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Original Research

Use of Electrically Heated Metal Catalytic Converter in Cold Starting To Reduce Automotive Emissions

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Abstract

The environmental degradation all over the world has led the researchers to work towards the development of Low Emission Vehicle (LEV) and Ultra Low Emission Vehicle (ULEV). Automobile vehicles emit substantial quantities of hydrocarbons (HC), carbon monoxide (CO) and particulate matter. These pollutants have significant adverse health effects and deteriorate environmental quality. To address the serious pollution problems posed by vehicles, growing number of countries worldwide? Catalytic converters have implemented that in motor vehicle pollution control programs aimed substantially reducing harmful emissions from spark ignited vehicles. Catalytic exhaust controls have been developed as a result of these regulations and are generally recognized to be the most cost—effective way to meet stringent emission standards. The catalytic converter does a great job at reducing the pollution, but it can still be improved substantially. One of its biggest shortcomings is that it only works at a fairly high temperature. When car start at cold, the catalytic converter does almost nothing to reduce the pollution from exhaust. Preheating the catalytic converter is a good way to reduce emissions. The easiest way to preheat the converter is to use electric resistance heaters. The electrical systems on most cars provide enough energy or power to heat the catalytic converter fast enough. So, in this research the main converter remains its usual position, whereas the heated catalyst is placed close to the exhaust manifold. The EHMC quickly reaches high temperature levels due to the heat supply from external source, sensible heat of the exhaust and the heat generated by the exothermic oxidation. This in turn helps the faster light off of the main converter.

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INTRODUCTION

Spark-Ignition (SI) and diesel engine (CI) are major sources of urban air pollution. The SI engine exhaust gases contain oxides of nitrogen (NO_x), carbon monoxide (CO) and unburned or partially burned hydrocarbons (HC). The catalytic converter is the most important exhaust emission control component. During normal operation, it catalyzes up to 97% Hydro carbon (HC) harmful gases. Although it is highly effective in neutralizing the harmful substances in the exhaust gases, the catalytic converter suffers from certain limitations. According to the Environmental Protection Agency (EPA) www.epa.gov/international report current technology vehicles emit the majority of tailpipe HC and CO emission during the first minute or few of operations following the cold start.

Reduction of nitrogen oxides to nitrogen and oxygen:

$$2NO_x \rightarrow xO_2 + N_2$$

Oxidation of carbon monoxide to carbon dioxide:

$$2CO + O_2 \rightarrow 2CO_2$$

Oxidation of un burnt hydrocarbons (HC) to carbon dioxide and water:

$$C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O$$

The catalytic converter was invented by Eugene Houdry, a French mechanical engineer and expert in catalytic oil refining who lived in the United States. About 1950, when the results of early studies of smog in Los Angeles were published, Houdry became concerned about the role of automobile exhaust in air pollution and founded a special company, *Oxy-Catalyst*, to develop catalytic converters for gasoline engines - an idea ahead of its time for which he was awarded a patent (US2742437) and then vast development this technology from year 1948 to today as shown in figure.1. Widespread adoption had to wait until the extremely effective anti-knock agent tetra-ethyl lead was eliminated from most gasoline over environmental concerns, as the agent would "poison" the converter by forming a coating on the catalyst's surface, effectively disabling it. Air pollution generated from mobile sources is a problem of general interest. In the last 60 years the world vehicle fleet has increased from about 40 million vehicles to over 700 million; this figure is projected to increase to 920 million by the year 2010 (Guibet and Faure-Birchem,1999). The environmental concern originated by mobile sources is due to the fact that the majority of engines employ combustion of fuels derived from crude oil as a source of energy. Burning of hydrocarbon (HC) ideally leads to the formation of water and carbon dioxide, however, due to non-perfect combustion control and the high temperatures reached in the combustion chamber, the exhaust contains significant amounts of pollutants which need to be transformed into harmless.

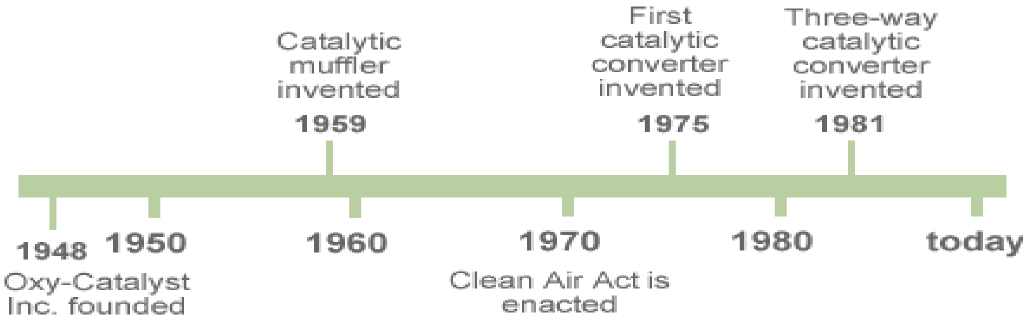

Figure1: Automotive technological development with catalytic converter

Diesel engine regulations are similarly varied, with some jurisdictions focusing on NO_x (nitric oxide and nitrogen dioxide) emissions and others focusing on particulate emissions (Mani, Subash, and Nagarajan, 2009). This can cause problems for the engine manufacturers as it may not be economical to design an engine to meet two sets of regulations. Regulations of fuel quality vary across jurisdictions. In North America, Europe, Japan, and Hong Kong, gasoline and diesel fuel are highly regulated, and CNG and LPG are being reviewed for regulation, too. In most of Asia and Africa this is not true - in some places sulfur content of the fuel can reach 20,000 parts per million (2%). Any sulfur in the fuel may be oxidized to SO_2 (sulfur dioxide) or even SO_3 (sulfur trioxide) in the combustion chamber. If sulfur passes over a catalyst, it may be further oxidized in the catalyst, i.e. (SO_2 may be further oxidized to SO_3). Sulfur oxides are precursors to sulfuric acid, a major component of acid rain. While it is possible to add substances like vanadium to the catalyst wash coat to combat sulfur oxide formation, such addition will reduce the effectiveness of the catalyst. The most effective solution is to further refine fuel at the refinery to produce ultra-low sulfur diesel. Regulations in Japan, Europe, and North America tightly restrict the amount of sulfur permitted in motor fuels. However, the expense of producing such clean fuel makes it not practical for use in many developing countries. As a result, cities in these countries with high levels of vehicular traffic suffer from acid rain, which damages stone and woodwork of buildings and produces deleterious effects on the local ecosystem.

Catalytic Converter

It is a device that uses a catalyst to convert three harmful compounds in car exhaust into harmless compounds. The three harmful compounds are:

- Hydrocarbons (in the form of unburned gasoline)
- Carbon monoxide (formed by the combustion of gasoline)
- Nitrogen oxides

Carbon monoxide is a poison for any air-breathing animal. Nitrogen oxides lead to smog and acid rain, and hydrocarbons produce smog. In a catalytic converter, the catalyst (in the form of platinum and palladium) is coated onto a ceramic honeycomb or ceramic beads that are housed in a muffler-like package attached to the exhaust pipe (William R. Miller and John T. Klein, 2000). The catalyst helps to convert carbon monoxide into carbon dioxide. It converts the hydrocarbons into carbon dioxide and water. It also converts the nitrogen oxides back into nitrogen and oxygen.

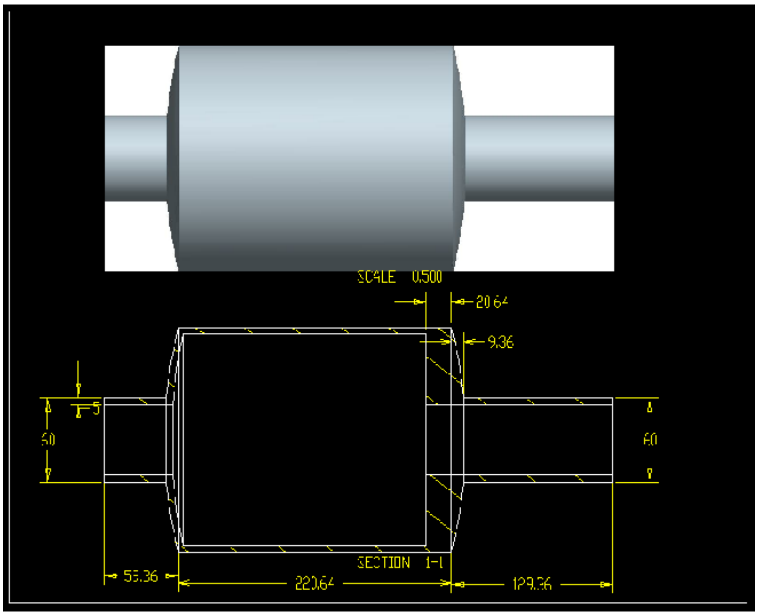

Figure 2: Outer design of converter.

Pollutants Produced by a Vehicle Engine

The main emissions of a car engine are Nitrogen gas (N_2) - Air is 78-percent nitrogen gas, and most of this passes right through the car engine.Carbon dioxide (CO_2) - This is one product of combustion. The carbon in the fuel bonds with the oxygen in the air. Water vapor (H_2O) - This is another product of combustion. The hydrogen the fuel bonds with the oxygen in the air.

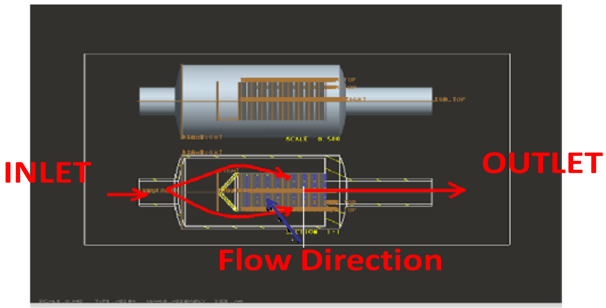

Figure 3: Gas flow.

These emissions are mostly benign, although carbon dioxide emissions are believed to contribute to global warming (Gieshoff, M. Pfeifer, Schäfer - Sindlinger, Spurk, 2001). Because the combustion process is never perfect, some smaller amounts of more harmful emissions are also produced in car engines. As shown in figure.3Catalytic converters are designed to reduce all three following gases:

Carbon monoxide (CO) is a poisonous gas that is colorless and odorless, Hydrocarbons or volatile organic compounds (VOCs) are a major component of smog produced mostly from evaporated, unburned. Nitrogen oxides (NO_x) (created when the heat in the engine forces nitrogen in the air to combine with oxygen).

Catalytic Converter Design

Passenger vehicle manufacturers have made tremendous progress in reducing emissions since the introduction of the first automotive catalytic converter in the mid-1970s. Early converters, called "two-way" converters, burned a percentage of the unused hydrocarbons (HC) and carbon monoxide (CO) produced by the relatively inefficient, low compression engines of the day. Two-way (oxidizing) converters burn HC and CO molecules with the assistance of a precious metals catalyst. This process "converts" these harmful gasses into water vapor and carbon dioxide (CO_2). The two-way catalytic converters are most effective when used with engines that have a lean air/fuel mix because this condition provides ample oxygen to "burn" the pollutants by the structure of Catalytic Converter as shown in figure 4.

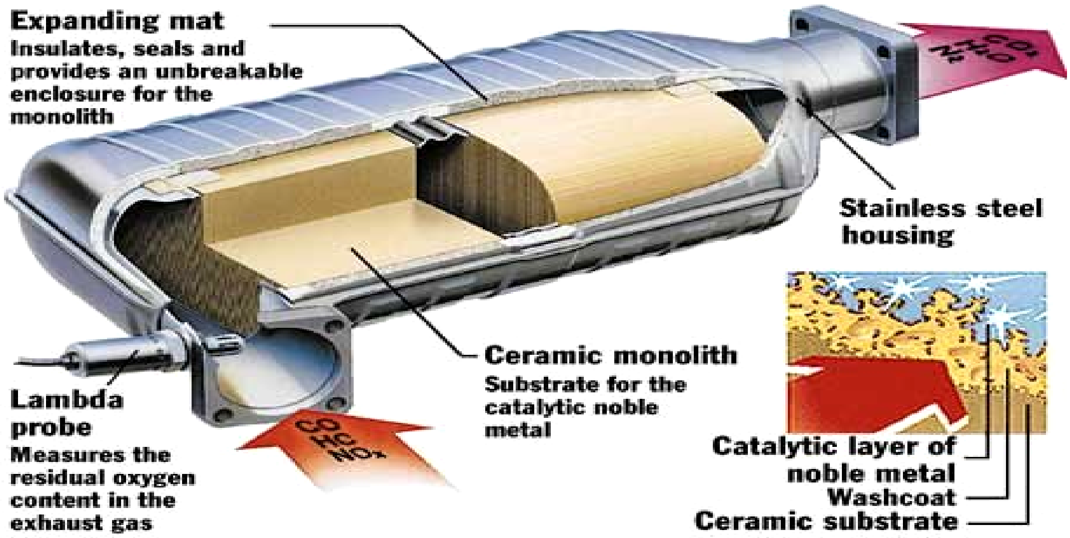

Figure 4: Structure of Catalytic converter.

Reaction in Catalytic Converter-Electrically Heated Metal Catalytic Converter (EHMC)

The major problem in the implementation of Electrically Heated Catalytic converter technology to automobiles is the high electrical power requirement and the time required for heat-up. Both can be successfully reduced with the use of Low Mass Electrically Heated Metal Catalytic (EHMC) converter. In this technique the main converter remains its usual position, whereas the heated catalyst is placed close to the exhaust manifold (Gieshoff *et al*., 2011). The EHMC quickly reaches high temperature levels due to the heat supply from external source, sensible heat of the exhaust and the heat generated by the exothermic oxidation. This in turn helps the faster light off of the main converter.

Research in Electrically Heated Metal Catalytic Converter (EHMC)

The catalytic converter does a great job at reducing the pollution, but it can still be improved substantially. One of its biggest shortcomings is that it only works at a fairly high temperature (Farrauto, Heck and Catal, 1999). When start car at cold, the catalytic converter does almost nothing to reduce the pollution in exhaust. One simple solution to this problem is to move the catalytic converter closer to the engine. This means that hotter exhaust gases reach the converter and it heats up faster, but this may also reduce the life of the converter by exposing it to extremely high temperatures. Most carmakers position the converter under the front passenger seat, far enough from the engine to keep the temperature down and that will not harm it. Preheating the catalytic converter is a good way to reduce emissions. The easiest way to preheat the converter is to use electric resistance heaters.

Experimental Set-Up of Exhaust

Experimental setup consists of a multi-cylinder, vertical, water-cooled, four stroke, spark ignition engine, coupled to a hydraulic dynamometer. The engine is mounted on the bed with suitable connections for lubrication and cooling water supply. The fuel is supplied from a fuel tank with three-way cock for fuel consumption measurement. The Low Mass Electrca1ly Heated Metal Catalytic converter s placed before the main catalytic converter on the exhaust pipe. The EHC was placed inside the EHMC is shown in the figure.5. Three different volumes of 145cc, 271cc and 378cc amounting to 10%, 20% and 30% of the main converter were chosen for the experiment. The main converter used is the commercially available converter that has been exposed to approximately 5000 kilometers of vehicle operation. Cromel-alumel thermocouples were provided for the measurement of the inlet, bed, and outlet temperatures of the EHMC and the bed temperature of the main converter. All these thermocouples were connected to a PC based 8 channels. 12bit data logging system to collect and store the temperatures. The gas analyzer (Crypton 285 OIML II- SPEC) was used for the measurement of HC & CO in the exhaust.

Experiment and Validation of Exhaust

First, the tests were conducted at idling speed of 1750 rpm for 20 seconds. During this period, emission measurements were taken without any after treatment device using the gas analyzer and data logging system. Immediately after this idling period of 20 seconds, 50% load was applied at 1750 rpm and again these measurements were for the next 160 seconds. Then the engine was allowed to cool back to the cold start conditions and same procedure for further repeated test. Later a commercially available main converter was fitted to the engine exhaust system and the experiments were repeated. Further an EHC of different volumes and LOC filled with Copper oxide were connected in front of MC in the exhaust system. Temperature and emission measurements were made. Then the EHC was heated with 1.5 KW band type electrical heater and the experiments were repeated.

Figure 5: Experimental setup with electrically heated metal. Cataly11c (EHMC) converter.

Figure 6: Performance of electrically heated metal. Catalyt1c (EHMC) converter with emission test set up.

Gas flow from automobile exhaust enters from left to right. Exhaust flow rate is 187 m^3/hr. Velocity 20m/sec. The temperature of the entering gas is in the table given below. This shows how the temperature varies over the first 130 seconds. The temperature is given in °C as shown in Table 1.

Table 1: Efficiency of engine at various engine speeds.

Engine Speed (RPM)	Load (KG)	Mano-Meter Reading: Height in left tube [h1] cm	Mano-Meter Reading: Height in right tube [h2] cm	Average Height H=h2-h1 cm	Time Taken For 10 Cm Fuel sec	Total Fuel Consumption (TFC)	Specific Fuel Consumption (SFC)	Efficiency %
3800	0	14.9	15.1	0.2	28	1.002	7.0729	69.46
3750	2	14.8	15.2	0.43	24	1.109	8.2594	59.67
3700	3.5	14.7	15.2	0.5	21	1.337	9.4376	52.06
3650	6	14.6	15.3	0.7	19.5	1.440	10.164	48.33
3600	8	14.55	15.35	0.8	18	1.568	11.01	44.62

Table 2: Result analysis of emission.

State/ Emission	Engine speed (RPM)	Without Catalytic Converter		With Catalytic Converter		Heating Element With Converter	
		Readings	Average	Readings	Average	Readings	Average
CO in %	3800	2.83		0.52		0.19	
	3700	2.85	**2.85**	0.50	**0.50**	0.18	**0.19**
	3600	2.88		0.50		0.19	
HC in ppm	3800	248		136		81	
	3700	246	**247**	132	**135**	84	**83**
	3600	247		138		83	
CO_2 in %	3800	8.90		0.60		14.21	
	3700	8.98	**8.90**	0.60	**0.60**	14.20	**14.20**
	3600	8.95		0.61		14.22	
NO_x in ppm	3800	72		42		17	
	3700	68	**70**	36	**39**	18	**18**
	3600	71		39		18	

CONCLUSION

From this investigations on cold start emission control of four stroke spark ignition engine using EHMC converter with EHCs of different volume without and with heating the conclusions are arrived. EHMC with different volumes of EHC filled with Copper oxide catalyst under no heat configuration gives lowest reduction of NO_x emission during cold start. EHMC with different volumes of EHC filled with copper oxide catalyst with heating configuration gives better reduction of NO_x emission during cold start compared with EHC. So, with EHC low emission in cold start.

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