PARAMETRIC STUDIES AFFECTING LIGHT OFF TIME OF CATALYTIC CONVERTERS

Mr. Arpit.J.Pandya[1], Prof. V.M.Patel[2]

[1]*Student, ME(IC Engine & Automobile), L.C Institute of Technology, Bhandu, Gujarat, India*
[2] *Assistant Professor, Mechanical Department,L.C Institute of Technology, Bhandu, Gujarat, India*

ABSTRACT

Control of harmful emissions during cold start of the engine has become a challenging task over the years due to the ever increasing stringent emission norms. Positioning of the catalytic converter closer to the exhaust manifold is an efficient way of achieving rapid light-off temperature. On the other hand, the resulting higher thermal loading under high- load engine operation may substantially cause thermal degradation and accelerate catalyst ageing. The objective of the present work is to reduce the light-off time of the catalyst and at the same time to reduce the thermal degradation and ageing of the catalyst to the minimum possible extent. In the present work two innovative approaches namely Parallel Catalytic Converter (CCP) System and Catalytic Converter in Series at Different Position (CCSP) have been adopted to reduce the light-off time of the catalyst. The tests were conducted on a 4 cylinder Spark Ignition Engine under cold start condition. It was established that considerable reduction in the light-off time was achieved by using CCSP. Further reduction in the light-off time was achieved by using pre catalysts (40%vol). It has been found that 13% reduction in CO light-off time was achieved with pre-catalyst (40%vol.) when compared to CCSP. Also 14% reduction in HC light-off time was achieved with pre-catalyst (40%vol.). It was also established that light-off time of CCSP can be brought down to 10 seconds using hot air injection.

KEYWORDS: *-Internal combustion engine, Cold Start Emission, Catalytic Converter, Pre-Catalyst, Light-off Temperatur*

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1. Introduction

Air pollution generated from automobile sources is a serious problem to human kind. During the last 60 years the world vehicle fleet has increased from about 40 million vehicles to over 1 billion. The figure is projected to double in another 20 years. Emission in Internal Combustion Engines (I.C. Engines) affects the quality of air leading to global warming and degeneration of human health. Vehicles emit the harmful exhaust emissions within the first 2-3 minutes after engine cranking following a “cold-start”. During the cold start, rich mixture is supplied to the engine and oxygen supply is insufficient for complete combustion of hydro carbon. Due to incomplete combustion, potentially harmful products like un-burnt hydrocarbons and carbon monoxides are produced.

Catalytic converters are effective in reducing the emissions only after they reach the “light-off” temperature, at which the catalysts become active, normally at around 250-300°C. The time period at which the catalyst becomes active is referred to as light-off time. The catalyst is said to be active for a particular emission when the conversion efficiency reaches 50%. Nearly 60 to 80% of the engine out emission occurs in the cold start. Efficiency of a conventional catalytic converter declines very steeply at low temperature. During cold start and warming period the converter efficiency is very close to zero. (Bielaczyc, P, et al., 2013). To reduce the cold start emission, light-off temperature has to be attained rapidly. There are active and passive methods for rapid light-off. The active methods include electrically heated metal catalyst, catalyzed fuel burner, exhaust gas ignition with secondary air injection. Passive methods include close coupled catalyst (CCC), use of pre-catalysts, air gap insulation, Phase change material and variable conductance insulation. Using air gap and insulating material over the catalyst outer surface, it retains the temperature of the catalyst even hours after the engine is stopped (Hummel, K et al., 2001).

Electrically heated catalyst using an external heater helps the catalyst to reach light off before starting the engine (Bhaskar, K, et al., 2004). The pre catalyst will attain the light off much earlier and hence reduces the cold start emission the catalyst is close coupled with exhaust manifold and hence exhaust gases take much lesser time to light off the catalyst (Lee, D et al., 2010). Burch et al. (1995) observed vacuum insulation and phase change thermal storage could be used to enhance the heat retention of a catalytic converter. Storing heat in the converter between trips allows exhaust gases to be converted rapidly thereby reducing the cold start emission. Geon Seog Son et al. (2000) suggested and studied a photo catalyst to reduce cold-start emissions. Conventional TWC can reduce more than 96% of harmful emissions after the activation, but under a cold-start condition it needs a lot of energy to activate. Cameron W et al. (2009) investigated that more than 75% of emission through an FTP-75 regulatory test are released in the few seconds after cold-start. A factor that controls the time to catalytic light-off is the heat capacity of the catalytic converter substrate.

Karthik et al. (2004) in their paper used a transient one-dimensional two-phase model to obtain an explicit light-off criterion and to estimate the transient time and cumulative cold-start emissions from a catalytic monolith for the case of non-uniform catalyst loading. Rong-Fang Horng et al. (2003) studied the effects of heating energy and heating position on the conversion efficiency of an electrically heated catalyst of a four stroke motorcycle engine under cold start conditions were investigated in this study. It was found in this paper that by applying heat to the catalyst however, there action of the catalyst could be promoted, which, consequently, improved the conversion efficiency. Lee and Heywood (2010) performed an experimental study to develop a more fundamental understanding of the effects of secondary air injection (SAI) on exhaust gas emissions and catalyst light-off characteristics during cold start of a modern SI engine. Bauer et al. (1999) studied the SI engine thermal management system with closed coupled catalytic converter. They measured the catalytic converter mantle temperature by three insulating methods like air gap insulation, air gap insulation with additional heat shield and air gap filled with ceramic fibers.

The objective of the present work is to reduce the light-off time of the catalyst to the minimum possible extent. Parallel Catalytic Converter (CCP) System and Catalytic Converter in Series at Different Position (CCSP) is suggested to achieve rapid light off and at the same time to overcome the damages caused to the catalyst due to the close proximity of the catalyst. In this approach, the catalyst is kept very close to the exhaust manifold during cold start of the vehicle and once it attains the light-off temperature the same catalyst is moved to a faraway position as any other conventional catalyst. The experiments were also conducted with hot air injection to reduce the light-off time further.

2. Experimental Setup:

The experimental setup to be used for study is the one with is available in institute laboratory which is in line 4 cylinder petrol engine test-rig with hydraulic dynamometer loading system. Detailed engine specifications are mentioned in below Table 1.

Table 1 Specification of Test engine to be used

Manufacturer	*ISUZU*
Engine Type	*4 stroke in-line*
BHP	*10 HP*
Rated RPM	*1500 RPM*
Compression Ratio	*8.5:1*
Bore (mm)	*84mm*
Stroke(mm)	*82mm*
No. of cylinders	*4*
Cubic Capacity(cc)	*1,817 cc*
Cooling Type	*Water cooled*
Dynamometer	*Hydraulic dynamometer loading system*
Loading Radius	*0.32 m*
Dynamo type	*Water Loaded*

The experimental investigations were carried out with the following experimental setups.
1. Parallel Catalytic Converter (CCP) System.
2. Catalytic Converter in Series at Different Position (CCSP).

In the real time driving cycle of a vehicle, the load on the engine increases as it starts from idling to maximum speed. Hence the investigation was conducted at different load condition to study the effect of loading on light-off time of the catalyst.

2.1Parallel Catalytic Converter System (PCCS):

Conventional underfloor catalytic convertors are normally placed at a distance of around 1m from the exhaust manifold, which takes 2 to 3 minutes to reach the light-off temperature. Close coupled catalyst is a good solution to reduce the light-off time. However, close proximity of the catalyst from the engine added with high temperature of exhaust gases creates thermal degradation of the catalyst and accelerates catalyst ageing. Parallel catalytic convertor is a solution to reduce the light-off time and at the same time protects the catalyst from early ageing. In CCP, two catalysts namely Pre catalyst (PC) and a main catalyst (MC) are arranged in parallel. PC is located very close to the exhaust manifold and MC is kept far away from the engine to keep the temperature down to levels that will not harm the catalyst. The schematic representation of CCP is shown in Figure 1.

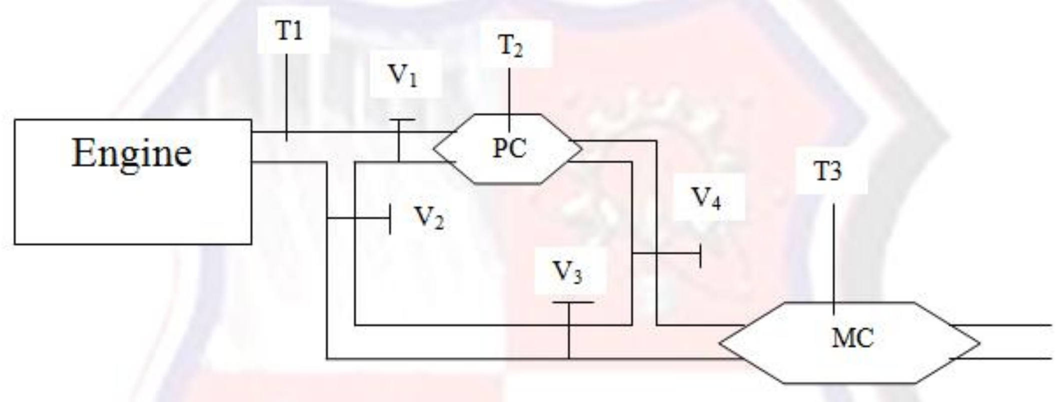
In the present work the PC is attached at a distance of 15cm from exhaust manifold and the MC parallel to the PC is kept at a distance of 90cm from the exhaust manifold. The study has been conducted at various engine load conditions. Since the PC is close to the exhaust manifold, the light-off temperature is achieved very quickly. The exhaust entering the PC undergoes exothermic oxidation and passes through the main catalyst. The exothermic heat carried away by the exhaust gas heats the MC quickly and hence it attains earlier light-off. When the MC reaches the light-off, the flow of exhaust gas through PC is cut off and the exhaust is directed to flow directly through the MC. The butterfly valves V1, V2 and non return valves V3, V4 are mounted at appropriate positions to control the flow of exhaust gas through PC and MC. The temperatures are measured using K type thermocouples.

2.2Experimental Procedure for PCCS:

Emission test has been conducted with parallel catalytic converter system at different loading conditions namely no load, half load and full load conditions. Initially the valve V1 will be kept opened and the valve V4 will be kept closed and exhaust is allowed to flow through PC and then through MC to the tail pipe. Once the MC reached the light-off, the valve V1 would be close and the valve V2 would open. The exhaust gas would directly flow through the MC till the engine stops. During the subsequent start of the engine the temperature of MC would have dropped below the light-off temperature and the valve V1 will be opened and to close the valve V2 .This enables the exhaust to flow through the PC and then to MC till MC reaches light-off. This process will be repeated during every fresh start. Thus during every cold start the exhaust first flows through the PC for first few seconds until MC reaches light-off temperature and then directed to flow directly through the MC for the remaining period of engine operation. Hence PC acts as a bypass catalyst for the first few seconds only and thus prevented from thermal damage and early ageing. Following parameters are measured in the investigation. The temperature of the catalyst was measured at the following points using K type thermocouple and data logger. Emission values of CO and HC were measured using AVL Digas analyzer at no load, half load and full load conditions. The test was conducted at an ambient temperature of 32°C.

2.3Catalytic Converter in Series at Different Position (CCSP):

A telescopic catalytic converter system consists of number of pipes of increasing diameter which can be stacked one inside the other so that the length of the pipe can be extended or shortened. One end of the telescopic pipe is attached to the exhaust manifold of the engine and the other end is attached to the catalytic converter. In the present work the telescopic pipe consists of 6 pipes each measuring 150mm length. The maximum diameter of the pipe being 60mm and the succeeding pipes have the diameters 50 mm,40mm, 30mm, 25mm and 20mm. The CCSP moves on the rails provided on the frame as shown in Figure 2. The photographic view of Experimental setup with CCSP is shown in Figure 4. The temperature of CCSP is measured with the help of K-Type thermocouple. When the engine is cold started the CCSP will be at minimum distance of 150mm from exhaust manifold. The temperature sensor senses the temperature continuously and once it reaches light-off, CCSP is extended to next position. At each position of CCSP once light-off temperature is sensed it is moved to the next position and reaches the maximum distance at 900mm from the exhaust manifold. The catalyst will be positioned at the maximum distance till the engine is stopped. Thus the catalyst remains safe under thermal degradation and prevented from early ageing.



PC: Pre catalyst MC: Main catalyst

Figure. 1 Schematic of Parallel Catalytic Converter System

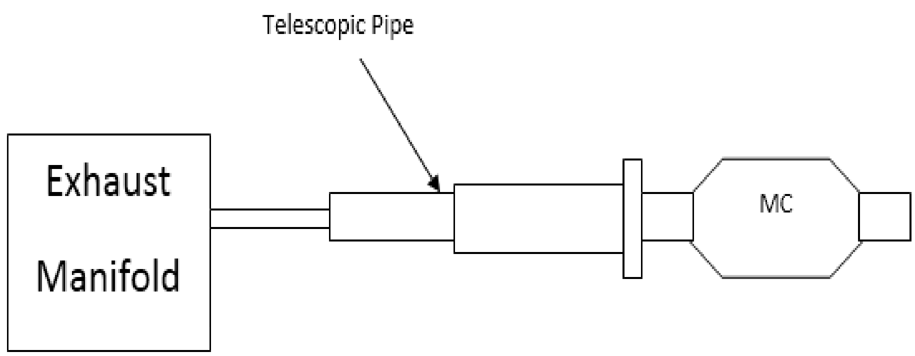


Figure.2 Schematic Arrangement of Telescopic Catalytic Converter System

Figure.3 Photographic View of Telescopic Pipe and Catalytic converters used

Figure.4 Photographic View of Experimental Setup with TCCS

3. Results and discussion:

From the figure 5, it is found that for CCSP under no load condition CO-light-off time decreases from 109 seconds to 44 seconds, from Position 6 to Position 1 with 60% reduction in light-off time, while HC light-off time decreases from 117 seconds to 52 seconds with 56% reduction .Similarly in case of Half load condition CO-light-off time has reduced by 54% and HC light-off time has reduced by 53% from Position 6 to Position 1.In case of full load CO light-off has reduced by 56% and HC-light-off has reduced by 51% from Position 6 to Position 1.It is also observed that the CO light-off time is minimum at full load condition at all positions.CO light-off time at Position 1 has reduced from 44 seconds to 30 seconds from no load to full load condition, with 32% reduction in light-off time. Similarly HC light-off time has reduced by 33% from no load to full load condition.

From Figure 6 for CCSP with PC, under no load condition CO-light-off time decreases from 64seconds to 35 seconds, from Position 6 to Position 1 with 45% reduction in light-off time, while HC light-off time decreases from 70 seconds to 40 seconds with 43% reduction .Similarly in case of Half load condition CO-light-off time has reduced by 45% and HC light-off time has reduced by 42% from Position 6 to Position 1.In case of full load CO light-off has reduced by 43% and HC-light-off has reduced by 46% from Position 6 to Position 1.It is also observed that the CO- light-off time is minimum at full load condition compared to no load and half load condition.CO light-off time at Position 1 has reduced from 35 seconds to 26 seconds from no load to full load condition, with 26% reduction in light-off time. Similarly HC light-off time has reduced by 25% from no load to full loadconditionatPosition1.The reduction of light-off time at full load condition is due to combustion of more fuel mixture at full load condition compared to no load and half load conditions.

From Figure 7 following results are obtained at different load condition for PC and MC. PC reached CO-light-off in 40, 35 and 30 seconds and HC light-off in 45, 40 and 36 seconds at no load, half load and full load conditions respectively. MC under TC2 reached CO-light-off in 130,120,100 seconds and HC light-off in 140,128,114 seconds. It has been observed that light-off time of CO and HC has reduced as the load on the engine increased. The reason is that there will be increase in temperature of exhaust gas at higher load due to combustion of more fuel mixture. It has also been noticed that light-off time for HC emission is slightly higher than the light-off time of CO, the reason being HC gets oxidized at higher temperature and requires more heat to burn compared to CO. Also oxidation of carbon monoxide to carbon dioxide is a single step reaction and requires less activation energy for the conversion, whereas hydro carbon requires more activation energy.

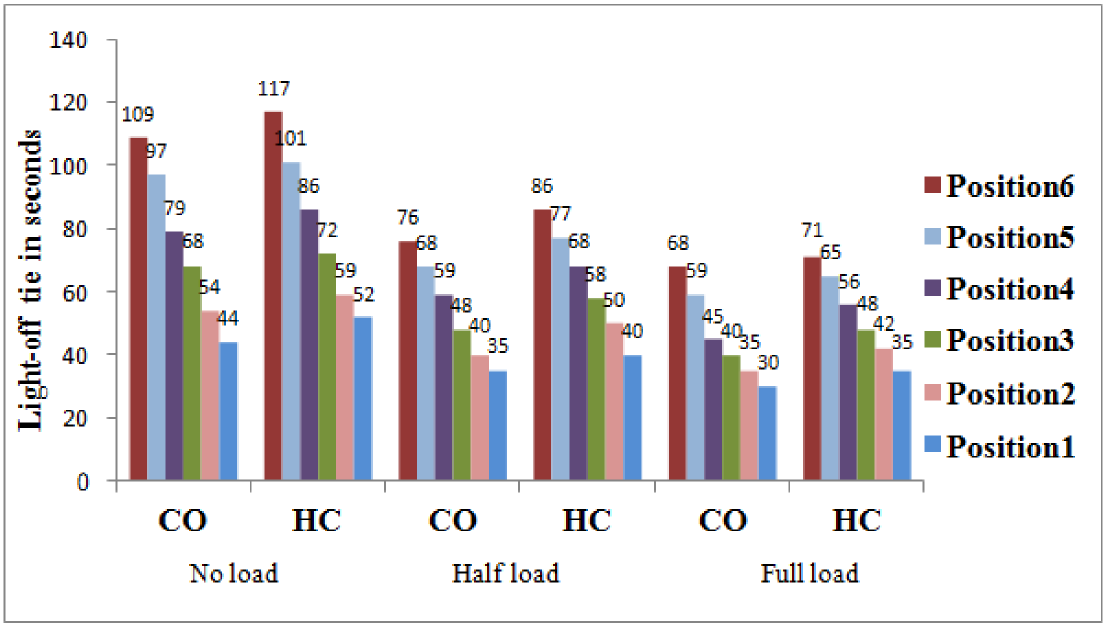


Figure.5Variation of CO/HC Vs Light Off Time in Seconds for Different Loads and DifferentPositions

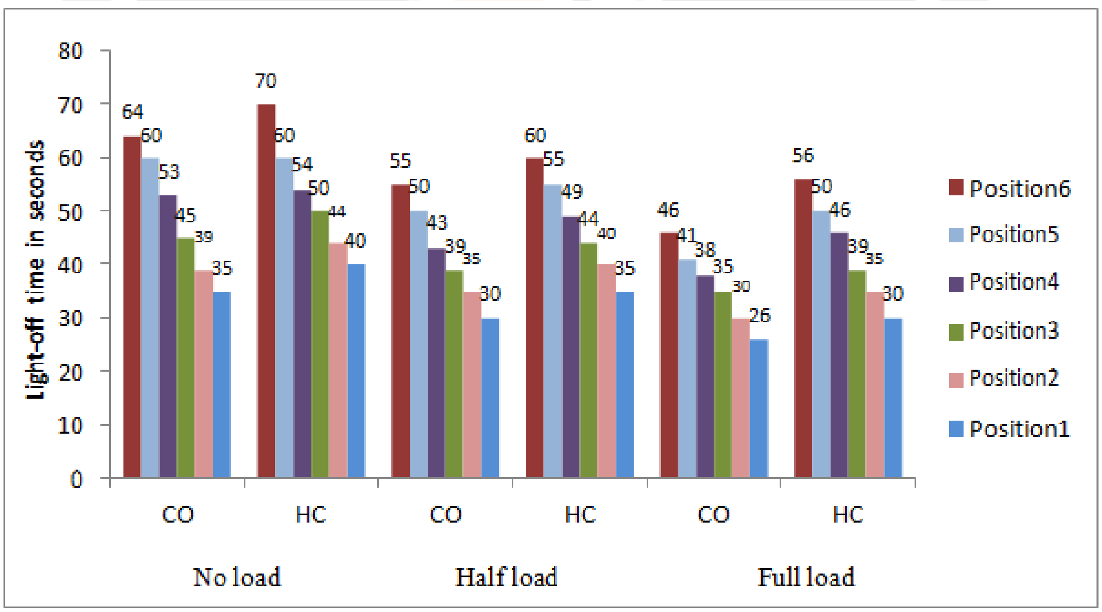


Figure.6Consolidated Results of CCSP with PC at Various Positions of the Catalyst

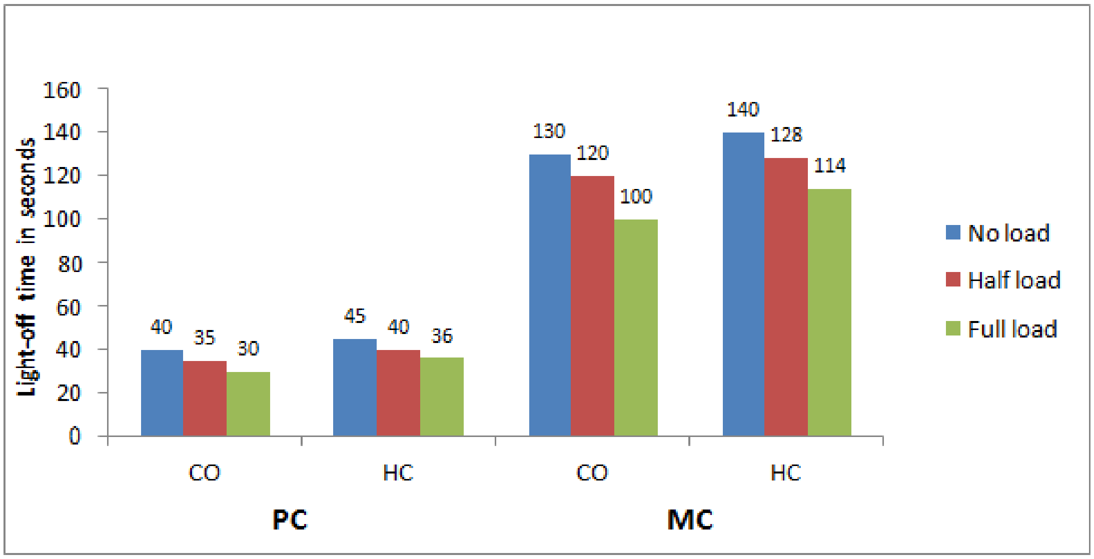


Figure.7Consolidated Results of CCP at Various Load Condition

4. Conclusion

- IN PARALLEL CATALYTIC CONVERTER (CCP) SYSTEM

The CO and HC light-off time for PC has been reduced by 25 % and 22% and for MC the light-off time has been has reduced by 23 % and 21% respectively at full load condition compared with no load condition. Also we have observed that PC reached CO light-off in 30 seconds and HC light-off in 35 seconds at full load condition. When the engine load increases from no load to full load CO light off time reduces from 40 seconds to 30 seconds and HC light-off time reduces from 45 seconds to 36 seconds for PC.

- IN CATALYTIC CONVERTER IN SERIES AT DIFFERENT POSITION (CCSP) SYSTEM

The minimum CO and HC light-off time occurred in 30and 35 seconds at Position 1 for CCSP under full load condition. It has been found that there is 56% reduction in CO light-off time at Position 1 compared to Position 6 at full load condition. Also it has been found 51% reduction in HC light-off time at Position 1 compared to Position 6.When the engine load increases from no load to full load the CO light-off time reduces from 44 seconds to 30 seconds and HC light off time reduces from 52 seconds to 35 seconds.

- CCS WITH PRE-CATALYST

The minimum CO and HC light-off time occurred in 26 and 30 seconds at Position 1 for CCS with pre-catalyst under full load condition. It has been found that there is 13% reduction in CO light-off time and 14% reduction in HC light-off time when compared to TCCS without pre-catalyst at Position 1. When the engine load increases from no load to full load the CO light-off time reduces from 35 seconds to 26 seconds and HC light off time reduces from 40seconds to 30 seconds.

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