# Reduction of Cold Start Exhaust Emissions from a Diesel Engine using Electrical Catalytic Converter – An Experimental Study

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***Abstract:*** Current catalytic converters to reach their light-off temperature requires the exhaust gas temperature of about 250-3500C at their inlet. Exhaust gases to reach this temperature take about 120 seconds of engine running from cold start. Therefore, catalytic converter takes some time to attain its light-off temperature and thereby 80% of the unburned hydrocarbons (HC) are emitted during this period. Therefore, cold start exhaust emissions represent the greatest contribution to the air pollution from today's vehicles fitted with catalytic converters.

This paper deals with the experimental investigations carried out to reduce the cold-start hydrocarbon (HC) and carbon monoxide (CO) emissions from naturally aspirated DI diesel engine with the help of an Electrically Heated Catalytic Converter (EHC) and with an Electrically Initiated Chemically Heated Catalytic Converter (EICHC). In both the cases, catalytic converters are heated either electrically or chemically or by both before starting the engine from cold conditions.

In this work, an electrically heated and an electrically initiated chemically heated catalytic converter have been designed and developed. In the former, electrical heating is utilized to reach the light-off temperature of the catalytic converter. In the later, heating of the catalytic converter is done in two stages; first, heated electrically to a certain predetermined surface temperature and then further heating was done through an exothermic chemical reaction by injecting methanol and secondary air into exhaust manifold. These systems are tested on a single cylinder, DI, diesel engine. Experiments are conducted with the above catalytic converters to evaluate the cold-start HC and CO emissions. All the tests are conducted during the first 180 seconds of engine running from cold, for four different configurations of engine operation viz., (i) running without catalytic converter, (ii) with catalytic converter alone, (iii) with EHC and (iv) with EICHC.

By comparing the results, it is found that, using EICHC system; about 40 to 60% reduction in peak value of cold start HC and CO has been achieved compared to emissions without catalytic converter. Also, it is found that electrical energy consumption by EICHC system is about 50% compared to that for EHC system. Finally, using EICHC, total light-off period is reduced by about 10 seconds.

***Keywords:*** Cold Start Exhaust Emissions; Diesel Engine; Electrical Catalytic Converter

## I. INTRODUCTION

The future vehicle emission legislation for HC, CO and nitrogen oxides (NOx) will be more stringent, such as European Stage-IV and the Californian low emission vehicles, etc. Therefore, it is necessary to modify the current exhaust systems in order to achieve significant reduction of above exhaust pollutants. Catalytic converter is one of most popular pollution abatement device ever invented to accomplish the stringent emission norms. But, 80% of HC are emitted during the first 180 seconds of cold starting before the catalytic converter reaches its working temperature (200-3000C). Therefore, the cold start exhaust pollutant represents the greatest contribution of the exhaust emissions from today's vehicles fitted with catalytic converters.

Rapidly increasing the surface temperature of the catalytic converter during 'cold-start' conditions is of paramount important in reducing cold start emissions. Over the past decade, several attractive potential solutions have been investigated to achieve rapid catalyst 'light-off' temperature, viz, close-coupled catalytic converters [2 - 3], hydrocarbon traps [4 - 5], exhaust gas ignition (EGI) [6], burner-heated catalyst (BHC) [7], electrically heated catalytic converter (EHC) [8] and electrically initiated chemically heated catalyst (EICHC) [9], etc.

In all the above techniques, electrical heating of the catalytic converter (EHC) has received the most attention in the automotive industry [8]. In this system, the electrical power is usually supplied by the battery to heat a low light-off catalytic converter located in front of the main catalytic converter. However, the high energy requirements associated with the EHC have hindered its commercialization. The EHC requires about 2 kW of power and a high current of the order of 150-250 amperes, for a minimum period of 20 seconds. The alternator used in vehicle is capable of providing up to 3 kW power at required voltage. Additionally, the integration of EHC system into automobiles requires significant modifications of the electrical system of the vehicles.

In the EICHC, surface temperature of the EHC converter module is first heated to a certain intermediate level. Then, it is further heated chemically through an exothermic catalytic oxidation of certain organic chemicals. In this way, limiting the electrical heating reduces the power drain of the battery or the alternator. Certain organic chemicals have the ability to undergo kinetically fast catalytic oxidation over highly dispersed noble metals like platinum or rhodium surface at relatively low temperatures and release large amounts of heat energy. A strategy for almost instantaneous heating of the catalytic converter based on EICHC approach is discussed in this study and methanol is used as organic compound. In addition, EHC system has also been tried.

## II. EXPERMIENTAL WORK {EICHC SYSTEM [1]}

EICHC is a combination of four systems, viz, electrical heating circuit, fuel injection system, secondary air supply system and catalytic oxidation system. Figure 1 shows the schematic diagram of EICHC system. An air blower (1) of suitable capacity has been used to supply secondary air to the EICHC system. An orifice flow meter (2) with u-tube manometer (3) was fitted to measure the flow rate of secondary air. A bypass valve (4) is used to control the secondary air flow. To inject methanol into the exhaust manifold, a solenoid operated fuel injector (5) is fitted onto the exhaust pipe line at an inclination of 450 angle to the manifold axis, so that methanol and secondary air are well mixed before entering the catalytic converter. The injector was supplied with fuel from an electrical fuel pump (6). A signal trigger (7) to on/off the injector valve is used to supply metered quantity of methanol. Electrical heating coil (9) of 3 kW capacities is wound around the first uncoated catalytic converter (10). The auto transformer (11) regulates the power input to the heating coil. The main catalytic converter (12) is fitted next to the uncoated catalytic converter in series, where the main oxidation takes place. As shown in Fig.1, four thermocouples (13) (at positions D, E, F & G) and three gas sample tubes (14) were fitted on the exhaust manifold: near to the engine (at position A), after the electrical heater (at position B) and after the coated catalytic converter (at position C). Non-dispersive infrared (NDIR) (15) and flame ionization detector (FID) (16) exhaust gas analyzer were used to measure CO and HC emissions respectively. Figure 2 shows the photographic view of the EICHC system fitted onto the exhaust system and the experimental setup used for experiments. The engine used in this work is a single cylinder, naturally aspirated, water cooled, diesel engine. The detailed specifications of the engine are given in Appendix.

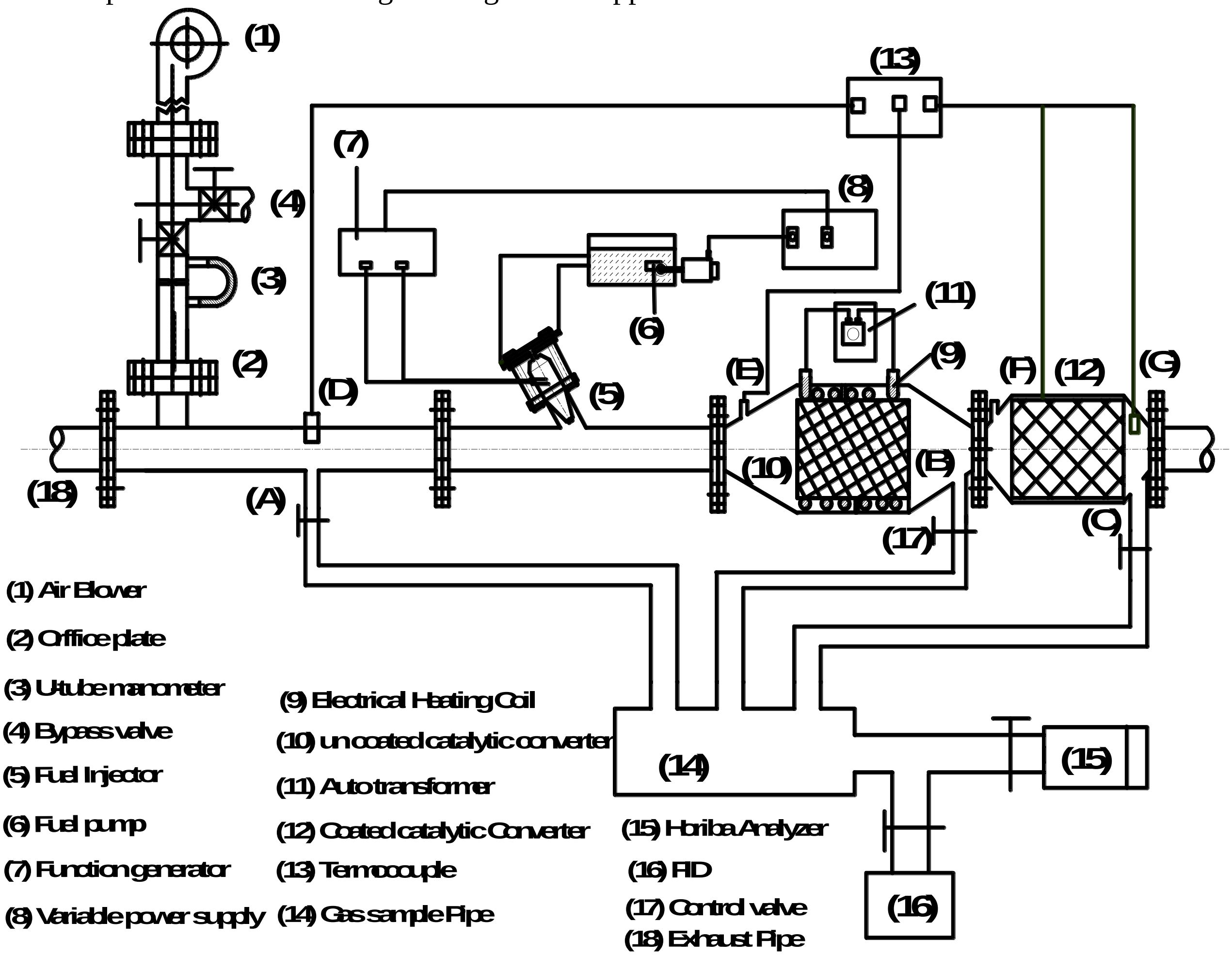


Fig.1. Schematic diagram of EICHC system developed

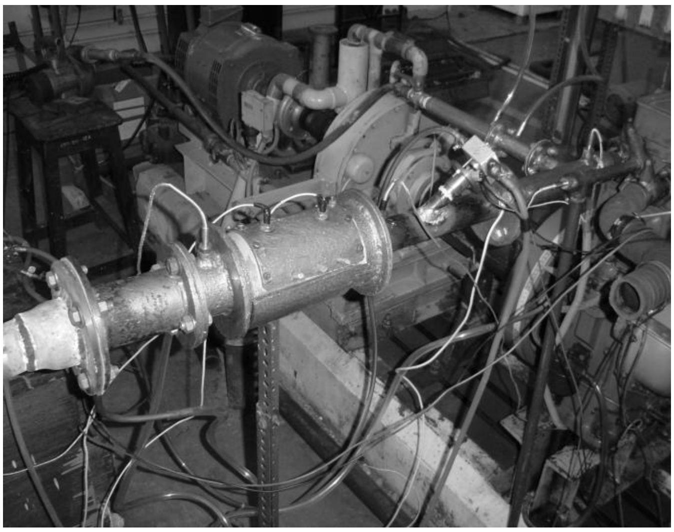

Fig.2. Photograph of the EICHC system developed

## III. EXPERIMENTAL PROCEDURE:

Experiments were conducted in the following configurations of engine operation: i) without catalytic converter (base line reading), ii) with catalytic converter without preheating and injection, iv) with EHC and v) with EICHC.

In the case of EHC system, electrical heating was done by 3 kW electric coil until the surface temperature of uncoated catalytic converter reaches to about 2770C (550 K). Then electrical heating was stopped and immediately engine was started and measurements were done. In the case of EICHC system, electrical heating was done with 3 kW electric coils for about 20 seconds until the surface temperature of uncoated catalytic converter reaches to a predetermined value (say 1000C). Then, the electrical heating was stopped and immediately, the methanol was fed at a predetermined flow rate into exhaust pipeline. Simultaneously, the secondary air was also supplied with regulated flow rate. When, the surface temperature of the coated catalytic converter reaches to about 2770C, the methanol supply was turned-off. Then, immediately engine was started and measurements were done. During first 180 seconds of the engine running period, at three locations (at positions D, F & G as in Fig.1), the exhaust gas temperature and HC and CO emissions (at positions A, B & C) were measured for first 180 seconds of engine running.

## IV. RESULTS AND DISCUSSIONS

All the tests were conducted during first 180 seconds of engine running from cold at no load and idling speed. The results are presented and discussed as follows: A) base line readings, B) with catalytic converter, C) with EHC and D) with EICHC. In the following sections, zero time refers to the starting of the engine

### *A.* ***Base line readings***

Baseline readings were taken by measuring the emissions at position A and exhaust gas temperature at position D i.e., without the action of catalytic converter. Figures 3 to 5 show the base line results of HC, CO and exhaust gas temperature respectively (without catalytic converter). It was found that during the first 40 seconds of engine running, the emission levels were higher. During this period, peak value of HC emission of about 7120 ppm and CO of about 20000 ppm were recorded. Between 40 and 120 seconds of engine running, very slow reduction of both HC and CO emissions took place. The exhaust gas temperature reached to its peak value of 432 K. During the next 60 seconds, HC, CO emissions and exhaust gas temperature were remaining almost constant.

### *B.* ***Effect of Catalytic Converter***

In this configuration, uncoated catalytic converter was not heated, secondary air and methanol were not supplied and coated catalytic converter was only active. The measurements were taken at position C for emissions and at position G for exhaust gas temperature.

The variation of HC and CO emissions can be seen in Figs 3 and 4, with and without catalytic converter action. During the first 40 seconds of engine running, the HC emissions for both configuration of operation were almost equal; a difference of 20 ppm of HC and 50 ppm of CO emission was recorded after 20 seconds. This is because; catalytic converter was not able to reach its working temperature during this period.

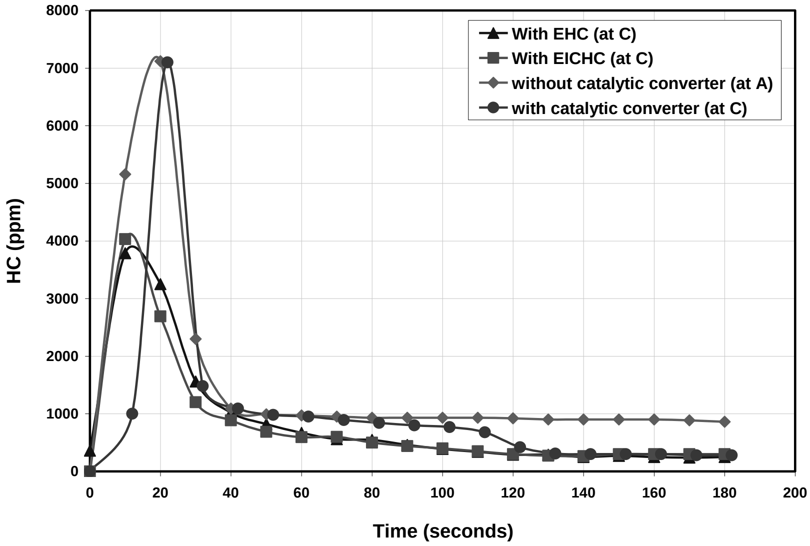


Fig.3. Variation of HC emissions under different configuration of engine operation

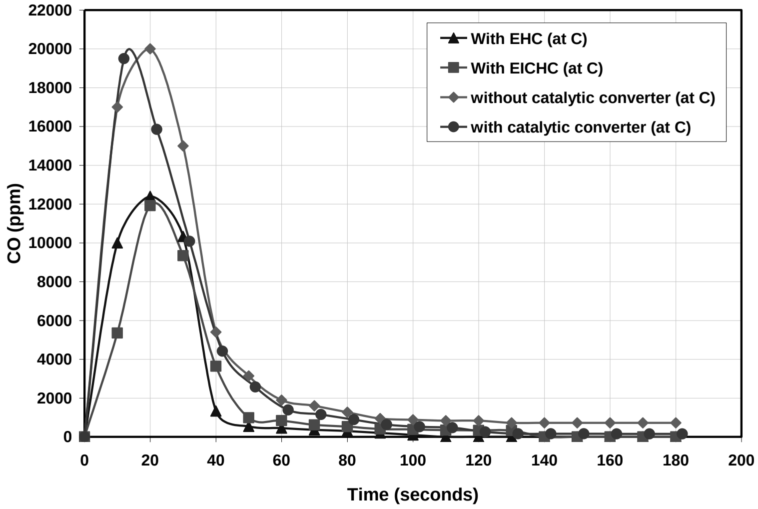


Fig.4. Variation of CO emissions under different configuration of engine operation

Between 40 and 120 seconds of engine running, no significant reductions of HC and CO emissions were observed. The average emissions measured before catalytic converter (at position A) were about 947 ppm of HC and 1388 ppm of CO and after the catalytic converter (at position C), the values were 850 ppm of HC and 1088 ppm of CO emissions. Therefore, it can be concluded that the catalytic converter was not fully effective at this stage because of low working temperature during this period.

During 120 to 180 seconds of engine operation, a significant reduction of HC emission was observed with catalytic converter. An average of about 895 ppm of HC and 735 ppm of CO emissions were recorded before the catalytic converter (at position A) and an average of about 312 ppm of HC and 147 ppm of CO emissions were recorded with catalytic converter (at position C). During this period, reduction of about 65% of HC and about 80% of CO emissions were recorded. This is mainly because of the catalytic converter reaching its working temperature during this period.

Figure 5 shows the exhaust gas temperature without and with the action of catalytic converter. In both the cases, the exhaust gas temperature reaches to about 420 K after 80 seconds of engine operation. Before this, exhaust gas temperature is low to activate the catalytic converter. Therefore, conventional catalytic converters can reduce emissions only after reaching their working temperature and a minimum of 120 seconds are required to attain this.

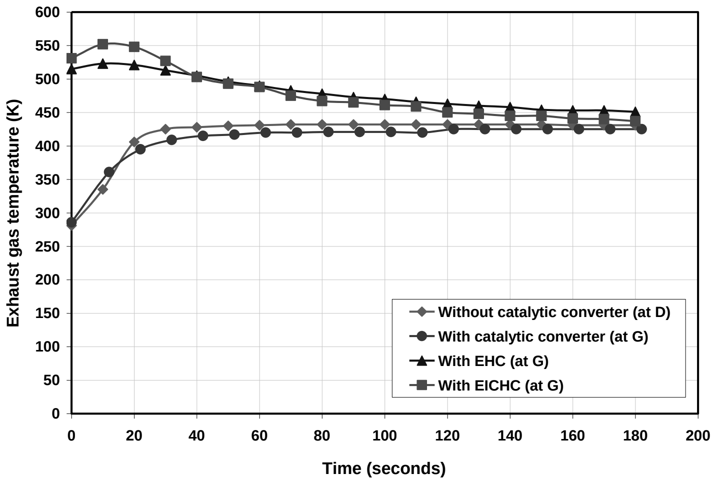


Fig.5. Variation of exhaust gas temperature under different configuration of engine operation

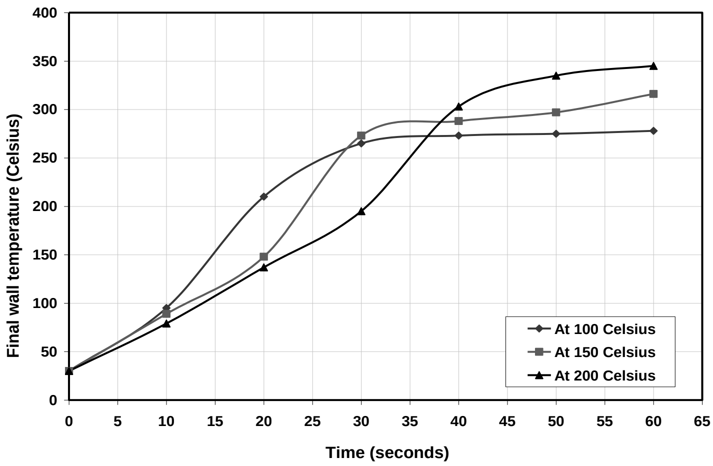


Fig.6. Effect of injecting methanol at different surface temperatures

## *C.* ***Effect of EHC***

In this configuration, preheating the surface of the uncoated catalytic converter placed before the coated catalytic converter was done, so that the surface temperature of uncoated catalytic converter reaches to about 550 K, before starting of the engine and methanol and secondary air were not supplied. The electrical heating coil used, for this configuration, consumes the power at rate of about 3 kW for a period of 30 seconds to reach the pre-determined surface temperature of about 550 K.

In figures 3 and 4, the variations of cold start HC and CO emissions with EHC operation for first 180 seconds of engine running are showing. From Figs.3 and 4, it is noted that during first 40 seconds of engine operation, peak values of cold start HC and CO emissions were recorded to be about 3700 ppm and 12400 ppm respectively with EHC system. However, at the same condition, baseline readings were about 7120 ppm and 20000 ppm respectively. Thereby, 48% of unburned HC and 38% of CO were able to oxidize during the first 40 seconds of engine operation due to electrical preheating of the uncoated catalytic converter, which has enhanced the working temperature of coated catalytic converter.

During 40 to 120 seconds of engine running, average values of 312 ppm of HC and 308 ppm of CO emissions were recorded. In this period, a reduction of 68% of HC and 78% of CO emissions was achieved compared to the average emissions of standard engine (947 ppm of HC and 1388 ppm of CO). This is because the catalytic converter reaching its working temperature quickly where it can work efficiently.

During 120 to 180 seconds of engine operation, percentage reduction of HC for both EHC (67%) and with catalytic converter (65%) is almost equal. In this period, CO emissions were almost zero for both configuration of engine. This is because of almost the same exhaust gas temperature for both the configuration of engine (Fig.5).

### *D.* ***Effect of EICHC***

In this configuration, surface temperature of uncoated catalytic converter was heated to about 550 K in two stages. First, by preheating the uncoated catalytic converter electrically, so that the surface temperature reaches to a pre-determined value of about 373 K (1000C). Next, methanol was injected into the exhaust manifold at the entry of the uncoated catalytic converter, which undergoes an exothermic chemical reaction to liberate additional heat energy, so that the surface temperature of the uncoated catalytic converter reaches to about 550 K.

Figures 3 and 4 showing, the variations of cold start HC and CO emissions for the engine with EICHC system. They show that the cold start HC and CO emissions with EICHC system is almost follows the same trend as that with EHC system. With this system, a reduction of about 43% of HC and 58% of CO emissions were recorded during the first 40 seconds of engine operation. During 40 to 120 seconds of engine operation, a reduction of 45% of HC and 68% of CO emissions was recorded compared to the emissions of standard engine. During 120 to 180 seconds of engine operation, it was observed that a reduction 61% of HC was achieved. This is almost equal to the reduction achieved with the configuration of catalytic converter alone. In this period, it was found that, the CO emission was almost zero. This is due to sustainable oxidation process taking place in the coated catalytic converter.

Figure 5 shows the exhaust gas temperatures for all four configurations of engine operation. It was found that a sudden shoot up of exhaust gas temperature was recorded during the first 25 seconds with EICHC system. This may be due to the exothermic chemical reactions of the remaining methanol droplets, which were segregating on the coated catalytic converter substrates. Therefore, the exhaust gas temperature found to increase further, which was helpful to oxidize the remaining unreacted methanol before leaving to atmosphere. Therefore, EICHC system improved the light-off time by about 10 seconds as compared to EHC system apart from significant reduction of cold start emissions. With EICHC system, 50% of reduction of electrical energy consumption was recorder compared to the EHC system.

### *E.* ***The Effect of Injecting Methanol at Different EHC Temperature***

The effect of injecting methanol at different surface temperature of the uncoated catalytic converter (100, 150 and 200oC) is shown in Fig.6. The injection rate of methanol was maintained at 50 ml/min and the secondary airflow was maintained at 320 liter/min for all the temperatures. It was found that, the total time required to achieve light-off time has increased, when methanol was injected at higher surface temperatures. This is because more time required for electrical preheating to reach predetermined surface temperature of uncoated catalytic converter. Even though higher surface temperature by electrical heating accelerates the rate of chemical reaction, it also increases the total light-off time. Therefore, it is advisable to heat the uncoated catalytic converter using electrical heating to a lowest surface temperature where complete exothermic chemical reactions would be possible.

Table 1: Percentage reduction of cold start emissions

| Time | Configurations of engine operation | | | | | |
|---|---|---|---|---|---|---|
| | **With catalytic converter** | | **With EHC system** | | **With EICHC system** | |
| | HC (%) | CO (%) | HC (%) | CO (%) | HC (%) | CO (%) |
| 0 to 40 seconds | 0.3 | 0.3 | 48 | 38 | 43 | 58 |
| 40 to 120 seconds | 0.2 | 22 | 68 | 78 | 45 | 68 |
| 120 to 180 seconds | 65 | 80 | 67 | 100 | 61 | 100 |

## V. CONCLUSIONS

1. In this work, EHC and EICHC systems are successfully designed, developed and tested on an experimental engine.

2. For the engine operating with three configurations of catalytic converters, the percentage reduction of cold start HC and CO emissions are compared and summarized in Table 1.

3. The total light-off period increases when the methanol is injected at higher EHC temperatures.

4. Even though the higher temperature creates a good ground for rapid chemical reaction, it takes more time to attain light-off temperature. Therefore, it is advisable to inject methanol at the minimum temperature at which a complete exothermic chemical reaction is possible.

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**APPENDIX:** Engine Specifications

| | |
|---|---|
| **Model** | Kirlosar, AV1 - 5 hp @ 1500 rpm |
| **Type** | Water-cooled, Vertical, 4 stroke cycle, Direct injection, Naturally aspirated. |
| **No. of cylinders** | One |
| **Bore x Stroke** | 80 x 110 mm |
| **Cubic Capacity** | 0.553 liter |
| **Compression Ratio** | 16.5:1 |
| **Rated Output** | 3.7 kW (5.0 hp) at 1500 rpm. |