Effect of Creating Turbulence on the Performance of Catalytic Converter

MANTHAN KUMAR, MOHIT BHANDWAL, MANISH SHARMA, ANMOL VERMA, UTKARSH SRIVASTAVA and RAM K. TYAGI

Amity University Uttar Pradesh, India

(Received on July 25, 2015, Revised on October 29, 2015)

Abstract: This paper presents the effects of implementing turbulence device on the effectiveness of catalytic converter which represents the reduction in pollution rate through vehicles by minimizing the harmful emissions. This effectiveness basically deals with the rate of redox reactions of exhaust gases with the catalysts present inside the catalytic converter such as palladium (Pd), platinum (Pt) and rhodium (Rh). Chief purpose of the turbulence is to increase the catalytic reactions in the catalytic converter for cleaner emissions. Devices used are designed in such a manner that they don’t cause any backpressure on the combustion system that might affect the engine performance. By creating turbulence just before the catalytic converter, it creates high degree of randomness in the exhaust gases particles and due to this random movement they face larger contact area with the catalysts inside the catalytic converter and thus improves the effectiveness of the catalytic converter by increasing the rate of redox reactions. Different sets of readings has been recorded by noting down the pre and post position temperatures of the catalytic converter at different engine speeds and analyzed to obtain the best out of the designed turbulence devices.

Keywords: Effectiveness, emissions, turbulence, catalyst, catalytic converter

Notation

\[ NO_x \] Nitrogen Oxide
\[ CO \] Carbon Mono oxide
\[ HC \] Hydro Carbon
\[ NO \] Nitrogen Oxide
\[ NO_2 \] Nitrogen Di-oxide
\[ CO_2 \] Carbon Dioxide
\[ \eta_e \] Net Conversion Effectiveness
\[ L_d \] Heat loss due to dry gas
\[ L_{CO} \] Heat loss from formation of CO
\[ W_f \] The weight of the flue gases
\[ C_p \] Specific heat of the exhaust gas mix
\[ T_{flue} \] Flue temperature
\[ T_{supply} \] Combustion supply air temperature
\[ C_b \] Specific carbon content of fuel
\[ RPM \] Revolution Per Minute
\[ H_f \] Flue Heat losses
\[ H_a \] Fuel Heating Value (42550 Btus/Kg)

1. Introduction

Emissions are the main cause of Air Pollution in the environment. The incomplete combustion of the fossil fuels in the Automobile engines lead to increase in the Pollution leading to global warming and depletion of the Ozone layer [1]. The toxic pollutants from incomplete combustion are NO\(_x\), CO and HC [2, 3]. These toxic emissions and particulate
matter are present in the atmosphere in various percentages. The Main Pollutants released through the exhaust system are HC and CO. CO is the most toxic pollutant, which has no odor, taste and color and is thus difficult to be detected. The main element of Nitrogen oxides is NO and has a small amount of NO₂ present in it [4].

The combustion process in the diesel engine produce smoke and other toxic particulate matter, which lead to harmful diseases of lung cancer, Asthma and other Life taking diseases [5]. These matters contaminate the air, which is harmful for the human beings. The properties or the factors which account for the level of pollution in the atmosphere are the ambient conditions, ambient temperature, condition of the vehicle being driven and the way the vehicle is being driven, and the maintenance and handling of the vehicle are a very important factor for the emissions of the engine [6]. As the age of the vehicle increases over the years of its manufacturing and its usage, the amount of emissions released by the vehicle also increases [7, 8].

With the increase in the manufacturing of the vehicles, the pollution percentage has also increased in the atmosphere. Thus to follow the rules of emissions the need of emission standards had arrived and these standards are followed by the manufacturing units while manufacturing the vehicles. These standards made way for the new way of designing the vehicle system, engine designing and advancement in the vehicle’s exhaust system, these new rules made a rise in the scope of increase in the use of fossil fuels leading to increase in the prices of diesel and petroleum [13, 14, and 15]. The alternative source of fuel got introduced in the automobile industry to make these regulations obeyed in the current manufactured vehicles. The use of Compressed Natural Gas (CNG) in the engine has shown some reductions in the emissions in the percentage of CO₂ and CO but an increase in the emissions of HC was observed [9]. The use of the hydrogen-based fossil fuels has also showed some reduction in the exhaust emissions released during the run of an engine in normal conditions [10]. The Toxic emissions are reduced with the methods or measures which are of two types, Primary and secondary measures or methods. In the primary approach the processes are multistage injection of fuel, Exhaust gas Recirculation and loading of water inside the cylinder [11, 12]. In the secondary approach the processes used are oxidation and absorption of the toxic emissions and particulate matter which leads to reduction the percentage of CO, HC, NOx and toxic emissions which meet the standards of emissions [13].

The most efficient device to reduce the exhaust emissions in the internal combustion engines is Catalytic Converter. It works on the principle of chemical reactions, which absorb these toxic emissions, and this device is an ideal sound device for reducing the toxic emissions [16]. In India, the installation of the catalytic converter is compulsory for the vehicles being manufactured in the current years to control the exhaust emissions and to meet the standard norms. The catalytic converter is a chemically passive device, which can control the light pressure during the engine run, and the device is stable at even high operating temperatures of 1300°C. The catalysts used in the instrument are rhodium, platinum, palladium, and gold, these catalysts undergo successive chemical reactions with the toxic emissions in different stages and phases to reduce these emissions [17].

In our process of testing, we achieved a reduction in the exhaust emissions from a 2007 model of TATA INDICA engine. The three turbulence devices, Swirl Venturi, Swirl Blades and Swirl contour, used before the catalytic converter on installation have caused turbulence in the gases flowing through the exhaust system. The main objective of creating turbulence was to increase the contact area of the gases coming into contact with
the catalysts in the catalytic converter, thus as the surface area is increased the intensity of chemical reactions increases leading to a reduction in the percentage of exhaust emissions. During the test, a temperature was observed with the temperature gun at the point before the catalytic converter and the three devices.

The effectiveness of the catalytic converter refers to the amount of toxic emissions absorbed and reduced by the catalytic converter. The catalysts used in the catalytic converter have reduced the emissions what refers to the term effectiveness. The turbulence devices installed before the catalytic converter has increased the emission effectiveness of the catalytic converter leading to a reduction in the percentage of toxic emissions being released from the engine.

2. Experimental Setup and Description

For the broad variety of applications, we fabricated and implemented the cost-effective testing devices. Figure 2 shows, the Swirl Venturi, Swirl Blades, and Swirl Contour are turbulence creating devices. The experimental setup consists of a test diesel engine, fuel tank, battery, and the exhaust assembly having a catalytic converter, resonator, muffler, the turbulence device, tachometer, and temperature gun. The setup is mounted on a rigid frame to make it movable and convenient to perform the tests and to avoid vibrations. Fig.1 shows the line diagram of the experimental test. The four cylinders Tata Indica V2 diesel engine is used as the test engine. Contact type tachometer measures the engine rpm. Temperature gun measures the pre and post catalytic converter temperatures during the operation. At different RPM, readings are taken and noted down. At various speeds and with various devices readings the noted before heating and after heating the catalytic converter.

![Figure 1: Line Diagram of the Test Model](image)

![Figure 2: (a) Swirl Venturi, (b) Swirl Blades, (c) Swirl Contour](image)
Table 1: Temperature of the Devices at Different Engine Speeds

<table>
<thead>
<tr>
<th>Device</th>
<th>989 rpm (Engine Idling)</th>
<th>4600 rpm (Engine at 4600 rpm)</th>
<th>6432 rpm (Wide open throttle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>En. Temp. (°C)</td>
<td>Ex. Temp. (°C)</td>
<td>En. Temp. (°C)</td>
<td>Ex. Temp. (°C)</td>
</tr>
<tr>
<td>Default Exhaust System</td>
<td>419</td>
<td>425</td>
<td>767</td>
</tr>
<tr>
<td>Swirl Venturi</td>
<td>428</td>
<td>437</td>
<td>776</td>
</tr>
<tr>
<td>Swirl Blades</td>
<td>431</td>
<td>442</td>
<td>773</td>
</tr>
<tr>
<td>Swirl Contour</td>
<td>430</td>
<td>439</td>
<td>776</td>
</tr>
</tbody>
</table>

3. Result and Discussions

The test has been performed on a 4-cylinder diesel engine and three sets of experiments have been performed i.e. at engine idling condition, engine at 4600 rpm and at full throttle condition at 6432 rpm. The temperature (°C) readings have been taken for different turbulence devices at different rpm’s of engine. Table 1 shows the different temperature values obtained before entering the catalytic converter and after exiting the catalytic converter by clamping different turbulence devices before the catalytic converter of the exhaust assembly.

Table 2 shows the effectiveness of emission reduction which has been calculated after finding out the flue heat losses, diesel fuel heating value and the carbon content of the diesel fuel. Conversion effectiveness is represented as a factor determined by, dividing a percentage of fuel’s heating value, from the total heating value of the fuel.

\[
\eta_e = \frac{H_f}{H_a} \quad (1)
\]

\[
H_f = L_g + L_{co} \quad (2)
\]

\[
L_g = W_g \cdot C_p \cdot (T_{f\text{lu}} - T_{s\text{upply}}) \quad (3)
\]

\[
W_g = \frac{44CO_2 + 32O_2 + 28N_2 + 28CO}{12(CO_2 + CO)} \quad C_b \quad (4)
\]

\[
C_p = 0.240 + 0.000038 \cdot (T_{f\text{lu}} - 200) \quad (5)
\]

\[
L_{co} = \frac{%CO}{%CO_2 + %CO} \times 10160 \times C_b \quad (6)
\]
Figure 3, figure 4, to figure 5 shows pie charts of calculated emission reduction effectiveness’s of the different devices at different engine speeds. It is found that the most effective result has been obtained from the Swirl Venturi device giving the most optimized results overall. However, it is also found that the Swirl Blades device has came up with significant results but only at wide open throttle (WOT) condition i.e. at high engine rpm.

Table 2: Conversion Effectiveness

<table>
<thead>
<tr>
<th>Engine Speed</th>
<th>Turbulence Devices</th>
<th>$W_p$</th>
<th>$C_p$</th>
<th>$L_d$</th>
<th>$L_{co}$</th>
<th>$H_f$</th>
<th>$\eta_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>980 RPM</td>
<td>Default Exhaust System</td>
<td>3262</td>
<td>0.248555</td>
<td>320982</td>
<td>4100</td>
<td>325082</td>
<td>7.64</td>
</tr>
<tr>
<td></td>
<td>Swirl Venturi</td>
<td>3392</td>
<td>0.249196</td>
<td>348319</td>
<td>1417</td>
<td>349737</td>
<td>8.22</td>
</tr>
<tr>
<td></td>
<td>Swirl Blades</td>
<td>3696</td>
<td>0.249006</td>
<td>313812</td>
<td>2586</td>
<td>316398</td>
<td>7.43</td>
</tr>
<tr>
<td></td>
<td>Swirl Contour</td>
<td>3805</td>
<td>0.249082</td>
<td>306171</td>
<td>3761</td>
<td>309993</td>
<td>7.28</td>
</tr>
<tr>
<td>4600 RPM</td>
<td>Default Exhaust System</td>
<td>3234</td>
<td>0.262116</td>
<td>479788</td>
<td>19261</td>
<td>499049</td>
<td>11.73</td>
</tr>
<tr>
<td></td>
<td>Swirl Venturi</td>
<td>3231</td>
<td>0.262838</td>
<td>654774</td>
<td>9454</td>
<td>664228</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>Swirl Blades</td>
<td>3221</td>
<td>0.262648</td>
<td>648135</td>
<td>10773</td>
<td>658908</td>
<td>15.48</td>
</tr>
<tr>
<td></td>
<td>Swirl Contour</td>
<td>3112</td>
<td>0.262762</td>
<td>628948</td>
<td>13004</td>
<td>641953</td>
<td>15.08</td>
</tr>
<tr>
<td>6432 RPM</td>
<td>Default Exhaust System</td>
<td>1749</td>
<td>0.269678</td>
<td>448726</td>
<td>27542</td>
<td>525874</td>
<td>11.19</td>
</tr>
<tr>
<td></td>
<td>Swirl Venturi</td>
<td>2551</td>
<td>0.270134</td>
<td>663817</td>
<td>19142</td>
<td>682960</td>
<td>16.05</td>
</tr>
<tr>
<td></td>
<td>Swirl Blades</td>
<td>2759</td>
<td>0.270742</td>
<td>731422</td>
<td>18390</td>
<td>749813</td>
<td>17.62</td>
</tr>
<tr>
<td></td>
<td>Swirl Contour</td>
<td>2472</td>
<td>0.270248</td>
<td>645349</td>
<td>22655</td>
<td>668005</td>
<td>15.69</td>
</tr>
</tbody>
</table>

3. Conclusions

The emission reduction effectiveness of the turbulence devices in a four cylinder diesel engine under different engine speeds have been investigated and significant conclusions has been drawn. Comparatively, lower concentrations of emissions, i.e., NOx, CO, CO2 and HC were generated by mounting turbulence devices before the catalytic converter. The emissions were significantly reduced without causing any major backfire issues for all the turbulence devices even at full throttle conditions. The optimization of the devices has been discussed in the terms of emission reduction effectiveness.

The tests performed has clearly shown that by the application of turbulence devices just before the catalytic converter has resulted in the increase in the chemical reactions i.e., the oxidation and reduction reactions, that occurs inside the catalytic converter when exhaust gases passes through it.

A detailed study of the test and the calculated values shown in Table 2 has led to the conclusion that the Swirl Venturi device shows up to be the most effective turbulence device for the overall set of tests performed. The reason being the throughout constant variation of the cross-sectional contact area for the contact gases. It is also found that at wide open throttle condition (WOT) or high engine rpm conditions; the Swirl Blades device proves to be most effective for emission reduction and can be used for high-speed applications.

References

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Manthan Kumar, Manish Sharma, Anmol Verma and Utkarsh Srivastava are working currently towards B.Tech. degree in Mechanical and Automation in Amity University Uttar Pradesh. Their research interest is focused on automotive intake and exhaust system, and catalytic converter.

Mohit Bhandwal is currently working as assistant professor in Amity University and co-guide of the students in the above topics. He has M.Tech from SRM University Chennai in the field of Robotics. He has filled 4 patents in different fields. His research areas are AI, design aspects of I.C. engine, Robotics, automotive exhaust system.

R. K. Tyagi is currently working as associate professor in department of Mechanical and Automation Engineering in Amity University Uttar Pradesh. He has an M.Tech. in design and Ph.D. in non-traditional machining process. He has filled 19 patents in different field. His research area is composite material, design aspects of IC engine, non-traditional machining process and automotive exhaust system.