreased dissociated losses, specific heat losses and cooling losses due to lower combustion temperatures. High heat of evaporation of methanol, which caused the reduction the gas temperatures resulting in a lower ratio of specific heats leading to more efficient conversion of heat into work. The increase in efficiency with methanol blended gasoline might also be with lower stoichiometric oxygen requirement of methanol blended gasoline over neat gasoline operation. CCE showed higher thermal efficiency when compared to CE with both test fuels at loads, particularly at near full load operation, due to efficient combustion with catalytic activity, which was more pronounced at full load, as catalytic activity increases with prevailing high temperatures at full load. Methanol blended gasoline increased peak BTE by 8% with CE at 25^o bTDC and 8% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline increased peak BTE by 8% at 25^o bTDC and 7% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation increased peak BTE by 4% at recommended injection timing of 25^o bTDC and 4% at optimum injection timing in comparison with CE with gasoline operation.CCE with methanol blended gasoline operation increased peak BTE by 3% at 25^o b TDC and 4% at optimum injection timing in comparison with CE with methanol blended gasoline operation. Combustion improved with catalytic activity of combustion chamber producing higher peak BTE with CCE with both test fuels.

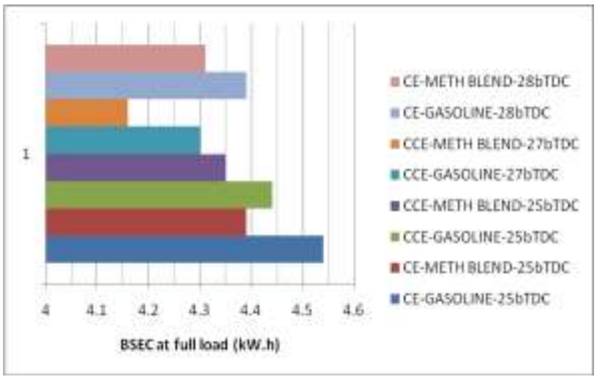


Fig.5. Bar charts showing variation of brake specific energy consumption (BSEC) at full load

Fig.5 presents bar charts showing the variation of brake specific energy consumption (BSEC) at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. BSEC is defined as energy consumed by the engine in producing unit brake power. Lesser the BSEC, the better is the performance of the engine. From Fig.5, it is noticed that brake specific energy consumption (BSEC) at full load operation decreased with methanol induction when compared with neat gasoline operation on both versions of the combustion chamber. Induction of methanol resulted in more moles of working gas, which caused high pressures in the cylinder. The observed increased in the ignition delay period would allow more time for fuel to vaporize before ignition started. This means higher burning rates resulted more heat release rate at constant volume, which was a more efficient conversion process of heat into work. BSEC at full load operation decreased with advanced ignition timing with both versions of the combustion chamber with test fuels. Utilization of oxygen to full extent with advanced ignition timing might have improved performance of the engine with methanol induction. Methanol blended gasoline decreased BSEC at full load by 3% with CE at 25^o bTDC and 2% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline decreased BSEC at full load by 2% at 25^o bTDC and 3% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation decreased BSEC at full load by 2% at recommended injection timing of 25^o bTDC and 3% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation showed comparable BSEC at full load at 25^o b TDC and 3% at optimum injection timing in comparison with CE with methanol blended gasoline operation. Combustion improved with catalytic activity of combustion chamber producing lower BSEC at full load with CCE with both test fuels.

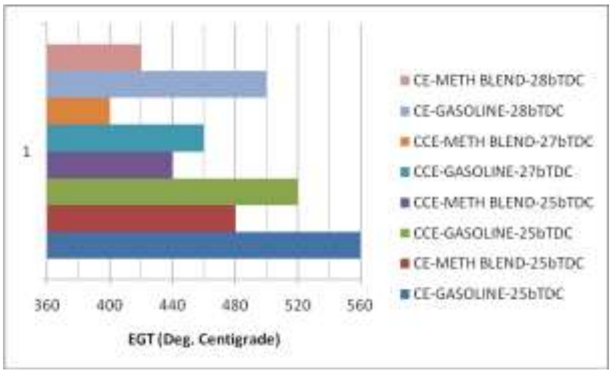


Fig.6. Bar charts showing variation of exhaust gas temperature (EGT) at full load

Fig.6 presents bar charts showing the variation of exhaust gas temperature (EGT) at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig.6, EGT at full load was observed to be less with methanol blended gasoline in comparison with neat gasoline in both versions of the engine. Higher latent heat of evaporation of methanol might have absorbed heat from combustion. Neat gasoline operation on CE recorded higher EGT at full load, while methanol blended gasoline operation on CCE gave lower EGT, as with methanol blended gasoline, work transfer from piston to gases in cylinder at the end of compression stroke was too large, leading to reduction in EGT. From same Fig, it is noticed that EGT at full load decreased with advanced ignition timing with both versions of the combustion chamber, Improved oxygen-fuel ratios, incident time and higher expansion of exhaust gases might have improved combustion and causing less heat rejection with advanced ignition timing. CE with methanol blended gasoline reduced EGT at full load by 14% at 25^o bTDC and 16% at 28^o bTDC when compared with CE with gasoline operation. CCE with methanol blended gasoline reduced EGT at full load by 15% at 25^o bTDC and 13% at 27^o bTDC when compared with CCE with gasoline operation. Methanol blended gasoline decreased EGT at full load by 21% with CE at 25^o bTDC and 16% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline decreased BSEC at full load by 15% at 25^o bTDC and 13% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation decreased EGT at full load by 7% at recommended injection timing of 25^o bTDC and 8% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation decreased EGT at full load by 8% at 25^o bTDC and 5% at optimum injection timing in comparison with CE with methanol blended gasoline operation. Combustion improved with catalytic activity of combustion chamber producing useful work and causing less heat rejection, with CCE with both test fuels.

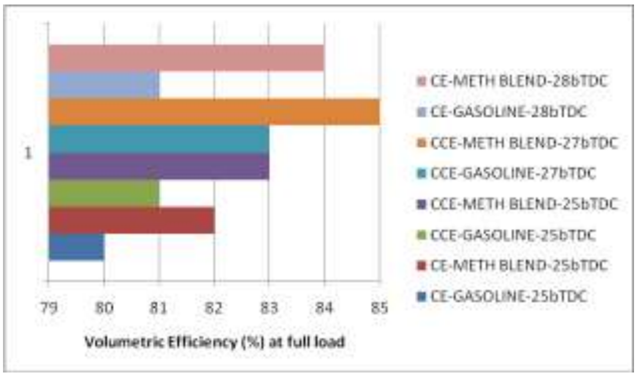


Fig. 7. Bar charts showing variation of volumetric efficiency at full load

Fig.7 presents bar charts showing the variation of volumetric efficiency at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig, 7, it indicates that methanol blended gasoline showed higher volumetric efficiency at full load in comparison with neat gasoline operation on both configuration of the engine with an increase of mass and density of air with reduction of the temperature of air due to high latent heat of evaporation of methanol. CCE showed higher volumetric efficiency in comparison with CE with different test fuels. Reduction of combustion chamber wall temperatures which in turn depends on EGT might have increased volumetric efficiency at full load. Volumetric efficiency marginally increased with advanced ignition timing with both versions of the combustion chamber. Reduction of EGT might have improved volumetric efficiency. Methanol blended gasoline increased volumetric efficiency at full load by 2% with CE at 25^o bTDC and 4% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline increased volumetric efficiency at full load by 2% at 25^o bTDC and 2% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation showed comparable volumetric efficiency at full load at recommended injection timing of 25^o b TDC and 2% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation showed comparable volumetric efficiency at full load at 25^o b TDC and at optimum injection timing in comparison with CE with methanol blended gasoline operation.

3.2 Exhaust Emissions

As mentioned in earlier article, breathing of exhaust emissions from SI engine causes health hazards. Hence control of these emissions is an important and an urgent task. Fig.8 presents bar charts showing the variation of carbon mono oxide (CO) emissions at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig, 8, it is noticed that methanol blended gasoline decreased CO emissions at full load when compared to neat gasoline operation on CCE and CE, as fuel-cracking reactions were eliminated with methanol. The combustion of methanol produced more water vapor than free carbon atoms as methanol has lower C/H ratio of 0.25 against 0.44 of gasoline. Methanol has oxygen in its structure and hence its blends have lower stoichiometric air requirements compared to gasoline. Therefore more oxygen that was available for combustion with the blends of methanol and gasoline, lead to reduction of CO emissions. Methanol dissociated in the combustion chamber of the engine forming hydrogen, which helped the fuel-air mixture to burn quickly and thus increases combustion velocity, which brought about complete combustion of carbon present in the fuel to CO_2 and also CO to CO_2 thus made leaner mixture more combustible, causing reduction of CO emissions. CCE reduced CO emissions in comparison with CE. Copper or its alloys acted as catalyst in combustion chamber, whereby facilitated effective combustion of fuel leading to formation of CO_2 instead of CO. CO emissions decreased with advanced ignition timing with both version of the combustion chamber. More utilization of oxygen and with increase of combustion period with advanced ignition timing might have reduced CO emissions at full load.

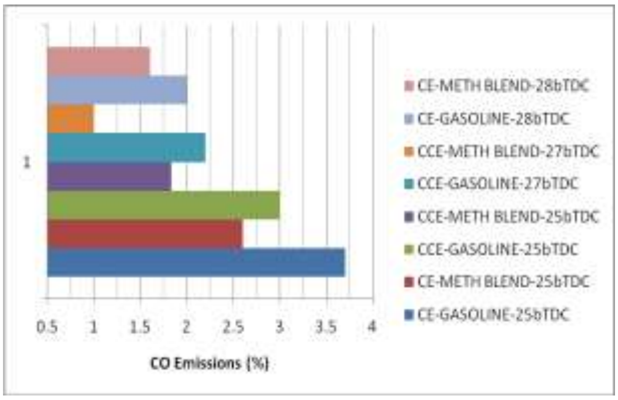


Fig. 8.Bar charts showing variation of carbon mono oxide (CO) emissions at full load

Methanol blended gasoline decreased CO emissions at full load by 30% with CE at 25^o bTDC and 20% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline decreased CO emissions at full load by 40% at 25^o bTDC and 54% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation decreased CO emissions at full load by 18% at recommended injection timing of 25^o bTDC and 10% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation decreased CO emissions at full load by 31% at 25^o b TDC and 29% at optimum injection timing in comparison with CE with methanol blended gasoline operation.

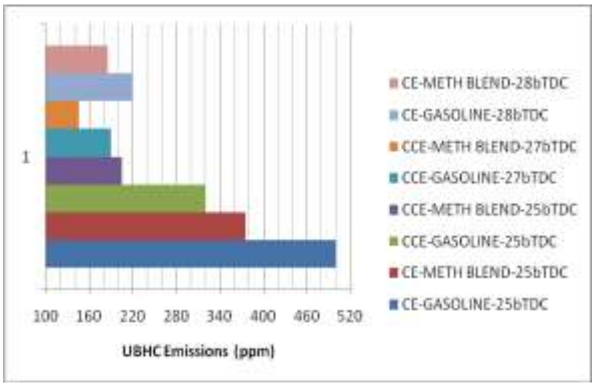


Fig. 9. Bar charts showing variation of un–burnt hydrocarbons (UBHC) at full load

Fig.9 presents bar charts showing the variation of un-burnt hydro carbons (UBHC) at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig, it is observed that, UBHC emissions followed the similar trends as CO emissions in CCE and CE with both test fuels, due to increase of flame speed with catalytic activity and reduction of quenching effect with CCE. Methanol blended gasoline decreased UBHC emissions at full load by25% with CE at 25^o bTDC and 16% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline decreased UBHC emissions at full load by 36% at 25^o bTDC and 16% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation decreased UBHC emissions at full load by 36% at recommended injection timing of 25^o b TDC and 14% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation decreased CO emissions at full load by 45% at 25^o b TDC and 19% at optimum injection timing in comparison with CE with methanol blended gasoline operation.

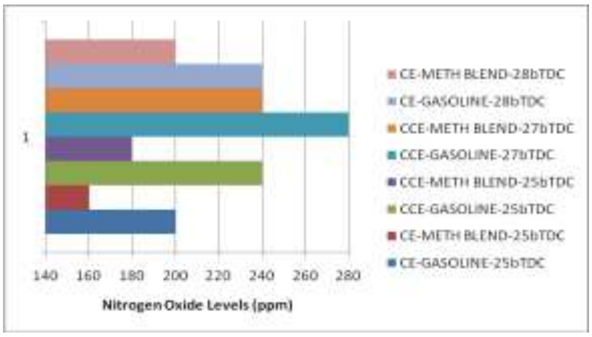


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Fig.10 Bar charts showing the variation of nitrogen oxide levels**.**

Fig.10 presents bar charts showing the variation of nitrogen oxide (NO_x) levels at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. Methanol blended gasoline reduced NO_x levels effectively in comparison with neat gasoline with both versions of the engine. High latent heat of vaporization of methanol might have reduced combustion temperatures leading to decrease NO_x levels. However, CCE marginally increased NO_x emissions with gasoline operation at recommended ignition timing, as combustion chamber was more hot. With advanced ignition timing, NO_x emissions increased with both versions of the engine with both test fuels. Many researchers confirmed this trend with CE with gasoline as fuel with an increase of resident time and gas temperatures. **[**1–3, 16–18**].** When spark plug timing was advanced, maximum heat release at full load during combustion increased, which confirmed the trend of NO_x emissions with advanced ignition timing. [Fig.16]. Methanol blended gasoline decreased NO_x emissions at full load by 20% with CE at 25^o bTDC and 16% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline decreased NO_x emissions at full load by 25% at 25^o bTDC and 21% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation increased NO_x emissions at full load by 20% at recommended ignition timing of 25^o bTDC and 16% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation increased NO_x emissions at full load by 12% at 25^o b TDC and 20% at optimum injection timing in comparison with CE with methanol blended gasoline operation.

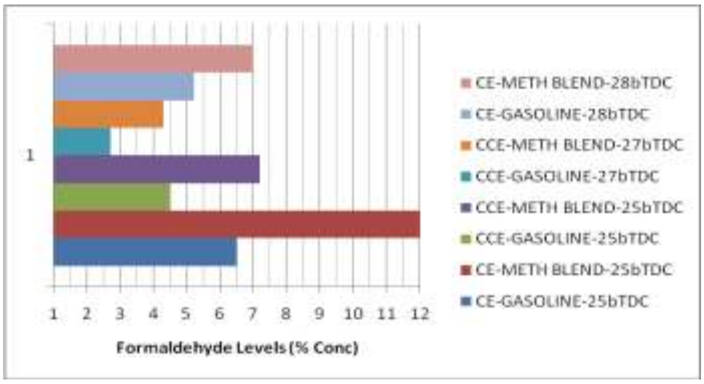

Fig 11. Bar charts showing variation of formaldehyde concentration at full load

When the engine is run with alcohol, aldehydes levels should be checked. These aldehydes are carcinogenic in nature. Hence control of aldehydes is an important task. Fig.11 presents bar charts showing the variation of formaldehyde concentration at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. It is observed from Fig.11, that formaldehyde emissions were higher with methanol blended gasoline operation in both versions of the combustion chamber in comparison with gasoline operation. Partial oxidation of alcohol might have caused higher aldehyde levels, compared to neat gasoline. The low combustion temperature lead to produce partially oxidized carbonyl (aldehyde) compounds with methanol blended gasoline. Formaldehyde emissions were quiet low with non-alcoholic fuels with engine with copper coated combustion chamber as noticed from the same table. Formaldehyde emissions at full load decreased with advanced ignition timings with both versions of the combustion chamber. Reduction of formation of intermediate compounds during combustion with increased resident time with fuel and oxygen might have caused reduction of formaldehyde levels at full load operation. Formaldehyde emissions were reduced by 20% with CE and 40% with CCE, when the ignition timings were advanced to their optimum values, which confirmed that combustion improved with CCE with advanced ignition timing. Methanol blended gasoline increased formaldehyde emissions at full load by 85% with CE at 25^o bTDC and 35% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline increased formaldehyde emissions at full load by 60% at 25^o bTDC and 59% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation decreased formaldehyde emissions at full load by 31% at recommended injection timing of 25^o bTDC and 48% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation decreased formaldehyde emissions at full load by 40% at 25^o bTDC and 38% at optimum injection timing in comparison with CE with methanol blended gasoline operation. This showed that CCE effectively reduced formaldehyde emissions at full load.

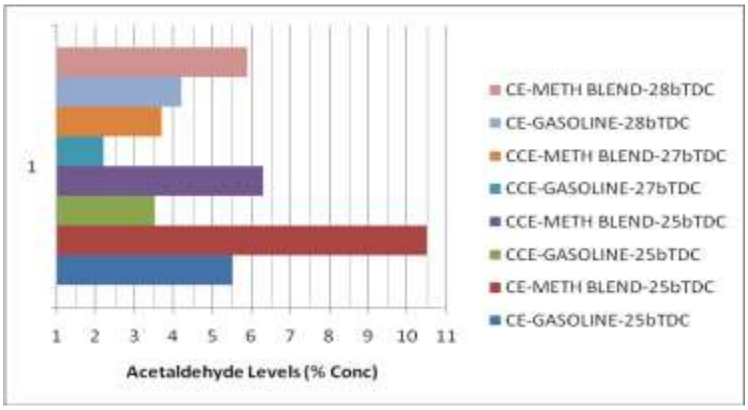

Fig.12.Bar charts showing variation of acetaldehyde concentration at full load

Fig.12 presents bar charts showing the variation of acetaldehyde concentration at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. Acetaldehyde emissions followed the similar trend as in case of formaldehyde emissions with both versions of the combustion chamber. Methanol blended gasoline increased acetaldehyde emissions at full load by 91 % with CE at 25^o bTDC and 41% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline increased acetaldehyde emissions at full load by

80% at 25° bTDC and 68% at 27° bTDC when compared with CCE with gasoline operation. CCE with gasoline operation decreased acetaldehyde emissions at full load by 36% at recommended injection timing of 25° bTDC and 48% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation decreased acetaldehyde emissions at full load by 40% at 25° b TDC and 37% at optimum injection timing in comparison with CE with methanol blended gasoline operation. This showed that CCE effectively reduced acetaldehyde emissions at full load.

3.2.1. Catalytic Converter for Control of CO and UBHC Emissions

Table.4 shows data of pollution levels with SI engine provided with catalytic converter with sponge iron as catalyst with different operating conditions as mentioned in earlier article. The catalytic converter was operated with void ratio of 0.6, as void ratio of 0.6 was found to be an optimum by earlier researchers [36–39]. Void ratio is defined as ratio of volume occupied by catalyst to the volume occupied by the catalytic chamber. Set–B operation (with the use of catalyst) of the catalytic converter with sponge iron as catalyst decreased pollution levels of CO, UBHC and aldehyde emissions by 40% when compared with Set–A operation (without use of catalytic chamber) with test fuels. Improved oxidation reaction of the catalyst might have reduced pollution levels Set–C operation (with the use of catalytic converter and air injection) of the catalytic converter with sponge iron as catalyst further decreased pollution levels by 70% when compared with Set–A condition of the catalytic converter. Sponge iron was proved to be efficient in reducing formaldehyde emissions due to its large surface area. [26, 47–50]. Catalytic converter reduced pollutants of CO, UBHC and aldehyde emissions considerably with CE and CCE. Air injection into catalytic converter further reduced pollution levels. Similar trends were reported on reduction of these pollutants with catalytic converter employed to two–stroke copper coated SI engine of brake power 2.2 kW at a speed of 3000 rpm and compression ratio of 9:1 [70–71].

Table.4

Data of Pollution Levels at full load with catalytic converter at 25° bTDC

Pollutant	Set	Gasoline		Methonol Blend(MB)	
		CE	CCE	CE	CCE
CO Emissions (%0)	Set-A	3.7	3.0	2.6	1.83
	Set-B	2.2	1.8	1.6	1.1
	Set-C	1.1	0.9	0.8	0.5
UBHC Emission(ppm)	Set-A	500	320	375	205
	Set-B	300	195	225	125
	Set-C	150	95	115	65
Formaldehyde Levels (% Concentration)	Set-A	6.5	4.5	12	7.2
	Set-B	4.0	2.7	7.5	4.5
	Set-C	1.9	1.3	3.5	2.2
Acetaldehyde Levels (% Concentration)	Set-A	5.5	3.5	10.5	6.3
	Set-B	3.3	2.0	6.5	3.8
	Set-C	1.7	1.1	3.2	1.9

3.2.2 Catalytic Converter for Control of NO_x Emissions

NO_x emissions increased with engine with CCE with test fuels, causing severe health hazards as mentioned in earlier article. Hence the attention was focused in reducing NO_x emissions by providing catalytic converter which employed the principle of selective catalytic reduction technique. The catalytic chamber was operated with void ratio of 0.6, as void ratio of 0.6 was proved to be an optimum. [53–56]. That means catalysts were more efficient in reduction of NO_x at a void ratio of 0.6, beyond which a declination in catalytic activity was observed with test fuels. This could be due to reduction in extent of exposure of catalyst to the exhaust gases. Increase of backpressure on engine beyond void ratio of 0.6 might have reduced catalytic activity.

Table.5

Data of NOx Emissions

Ignition Timing in degrees before Top Dead Center	Operating Condition of Catalyst	CE		CCE	
		Gasoline	Methanol blended gasoline	Gasoline	Methanol blended gasoline
25	Without catalyst	200	160	240	180
	With Catalyst–A	160	120	190	140
	With Catalyst–B	120	90	150	110
27	Without catalyst	--	---	280	240
	With Catalyst–A	---	---	225	180

	With Catalyst-B	---	---	170	145
28	Without catalyst	240	200	---	---
	With Catalyst–A	190	150	---	---
	With Catalyst–B	145	110	---	---

Table.5 shows data of NO_x emissions with use of catalyst-A (modified zeolite) and Catalyst-B (lanthanum zeolite infused with urea). The recommended ignition timing was at 25^o bTDC, while optimum ignition timing was 27^o bTDC for CCE with both test fuels. The optimum ignition timing was 28^o bTDC with CE with both test fuels.

Urea decomposed into ammonia which reacted with NO and NO_2 present in exhaust gases.

The two main reactions are

$4NH_3 + 2NO + 2NO_2 \rightarrow 4N_2 + 6H_2O$

$2NH_3 + 2NO_2 \rightarrow NH_4NO_3 + N_2 + H_2O$.

From Table. 4, it is observed that higher levels of NO_x emissions in CCE in comparison with CE was due to prevailing of high temperatures in the combustion chamber leading to formation of higher levels of NO_x by the oxidation reaction. Catalyst–B reduced NO_x levels more effectively than catalyst–A for CE with test fuels. The hydrolysis of urea in catalyst–B gave ammonia which also reduced NO_x to nitrogen apart from cracking reaction of NO_x. A decline in percentage reduction of NO_x content with catalyst–B on engine with CCE compared to conventional engine could be due to dissociation of urea at higher temperature. Catalyst–A with CE at 25^o bTDC with gasoline operation reduced NO_x levels at full load by 20% in comparison with gasoline operation without catalyst. At 25^o bTDC, Catalyst–A with CE with methanol blended operation decreased NO_x emissions by 25% in comparison with methanol blended gasoline operation without catalyst. Catalyst–B with CE at 25^o bTDC with gasoline operation reduced NO_x levels at full load by 40% in comparison with gasoline operation without catalyst. At 25^o bTDC, Catalyst–B with CE with methanol blended operation decreased NOx emissions by 44% in comparison with methanol blended gasoline operation without catalyst. At 25^o bTDC, Catalyst–A with gasoline operation on CCE reduced NO_x levels at full load by 21% in comparison with CCE with gasoline operation without catalyst. At 25^o bTDC , Catalyst–A with methanol blended gasoline operation on CCE reduced NO_x levels at full load by 22% in comparison with CCE with methanol blended gasoline operation. At 25^o bTDC, Catalyst–B with gasoline operation on CCE reduced NO_x levels at full load by 38% in comparison with CCE with gasoline operation without catalyst. Catalyst–B with methanol blended gasoline operation on CCE reduced NO_x levels at full load by 39% in comparison with CCE with methanol blended gasoline operation without catalyst. At optimum injection timings also, similar trends were observed with both versions of the engine with both test fuels. CE at an optimum ignition timing of 28^o bTDC with gasoline operation with Catalyst–A, showed comparable NO_x levels, while with catalyst–B, it showed a reduction of 28% with in comparison with CE with gasoline operation at 25^o bTDC. CE at an optimum ignition timing of 28^o bTDC with methanol blended gasoline with Catalyst–A reduced NO_x levels by 25%, while with catalyst–B, it showed a reduction of 45% in comparison with CE with gasoline operation at 25^o bTDC. CCE at an optimum ignition timing of 27^o bTDC with gasoline operation with Catalyst–A increased NO_x levels by 13%, while with catalyst–B, it reduced them by 15% in comparison with gasoline operation on CE at 25^o bTDC. CCE at an optimum ignition timing of 27^o bTDC with methanol blended gasoline operation with Catalyst–A reduced NO_x levels by 10%, while catalyst–B showed a reduction of 28% in comparison with CE with gasoline operation at 25^o bTDC.

3.3 Combustion characteristics

Fig.13 presents bar charts showing the variation of peak pressure at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. Methanol blended gasoline increased PP at full load by 32% with CE at 25^o bTDC and 30% at 28^o bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline increased PP at full load by 32% at 25^o bTDC and 32% at 27^o bTDC when compared with CCE with gasoline operation. CCE with gasoline operation increased peak pressure at full load by 30% at recommended injection timing of 25^o b TDC and 3% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation increased peak pressure at full load by 29% at 25^o bTDC and 3% at optimum injection timing in comparison with CE with methanol blended gasoline operation. Combustion improved with catalytic activity of combustion chamber producing higher peak pressure with CCE with both test fuels. Assuming all the fuel enter the engine completely evaporated, the fuel giving largest number of moles of product per mole of reactant should produce the greatest pressure in the cylinder after the combustion, all other factors being equal (which incidentally are not) The greater pressure taken alone would result in an increase in engine power. 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. Consider the fuel to enter the cylinder in liquid state points to a somewhat enhanced power output from methanol on this rather simple basis (Table 6).

Table.6

Comparative moles of products per moles of air at chemically correct mixture ratio neglecting dissociation.

Fuel	Dry Basis		Wet Basis	
	Ratio	Compared to gasoline	Ratio	Compared to gasoline
Gasoline	1.058	1.00	1.075	1.00
Methanol	1.061	1.004	1.140	1.061

The ratios of moles of products to the reactants for gasoline and alcohols are as follows:

$1.0588C_8H_{18}+12.5O_2+47N_2 \rightarrow 8CO_2+9H_2O+47N_2$

(60.5 mol) (64.0 mol)

$1.061CH_3OH+1.5O_2+5.65N_2 \rightarrow CO_2+2H_2O+5.65N_2$

(8.15 mol) (8.65 mol)

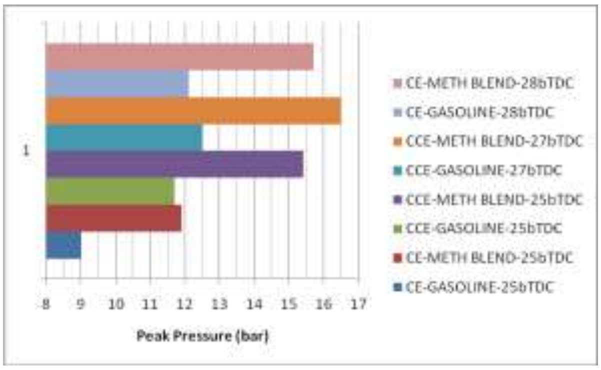

Fig. 13. Bar charts showing variation of peak pressure at full load

Fig.13 presents bar charts showing the variation of time of occurrence of peak pressure (TOPP) at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig.14, it is noticed that TOPP decreased with methanol blended gasoline operation in comparison with pure gasoline operation on both versions of the engine, which confirmed that performance improved with efficient combustion with CCE. This was because CE exhibited higher temperatures of combustion chamber walls leading to continuation of combustion, giving peak pressures away from TDC. However, this phenomenon was nullified with CCE with methanol blended gasoline because of reduced temperature of combustion chamber walls thus bringing the peak pressures closure to TDC. CE with gasoline operation exhibited pressure on the piston by the time the piston already started executing downward motion from TDC to BDC leading to decrease PP and increase TOPP. Higher PP and lower TOPP confirmed that performance of the CCE with methanol blended gasoline improved causing efficient energy utilization on the piston. Methanol addition improved the combustion process, reduced the crevices flow energy, reduced the cylinder temperature, reduced the ignition delay, speeded up the flame front propagation, and reduced the duration of combustion. TOPP at full load was found to be lower (nearer to TDC) with CCE with methanol blended gasoline compared with CE with neat gasoline.

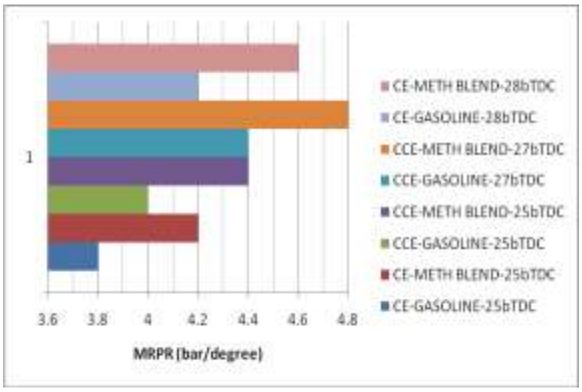

Fig. 14. Bar charts showing variation of maximum rate of pressure rise (MRPR) at full load

Fig.14presents bar charts showing the variation of maximum rate of pressure rise (MRPR) at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. From Fig.12, it is observed that the trends of MRPR were similar to those of PP. MRPR at full load increased with induction of methanol blended gasoline with both versions of the engine. Combustion improved with methanol induction with lean mixtures as stoichiometric air fuel ratio is lower with methanol blend. CCE increased MRPR at full load marginally with improved combustion as catalytic activity is more pronounced at full load. Methanol blended gasoline increased MRPR at full load by 42% with CE at 25^{o} bTDC and 10% at 28^{o} bTDC in comparison with neat gasoline operation. CCE with methanol blended gasoline increased MRPR at full load by 10% at 25^{o} bTDC and 9% at 27^{o} bTDC when compared with CCE with gasoline operation. CCE with gasoline operation showed comparable MRPR at full load at recommended injection timing of 25^{o} bTDC and at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation showed comparable MRPR at full load at 25^{o} bTDC and at optimum injection timing in comparison with CE with methanol blended gasoline operation.

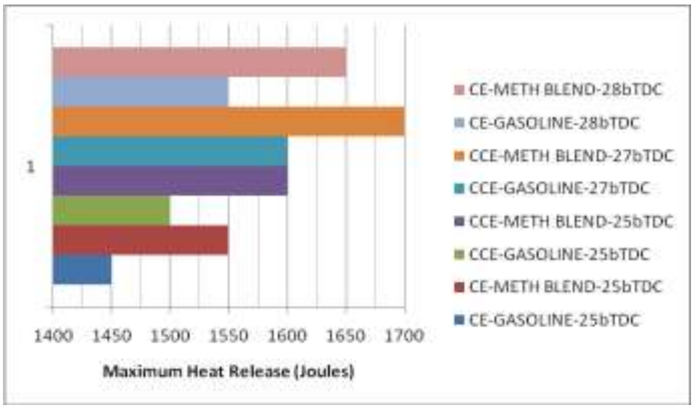

Fig.15. Bar charts showing variation of maximum heat release at full load

Fig.15 presents bar charts showing the variation of maximum heat release at full load with different versions of the engine at recommended ignition timing and optimum ignition timing with test fuels at a compression ratio of 9:1 and speed of 3000 rpm. Combustion of lean mixtures of methanol blended gasoline might have improved the performance of the engine causing higher heat release rate. Methanol blended gasoline increased maximum heat release at full load by 7% with CE at 25^{o} bTDC and 6% at 28^{o} bTDC in comparison with neat gasoline operation. The presence of oxygen in methanol might have improved combustion causing higher heat release at full load with methanol blended gasoline. CCE with methanol blended gasoline increased maximum heat release at full load by 32% at 25^{o} bTDC and 32% at 27^{o} bTDC when compared with CCE with gasoline operation. CCE with gasoline operation by 3% at recommended injection timing of 25^{o} bTDC and 3% at optimum injection timing in comparison with CE with gasoline operation. CCE with methanol blended gasoline operation increased maximum heat release rate at full load by 3% at 25^{o} bTDC and 3% at optimum injection timing in comparison with CE with methanol blended gasoline operation. Increase if turbulence with pronounced activity of catalytic chamber caused higher heat release rate.

IV. Conclusions

The optimum ignition timing was obtained with CE was 28^{o} bTDC while it was 27^{o} bTDC with CCE with test fuels. Engine with copper coated combustion chamber showed improved performance over CE with test fuels at recommended ignition timing and optimum ignition timing. Methanol blended gasoline improved performance over gasoline operation on both versions of the combustion chamber. Increased ignition advance showed improved performance, reduction of exhaust emissions and improved combustion characteristics with both versions of the combustion chamber. Catalytic converter with sponge iron as catalyst along with air injection effectively reduced pollution levels of CO, UBHC and aldehydes with both versions of the combustion chamber with test fuels. CE at an optimum ignition timing of 28^{o} bTDC with methanol blended gasoline with Catalyst–A reduced NO_x levels by 25%, while with catalyst–B, it showed a reduction of 45% in comparison with CE with gasoline operation at25^{o} bTDC. CCE at an optimum ignition timing of 27^{o} bTDC with methanol blended gasoline operation with Catalyst–A reduced NO_x levels by 10%, while with catalyst–B, it reduced them by 28% in comparison with CE with gasoline operation at 25^{o} bTDC.

Scientific Significance

The performance of spark ignition engine is improved by change of i) fuel composition (gasoline to alcohol blended gasoline), ii) configuration of the engine (from conventional engine to copper coated engine and iii) with provision of catalytic converter with varied ignition timing.

Social Significance:

Methanol is a renewable fuel. It can be used as fuel in SI engine as blended fuel with gasoline in order to combat economy problem in importing crude petroleum, so as to save foreign exchange which otherwise can be spent for important sectors like poverty, health, agriculture, education, industry and defense. Rural employment can be improved in cultivating waste lands.

Future Scope of Studies

Spark ignition engine can be run with 100% alcohol with adjusting spark plug timings. The durability of copper coating can be tested.

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