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CONTROL OF POLLUTANTS FROM COPPER COATED SPARK IGNITION ENGINE WITH BUTANOL BLENDED GASOLINE

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ABSTRACT

Exhaust emissions of carbon mono oxide (CO), ub0 burnt hydro carbons (HC) emissions and nitrogen oxide (NO_x) levels from spark ignition (SI) engine cause health hazards, environmental impact and green-house effect. Alcohols are important substitutes for gasoline, as their properties are comparable to gasoline fuel. If engine is run with alcohol, aldehydes, which are carcinogenic in nature, are also to be checked. Investigations were carried out to control pollutants from a four % stroke, variable speed, variable compression ratio, single % cylinder, spark ignition (SI) engine, with normal butanol blended gasoline (80% gasoline and 20% butanol by volume) having copper coated combustion chamber [CCE, copper-(thickness, 300 ìm) coated on piston crown, inner side of cylinder head and on liner] provided with catalytic converter with copper as catalyst and compared with conventional SI engine (CE) with neat gasoline operation. Exhaust emissions of CO, HC, and NO_x were evaluated at different values of brake mean effective pressure of the engine. A microprocessor-based analyser was used for the measurement of nitrogen oxide levels and CO/HC in the exhaust of the engine. Aldehydes of formaldehyde and acetaldehyde levels were measured by wet-method. The engine was provided with catalytic converter with copperas catalyst along with air injection. Copper coated combustion chamber with butanol blended gasoline considerably reduced pollutants in comparison with CE with neat gasoline operation. Catalytic converter with air injection significantly reduced pollutants with test fuels on both configurations of the engine.

KEY WORDS : S.I. Engine, copper coated combustion chamber, Alternative fuels, Exhaust emissions, Catalytic converter, Air injection.

INTRODUCTION

It is concluded that SI engine is preferred over compression ignition (CI) engine as CI combustion is time controlled, which is diffusion combustion.SI combustion is speed controlled, which is premixed combustion (Ferguson *et al.,* 2001).

Engine modification 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 improved with copper coating. Nedunchezhian and Dhandapani, 2000; Murali Krishna *et al.,* 2012 a; Murali Krishna *et al.*, 2012.b). The use of catalysts to promote combustion is an old concept. More recently copper was coated over piston crown and inside of cylinder head wall. They reported that the catalyst improved the fuel economy and increased combustion stabilization. However, in previous studies, copper coating was restricted to crown of the piston and inside portion of cylinder head only. However, copper coating was not attempted on inside potion of liner. That too, investigations were carried out with two-stroke engine but not on four-stroke engine. Due to heavy consumption of gasoline fuels in SI engines being used for individual transport, improper maintenance of the vehicles, bad layout of roads and poor mass transport systems, the major concern has been the effective fuel utilization and energy conservation. These factors force the engine manufacturers, users and researchers to involve in combustion and alternative fuel research. The main objective of any engine designer is that the engine should give maximum thermal efficiency with minimum pollution levels. To achieve this, different alternative and renewable fuels have been used in SI engines by many researchers. Among all the fuels, alcohols are the most promising fuels for future as they are renewable and oxygenated fuels. Engine designs are modified to improve the thermal efficiency and to minimize the pollutants from the spark ignition engines. Catalytic converters provide a simple solution to control the pollutants with abundantly available and inexpensive catalysts. Carbon monoxide (CO) and un-burnt hydrocarbons (UBHC), major exhaust pollutants formed due to incomplete combustion of fuel, cause many human health disorders (Usha Madhuri *et al*., 2003; Fulekar *et al*., 2004; Sharma, 2004; Ghose *et al*., 2004; Khopkar, 2005). These pollutants cause asthma, bronchitis, emphysema, slowing down of reflexes, vomiting sensation, dizziness, drowsiness, etc. Such pollutants also cause detrimental effects on animal and plant life, besides environmental disorders (Fulekaret a, 2004). Age and maintenance of the vehicle are some of the reasons for the formation of pollutants (Usha Madhuri *et al.,* 2003). Alcohol was blended with gasoline to reduce pollutants. Aldehydes which are intermediate compounds formed in combustion, are carcinogenic in nature and cause detrimental effects on human health and hence control of these pollutants is an immediate task (Murthy *et al*., 2010; Murthy et al, 2011; Indira Priyadarshni *et al*., 2014; Nagini *et al*., 2014).

CO and UBHC emissions reduced with blends of alcohol with gasoline (Liu Shenghua *et al.,* 2007; Murali Krishna and Kishor, 2008; Ibrahim Thamer Nazzal, 2011). Methanol is high volatile fuel and has low C/H ratio (C=Number of carbon atoms and H=Number of hydrogen atoms in fuel composition). However, the consumption of methanol causes ill effects for health particularly eyesight. Ethanol has higher calorific value than methanol, but higher C/H ratio. It is also considered as dangerous fuel, as nervous system will be damaged with the consumption of ethanol. Butanol improves the homogeneity of the fuel and it mixes readily with gasoline fuel. Excess of butanol content (more than 20% by volume) with gasoline absorbs combustion temperatures leading to poor start ability of the engine at constant ignition timing. Catalytic converter is one of the effective methods to reduce pollutants in SI engine (Murali Krishna *et al*., 2010; Narasimha Kumar *et al*., 2011; Indira Priyadarshni *et al*., 2014; Nagini *et al*., 2014). Reduction of pollutants depended on mass of the catalyst, void ratio (ratio of volume occupied by the catalyst to volume of the catalytic chamber), temperature of the catalyst, amount of air injected in the catalytic chamber.A reduction of 40% was reported with use of sponge iron catalyst while with air injection in the catalytic chamber reduced pollutants by 60%.

The objective of the present paper is to control the pollutants from of four-stroke, SI engine with butanol blended gasolinewith butanol blended gasoline (80% gasoline and 20% butanol by volume) having copper coated combustion chamber [CCE, copper-(thickness, 300 μm) coated on piston crown, inner side of cylinder head and on liner] provided with catalytic converter with copper as catalyst and compared with conventional SI engine (CE) with neat gasoline operation.

The experiments were conducted with emphasis on the change of fuel composition (neat gasoline to gasoline blended gasoline), combustion chamber design (conventional combustion chamber to copper coated combustion chamber) and with the provision of the catalytic converter.

MATERIALS AND METHODS

Butanol has higher calorific value (36500 kJ/kg) than ethanol (26,700 kJ/kg) and methanol (19,700 kJ/kg). Its research octane number (RON) is 108. It is manufactured from biomass or municipal waste. The properties of butanoland gasoline are given in Table 1.

In catalytic coated combustion chamber, crown of the piston and inner surface of cylinder head were 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 was sprayed over which copper (89.5%), aluminium (9.5%) and iron (1%) alloy of thickness 300 microns was coated with METCO flame spray gun. The coating has very high bond strength and does not wear off even after 50 h of operation (Nedunchezhian and Dhandapani, 2000).

Fig. 1. shows schematic diagram for experimental

set-up used for investigations. A four- stroke, single-cylinder, water-cooled, SI engine (1) (brake power 2.2 kW, rated speed 3000 A rpm) was coupled to an eddy current dynamometer (2) for measuring its brake power. The bore of the cylinder was 70 mm while stroke of the piston was 66 mm. Load box (3) arrangement was provided to change the load. Air consumption of the engine was determined with the help of air circuit, consisting of an orifice meter (4), U-tube water manometer (5) and air-box (6). Fuel consumption of the engine was determined by fuel circuit, consisting of fuel tank (7), three-way valve (8) and burette (9). The exhaust gas temperature of the engine was measured with temperature sensors (10). Compression ratio of engine was varied (3:1-9:1) with change of clearance volume by adjustment of cylinder head, threaded to cylinder of the engine.Engine speeds were varied from 2400 to 3000 rpm. The shape of the combustion chamber is T-head type. The combustion chamber has one inlet valve and one exhaust value. The spark plug is centrally located at cylinder head. Netel Chromatograph Multi-analyser (11) was used to measure carbon monoxide (CO) emissions, un-burnt hydrocarbons (UBHC) and oxides of nitrogen (NO_x) The range of CO levels, UBHC emissions and NO_x levels are 0-10%, 0-2000 pm and 0-5000 pm. The accuracy of the measurement of these analysers is shown in Table 2. The engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Recommended spark ignition timing (RIT) was 25°bTDC (before top dead centre).

Air compressor (12) was used to send air into catalytic converter at a pressure of 0.8 bar. Outlet jacket temperature indicator (13) and outlet jacket water flow meter (14) were used to determine temperature of the coolant and its mass flow rate. Outlet jacket temperature was a temperature sensor. Direction valves (15) were used to change the direction of the gases. Rotometer (16) was used to send fixed quantity (6l/m) of air into catalytic converter. Catalytic converter consisted of two chambers, air chamber (17) and catalytic chamber

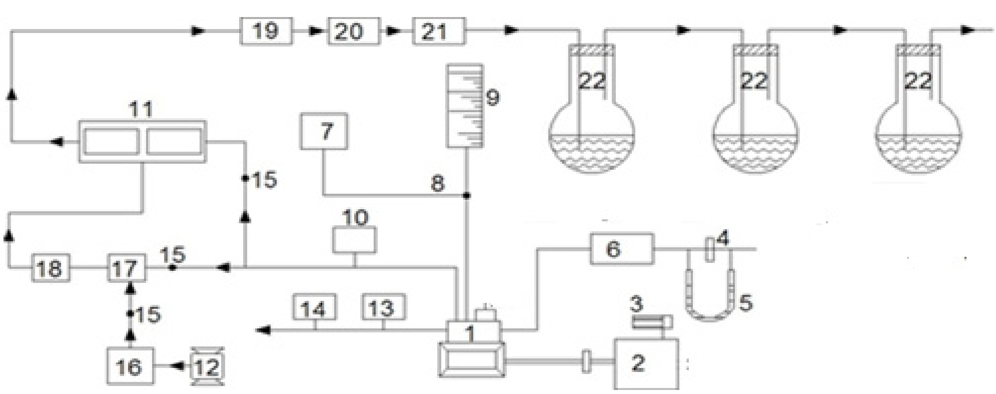


Fig. 1. Schematic Diagram of Experimental set up

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 sensors, 11 Multi analyzer, 12. Air compressor, 13. Outlet jacket water temperature indicator, 14. Outlet jacket water flow meter, 15. Directional valve, 16. Rotameter, 17. Air chamber, 18. Catalytic chamber, 19. Filter, 20. Rotameter, 21.Heater, 22. Round bottom flasks containing DNPH solution

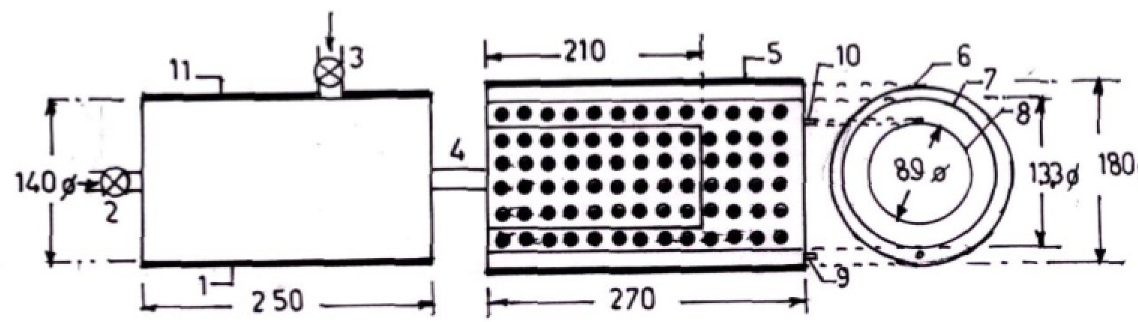
Table 1. Properties of butanol and gasoline

Fuel Property		Butanol	Gasoline
Formula		CH_4H_9OH	C_8H_{15}
Research Octane Number		108	90-99
Composition (C,H,O)	(% mass)	65,13.5,21.5	86,14,0
Density (kg/m^3) at 20°C		810	745
Boiling point (°C)		117.7	25-215
Latent heat of vaporization (kJ/kg) at 20°C		582	223.2
Saturation pressure (kPa) at 38°C.		2.27	31.01
Low heating value (MJ/kg)		33.3	43
Auto ignition temperature (°C)		385	420
Stoichiometric air/fuel ratio		11.12	14.7

(18). A catalytic converter (Fig. 2) was fitted to exhaust pipe of engine. Provision was also made to inject a definite quantity of air (6 l/m) and pressure (0.8 bar) into catalytic converter. Air quantity drawn from compressor and injected into converter was kept constant so that backpressure does not increase. A definite quantity (250 grams each) of sponge iron/ copper/anthracite coal was taken for reduction of pollutants in the experiment. There was provision for the catalytic chamber to deposit catalyst. These catalysts were grounded to size of 2cm×2 cm. Experiments are carried out on CE and copper coated combustion chamber with different test fuels [neat gasoline and butanol blended gasoline (20% by vol)] 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.

For measuring aldehydes in the exhaust of the engine, a wet chemical method is employed. (Murthy *et al.,* 2010). The exhaust of the engine was purified by means of filter (19). A fixed quantity (2 l/m) of exhaust determined by a rotometer (20) was heated up to 140°C by means of heater (21) and bubbled through 2,4-dinitrophenyl hydrazine (DNPH) in hydrochloric acid solution taken in round bottom flask (22). Hydrazones formed from aldehydes were extracted into chloroform and were analysed by high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine.

Fig. 2 shows schematic diagram of details of catalytic converter. Catalytic converter contained air chamber (1). It has got inlet from engine (2) and inlet from compressor (3). The outlet (4) of air chamber was connected to catalytic chamber (5). It contained outer cylinder (6), intermediate cylinder (7) and inner cylinder (8). Provision (9) was made for the exhaust gas to leave from catalytic chamber. There was provision (10) made to deposit the catalyst. Insulation (11) was provided to avoid the loss of heat.



Note: All dimensions are in mm.

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

Table 2. Shows accuracies involved with instruments.

Accuracies Associated with Instruments		
Instrument	Purpose	Accurary
EGT indicator	For measuring exhaust gas temperature (EGT)	±5 °C
Tachometer	For measuring speed of the engine	5 ± rpm
Burette	For measuring flow rate of fuel to the engine	0.5 cc/s
Stop watch	For noting down time taken for 10 cc of fuel	0.5 Sec
Hydrometer	For noting density of fuel	0.1 gm/cc
Dynamometer	For measuring brake power of the engine	1 watt
Water flow meter	For measuring water flow rate to the engine	5 gm/s
CO Analyzer	For measuring CO emisions	0.1%
UBHC Analyzer	For measuring UBHC emisions	1 pp,
NOx Analyzer	For measuring nitrogen oxide levels	5 ppm

RESULTS AND DISCUSSION

As the experimental engine was a variable compression ratio engine, higher compression ratio was preferred as it improves thermal efficiency of the engine. Butanol with a RON of 108 allowed compression ratio of 9:1. Hence throughout the experiment the compression ratio was maintained as 9:1. The engine was variable speed engine, with 2400 rpm- 3000 rpm. Higher speed increases turbulence which promotes combustion. Hence throughout the experiment, higher speed of 3000 rpm was maintained with the engine (Nedunchezhian and Dhandapani, 2000). The maximum blend ratio of butanol with neat gasoline was found to be 20% by volume. Excess butanolthan optimum quantity would absorbcombustion temperatures and thus lowers efficiency of the engine.

Fig. 3 shows the variation of carbon monoxide (CO) emissions with brake mean effective pressure (BMEP) in different versions of the engine with both neat gasoline and butanol blended gasoline at a compression ratio of 9:1 and speed of 3000 rpm at an ignition timing of 25 ^{0}bTDC. CO emissions decreased with butanol blended gasoline at all loads when compared to neat gasoline operation on copper coated combustion chamber and CE, as fuel-cracking reactions were eliminated with butanol

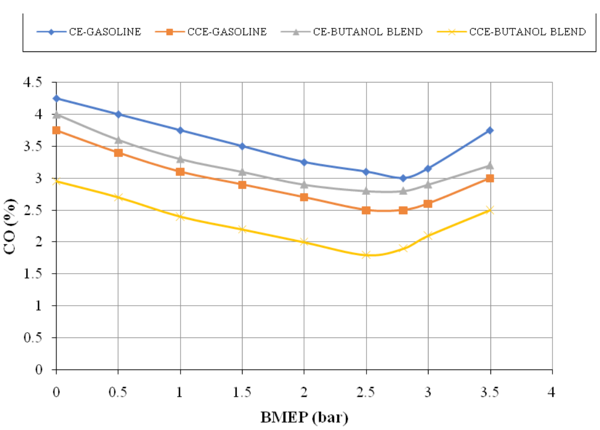


Fig. 3. Variation of carbon monoxide levels (CO) with brake mean effective pressure (BMEP)

(Murthy *et al.*, 2010). The combustion of butanol produces more water vapor than free carbon atoms as butanolhas lower C/H ratio of 0.4 against of 0.50 of gasoline. Butanol 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 butanol, leads to reduction of CO emissions. Butanol dissociates in the combustion chamber of the engine forming hydrogen, which helps the oxygen-air mixture to burn quickly and thus increases combustion velocity, which brings about complete combustion of carbon present in the fuel to CO_2 and also CO to CO_2 thus makes leaner mixture more combustible, causing reduction of CO emissions. CCE reduced CO emissions in comparison with CE at all loads with both test fuels. Copper or its alloys acts as catalyst in combustion chamber, whereby facilitates effective combustion of fuel leading to formation of CO_2 instead of CO.

Table 3 shows the data of CO emissions and UBHC emissions with different test fuels at recommended ignition timing (RIT) and optimum ignition timing (OIT) with different versions of the engine at different operating conditions of the catalytic converter with different catalysts. The catalytic converter was operated at room temperature with the weight of the catalyst as 500 grams. The flow rate of air was maintained at optimum configuration of 6 l/s measured with rotameter. From Table, it can be observed that CO emissions deceased considerably (40%) with catalytic operation in set-B with butanol blended gasoline and further decrease (60%) in CO was pronounced with air injection with the same fuel. The effective combustion of the butanol blended gasoline itself decreased CO emissions in both configurations of the combustion chamber. CO emissions at full load were observed to be lower with butanol blended gasoline operation in comparison with neat gasoline operation in both versions of the combustion chamber at different operating conditions of the catalytic converter.

Table 3. Data of CO emissions (%) and un-burnt hydrocarbons (HC) fullload (ppm)

Set	Conventional Engine(CE)				Copper Coated Engine (CCE)			
	Neat Gasoline		Butanol blended gasoline		Neat Gasoline		Butanol blended gasoline	
	CO (%)	HC (ppm)	CO(%)	HC(ppm)	CO(%)	HC(ppm)	CO(%)	HC(ppm)
Set-A	3.7	500	2.5	280	3.0	320	1.8	230
Set-B	1.8	250	1.3	110	1.4	155	0.9	80
Set-C	0.9	125	0.6	65	0.8	70	0.4	50

Lower C/H ratio of butanol blended gasoline have lowered CO emissions at full load. Advanced ignition timing reduced CO emissions with different versions of the engine with test fuels. More time was allowed for combustion reactions to take place leading to improve combustion and improved atomization of fuel lowered CO emissions. Copper as catalyst reduced CO, HC emissions considerably, as it is good oxidizing agent.

Fig. 4 shows the variation of un-burnt hydro carbon emissions (HC) with brake mean effective pressure (BMEP) with different versions of engine with test fuels, at a speed of 3000 rpm, compression ratio of 9:1 and spark ignition timing of 25^0bTDC. UBHC emissions followed the similar trends as CO emissions with 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.

From Table 3, it is observed that HC emissions followed similar trends with CO emissions in both versions of the combustion chamber with both test fuels. From Table, it is observed that catalytic converter reduced HC emissions considerably with both versions of the combustion chamber and air injection into catalytic converter further reduced pollutants. In presence of catalyst, pollutants further oxidised to give less harmful emissions like CO2. Similar trends are observed with neat gasoline operation on copper coated combustion chamber (Khopkar, 2005). From Table 3 it is observed that HC emissions at full load decreased with advanced ignition timing with different versions of the engine. Improved combustion with atomization of fuel decreased accumulated volume of fuel in crevices between piston and liner with advanced ignition timing reduced HC emissions.

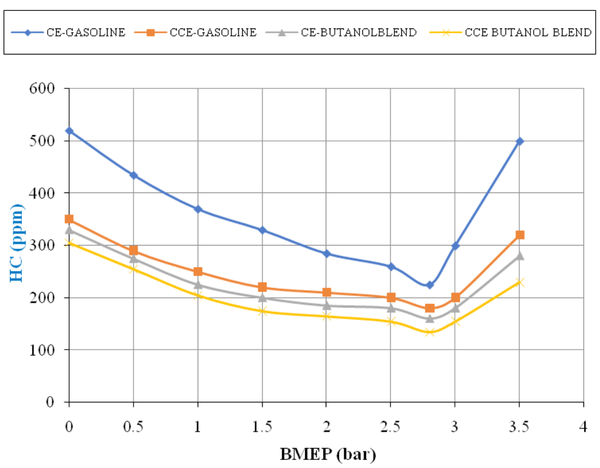


Fig. 4. Variation of un-burnt hydrocarbon levels (HC) with brake mean effective pressure (BMEP)

Fig. 5 shows the variation of nitrogen oxide levels with brake mean effective pressure (BMEP) in different versions of the engine with both neat gasoline and butanol blended gasoline at a compression ratio of 9:1 and speed of 3000 rpm at an ignition timing of 25^0bTDC. NO_x levels increased with an increase of load due to increase of combustion temperatures. CCE increased NO_x emissions marginally with both test fuels in comparison with neat gasoline operation on conventional engine (CE). Increase of combustion temperatures with catalytic activity of copper increased nitrogen oxide levels. However, these levels decreased with butanol blended gasoline in comparison with neat gasoline. Absorption of combustion temperatures of Butanol have lowered nitrogen oxide levels. The system of catalytic converter was not applied for the reduction of nitrogen oxide levels in engine exhaust, because the catalyst employed was oxidizing agent.

Data of formaldehyde and acetaldehyde emissions are listed in Table 4 at full load with different versions of the engine at different operating conditions of the catalytic converter with different test fuels of neat gasoline and butanol blended gasoline at recommended ignition timing (RIT) and optimum ignition timing (OIT). The formaldehyde emissions in the exhaust decreased considerably (35%) with the use of catalytic converter, which was more pronounced with an air injection (65%) into the converter. Butanol blended gasoline increased formaldehyde emissions considerably due to partial

Table 4. Data of Formaldehyde levels (F), (% Concentration) and Acetaldehyde (A) (% Concentration) at full load

Set	Conventional Engine(CE)				Copper Coated Engine (CCE)			
	Neat Gasoline		Butanol blended gasoline		Neat Gasoline		Butanol blended gasoline	
	F	A	F	A	F	A	F	A
Set-A	6.5	5.5	11.0	15	4.5	3.5	10.0	10.1
Set-B	2.5	2.0	6.3	8.3	1.5	1.5	4.0	4.9
Set-C	1.5	0.5	3.2	3.0	0.5	0.3	1.3	1.5

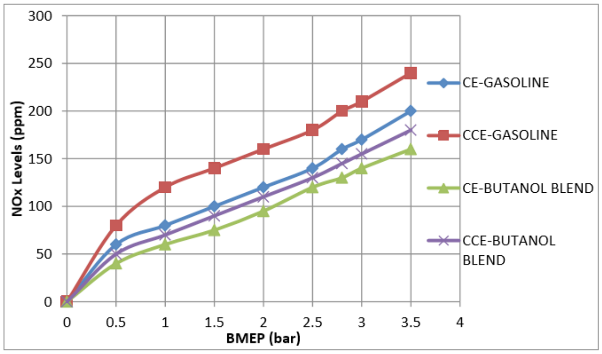


Fig. 5. Variation of nitrogen oxide levels (NO_x) with brake mean effective pressure (BMEP)

oxidation compared with neat gasoline. The low combustion temperature lead to produce partially oxidized carbonyl (aldehyde) compounds with butanol blended gasoline.

Copper coated combustion chamber decreased formaldehyde emissions when compared with CE. Copper as a catalyst in catalytic converter reduced formaldehyde emissions considerably in comparison with other catalyst as copper is a good oxidizing agent.

The trend exhibited by acetaldehyde emissions is same as that of formaldehyde emissions. The partial oxidation of butanol blended gasoline during combustion predominantly leads to formation of acetaldehyde. Copper (catalyst) coated engine decreased aldehydes emissions considerably by effective oxidation when compared to CE. Catalytic converter with air injection drastically decreased acetaldehyde emissions in both versions of the combustion chamber due to oxidation of residual aldehydes in the exhaust.

Aldehyde emissions (both formaldehyde and acetaldehyde emissions) decreased with advanced ignition timing with both versions of the engine with test fuels. Prolonged activity of combustion reduced aldehyde emissions with advanced ignition timing.

CONCLUSION

Carbon monoxide levels, un-burnt hydrocarbon levels and nitrogen oxide levelsdecreased, while formaldehyde levels and acetaldehyde levels at full load increased in comparison with neat gasoline operation.

Based on Configuration of the engine

Carbon monoxide levels, un-burnt hydrocarbon levels, nitrogen oxide levels and aldehyde levels decreased, at full load increased and combustion characteristics improved with copper coted engine in comparison with conventional engine.

Operating Condition of the catalytic converter

Set-B, (with catalytic converter and without air injection) effective reduced all the pollutants by 40% while Set-C (with catalytic converter and with air injection) considerably decreased the same by 60% at full load operation.

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