Parthiban et al. 2017. *Int. J. Vehicle Structures & Systems*, 9(2), 134-138
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.9.2.14

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Emission Control in Multi-Cylinder Spark Ignition Engines using Metal-Oxide Coated Catalytic Converter

K. Parthiban[a], K. Pazhanivel[b] and S. Jenoris Muthiya[c]

[a]*Dept. of Mech. Engg., Thanthai Periyar Govt. Institute of Tech., Vellore, Tamil Nadu, India*

[b]*Dept. of Mech. Engg., ARS College of Engg., Chennai, Tamil Nadu, India*

[c]*Dept. of Automobile Engg., MIT Campus, Anna University, Chennai, Tamil Nadu, India*
Corresponding Author, Email: jenoris.555@gmail.com

ABSTRACT:

Internal combustion engines generate undesirable emissions during the combustion process. The NO_X, HC, CO_2 and CO emissions exhausted into the surroundings pollute the atmosphere that leads harming the human beings. The major causes of the emissions of pollutants are non-stoichiometric combustion, oxidation and reduction of nitrogen and impurities in the fuel and air. Thermal or catalytic converters and particulate traps are used for the post-treatment of exhaust gases [5]. In this investigation, an attempt has been made to control the engine exhaust emissions by using metal-oxide coated filters. The coating is performed by using vacuum coating unit over the surface of the mesh. The results obtained from the experiments using the filter coated with copper oxide, magnesium oxide, ferric oxide, cobalt oxide, copper oxide and their combinations were analyzed. The emission control achieved by adopting this technique was found to be effective.

KEYWORDS:

Emission control; Combustion; Catalytic converter; Metal-oxide coating; Spark ignition engine

CITATION:

K. Parthiban, K. Pazhanivel and S.J. Muthiya. 2017. Emission Control in Multi-Cylinder Spark Ignition Engines using Metal-Oxide Coated Catalytic Converter, *Int. J. Vehicle Structures & Systems*, 9(2), 134-138. doi:10.4273/ijvss.9.2.14.

1. Introduction

Increasingly, the strong and stringent air pollution regulations on the emission standards provide serious challenges for automobile manufacturers. During the past decades, extensive research has been carried out to decrease the emission of toxic components of combustion gases into the environment. Considerable development has been made in fulfilling the standards in the recent years. New combustion systems and technologies contribute to these achievements [1]. Catalytic converters are commonly utilized as a solution in meeting legislated emission requirements. As emission regulations have tightened, the complexity of the catalytic converter system has also increased. Increased converter volume required the use of multiple catalytic converter elements within the vehicle exhaust system. Engler et al [2] used wash coat formulations for Palladium/Rhodium based monolithic catalysts and improved the conversion performance under FTP-75 test cycle. Brett et al [3] used catalysed hydrocarbon traps in conjunction with the Exhaust Gas Ignition (EGI) system and demonstrated that upto 30% reduction in the total hydrocarbon (THC) emissions during 0 to 195 seconds of the New European Drive Cycle.

Sakthivel et al [4] studied the effect of copper, nickel and chromium coatings on the spark ignition engine's performance. At full load, the maximum brake thermal efficiency for copper coated engine was 5% higher than the standard engine. Giechaskiel et al [5] examined the emission levels of 5 mopeds, 9 motorcycles, 2 tricycles and 1 quad on the basis of Particulate Number (PN) method. The PN method has missed significant proportion of solid particles. As an alternative technique for emission control, Kanchan et al [6] demonstrated that 2 minutes pre-heating of converter before the start of engine has also enhanced the performance of catalytic converter in four-cylinder spark-ignition engine. Other works include the use of copper catalyst with zero Platinum group metals for motorcycle emission control [7-8]. In order to achieve the required benefit on curtailing emissions, the metal catalyst must be durable, i.e. perform well even after thermal degradation.

In this work different catalytic converters are designed and fabricated to reduce the harmful pollutants from the combustion inside the four-stroke, four cylinder spar ignition (SI) engines. In this investigation, an attempt has been made to control the engine exhaust emissions by using metal-oxide coated filters. The main emissions studied were hydrocarbon (HC), Nitric oxides (NOx), Carbon dioxide (CO_2) and Carbon monoxide (CO). The coatings of copper oxide, magnesium oxide, ferric oxide, cobalt oxide, copper oxide and their combinations are used in the catalytic converters. The coating is performed by using vacuum coating unit over the surface of the mesh. The results obtained from the experiments for a range of engine thrusts are analysed to establish the effectiveness of each metal-oxide catalyst coating on the emission control.

2. Metal-oxide coating & engine test setup

Eight types of metal-oxide coated catalytic converters were used for the purpose of the experiment. For coating the metal-oxides, the HINDHIVAC vacuum coater, as shown in Fig. 1, was used. It consists of a cabinet containing a vacuum pumping system together with all electrical components necessary for the coating process. Metal-oxides selected include copper oxide (CuO_2), magnesium oxide (MgO_2), ferric oxide (FeO_2), cobalt oxide (CoO_2) and their combinations on the basis of economic considerations. The coated catalytic converter is shown in Fig. 2. Table 1 gives the specifications of the four cylinder 4-stroke SI engine used in the emission control testing. An electrical dynamometer with rated power of 7 kW and rated speed of 1500 rpm is used for loading the engine. Schematic diagram and photograph of the test engine setup with catalytic coated filters are shown in Fig. 3 and Fig. 4 respectively.

Fig. 1: HINDHIVAC vacuum coater

Fig. 2: Catalytic coated filter

Table 1: Four stroke, 4-cyclinder SI engine specification

Parameter	Value	Parameter	Value
Disp. volume	1089cc	Power	7.5kW
Comp. ratio	7.3:1	Max. speed	4500rpm
Start. system	Battery Ignition Sys.	Bore dia.	68mm
Cooling	Water	Stroke	75mm

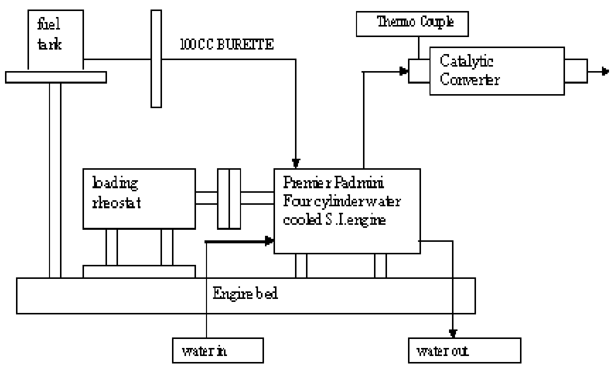

Fig. 3: Layout of engine test setup

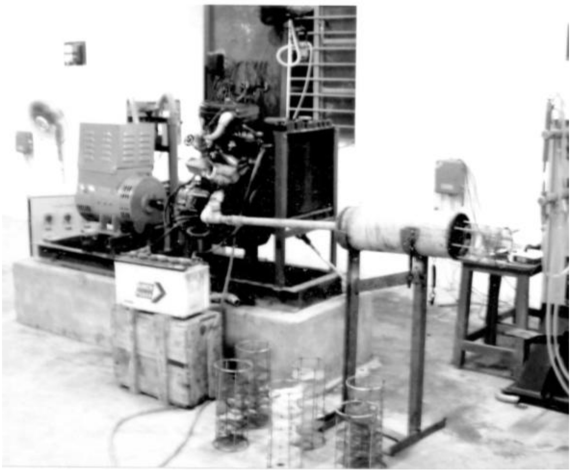

Fig. 4: Test engine setup with catalytic converter

Five gas analyzers were used for the measurement of HC, CO, NO_X and CO_2. Measurement was done with the help of automatic emission analyzer QRO-402 as shown Fig. 5. The analyzer is configured to perform a measurement by applying non-dispersive infrared (NDIR) method for analyzing CO, HC and CO_2 and electro-chemical method for analyzing NOx and O_2. In NDIR method, an infrared flashing lamp is attached at one end of the sample cell and a detecting sensor at the other end, so that it can detect the component of gas and in turn its density as shown in Fig. 6. Electro chemical method, as schematically shown in Fig. 7, measures the gas density by using the quantity of electrons produced at the time of oxidation and reduction of pollutant gases. The schematic steps for the measurement of emissions from the engine using automatic emission analyzer QRO-402 is shown in Fig. 8.

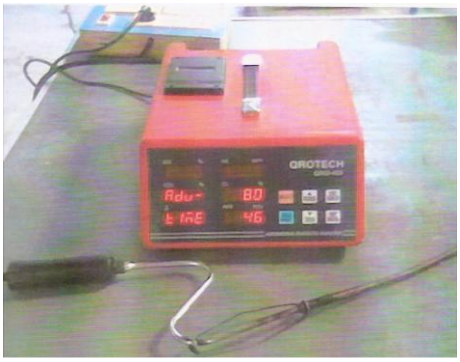

Fig. 5: Automatic exhaust emission analyzer

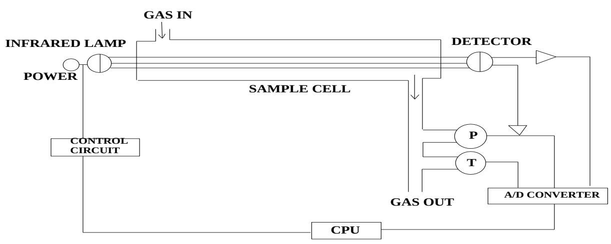

Fig. 6: NDIR method diagram

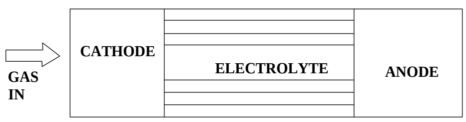

Fig. 7: Electrochemical method

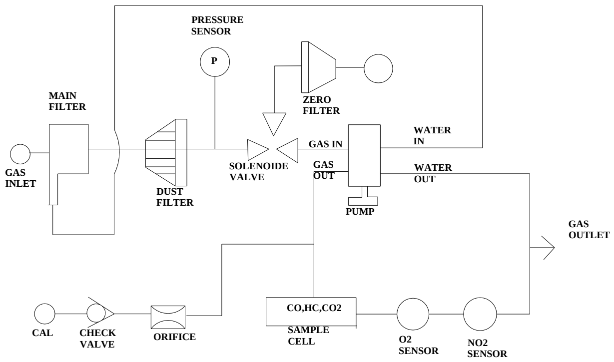

Fig. 8: Schematic of emissions measurement from engine test

3. Results and discussions

Experiments were initially carried out on the engine without catalytic converter in order to provide the base line data. The SI engine was run at a constant speed of 1500rpm. The engine was stabilized before all subsequent measurements were taken. The emission characteristics for various loads were measured using the exhaust-gas analyzer. The wire-meshes coated with different metal-oxides were introduced in the exhaust-line of the engine and the experiments were repeated to measure the emission characteristics for different load conditions. The variations in NOx emission data from the baseline test without catalytic converter and tests with various metal-oxides coated catalytic filter used in the exhaust line are shown in Fig. 9 and Fig. 10.

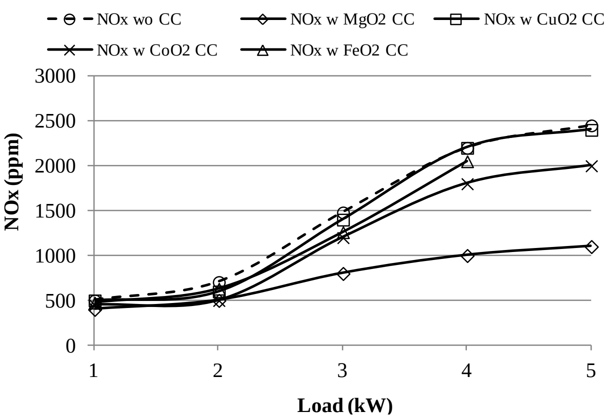

Fig. 9: NOx emission vs. Load for individual metal-oxide coating

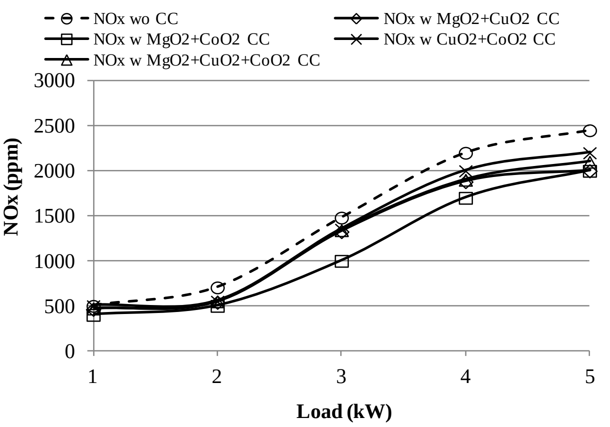

Fig. 10: NOx emission vs. Load for combined metal-oxides coating

The reduced NOx emission when compared with no catalytic converter is presented in Table 2. The catalytic converter with magnesium oxide coated mesh filter has shown the highest reduction of 55.1% for the maximum load of 5 kW. There was only about 10.2% to 18.4% reduction achieved with catalytic converter with a combination of metal-oxides coated mesh filter. The variations in HC emission data from the tests are shown in Fig. 11 and Fig. 12.

Table 2: Reduction in NOx emission due to various metal-oxides coated mesh in catalytic converter

Catalytic converter mesh coating	NOx % reduction vs. Load (kW)				
	1	2	3	4	5
MgO_2	20.0	29.1	45.9	54.5	**55.1**
CuO_2	0.0	**14.9**	5.4	0.0	2.0
CoO_2	10.0	**29.1**	18.9	18.2	18.4
FeO_2	5.0	10.6	**14.9**	6.8	-
MgO_2+CuO_2	7.6	**23.4**	10.5	14.5	18.4
MgO_2+CoO_2	20.0	29.1	**32.4**	22.7	18.4
CuO_2+CoO_2	0.0	**22.0**	8.8	9.1	10.2
MgO_2+CuO_2+CoO_2	6.0	**22.0**	9.5	13.6	14.3

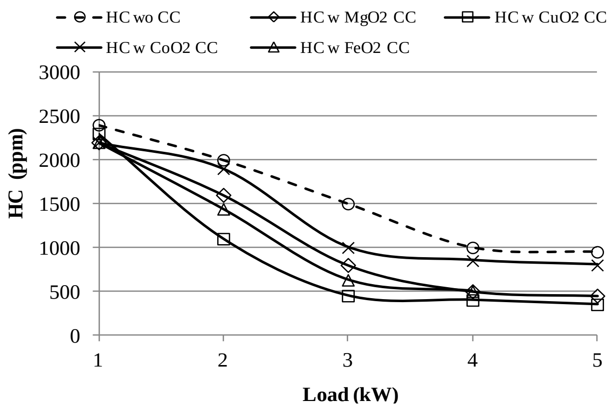

Fig. 11: HC emission vs. Load for individual metal-oxide coating

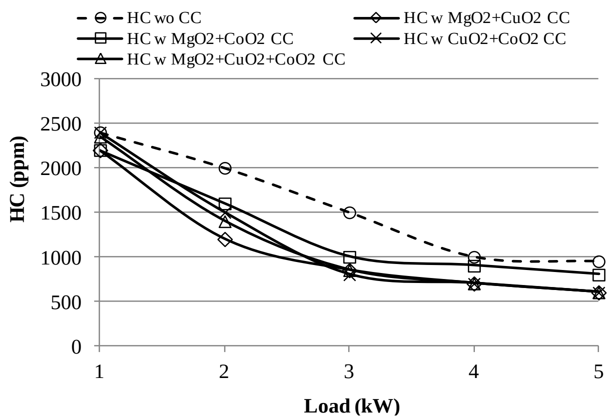

Fig. 12: HC emission vs. Load for combined metal-oxides coating

Table 3: Reduction in HC emission due to various metal-oxides coated mesh in catalytic converter

Catalytic converter mesh coating	HC % reduction vs. Load (kW)				
	1	2	3	4	5
MgO_2	8.3	20.0	46.7	50.0	**52.6**
CuO_2	4.2	45.0	**70.0**	60.0	63.2
CoO_2	8.3	5.0	**33.3**	15.0	15.8
FeO_2	8.3	28.0	**58.0**	50.0	-
MgO_2+CuO_2	8.3	40.0	**43.3**	30.0	36.8
MgO_2+CoO_2	8.3	20.0	**33.3**	10.0	15.8
CuO_2+CoO_2	0.0	25.0	**46.7**	30.0	36.8
MgO_2+CuO_2+CoO_2	2.1	30.0	**43.3**	30.0	36.8

The reduced HC emission when compared with no catalytic converter is presented in Table 3. The catalytic converter with copper oxide coated mesh filter has shown the highest reduction of 63.2% for the maximum load of 5 kW. There was only about 36.8% reduction achieved with catalytic converter with a combination of metal-oxides (except MgO_2+CoO_2) coated mesh filter. Generally the metal oxide coated mesh used in the catalytic converter has curtailed the HC emission more than the NOx emission. The variations in CO_2 emission data from the tests are shown in Fig. 13 and Fig. 14. The reduction in CO_2 emission due to metal-oxide coated mesh in catalytic converter is presented in Table 4. The catalytic converter with magnesium oxide as well as cobalt oxide coated mesh filters has shown the highest reduction of 29.4% for the maximum load of 5 kW. There was only about 6% reduction achieved with catalytic converter with a combination of metal-oxides coated mesh filter.

The variations in CO emission data from the tests are shown in Fig. 15 and Fig. 16. The reduction in CO emission due to metal-oxide coated mesh in catalytic converter is presented in Table 5. The catalytic converter with combination of magnesium oxide and cobalt oxide coated mesh filter has shown the highest reduction of 64.3% for the maximum load of 5 kW. There were only about 50-60% reduction achieved with catalytic converter with magnesium oxide as well as cobalt oxide coated mesh filters at optimum load. It should be noted that the emission data for 5kW when FeO_2 coated mesh filter used was not captured and hence were not presented. With the use of metal-oxide coated mesh filter, the CO_2 emission reduction was higher at lower loads; however the CO emission reduction was higher at optimum loads in the range of 4-5kW. Amongst the metal-oxides coatings considered, magnesium oxide, cobalt oxide, copper oxide and their combinations were more suitable for curtailing higher amount of emission.

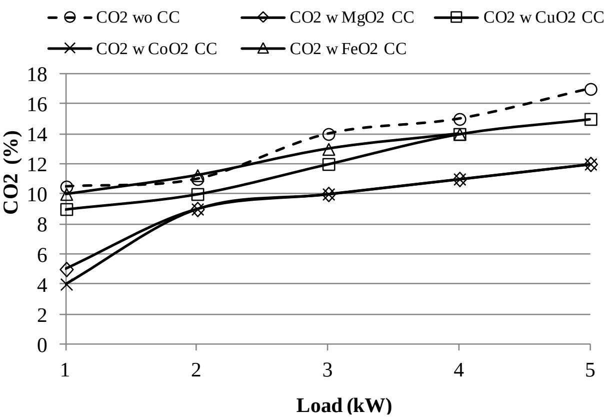

Fig. 13: CO_2 emission vs. Load for individual metal-oxide coating

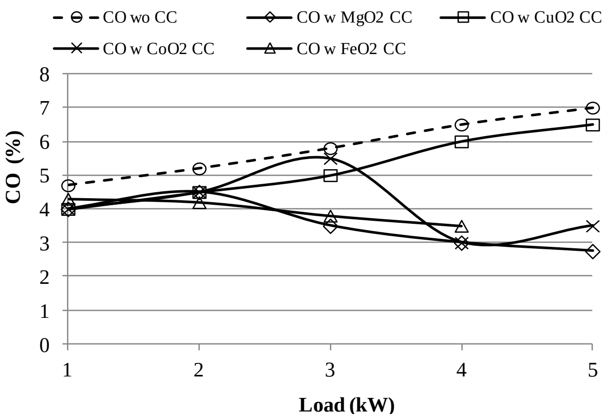

Fig. 15: CO emission vs. Load for individual metal-oxide coating

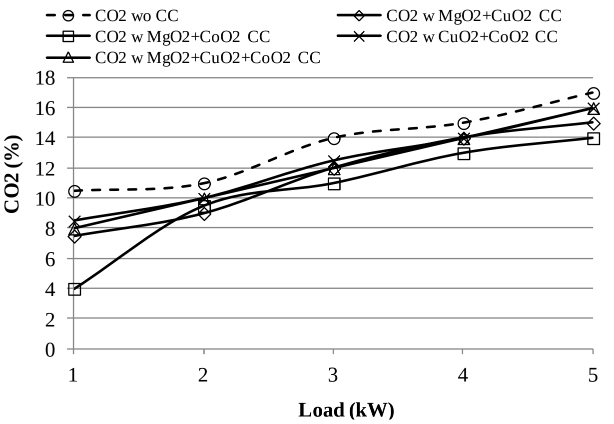

Fig. 14: CO_2 emission vs. Load for combined metal-oxides coating

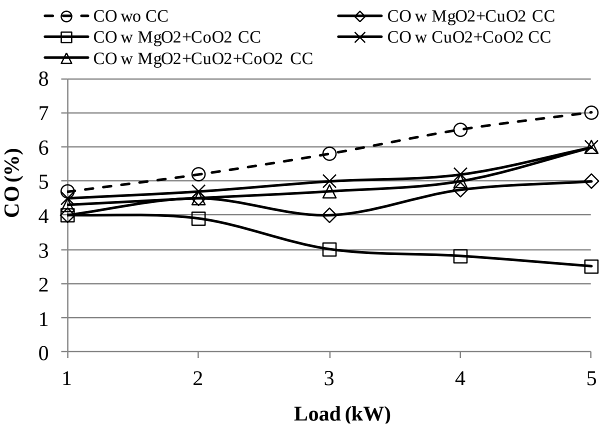

Fig. 16: CO emission vs. Load for combined metal-oxides coating

Table 4: Reduction in CO_2 emission due to various metal-oxides coated mesh in catalytic converter

Catalytic converter mesh coating	CO_2 % reduction vs. Load (kW)				
	1	2	3	4	5
MgO_2	**52.4**	18.2	28.6	26.7	29.4
CuO_2	**14.3**	9.1	14.3	6.7	11.8
CoO_2	**61.9**	18.2	28.6	26.7	29.4
FeO_2	4.8	-2.3	**7.1**	6.7	-
MgO_2+CuO_2	**28.6**	18.2	14.3	6.7	11.8
MgO_2+CoO_2	**61.9**	13.6	21.4	13.3	17.6
CuO_2+CoO_2	**19.0**	9.1	10.7	6.7	5.9
MgO_2+CuO_2+CoO_2	**23.8**	9.1	14.3	6.7	5.9

Table 5: Reduction in CO emission due to various metal-oxides coated mesh in catalytic converter

Catalytic converter mesh coating	CO % reduction vs. Load (kW)				
	1	2	3	4	5
MgO_2	14.9	13.5	39.7	53.8	**60.7**
CuO_2	**14.9**	13.5	13.8	7.7	7.1
CoO_2	14.9	13.5	5.2	**53.8**	50.0
FeO_2	8.5	19.2	34.5	**46.2**	-
MgO_2+CuO_2	14.9	13.5	**31.0**	26.9	28.6
MgO_2+CoO_2	14.9	25.0	48.3	56.9	**64.3**
CuO_2+CoO_2	4.3	9.6	13.8	**20.0**	14.3
MgO_2+CuO_2+CoO_2	8.5	13.5	19.0	**23.1**	14.3

4. Conclusions

In this work, experimental work was carried out to control the emissions in a four cylinder SI engine with metal-oxide coated mesh filters used on its exhaust line. Various metal-oxides were carefully coated onto the mesh filter using vacuum coating. Each experiment was carried out in a stable manner with variation in load upto 5kW. At each load, the engine was stabilised and then the emission data was measured. The use of magnesium oxide coated filter reduced the emission of NO_X by 55%. When oxidized copper mesh catalytic filter was used, the maximum reduction of HC emission achieved was 63%. Cobalt oxide catalytic coated filter has reduced the emission of CO and CO_2 by 50% and 29% respectively.

The magnesium oxide, copper oxide and cobalt oxide were the best catalyst to control the emission from the engines. When all these catalysts were used combined, it may yield better results in reducing the NO_x, HC, CO and CO_2. Having said, the combination of magnesium oxide and cobalt oxide coated mesh filter in the catalytic converter has proved to be optimal choice in significantly curtailing all the emissions.

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