Disambiguation of Catalytic Converter with Fluid Compounds using Automation and Reducing Cold Start Time with PCM

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ABSTRACT

Pollution is the biggest problem in today's world. Cars are the primary source of air pollution. They emit harmful gasses into the environment like HC, NO, and CO with hazardous health effects. To reduce the pollution cars are assembled with catalytic converter which works on chemical reactions. Due to the continuous use or gasket oil leak, the efficiency of the catalytic converter decreases. The aim of this research is to clean the catalytic converter using different fluid compounds (gaseous elemental compound, Acidic, Alkaline and Water based). For pressurized cleaning, an automatic system was developed which can be fitted before the catalytic converter. The phase change material (PCM) is used to maintain the temperature after the shut of engine which reduces the cold start time. Experimental setup is fabricated, and comparative study was done. Based on the experimental results it was observed that the best performance is obtained when the converter is cleaned with the acidic compound. After continuous use of acidic compound, the catalytic converter gets eroded, so only air and water should be used for pressurized cleaning. Furthermore, the decrease in the level of NO, CO, and HC by 16%, 54%, and 83% respectively was observed during the cold start time. The time was reduced for the cold start from 150 seconds to 75 seconds using the PCM material.

Keywords: Catalytic converter, Phase change material, cold start time, Emission, Fluid compounds

INTRODUCTION

The world is changing at a rapid rate. New diseases are entering into the daily life of human beings. As the medical facilities are improving so are the diseases. Recently, the world has seen what an unknown pandemic (COVID-19) did to this world. Pollution is also one of the reasons for spreading diseases into the environment. The population is increasing every year, and due to this, the number of automobiles is also growing. Cars are the primary source of pollution in the world. During the lockdown, everyone saw a decrease in pollution level significantly as there was no car on the road. Today, everyone depends on cars and they have become an essential part of our daily life. The light motor vehicle makes up 95 percent of the total, and currently, 1 billion vehicles are on roads, which will increase to 1.2 billion by 2022 [1]. This rise in vehicles count is also increasing pollution. Automobile emissions are harmful to the environment producing significant amounts of nitrogen oxides (NOx), carbon monoxide (CO), and other pollutants, contributing to 50-60 percent of air pollution [2]. NOx is a mixture of nitric oxide (NO) and nitrogen dioxide (NO2). NO is colorless and oxidizes in the atmosphere to form NO2. NO2 is the primary source of the yellow-brown color of the smog. The increasing level of NO2 is harmful to the human respiratory tract, making humans vulnerable to respiratory diseases. NO2 is also harmful to vegetation, fabrics, and surfaces [3]. CO is a colorless, odorless, tasteless, and toxic gas. The high CO content in the air leads to less oxygen transport via hemoglobin, which leads to headaches, chest pain for persons with heart disease, and a reduction in the reaction time. The increase in the concentration of CO also has topographical and meteorological effects that aggravate pollution [4].

Different types of HC are present in the emission gases like alkanes, aromatic HC, and aldehydes, and their toxicity level depends on the chemical composition. Alkanes cause loss of consciousness and have narcosis effects, while aromatic hydrocarbons are hemotoxic, neurotoxic, and have a cancerous effect, whereas aldehydes produce eye and skin irritations [5]. Researchers are working for a long time to find a solution to this problem. Literature demonstrates several methods to reduce pollution by controlling the inside engine condition known as primary methods and external engine conditions known as secondary methods. In the primary method, the change in the composition of fuel is occurring. Diesel blending with biofuel reduces harmful emissions [6][7]. Diesel blend with ethanol and biodiesel generates less CO2 (the primary source of the greenhouse effect), CO, and HC [8][9], however, increasing the NO level with the less transient performance [8]. Mixing biodiesel with metal-based additive shows promising results in reducing the NO, CO, and HC [10]. Multistage fuel injection method reduces the emission from automobiles. The small quantity of fuel injection before the primary fuel reduces the generation of HC, NOx, and particulate matter [11-13]. In recent era, companies are adopting secondary methods, including after-treatment processes such as filtration, absorption, and oxidation, helping reduce CO, HC, NOx, and particulate matter from the exhaust of internal combustion engines adhering to the emission standards [14]. For decades, many are inventing devices for reducing exhaust emissions. One such efficient device is a catalytic converter. Eugene Houdry, the French mechanical engineer, invented the catalytic converter and got it patented in 1950 for a gasoline engine [15-16]. The catalytic converter works on chemical reactions (Equation 1-3); it is a beneficial, efficient but expensive device fitted in the exhaust system [17].

Reduction: $2NOx \rightarrow XO2 + N2$ (1)

Oxidation: $2CO + O2 \rightarrow 2CO2$ (2)

$CXH2X+2 + [(3x+1)/2]\ O2 \rightarrow XCO2 + (X+1)\ H2O$ (3)

The catalytic converter uses noble metals like platinum, palladium, and rhodium to catalyze the chemical reaction, and temperature plays a vital role in activating them. The activating temperature range is 350 - 500 0C for the catalytic converter. However, before reaching this temperature, the catalytic converter's efficiency is very low; this is called the cold start phase. Automobiles emit the most harmful gases during the cold start phase. To solve this problem, researchers preheat the catalytic converter to reduce this cold start phase time [18-20]. A catalytic converter's efficiency is 99% when new, but it decreases to 95% after 4500 miles. However, if the efficiency decreases below 92%, it will exacerbate the emission to 150%. The faulty injector and oil entering the combustion chamber due to the lousy gasket leak also lead to the choking of catalytic converter, decreasing its efficiency [21]. Many researchers use the turbulence inducing devices to reduce the emission [22-27]. Moreover, electrochemical techniques have been used to reduce the emission [28-30].

Nearly all the literature focuses on biofuel blends, EGR, and heating in the cold start phase for emission reduction. However, no state-of-the-art prior studies reports phase change material (PCM) for storing the heat from the catalytic converter. Researchers are only working on enhancing the thermal conductivity of the PCM [31-32]. Also, no one is studying the effect of cleaning the catalytic converter.

In this background, present research aims to clean the catalytic converter using pressurized air, water, acid, and ethanol via automation techniques. Moreover, storing the heat from the catalytic converter, when the engine runs, in the form of the PCM's latent heat and use that heat to reduce the cold start time. The experimental setup, which consists of a Kirloskar engine, Single cylinder, 4 Stroke, water-cooled, stroke 110 mm, bore 87.5 mm, 661 cc, is designed and fabricated for conducting the experiments. An innovative and automatic device is fabricated and fitted before the catalytic converter. Notably, the catalytic converter was tested after cleaning it with pressurized air, water, alcohol (Ethanol), hydrochloric acid, alkaline cleaner and various set of experiments were performed at different engine operating conditions. As a result, the cold start time was reduced using the heat stored in the PCM.

EXPERIMENTAL SETUP

Fig. 1 shows the schematic diagram of the experiment setup developed in the present study to store the latent heat and study the aftereffects of cleaning the catalytic converter using pressurized fluid Air, Water, Acid, Ethanol, and Alkaline cleaner. Fig. 2 shows the experimental setup which consists of a Kirloskar research diesel engine, a catalytic converter enclosed inside the sealed PCM chamber, and a gas analyzer (AVL DIGAS 444) for characterizing the exhaust. The catalytic converter used is shown in fig. 3. Throughout the experiment, the temperature within the catalytic converter and temperature of the PCM chamber at different positions were measured using copper constantan (T-type) thermocouples. The data acquisition system of National Instruments (NI 9213) was configured with LABVIEW software to store temperatures in the computer throughout the experiment. An automatic system is fabricated, which consists of a probe for pressurized cleaning of the catalytic converter. During the operating condition, the probe is contained in a separate chamber, and when the engine is in shut mode, it is lowered into the exhaust pipe for cleaning. In this study, the converter is separately cleaned using the above-mentioned mechanism. The catalytic converter was mounted directly onto the exhaust pipe using the fasteners. The silicon-coated probe was inserted into the exhaust pipe's tail end to store the emission gases' contents digitally on the computer. The catalytic converter is enclosed inside the aluminum chamber, which is filled with the PCM. The aluminum chamber is insulated to avoid the heat loss. The PCM used is paraffin wax, a melting temperature of 70oC, and a latent heat capacity of 275 kJ/kg to keep the converter heated after the engine is turned off. Experiments are performed at different rpm using various cleaning techniques. A comparison study on the effects of different cleaning fluids was done.

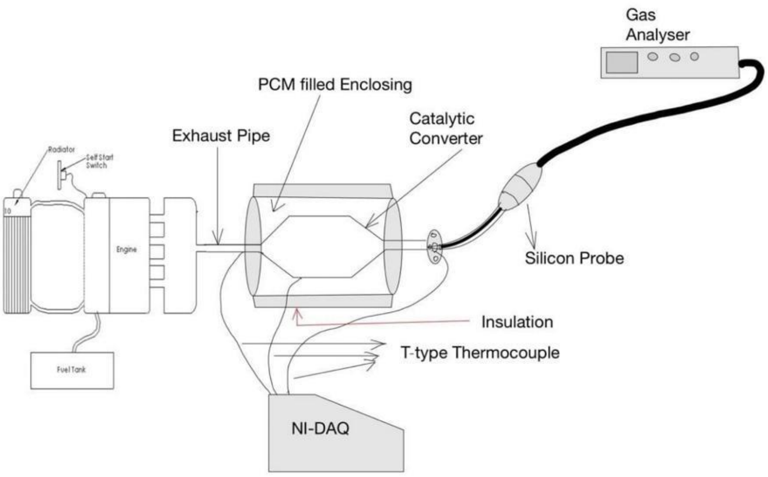

Figure 1: Schematic diagram of the experimental setup

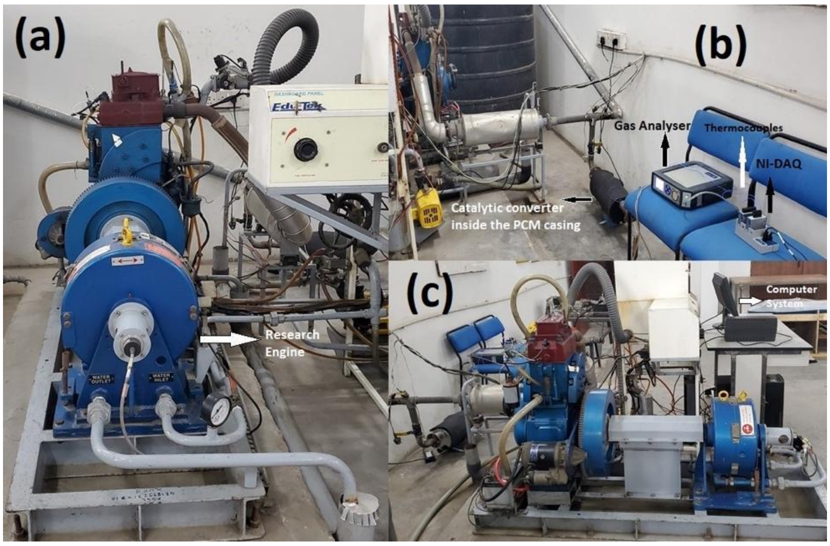

Figure 2: (a) Research Engine side view, (b) Experimental Setup, and (c) Front view of the Research Engine.

Figure 3: Catalytic converter

RESULTS AND DISCUSSIONS

The experimental studies generated the data under control condition and stored for analysis.

Fig. 4 shows the honeycomb structure inside the catalytic converter before and after cleaning. Converter was cleaned using different fluids air, water, ethanol, acid, and alkaline solution. The surface etched using acidic solution (Hydrochloric acid, HCl) provided extensive cleaning of the honeycomb structure.

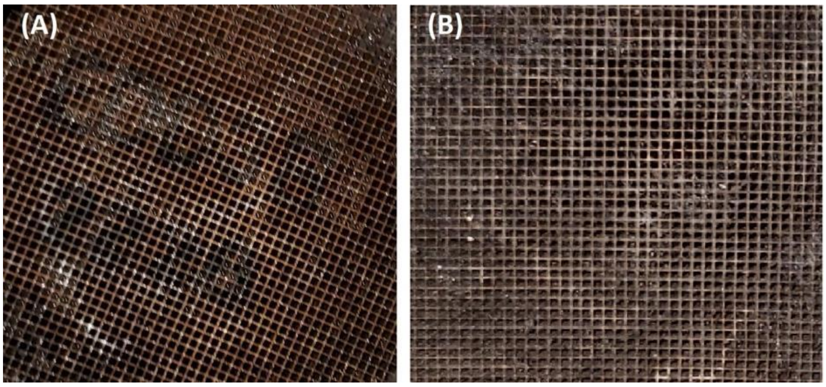

Figure 4: Catalytic converter inside honeycomb structure (A) After Cleaning, and (B) Before Cleaning

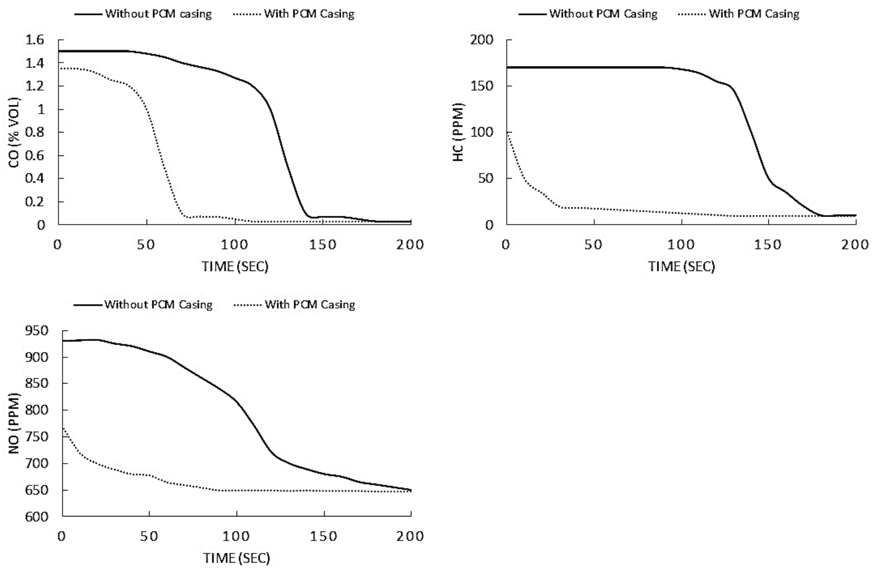

Figure 5: Graphical representation showing the decrease in cold start time in CO, HC, and NO emission.

The use of PCM has shown that the cold start time is reduced significantly which results in less emission for time duration of 75 seconds from 150 seconds. Fig. 5 shows the effect of reducing the cold start time in NO, CO, and HC emission.

The use of fluids for cleaning have shown a considerable decrease in the emission values of NO, HC, and CO. The data after cleaning with various fluids was plotted for comparing their effectiveness at the different speed as shown in fig. 6 & fig. 7(a-c). The acidic reagent, air, water, Ethanol, and alkaline solution provides significant enhancement in the system as compared to normal state. Among all these cleaning fluids, acidic reagent showed the best results.

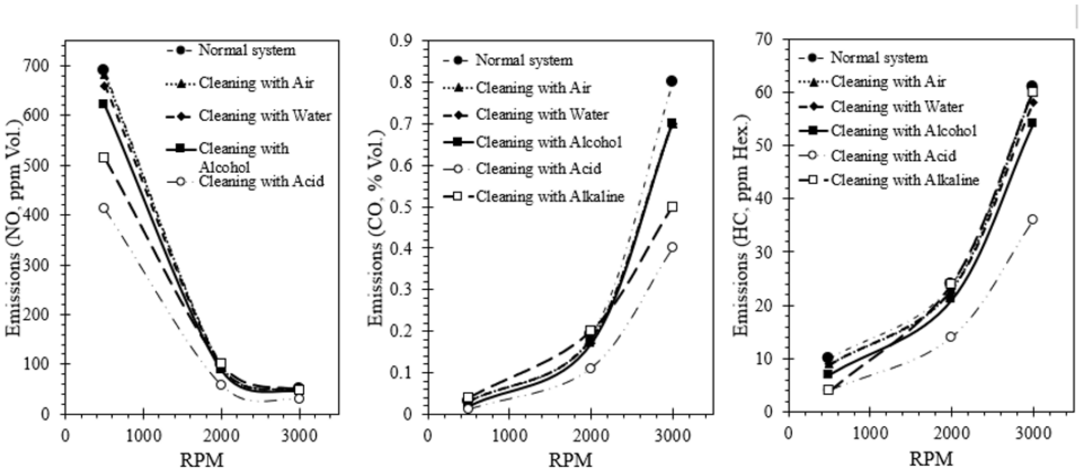

Figure 6: Emission of NO, CO, and HC with different cleaning fluids.

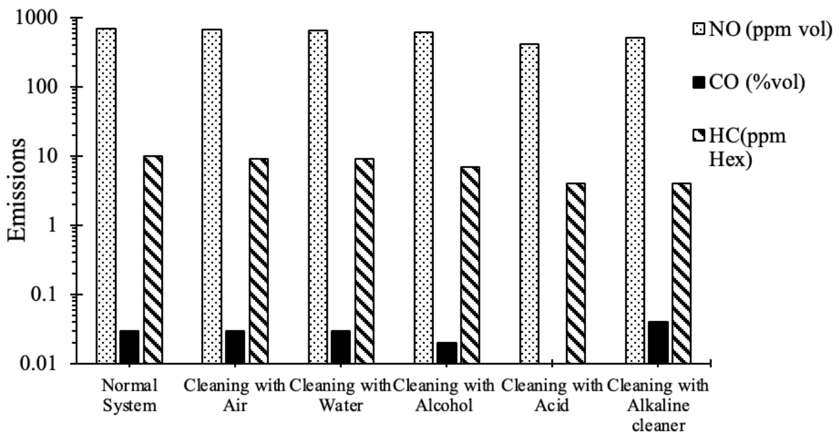

Figure 7(a). Comparative study at Idle speed.

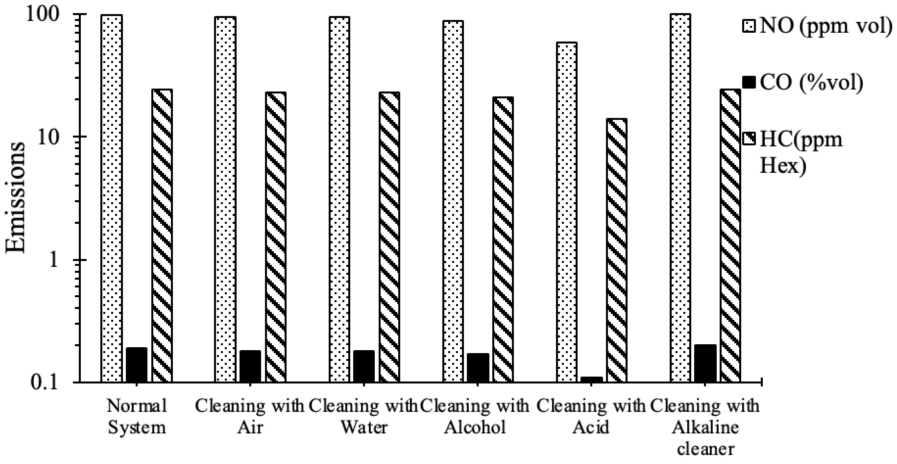

Figure 7(b): Comparative study at 2000 rpm

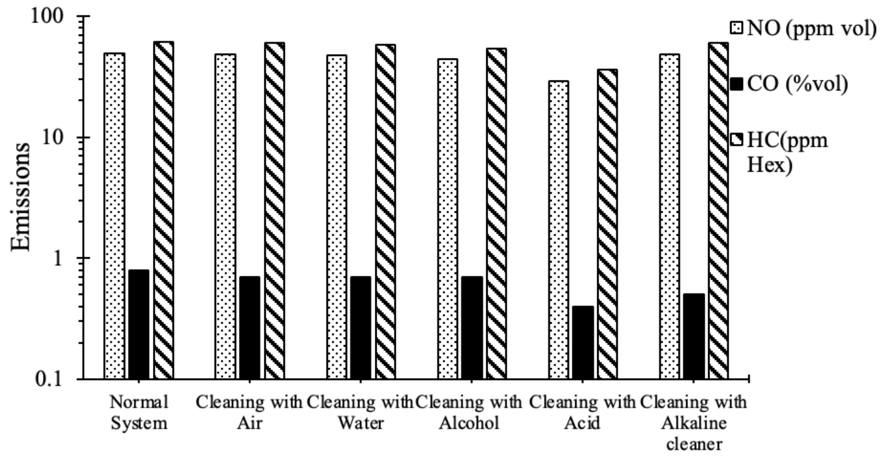

Figure 7(c): Comparative study at 3000 rpm

CONCLUSION

An experimental study was conducted to increase the effectiveness of the catalytic converter and reduce its cold start time using pcm. An automatic mechanism was fabricated for the cleaning purpose which consist of the probe for putting pressurized fluid into the catalytic converter. The pcm filled inside the enclosing of the catalytic converter has reduced the cold start time from 150 seconds to 75 seconds by absorbing the energy in the form of latent heat which have reduced the emission of NO, CO, and HC by 16%, 54%, and 83% respectively. The cleaning of the catalytic converter is done using different fluids and the result shows that the acid reagent is most effective. But for long term run the cleaning through the acid erodes the material of the catalytic converter which reduces its efficiency. As per our observation use of air and water for cleaning is much preferable rather than acidic and alcoholic reagents.

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