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ALDEHYDE EMISSIONS FROM TWO-STROKE AND FOUR-STROKE SPARK IGNITION ENGINES WITH CATALYTIC CONVERTER RUNING ON GASOHOL

Abstract

This paper reports aldehyde emissions from two-stroke and four-stroke, single cylinder spark ignition (SI) engines with gasohol (80 vol. % gasoline, 20 vol. % ethanol) having copper coated engine (copper-coated thickness, 300 μm) on piston crown and inner side of cylinder head) provided with catalytic converter with sponge iron as catalyst and compared with conventional SI engine with gasoline operation. Copper-coated engine showed reduction in aldehyde emissions when compared with conventional engine with both test fuels. Catalytic converter with air injection significantly reduced emissions with both test fuels on both configurations of the engine.

Introduction

Alcohol run engines increased emissions of carbonyls (aldehydes and ketones), ompared with pure gasoline on conventional engine[1-4]. Aldehyde emissions (both formaldehyde and acetaldehyde), major exhaust pollutants formed as intermediate compounds due to incomplete combustion of the fuel, cause many human health disorders[5-10]. Engine modification[11-12] with copper coating on piston crown and inner side of cylinder head improves engine performance, as copper is a good conductor of heat and combustion is improved. Catalytic converter is effective[13-15] in reduction of pollutants in spark ignition (SI) engine. The present paper reports the aldehyde emissions in two stroke spark ignition engine and four stroke spark ignition engine with copper-coated surface (CCE) along with catalytic converter run with gasohol (80 % gasoline, 20 % ethanol, by vol.) and compared with conventional engine (CE) with pure gasoline operation.

Materials and Methods

Figure 1 shows experimental set-up used for investigations on two-stroke SI engine. It is single-cylinder, water-cooled, with brake power 2.2 kW at the rated speed of 3000 rpm coupled to a rope brake dynamometer for measuring brake power. Compression ratio of engine is 9:1. Fuel consumption and exhaust gas temperature of engine are measured with electronic sensors.

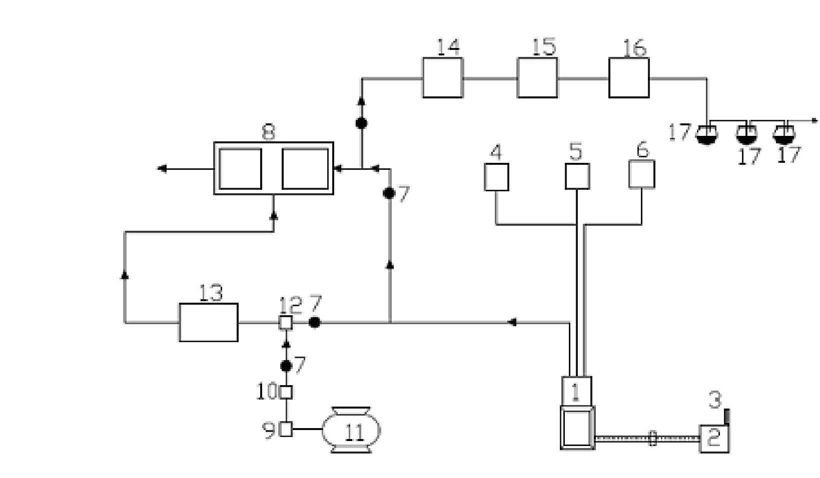

Figure 1: Experimental set up for Two-stroke SI engine

1. Engine, 2. Eddy current dynamometer, 3. Loading arrangement, 4. Fuel tank, 5. Fuel Sensor, 6. Exhaust temperature indicator, 7. Directional valve, 8. CO Analyzer, 9. Rotometer, 10. Heater, 11. Air compressor, 12. Air chamber, 13. Catalyst chamber, 14. Filter, 15. Rotometer, 16. Heater, 17. Round-bottom flasks containing DNPH Solution

Figure 2 shows experimental set-up used for investigations on four-stroke SI engine. It is single-cylinder, water-cooled, SI 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 speeds are varied from 2200 to 3000 rpm. The magnitude of the exhaust gas temperature is measured with iron-constantan thermocouples. The fuel consumption of the engine is measured with burette method, while air consumption is measured with air-box method.

In catalytic coated engine, piston crown and inner surface of cylinder head are coated with copper by plasma spraying. A bond coating of NiCoCr alloy is applied (thickness, 100 μm) using a 80 kW METCO plasma spray gun. Over bond coating, copper (89.5 %), aluminum (9.5 %) and iron (1.0 %) are coated (thickness 300 μm). The coating has very high bond strength and does not wear off even after 50 h of operation[10].

DNPH method[16] is employed for measuring aldehydes in the experimentation. The exhaust of the engine is bubbled through 2,4 dinitrophenyl hydrazine (2,4 DNPH) solution. The hydrazones formed are extracted into chloroform and are 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[13] (Figure 3) is fitted to exhaust pipe of engine. Provision is also made to inject a definite quantity of air into catalytic converter. Air quantity drawn from compressor and injected into converter is kept constant so that backpressure does not increase. Experiments are carried out on CE and CCE with different test fuels, pure gasoline and gasoline blended with ethanol (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 on different configurations of the engine such as two-stroke engine and four-stroke engine.

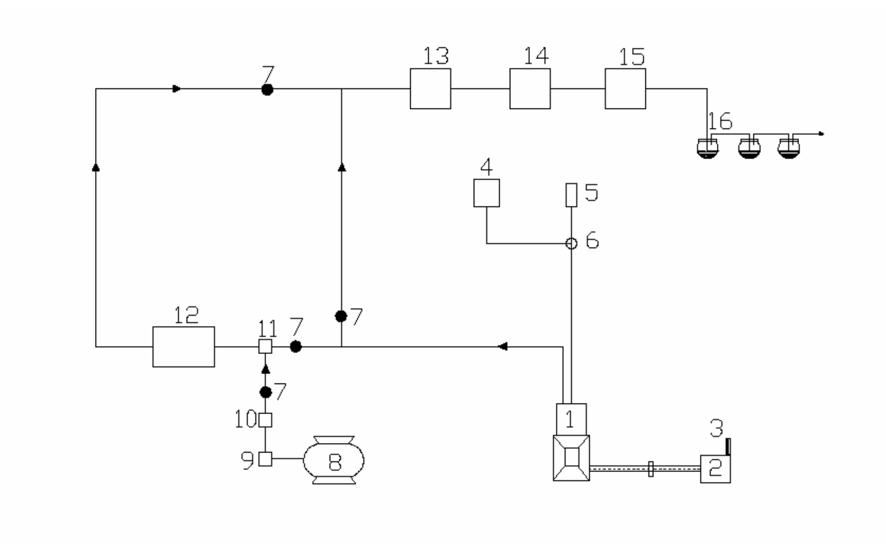

Figure 2: Experimental set up for Four-stroke SI engine

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

Results and Discussion

Two-stroke SI engine

Table 1 shows the data of formaldehyde emissions in two-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter. Formaldehyde emissions increased drastically with ethanol blended gasoline in both versions of the engine in comparison with pure gasoline operation. However, the percentage increase in formaldehyde emissions is less with copper coated engine when compared with conventional engine. This shows that copper coated engine decreases formaldehyde emissions considerably. With the both test fuels, CCE drastically decreased formaldehyde emissions in comparison with conventional engine. Formaldehyde emissions in CCE will not be formed, as there are no intermediate compounds. This shows combustion is improved with catalytic activity in CCE, which decreased formaldehyde emissions.

Table 1: Data of formaldehyde emisisons in two-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter

Set	CONCENTRATION, vol. %			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	9.1	14.63	6.8	9.31
Set-B	6.3	7.0	4.1	5.0
Set-C	3.5	5.9	3.2	3.93

Formaldehyde emissions decreased with Set-B operation and further decreased in Set-C operation in both versions of the engine with both test fuels. This is due to increase of oxidation reaction with the use of catalyst and air, which caused reduction of formaldehyde contents. Set-B operation with catalytic converter decreased pollutants considerably with both test fuels with different configuration of the engine, while further decrease in pollutants is pronounced with Set-C operation. This is due to improved oxidation reaction of the catalyst and air.

Table 2 shows the data of percentage deviation of formaldehyde emissions in two-stroke SI engine with different test fuels with different configurations of the engine in comparison with pure gasoline operation in conventional engine under different operating conditions of the catalytic converter.

Table 2: Data of percentage deviation of formaldehyde emissions with different test fuels in different configurations of two-stroke SI engine in comparison with pure gasoline operation on conventional engine

Set	Formaldehyde emissions (vol. %)			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A		+90%	-25%	+2%
Set-B	-36%	-23%	-55%	-45%
Set-C	-72%	-35%	-65%	-57%

From the table it can be observed, the percentage deviations are high with both test fuels on copper coated engine, which shows the importance of CCE engine in decreasing formaldehyde emissions. However, pure gasoline in CCE is more active in comparison with ethanol blended gasoline as catalytic activity decreased with decrease of combustion temperature due to high latent heat of evaporation of ethanol, which absorbs temperature from surroundings leading to decrease of catalytic activity.

Table 3 shows the data of acetaldehyde emissions in two-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter.

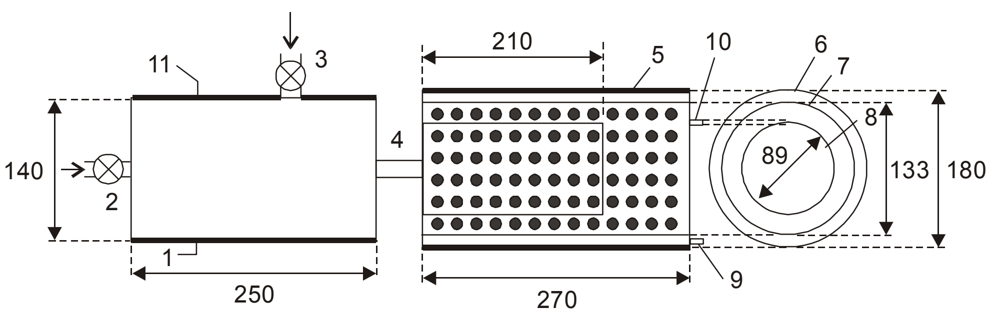

Figure 3: Details of catalytic converter (dimensions are in mm)

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,
11. Insulation

Table 3: Data of acetaldehyde emisisons in two-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter

Set	CONCENTRATION, vol. %			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	7.7	16.8	4.9	12.6
Set-B	4.9	8.4	3.5	7.5
Set-C	2.1	7.0	1.4	5.2

The trend exhibited by acetaldehyde emissions is similar to that of formaldehyde emissions. However, with ethanol blended gasoline the magnitude of acetaldehyde emissions are higher when compared with formaldehyde emissions. Table 4 shows the data of percentage deviation of formaldehyde emissions in two-stroke SI engine with different test fuels with different configurations of the engine in comparison with pure gasoline operation on conventional engine at different operating conditions of the catalytic converter. As it is noticed from the table, similar trends are observed with those of formaldehyde emissions. CCE engine decreased acetaldehyde emissions considerably with catalytic converter and air injection operation. Improved combustion with increased rate of oxidation reaction decreased acetaldehyde emissions considerably. Gasohol operation with CCE decreased acetaldehyde emissions considerably in comparison with conventional engine as combustion is improved with catalytic reaction. However, when compared with gasohol, pure gasoline operation on copper coated engine decreased acetaldehyde emissions considerably. This is due to decrease of combustion temperature with gasohol operation, which decreased activity of copper leading to increase of pollutants. Acetaldehyde emissions decreased with Set-B operation with pure gasoline operation on different configurations of the engine.

Table 4: Data of percentage deviation of acetaldehyde emissions with different test fuels in different configurations of two-stroke SI engine in comparison with pure gasoline operation on conventional engine

Set	Acetaldehyde emissions (vol. %)			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	--	+118%	-36%	+64%
Set-B	-36%	+9%	-55%	-32%
Set-C	-72%	-9%	-82%	-42%

Four-stroke SI engine

Table 5 shows the data of formaldehyde emissions in four-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter. The trends observed on these aspects with four stroke SI engine are similar to those of two stroke SI engine. With four-stroke engine, pure gasoline operation on copper coated engine decreased formaldehyde emissions considerably when compared with conventional engine. This shows that combustion is improved with catalytic activity, which reduces aldehyde emissions. Ethanol blended gasoline increased aldehyde emissions considerably when compared with pure gasoline operation on both versions of the engine. However, CCE decreased aldehyde emissions drastically with ethanol blended gasoline when compared with conventional engine. Formaldehyde emissions in four-stroke engine are lower when compared with two-stroke engine in both versions of the engine with both test fuels. This is due to loss of fuel in two stroke engine through the exhaust port without participating in combustion reactions. Set-B operation and Set-C operation decreased pollutants by oxidation reaction.

Table 5: Data of formaldehyde emisisons in four-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter

Set	CONCENTRATION, vol. %			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	6.5	12	4.5	9.0
Set-B	4.5	5.6	2.5	5.1
Set-C	2.5	4.8	1.5	3.4

Table 6 shows the data of percentage deviation of formaldehyde emissions in four-stroke SI engine with different test fuels with different configurations of the engine in comparison with pure gasoline operation on conventional engine at different operating conditions of the catalytic converter. Formaldehyde emissions in four-stroke SI engine followed similar trends as two-stroke engine. However, two-stroke engine produces higher volume of emissions when compared with four-stroke engine as the charge in two-stroke engine will not participate in the combustion reaction and the configuration of the engine itself promotes high levels of pollution.

Table 7 shows the data of acetaldehyde emissions in four-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter. The trends observed on these aspects with four stroke SI engine are similar to those of two stroke SI engine.

Table 6: Data of percentage deviation of formaldehyde emissions with different test fuels in different configurations of four-stroke spark igntion engine in comparison with pure gasoline operation on conventional engine

Set	Formaldehyde emissions (vol. %)			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	--	+84%	-30%	+38%
Set-B	-30%	-14%	-61%	-21%
Set-C	-61%	-26%	-77%	-47%

Table 7: Data of acetaldehyde emisisons in four-stroke SI engine with different test fuels with different configurations of the engine at different operating conditions of the catalytic converter

Set	CONCENTRATION, vol. %			
	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	5.5	10.45	3.5	6.6
Set-B	3.5	4.7	2.5	3.4
Set-C	1.5	3.7	1.0	2.3

Table 8 shows the data of percentage deviation of acetaldehyde emissions in four-stroke SI engine with different test fuels with different configurations of the engine in comparison with pure gasoline operation on conventional engine at different operating conditions of the catalytic converter.

Table 8: Data of percentage deviation of acetaldehyde emissions with different test fuels in different configurations of four-stroke SI engine in comparison with pure gasoline operation on conventional engine

Set	Conventional engine		Copper coated engine	
	Pure gasoline	Gasohol	Pure gasoline	Gasohol
Set-A	--	+90%	-36%	+20%
Set-B	-36%	-14%	-54%	-38%
Set-C	-72%	-32%	-82%	-58%

From the table 8, it can be observed that percentage increase of acetaldehyde emissions with gasohol operation on CCE is less when compared with CE operation with the same test fuel which shows the suitability of CCE which decreased pollutants.

Conclusions

Formaldehyde emissions in two-stroke engine decreased by 45 % and 68 % with Set-B and Set-C operations respectively when compared with Set-A operation with pure gasoline, while they are 34 % and 46 %, respectively with, gasohol operation. In two-stroke engine, acetaldehyde emissions decreased by 45 % with Set-B operation, 72 % with Set-C operation with pure gasoline operation on conventional engine while they are 12 % and 25 % with gasohol operation on CCE, respectively, when compared with Set-A operation.

In four-stroke engine, Set-B operation and Set-C operation decreased formaldehyde emissions by 45 % and 69 % respectively with pure gasoline operation on conventional engine when compared with Set-A operation, while they are 18 % and 36 % with gasohol on CCE. In four-stroke engine, acetaldehyde emissions decreased by 45 % with Set-B operation, 77 % with Set-C operation with pure gasoline operation on conventional engine while they are 26 % and 45 % with gasohol operation on CCE respectively when compared with Set-A operation.

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UDK	ključne riječi	key words
547.281.2	acetaldehid	acetaldehide
621.434.068.3	ispušna emisija benzinskih motora	gasoline engine exhaust emission
665.734.5	biobazno bioETBE 20 %, benzinsko 80 % gorivo	biobased bio-ETBE 20%, gasoline 80% fuel
665.734.3	biobazno etanol 20 %, benzin 80 % gorivo Gasohol E20	biobased ethanol 20%, gasoline 80% gasohol E20 fuel
621.795	površinska obradba nano-šenjem sloja bakra plazmom	surface treatment by copper plating using plasma
621.434.13	benzinski dvotaktni motor	gasoline two stroke engine
621.434.12	benzinski četverotaktni motor	gasoline four-stroke engine

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