Control of aldehyde emissions from copper coated spark ignition engine fueled with alcohol blended gasoline

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Abstract
The major pollutants emitted from spark ignition (SI) engine are carbon monoxide (CO) and unburnt hydrocarbons, nitrogen oxides which are hazardous to human beings and environment. If the engine is run with alcohol blended alternate fuels, aldehydes are emitted as significant pollutants, which are carcinogenic and harmful in nature. Hence, control of these aldehyde emissions call for immediate attention. Present study is carried out for measurement and control of the aldehyde emissions from a variable- compression ratio, variable-speed, copper-coated spark ignition engine fueled with ethanol blended gasoline (20% V/V) and methanol blended gasoline (20%V/V) fitted with catalytic converter containing sponge iron catalyst. The influence of the engine parameters such as speed, compression ratio and configuration of the engine with and without catalytic converter on the pollutants is studied. The speed of the engine has marginal effect, while load and compression ratio are found to show significant influence on reduction of pollutants. Air injection into the catalytic converter has further reduced the aldehyde emissions by effective oxidation. Copper coated SI engine with alcohol blended gasoline found to decrease the aldehyde emissions considerably when compared to conventional engine with pure gasoline operation.

Keywords: *Aldehyde emissions; spark ignition engine; copper coated SI engine; alcohol blended gasoline; catalytic converter.*

Introduction:

The use of alcohol blended gasoline in spark ignition(SI) engines is increasing in recent years. The common pollutants[1-4] emitted from the SI engine fueled with gasoline are carbon monoxide (CO), carbon dioxide(CO_2), un-burnt hydro carbons and oxides of nitrogen (NO_x) which affect health and environment. But, when alcohol blended gasoline (gasohol) [5-7] is used as an alternate fuel, the aldehydes are also emitted as significant pollutants, which are carcinogenic[8, 9] and cause detrimental effects on human health [2, 10-12].The extent of emission of pollutants depends on the factors[13] like incomplete combustion of fuel, fuel composition, air-fuel ratio, temperature of the combustion chamber etc. Usually, the emission of harmful pollutant, CO is controlled by catalytic converter containing platinum group metals, which are costlier. However, a few studies are made regarding the measurement and control of the aldehydes in the exhaust[7,14] of SI engines compared to other pollutants. Therefore, attention is paid for measurement and control of aldehydes in the exhaust of the engine using cheaper catalyst. Accordingly, the present paper reports the study on the control of aldehyde (formaldehyde and acetaldehyde) emissions with different versions of the engine such as conventional engine and copper (catalyst) coated engine with catalytic converter having sponge iron catalyst and methanol blended gasoline and ethanol blended gasoline (20%V/V) as fuel.

Experimental Program

Experimental Setup

The experimental set-up employed in the study is shown in Fig.1. A four- stroke, single-cylinder, water-cooled, spark ignition engine of brake power 2.2 kW at a rated speed of 3000 rpm is used. The engine is coupled to an eddy current dynamometer for measuring its brake power. The compression ratio of the engine is varied from 3 to 9 with the change of the clearance volume by adjustment of cylinder head, threaded to the cylinder of the engine. The engine speed is varied from 2200 to 3000 rpm. Inorder to improve the effective combustion of fuel and to reduce the emission of pollutants, the piston crown and inner surface of the cylinder head are coated[15] with copper by plasma spraying. A bond coating of NiCoCr alloy of about 100 microns thickness is applied using 80 kW METCO plasma spray gun. Over the bond coating, copper (89.5%), aluminium (9.5%) and iron (1.0%) is coated for 300 microns thickness. The coating had very high bond strength and does not wear off even after 50 hrs of operation.

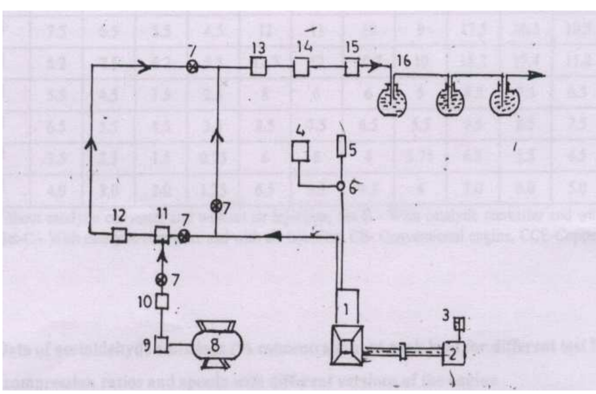
Catalytic Converter

A catalytic converter (Fig. 2) is fitted to the exhaust pipe of the engine. Provision is made to inject a definite quantity of air into the catalytic converter. The converter is filled with sponge iron catalyst with a void ratio of 0.7:1, (void ratio is the ratio between the volume occupied by the catalyst to the volume of the catalyst chamber), where the pollutants are found to be minimum.

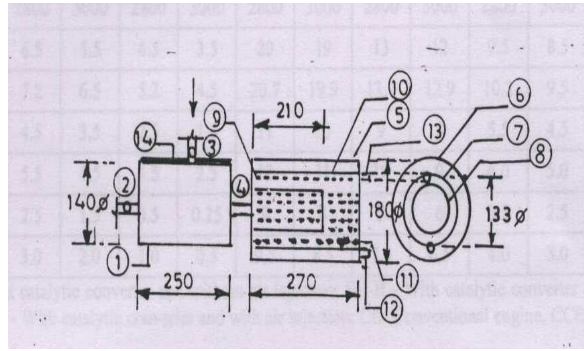
Measurement of Aldehydes

For measuring aldehydes in the exhaust of the engine, a wet chemical method[16] is employed. The exhaust of the engine is bubbled through 2,4-dinitrophenyl hydrazine (DNPH) in hydrochloric acid solution and the hydrazones formed from aldehydes are extracted into chloroform and are analyzed by high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine.

Various sets of the exhaust gases are drawn at three different locations, 1) immediately after the exhaust valve of the engine, 2) after the catalytic converter, and 3) at the outlet after air injection into the catalytic converter. The quantity of air drawn from the compressor and injected into the converter is kept constant so that the backpressure does not increase and reverse flow is not created in the converter. Experiments are carried out on different configurations of the engine i.e., conventional engine and copper coated engine with different test fuels, pure gasoline, ethanol blended gasoline (20%V/V) and methanol blended gasoline (20%V/V) under different operating conditions of the catalytic converter, 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.



1.Engine, 2.Eddy current dynamometer, 3. Loading arrangement, 4. Fuel tank, 5. Burette, 6. Three-way valve, 7. Directional valve, 8. Air compressor, 9.Rotometer, 10. Heater, 11 Air chamber, 12.Catalyst chamber, 13.Filter, 14.Rotometer, 15. Heater, 16. Round-bottom flasks containing DNPH Solution **Fig.1- 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. Outer cylinder 7. Intermediate-cylinder, 8. Inner-cylinder, 9.Inner sheet, 10.Intermediate sheet, 11. Outer sheet, 12. Outlet for exhaust gases, 13. Provision to deposit the catalyst and 14. Insulation.

Fig.2-Details of catalytic converter

Table-1.Data of % formaldehyde emissions at peak load for different test fuels at different compression ratios and speeds with different versions of the engine

Fuels		Gasoline				Ethanol blended gasoline (20%V/V)				Methanol blended gasoline (20%V/V)			
Engine version		[d]CE		[e]CCE		[d]CE		[e]CCE		[d]CE		[e]CCE	
Speed (rpm)		2800	3000	2800	3000	2800	3000	2800	3000	2800	3000	2800	3000
[a]Set-A	*8:1	7.5	6.5	5.5	4.5	12	11	10	9	17.5	16.5	10.5	9.5
	*9:1	8.2	7.5	6.2	5.5	12.7	12	10.7	10	18.2	17.4	11.2	10.4
[b]Set-B	*8:1	5.5	4.5	3.5	2.5	8	6	6	5	8.5	7.5	6.5	5.5
	*9:1	6.5	5.5	4.5	3.5	8.5	7.5	6.5	5.5	9.5	8.5	7.5	6.5
[c]Set-C	*8:1	3.5	2.5	1.5	0.75	6	5	4	3.75	6.5	5.5	4.5	3.5
	*9:1	4.0	3.0	2.0	1.25	6.5	5.5	4.5	4	7.0	6.0	5.0	4.0

[a]Set-A – Without catalytic converter and without air injection; [b]Set-B - With catalytic converter and without air injection; [c]Set-C - With catalytic converter and with air injection; [d]CE- Conventional engine, [e]CCE- Copper coated engine, * Compression ratio of the engine

Table-2.Data of % acetaldehyde emissions at peak load for different test fuels at different compression ratios and speeds with different versions of the engine

Fuels		Gasoline				Ethanol blended gasoline (20%V/V)				Methanol blended gasoline (20%V//V)			
Engine version		dCE		eCCE		dCE		eCCE		dCE		eCCE	
Speed(rpm)		2800	3000	2800	3000	2800	3000	2800	3000	2800	3000	2800	3000
aSet-A	*8:1	6.5	5.5	4.5	3.5	20	19	13	12	9.5	8.5	7.5	6.5
	*9:1	7.2	6.5	5.2	4.5	20.7	19.9	13.7	12.9	10.2	9.5	8.2	7.5
bSet-B	*8:1	4.5	3.5	2.5	1.5	11	10	9	8	5.5	4.5	3.5	2.5
	*9:1	5.5	4.5	4.5	2.5	12	11	10	9	6.0	5.0	4.0	3.0
cSet-C	*8:1	2.5	1.5	0.5	0.25	9	8	7	6	3.5	2.5	1.5	1.25
	*9:1	3.0	2.0	1.0	0.5	9.5	8.5	7.5	6.5	4.0	3.0	2.0	1.75

aSet-A – Without catalytic converter and without air injection; bSet-B - With catalytic converter and without air injection; cSet-C - With catalytic converter and with air injection; dCE- Conventional engine, eCCE- Copper coated engine, * Compression ratio of the engine

Results and Discussion

The data of formaldehyde and acetaldehyde emissions is listed in Table 1 and Table-2 respectively at peak load, different compression ratios and speeds with different versions of the engine at different operating conditions of the catalytic converter with ethanol blend and methanol blend of gasoline repetitively. It is observed that at each speed, the formaldehyde emissions in the exhaust decreased considerably with the use of catalytic converter, which is more pronounced with an air injection into the converter. Methanol blend increases formaldehyde emissions considerably due to partial oxidation compared to pure gasoline. The low combustion temperature lead to produce partially oxidized carbonyl (aldehyde) compounds with gasohols. Formaldehyde emissions are found to decrease with an increase in speed of the engine with different test fuels. Improved combustion with the increase of turbulence reduces the formaldehyde emissions. Copper-coated engine decreases formaldehyde emissions when compared to conventional engine. The catalytic activity of copper on combustion of fuel increases with temperature and combustion temperature increases with the increase of the speed of the engine. As the compression ratio decreased from 9:1 to 8:1, formaldehyde emissions decreased with different test fuels in both versions of the engine. This is due to increase of exhaust gas temperature with the decrease of compression ratio leading to oxidation of aldehydes in the exhaust manifold with different versions of the engine.

The trend exhibited by acetaldehyde emissions is same as that of formaldehyde emissions. However, acetaldehyde emission is observed to be more with ethanol blend compared to methanol blend of gasoline in both versions of the engine (Table-2). The partial oxidation of ethanol during combustion predominantly leads to formation of acetaldehyde. Copper (catalyst) coated engine decreases aldehydes emissions considerably by effective oxidation when compared to conventional engine. Catalytic converter with air injection drastically decreases aldehyde emissions in both versions of the engine due to oxidation of residual aldehydes in the exhaust.

Conclusions

The aldehyde emissions at peak load decreased by 15-20% with the change of the engine configuration from conventional version to copper (catalytic) coated engine with alcoholic fuels. The aldehyde emissions increased by 45- 50% with the change of fuel from gasoline to alcohol-blended gasoline in both versions of the engine. They also increased by 6-7% with the change of compression ratio from 8:1 to 9:1. They decreased by 20- 25% with the change of speed from 2800 rpm to 3000 rpm with different test fuels in both configurations of the engine under different operating conditions of the catalytic converter. An air injection decreased the aldehyde emissions by 20% with alcohol blended gasoline in comparison with pure gasoline operation with the same configuration of the engine. Thus, the catalytic oxidation of alcoholic fuels in the combustion chamber and aldehydes in the exhaust decreases considerably.Thus, the catalytic oxidation of alcoholic fuels in the combusiton chamber and catalytic oxidation of aldehydes in the exhaust by the catalytic converter decreases the emissions considerably.

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