Eco. Env. & Cons. 29 (1) : 2023; pp. (129-136)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i01.020

Experimental investigations on exhaust emissions of copper coated engine with methanol blended gasoline

N.V. Srinivasulu[1], K. Kishor[2], and M.V.S. Murali Krishna[3]*

[1]Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad 500 075, India

(Received 12 August, 2022; Accepted 12 October, 2022)

ABSTRACT

Investigations were carried out to evaluate the exhaust emissions of two stroke and four stroke of single cylinder, spark ignition (SI) engine having copper coated engine [CCE, copper-(thickness, 250 μ) coated on piston crown and inner side of cylinder head] provided with catalytic converter with copper as catalyst with methanol blended gasoline (85% gasoline and 15% methanol by volume) and compared with conventional engine (CE) with neat gasoline operation. Exhaust emissions of carbon mono oxide (CO), un-burnt hydro carbons (UBHC) were varied with different values of brake mean effective pressure (BMEP). Aldehdyes were measured at full load operation of the engine. The engine was provided with catalytic converter with copper as catalyst. There was provision for injection of air into the catalytic converter. Brake thermal efficiency increased with methanol blended gasoline with both versions of the engine. CCE showed improvement in the performance when compared with CE with both test fuels. 4-Stroke engine decreased exhaust emissions effectively in comparison with 2-stroke engine with both versions of the engine. Catalytic converter with air injection significantly reduced pollutants with different test fuels on both configurations of the engine.

Key words : *SI engine, Methanol, CE, CCE, Fuel Performance, Exhaust emissions and Catalytic converter*

Introduction

In the context of fast depletion of fossil fuels, the search for alternate fuels has become pertinent. Alcohols are probable candidates as alternate fuels for SI engines, as their properties are compatible close to gasoline fuels. If alcohols are blended in small quantities with gasoline fuels, no engine modification is necessary.

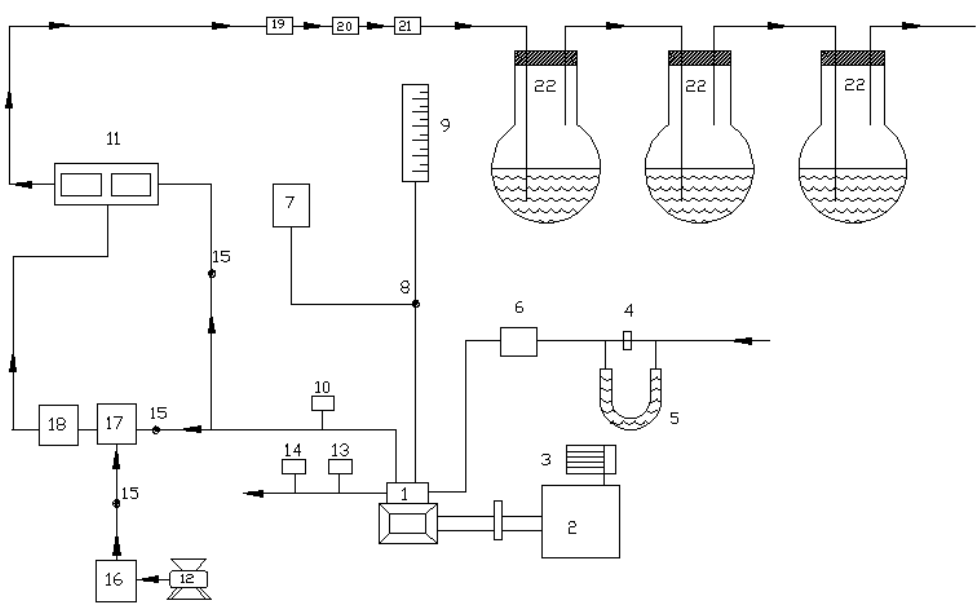
The major exhaust emissions from SI engine are carbon monoxide (CO) and un-burnt hydrocarbons (UBHC), formed due to incomplete combustion of fuel. Inhaling of these pollutants cause severe headache, vomiting sensation, loss of hemoglobin in the blood, respiratory problems etc,. (Fulekar, 1999; Usha Madhuri *et al.,* 2003; Khopkar, 2004; Ghose *et al.,* 2004; Murali Krishna *et al.,* 2005; Sharma, 2005) . Such pollutants also cause detrimental effects ; on animal and plant life, besides environmental disorders (Sharma, 2005). If the engine is run with alcohol, aldehydes are also to be checked. These aldehydes are carcinogenic in nature. The amount of exhaust emissions from the engine depends on driving engine condition, driving methodology, road layout, traffic density, etc,. (Usha Madhuri *et al.,* 2003). Hence control of these emissions is immediate and an urgent task. There are many methods to improve the performance of the engine out of which 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 and pre-flame reactions were improved with copper coating (Murali Krishna *et al.*, 2000; Nedunchezhian *et al.*, 2000; Murali Krishna *et al.*, 2010; Narasimha Kumar *et al.*, 2011a; Narasimha Kumar *et al.*, 2011b). Out of many methods available to control pollutants from SI engine, catalytic converter is effective in reduction of pollutants in SI engine. (Murali Krishna *et al.*, 2010; Narasimha Kumar *et al.*, 2010; Narasimha Kumar *et al.*, 2011; Murali Krishna *et al*, 2011a; Murali Krishna *et al.*, 2011b; Murali Krishna *et al.*, 2012). The reduction of CO and UBHC depends on mass of the catalyst, void ratio, temperature of the catalyst, air flow rate, BMEP, speed and compression ratio of the engine, Engine performance improved with change in fuel composition also (Al-Farayedhi, 2004; Abu-Zaid, 2004; Nakata, 2006; Pearson, 2007; Bahattin Celik, 2008; Bahattin Celik, 2008; Rodrigo, 2010). It was further improved with simultaneous change of fuel composition and engine modification (Murali Krishna *et al*, 2008; Murthy *et al.*, 2011; Murali Krishna *et al*, 2012a; Murali Krishna *et al*, 2012b; Murali Krishna *et al.*, 2012c) Alcohols are blended with gasoline and used in copper coated engine so as to improve the performance of the engine. However, no systematic investigations were reported with the use of methanol blended gasoline in 2 stroke and 4 stroke copper coated engine with varied engine parameters.

The present paper reported the performance evaluation of 2-stroke and 4-stroke CCE, with methanol blended gasoline. The exhaust emissions of CO, UBHC and aldehydes were controlled by catalytic converter with copper as catalyst.

Materials and Methods

Figure 1 consisted 4-stroke CCE with methanol blended gasoline, used in the experimentation. A four- stroke, 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. The bore of the engine was 70 mm while the stroke was 66 mm. Compression ratio of engine was varied (3-9) with change of clearance volume by adjustment of cylinder head, threaded to cylinder of the engine. Engine speeds were varied from 2000 to 3000 rpm. Exhaust gas temperature was measured with iron- constantan thermocouples. Fuel consumption of engine was measured with burette method, while air consumption was measured with an air-box method.

The experimental setup contained 2-stroke CCE



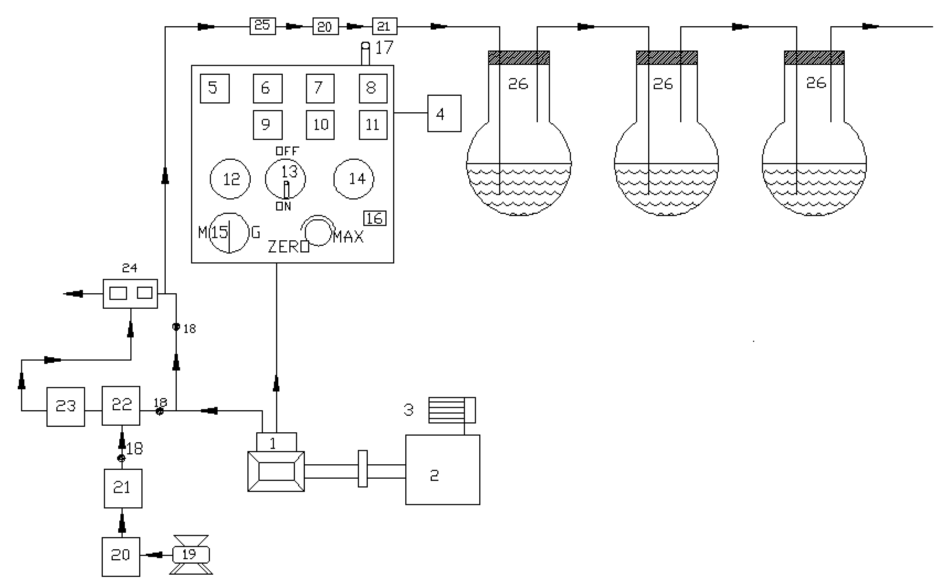
1. Engine, 2.Eddy current dynamometer, 3. Loading arrangement, 4. Orifice meter, 5. U-tube water monometer, 6. Air box, 7. Fuel tank, 8. Three-way valve, 9. Burette,10. Exhaust gas temperature indicator, 11 CO analyzer, 12. Air compressor, 13. Outlet jacket water temperature indicator, 14. Outlet jacket water flow meter,15. Directional valve, 16. Rotometer, 17. Air chamber and 18. Catalyst chamber 19. Filter, 20. Rotometer, 21. Heater, 22. Round bottom flasks containing DNPH solution

Fig. 1. Schematic diagram of experimental set up for four stroke engine

with methanol blended gasoline is shown in Figure 2. A two- stroke, single-cylinder, air -cooled, SI engine (brake power 2.2 kW at the speed of 3000 rpm) was coupled to a eddy current dynamometer for measuring its brake power. The bore and stroke of engine cylinder was 57 mm each. Compression ratio of engine was 7.5:1. Exhaust gas temperature, speed, torque, fuel consumption and air flow rate of the engine were measured with electronic sensors. Compression ratio and speed of 4-stroke engine was made equal (3000 rpm and 7.5:1) to that of 2-stroke engine in order to maintain same conditions for comparison purpose. 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. 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 (Trade name of the company) flame spray gun. The coating has very high bond strength and does not wear off even after 50 h of operation (Murali Krishna and Kishor, 2005).

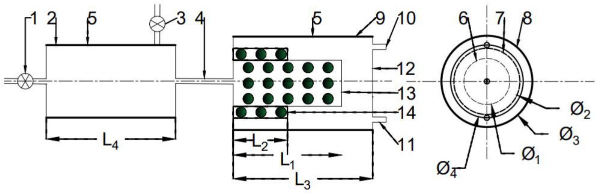
Performance parameters of brake thermal efficiency (BTE), exhaust gas temperature (EGT) and volumetric efficiency (VE) were evaluated at different values of brake mean effective pressure (BMEP) of the engine. CO and UBHC emissions in engine exhaust were measured with Netel Chromatograph analyzer. DNPH method (was employed for measuring aldehydes in the experimentation (Murthy *et al.*, 2010; Murali Krishna *et al.,* 2011; Murthy *et al.,* 2011). The exhaust of the engine was bubbled through 2,4 dinitrophenyl hydrazine (2,4 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.

A catalytic converter [12] (Figure .3) was fitted to exhaust pipe of engine. Provision was also made to inject a definite quantity of air into catalytic converter. Air quantity drawn from compressor and injected into converter was kept constant so that backpressure does not increase. Experiments were carried out on CE and CCE with different test fuels under different operating conditions of catalytic converter like set-A, without catalytic converter and without air injection; set-B, with catalytic converter and without air injection; and set-C, with catalytic converter and with air injection. The accuracy of the instrumentation used in the experimentation is 0.1%.



1. Engine, 2.Electrical swinging field dynamometer, 3. Loading arrangement, 4.Fuel tank, 5.Torque indicator/controller sensor, 6. Fuel rate indicator sensor, 7. Hot wire gas flow indicator, 8. Multi channel temperature indicator, 9. Speed indicator, 10. Air flow indicator, 11. Exhaust gas temperature indicator, 12. Mains ON, 13. Engine ON/OFF switch, 14. Mains OFF, 15. Motor/Generator option switch, 16. Heater controller, 17. Speed indicator, 18. Directional valve, 19. Air compressor, 20. Rotometer, 21. Heater, 22. Air chamber, 23. Catalytic chamber, 24. CO/HC analyzer, 25. Filter, 26. Round bottom flasks containing DNPH solution,

Fig. 2. Schematic diagram of the Experimental Set-up (2-Stroke)



Note: All dimensions are in mm.

1.Inlet to air chamber, 2. Air chamber, 3. Inlet for air chamber from compressor, 4.Outlet for air chamber, 5. Insulation, 6. Inner cylinder, 7. Intermediate cylinder, 8 Outer shell, 9. Catalytic chamber. 10. Outlet for exhaust gases, 11. Provision to deposit the catalyst, and, 12. Outer sheet 13. Inner sheet, 14. Intermediate sheet.

Fig. 3. Details of Catalytic converter

Results and Discussion

Performance Parameters

Fig.4 shows variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in two stroke engine with gasoline and methanol blended gasoline with both versions of the engine. Curves from Figure 4 indicate that BTE increased up to 80% of full load operation due to increase in fuel conversion efficiency and beyond that load it decreased due to increase of friction power with an increase of BMEP with test fuels at a compression ratio of 7.5:1 and speed of 3000 rpm with both versions of the engine. The reason for improving the efficiency with methanol blended gasoline at all loads over gasoline operation 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. This was also due to 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. 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. The increase in efficiency with methanol blended gasoline was also due to lower stoichiometric air requirement of methanol over pure 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 peak load, as catalytic activity increased with prevailing high temperatures at peak load.

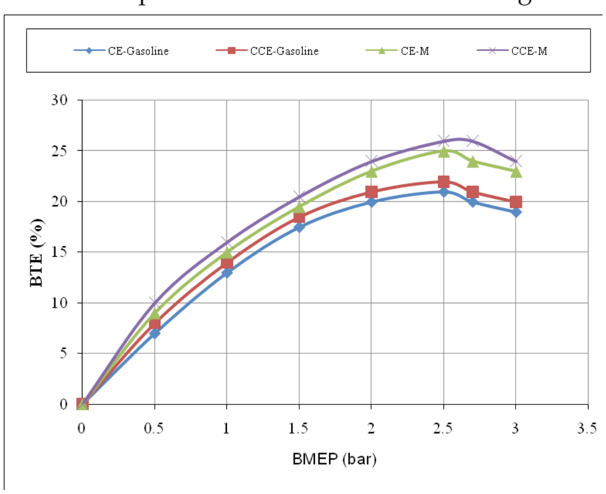


Fig. 4. Variation of BTE with BMEP of the 2-Stroke engine

Exhaust Emissions

Fig. 5 shows the variation of CO emissions with BMEP in two stroke engine with gasoline and methanol blended gasoline with both versions of the engine at a compression ratio of 7.5:1 and a speed of 3000 rpm. Curves from Figure 5 indicate that methanol blended gasoline operation decreased CO emissions at all loads when compared to pure gasoline operation on CCE and CE, as fuel-cracking reactions were eliminated with methanol. The combustion of alcohol produced more water vapor than free carbon atoms as methanol has lower C/H ratio of 0.33 against 0.44 of gasoline. Methanol has oxygen in its

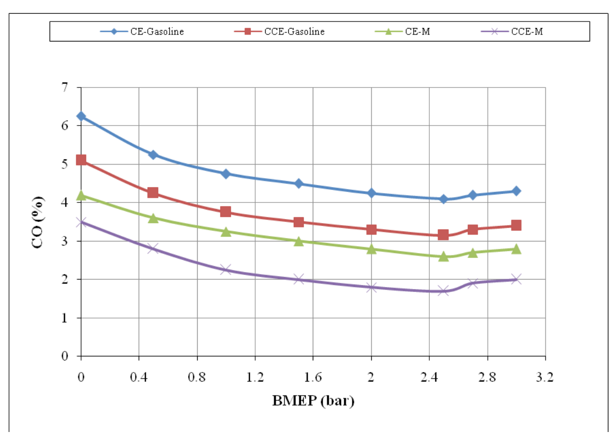


Fig. 5. Variation of CO emissions with BMEP of the 2-Stroke

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. Similar trends were observed with Reference-10 with pure gasoline operation on CCE.

Fig. 6 presents the bar chart showing the variation of peak BTE in two stroke engine and four stroke-engine at a compression ratio of 7.5:1 and a speed of 3000 rpm with gasoline and methanol blended gasoline operation. From Figure 6, it is noticed that CO emissions were observed to be lower with 4 stroke engine in comparison with 2 stroke engine at peak load operation on both versions of the engine. This was due to incomplete combustion of fuel in 2 stroke engine.

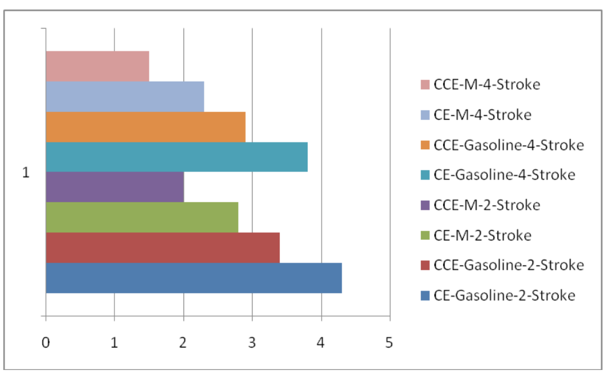


Fig. 6. Bar charts showing the variation of CO emissions of at peak load operation

Fig.7 shows the variation of UBH emissions with BMEP in two stroke engine with gasoline and methanol blended gasoline with both versions of the engine at a compression ratio of 7.5:1 and a speed of 3000 rpm.

Figure 12 indicates that UBHC emissions followed the same trend as CO emissions in CCE and CE with both test fuels, due to increase of flame

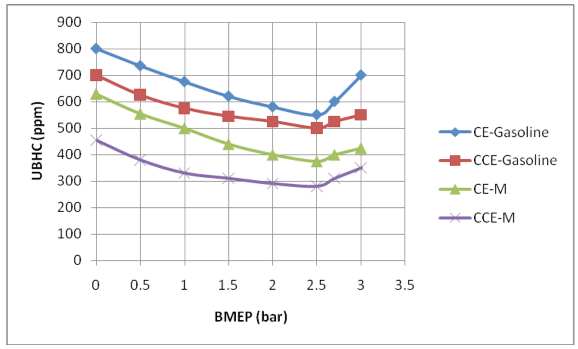


Fig. 7. Variation of UBHC emissions with BMEP of 2-Stroke

speed with catalytic activity and reduction of quenching effect with CCE. Catalytic converter reduced pollutants considerably with CE and CCE and air injection into catalytic converter further reduced pollutants. In presence of catalyst, pollutants get further oxidised to give less harmful emissions like CO_2. Fig. 8 presents the bar chart showing the variation of UBHC emissions at peak load in two stroke engine and four stroke-engines at a compression ratio of 7.5:1 and a speed of 3000 rpm with gasoline and methanol blended gasoline operation. From Figure 8, it is noticed that UBHC emissions at peak load operation were observed to be less with 4-stroke engine in comparison with 2-stroke engine at peak load operation on both versions of the engine. This was due to increase of quenching effect with 2-stroke engine leading to expel out of the fresh fuel without participating in combustion reactions causing higher amount of UBHC.

Catalytic Converter

Table 1 shows the data of exhaust emissions from two-stroke engine and four-stroke engine at full load. From Table 1, it is observed that CO emissions

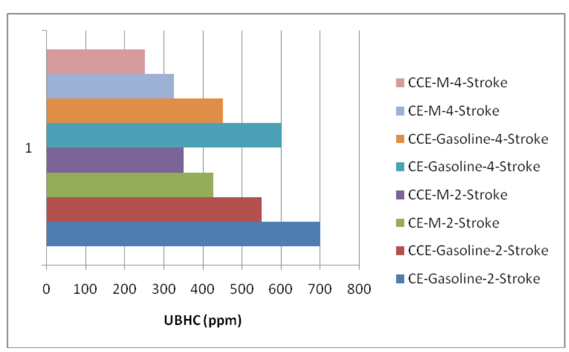


Fig. 8. Bar charts showing the variation of UBHC emissions at full load.

Table 1. Data of Exhaust Emissions in Four-stroke and Two-stroke SI engine at full load

Emissions	Set	Pure Gasoline Operation				Methanol Blended Gasoline			
		CE		CCE		CE		CCE	
		2 S	4S	2S	4S	2S	4S	2S	4S
CO (%)	Set-A	4.3	3.8	3.4	2.9	2.8	2.3	2.0	1.4
	Set-B	2.58	2.1	2.01	1.7	1.7	1.1	1.3	0.7
	Set-C	1.2	0.9	1.0	0.7	0.7	0.6	0.6	0.5
UBHC (ppm)	Set-A	700	490	550	375	425	350	350	227
	Set-B	370	300	250	220	235	175	190	129
	Set-C	160	110	130	110	100	90	80	69
Formaldehyde	Set-A	6.5	4.4	5.5	4.5	12	10	11	8
(% Concentration)	Set-B	3.5	2.4	1.5	1.2	4.0	3.5	3.8	2.9
	Set-C	2.2	1.6	1.5	0.8	4.2	3.8	2.9	1.9
Acetaldehyde	Set-A	8.5	7.8.	6.0	4.9	15	11.0	10	8.9
(% Concentration)	Set-B	5.5	3.9	4.5	2.9	9	6.9	8	6.9
	Set-C	4.0	2.9	3.3	2.0	8	5.9	7	4.9

Set-A= Without catalytic converter and without air injection,
Set- B= With catalytic converter and without air injection,
Set- C= With catalytic converter and with air injection, CE= Conventional engine, CCE= Copper coated engine.

decreased considerably with Set-B operation, while Set-C further decreased emissions in both versions of the engine with test fuels. Efficient combustion with methanol blended gasoline coupled with catalytic activity decreased CO emissions in CCE. From same Table, it can be noticed that UBHC emissions decreased considerably with Set-B operation, while Set-C further decreased emissions in both versions of the engine with test fuels. Improved combustion with methanol blended gasoline along with turbulence with catalytic activity decreased deposits in CCE causing decrease of UBHC emissions. CO and UBHC emissions were observed to be higher with 2 stroke engine in comparison with 4 stroke engine with different versions of the engine with different test fuels at same compression ration and speed.

From the Table, it can be noticed that formaldehyde emissions decreased considerably with Set-B operation, while Set-C further decreased emissions in both versions of the engine with test fuels. However, methanol blended gasoline increased aldehyde emissions considerably in comparison with pure gasoline operation. But CCE decreased aldehyde emissions in comparison with CE with both test fuels. This is due to improved combustion so that intermediate compounds will not be formed. 2-Stroke engine increased aldehyde emissions than 4 stroke engine as combustion reactions are incomplete with 2 stroke engine.

Conclusion

CO emissions decreased by 25% and UBHC emissions decreased by 29% with 4 stroke CCE with methanol blended gasoline operation.

In comparison with 4-stroke CCE engine with methanol blended gasoline, CO emissions decreased by 53% and UBHC emissions decreased by 50% when compared with CE with pure gasoline operation. CCE improved combustion and decreased exhaust emissions effectively in comparison with CE with test fuels. Set-B operation of the catalytic converter decreased the pollutants by 40%, while Set- C by 60%. The catalyst copper was proved to be more efficient in reducing pollutants.

Acknowledgements

Authors thank authorities of Chaitanya Bharathi Institute of Technology, Hyderabad for facilities provided. Financial assistance from Andhra Pradesh Council of Science and Technology (APCOST), Hyderabad, is greatly acknowledged.

References

Abu-Zaid., Badran, O. and Yamin, J. 2004. Effect of methanol addition on the performance of spark ignition engines. *Energy and Fuels*. 18: 312- 315, Al-Farayedhi, A.A., Al-Dawood, A.M. and Gandhidasan, P. 2004. Experimental investigation of spark ignition engine performance using oxygenated fuel. *ASME Journal of Engineering for Gas Turbines and Power.* 126: 178-191.

Bahattin Celik, M. 2008. Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine. *Applied Thermal Engineering*. 28: 396–404.

Fulekar, M.H. 1999. Chemical pollution – a threat to human life. *Indian Journal of Environmental Technology*. 1: 353-359.

Ghose, M.K., Paul, R. and Benerjee, S.K. 2004. Assessment of the impact of vehicle pollution on urban air quality. *Journal of Environmental Science and Engineering*. 46: 33-40.

Khopkar, S.M. 2004. *Environmental Pollution Analysis.* New Age International (P) Ltd, Publishers, New Delhi.180-190.

Murali Krishna, M.V.S. and Kishor, K. 2005. Control of pollutants from copper coated spark ignition engine with methanol blended gasoline. *Indian Journal of Environmental Projection.* 25(8) : 732-738.

Murali Krishna, M.V.S., Kishor, K., Murthy, P.V.K., Gupta, A.V.S.S.K.S. and Narasimha Kumar, S. 2012b. Comparative studies on emissions from two stroke copper coated spark ignition engine with alcohols with catalytic converter. *International Journal of Scientific & Technology Research.* 1(2): 85-90.

Murali Krishna, M.V.S. and Kishor, K. 2008. Investigations on catalytic coated spark ignition engine with methanol blended gasoline with catalytic converter. *Indian Journal (CSIR) of Scientific and Industrial Research.* 67: 543-548.

Murali Krishna, M.V.S., Kishor, K., Gupta, A.V.S.S.K.S, Narasimha Kumar, S. and Reddy, D.N. 2010. Investigations on reduction of carbon monoxide in spark ignition engine with gasohol with catalytic converter. *Ecology, Environment and Conservation.* 16(3): 389–393.

Murali Krishna, M.V.S., Kishor, K., Gupta, A.V.S.S.K.S., Murthy, P.V.K. and Narasimha Kumar, S. 2012. Performance of copper coated two stroke spark ignition engine with methanol blended gasoline with catalytic converter. *International Journal of Sustainable and Renewable Energy.* 4(1) : 013102.

Murali Krishna, M.V.S., Kishor, K., Murthy, P.V.K. and Gupta, A.V.S. S. K.S. 2011a. Emissions from copper coated two-stroke spark ignition engine with methanol blended gasoline with catalytic converter. *International Journal of Applied Engineering Research.* 6(21): 2507-2516.

Murali Krishna, M.V.S., Kishor, K., Murthy, P.V.K. and Gupta, A.V.S.S.K.S. 2012a. Control of exhaust emissions from copper coated two stroke spark ignition engine with methanol blended gasoline with catalytic converter. *International Journal of Engineering and Innovative Technology.* 1(5). 9-16.

Murali Krishna, M.V.S., Kishor, K., Murthy, P.V.K., Gupta, A.V.S.S.K.S. and Narasimha Kumar, S. 2010. Performance evaluation of copper coated four stroke spark ignition engine with gasohol with catalytic converter. *International Journal of Engineering Studies.* 2(4): 465-473.

Murali Krishna, M.V.S., Kishor, K., Murthy, P.V.K., Gupta, A.V.S.S.K.S. and Narasimha Kumar, S. 2012c. Comparative studies on performance evaluation of a two stroke copper coated spark ignition engine with alcohols with catalytic converter. *International Journal of Renewable and Sustainable Energy Reviews.* 16: 6333-6339.

Murali Krishna, M.V.S., Murthy, P.V.K., Narasimha Kumar, S. and Kishor, K. 2011b. Control of exhaust emissions from copper coated gasohol run two spark ignition engine with catalytic converter. *International Journal of Mechanical Engineering Research.* 1(1) : 24-37.

Murali Krishna, M.V.S., Narasimha Kumar, S. and Krishna Murthy, P.V. 2011. Control of aldehyde emissions from copper coated spark ignition engine fueled with alcohol blended gasoline. *International Journal of Engineering Research and Applications.* 1(2): 337-340.

Murali Krishna, M.V.S., Vara Prasad, C.M. and Ramana Reddy, Ch. V. 2000. Studies on control of carbon monoxide emissions in spark ignition engine, using catalytic converter. *Ecology, Environment, & Conservation.* 6(4) : 377-380.

Murthy, P.V.K., Murali Krishna, M.V.S., Narasimha Kumar, S., Kishor, K. and Giridhar Reddy, P. 2011. Performance of copper coated two stroke spark ignition engine with alternate fuels with catalytic converter. *International Journal of Engineering & Techno-Science*. 3 : 145-149.

Murthy, P.V.K., Narasimha Kumar, S., Kishor, K. and Murali Krishna, M.V.S. 2011. Aldehyde emissions from two-stroke and four-stroke spark ignition engines with catalytic converter running on gasohol. *International Journal of Fuels and Lubricants.* 50(2) **:**137-156.

Murthy, P.V.K., Narasimha Kumar, S., Murali Krishna, M.V.S., Seshagiri Rao, V.V.R. and Reddy, D.N. 2010. Aldehyde emissions from two-stroke and four-stroke spark ignition engines with methanol blended gasoline with catalytic converter. *International Journal of Engineering Research and Technology.* 3(3) : 793-802.

Nakata, K. 2006. The effect of ethanol fuel on a spark ignition engine, SAE Paper No. 2006-01-3380, 2006.

Narasimha Kumar, S., Kishor, K., Murali Krishna, M.V.S. and Murthy, P.V.K. 2011. Studies on exhaust emissions from copper coated gasohol run spark ignition engine with catalytic converter. *International Schol-*

arly Research Net Work (ISRN) in Mechanical Engineering. Article No. 57019: 1-6.

Narasimha Kumar, S., Murali Krishna, M.V.S., Krishna Murthy, P.V., Seshagiri Rao, V.V.R. and Reddy, D.N. 2010. Emissions from copper coated two-stroke spark ignition engine with gasohol with catalytic converter. *International Journal of Mechanical Engineering.* 3(2) : 163-167.

Narasimha Kumar, S., Murali Krishna, M.V.S., Murthy, P.V.K., Reddy, D.N. and Kishor, K. 2011b. Performance of copper coated two stroke spark ignition engine with gasohol with catalytic converter with different catalysts. *International Journal of Applied Engineering Research.* 2(1) : 205-218

Narasimha Kumar, S., Murali Krishna, M.V.S., Murthy, P.V.K., Seshagiri Rao, V.V.R. and Reddy, D.N. 2011a. Performance of copper coated two stroke spark ignition engine with gasohol with catalytic converter. *International Journal on Mechanical & Automobile Engineering.* 12(1) : 36-43.

Nedunchezhian, N. and Dhandapani, S. 2000. Experimental investigation of cyclic variation of combustion parameters in a catalytically activated two-stroke SI engine combustion chamber. *Engineering Today.* 2: 11-18.

Pearson, R.J. 2007. Alcohol based fuels in high performance engines, SAE Paper No - 2007-01-0056, 2007.

Rodrigo, C. Costa and José, R. Sodré, 2010. Hydrous ethanol vs. gasoline-ethanol blend: engine performance and emissions. *Fuel.* 89 : 287–293.

Sharma, B.K. 2005. *Engineering Chemistry*. Pragathi Prakashan (P) Ltd, Meerut. 150-160.

Usha Madhuri, T., Srinivas, T. and Ramakrishna, K. 2003. A study on automobile exhaust pollution with regard to carbon monoxide emissions. *Nature, Environment and Pollution Technology.* 2 : 473-474.