Investigation of Cu-ZSM5 catalyst for the Emission Reduction in ethanol-gasoline blends using iso-butanol as an additive in SI engine

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Abstract. In this experimental work, the Gasoline engine was used to find out the effects of Cu-ZSM5 zeolite coated catalytic converor on the emission characteristics of iso-butanol additive in ethanol-gasoline blends. The engine was tested under three speeds namely 2000rpm, 3000rpm, and 4000rpm. The volumetric proportion of the fuel samples taken for testing were gasoline (pure gasoline), E10 (90% gasoline, 10%ethanol), IB5 (95% E10, 5% Iso-butanol) and IB10 (90% E10, 10% Iso-butanol). The physiochemical properties of the fuels like heating value, kinematic viscosity, and density were analyzed for these samples as these values influence the emission formation characteristics. The heating value of the samples was decreased with the gasoline concentration in the fuel samples. E10, IB5, and IB10 produced the heating values of 2.34%, 3.13% and 5.05% respectively less than that of the gasoline. However the fuel properties like density, kinematic viscosity tens to increase with the alcohol concentration in the samples. From the performance results, the Brake specific fuel consumption decreased for E10, IB5 and IB10 of about 3.57%, 5.14%, and 7.13% respectively when compared to gasoline. Brake thermal efficiency of the fuel increased to a noticeable level with the addition of the alcohol in gasoline. Initially, the engine was tested by fitting the commercially purchased catalytic converter in the exhaust system and the emissions values were measured with the help of AVL 444 gas analyzer. Then the engine was fitted with the Cu-ZSM5 coated in-house fabricated catalytic convertor and the emission values were measured. At 3000rpm, it has been found that the zeolite coated catalytic converor reduces HC, CO and NOX emissions by 33%, 9% and 8.3% more than that of the commercial catalytic convertor.

1. Introduction
Due to the increase in the population of automobiles, the demand for crude oil has been constantly increasing in the past three decades. It has been estimated that the fossil fuel reserves in the world will exhaust in the next 50 years. Because of the depletion of fossil fuel sources, many types of research are carried out to use alcohol, non-edible vegetable oil and waste cooked oil as a fuel to fulfil the energy requirement [1]. Also, the use of fossil fuel in the internal combustion engines has resulted in the increase of harmful exhaust emissions like Hydrocarbons, Carbon monoxide, and Nitrogen Oxides. Alcohols can be produced from various agriculture products through fermentation and the alcohol blended with gasoline is gaining more attention by the researchers because of its favourable emission characteristics [2]. Ting-Nien Wu et al, have investigated the effect of various ratios of ethanol-
gasoline blends on the emission characteristics in an SI engine and concluded that the HC, CO and NOX emissions were reduced in all the ratios of ethanol-gasoline blends [3]. Palmer reported that the ethanol-gasoline blends will increase the overall octane number of the fuel and also the brake power of the engine [4]. Hasan conducted an experiment using the ethanol-gasoline blend in an SI engine and reported an increase of 9% brake thermal efficiency than that of the pure gasoline [5]. Kremer et al, have reported that more than 26% of the ethanol concentration in the gasoline will result in the power loss and drivability problems [6]. Stan et al, have reported that the addition of ethanol in gasoline specific fuel consumption of the engine and CO2 emissions in the exhaust [7]. Mourad et al, have investigated the effect of ethanol and Iso-butanol additive in gasoline and reported a reduction in the CO, HC and SFC formation of about 13.7%, 25.2% and 8.22% than that of gasoline [8]. Many types of research have proved that the use of ethanol-gasoline blends is favourable both in performance as well as emission characteristics, the improvement of the ethanol-gasoline blend has not been widely discussed especially using the Iso-butanol as an additive [9-12]. In this work, an attempt was made to use Iso-butanol as an additive in various ratios of the ethanol-gasoline blends namely gasoline (pure gasoline), E10 (90% gasoline, 10%ethanol), IB5 (95% E10, 5% Iso-butanol) and IB10 (90% E10, 10% Iso-butanol) for the performance and emission analysis. The existing three-way catalytic converter is suitable for the emission reduction for pure gasoline-fuelled engines, but the alcohol-gasoline blended fuel requires special care for the emission reduction. The zeolite-based catalytic convertors show an impressive catalytic reduction for emission formation in the lean-burn gasoline engines [13, 14]. Baik et al, have reported that the Cu-ZSM5 catalyst exhibits the highest activity towards the Nitrogen monoxide removal for a wide range of temperatures [15]. Zhang et al, have successfully synthesized the zeolite in the laboratory and doped with metal (Cu) for the selective reduction of Nitrogen Oxides in heavy diesel engines [16]. Liu et al, have prepared Cu-ZSM5 and CeO2 modified Cu-ZSM5 by wetimpregnation method for the selective reduction of NOX. They have reported that the CeO2 modified ZSM5 catalyst enhanced the selective reduction of NOX at lower temperature [17]. Wang et al, have reported that the Fe-ZSM5 zeolite can reduce the NOX emission in the presence of H2O steam at high temperatures up to 600°C without any destruction of the zeolite in the catalytic converter [18]. Li et al, have investigated three types of metals namely Molybdenum, Nickel and Tin doped in ZSM5 for the selective reduction of the NOX emission and reported that the Mo-ZSM5 was the best among the three catalysts [19]. Choung et al, have reported that the Pt-ZSM5 and Mg-Cu-ZSM5 catalysts were better choices for the reduction of NOX emissions than Cu-ZSM5 catalysts when the engine is running under lean-burn conditions [20]. Sato et al, have reported that the Cu-ZSM5 zeolite is the most active catalyst among all the ion-exchanged catalysts for the reduction of Nitric oxide emissions [21]. Most of the researches has focused on the investigation of the metal-doped catalysts for the emission reduction of the gasoline or diesel fuel, not for the alcohol-gasoline blends [22 - 24]. In this research, a two-way catalytic converter consists of an oxidation monolith (available in the market) and in-house made Cu-ZSM5 coated monolith was properly fitted in the exhaust of the gasoline engine for the reduction of the harmful emissions formed from alcohol-gasoline blended fuel.

2. Properties of Alcohol and Gasoline
Some physicochemical properties are very important to be considered for the use of alcohol in the gasoline engine. As the alcohol contains oxygen in it, the combustion process is better than that of the gasoline which is basically a hydrocarbon. Demirbas, have reported that the increase of the oxygen content in the fuel will decrease the heating value of the fuel [25]. So the addition of the alcohol in gasoline will result in a decrease of the heating value of the fuel [26-28]. The resistance of the fuel to flow is termed as viscosity. As the high viscous fuel reduce the atomization of the fuel, it may result in high carbon emissions from the unburned fuel droplets during the combustion process [29]. These carbon particles may deposit in the piston outer surface or on the inner surface of the cylinder. The viscosity of the alcohol is higher than that of the gasoline; this may result in an increase in the viscosity of the alcohol-gasoline blends [30]. However the percentage of the addition of alcohol in
gasoline is very less, so only a slight increase in the viscosity will occur. Density is also one of the important parameters to be considered for determining the mass flow rate of fuel and fuel spray characteristics during an injection [31]. Alcohols are considered for the blending with gasoline is mainly due to their high heat of vaporization and the presence of the oxygen content in it. In Brazil, most of the vehicles are operated by alcohol for powering up the engine by adapting Flexi-fuel technology. Around 85% of the vehicles in Brazil were equipped with this Flexi-fuel system, the user can choose between ethanol and gasoline for the vehicle [32]. Many types of research have proved that ethanol can be used as a potential fuel or blended with gasoline in various proportions [33-37]. Some properties of the gasoline, ethanol, and Iso-butanol were shown in table.1.

| Table 1. Fuel Properties of test fuels. [38,39] |
|--------------------------------------|
| Fuel Properties | Gasoline | Ethanol | Iso-Butanol |
| Lower Heating Value (MJ/kg) | 44.108 | 28.7 | 35.53 |
| Kinematic Viscosity @ 40˚C (mm2/s) | 0.54 | 1.24 | 3.1 |
| Density @ 15˚C (g/cm3) | 0.747 | 0.793 | 0.812 |
| Latent Heat of Vaporization (kJ/kg) | 348 | 922 | 682 |
| Research Octane Number | 95 | 107.3 | 105.2 |
| Oxygen Content (wt.%) | 0 | 34.7 | 21.6 |

The volumetric proportion the fuel samples were shown in the table.2. gasoline is the pure gasoline and E10 is the ethanol-gasoline blend having the volumetric proportion of 10% ethanol and 90% gasoline. IB5 is the concentration of Iso-butanol in ethanol-gasoline blend with the volumetric proportion of 5% Iso-butanol and 95% E10. IB10 is also an Iso-butanol additive in the ethanol-gasoline blend having the volumetric proportion of 10% Iso-butanol and 90% E10.

| Table 2. Volumetric proportion of the test fuel. |
|---------------------|
| Fuel Sample | Gasoline | Ethanol | 10%Ethanol | Iso-Butanol |
|---------------------|
| Gasoline | 100% | 0% | 0% | 0% |
| E10 | 90% | 10% | 0% | 0% |
| IB5 | 0% | 0% | 95% | 5% |
| IB10 | 0% | 0% | 90% | 10% |

The properties like lower heating value, kinematic viscosity and the density for the blends were measured by the corresponding ASTM methods. The measured properties of the blends were shown in table.3. From the table.3, the heating value of the gasoline fuel is found to be maximum of about 44.108 MJ/kg, which is 2.36%, 3.22% and 5.2% more than that of the E10, IB5 and IB10 respectively. As the concentration of alcohol increases the lower heating value of the test fuel decreased. The kinematic viscosity of E10, IB5 and IB10 is 37.9%, 45.4%, and 48.1% more than that of the gasoline fuel. These results were found to be in accordance with the findings of the Kumbar and Dostal [40]. This increase in the kinematic viscosity will decrease the atomization of the injected fuel in the combustion chamber and reduce the spray angle during the injection. The change in the molecular structure of the ethanol and Iso-butanol with that of the gasoline is also responsible for this variation in the kinematic viscosity. The density of the test fuel is slightly increasing with the increase in alcohol concentration and the results obtained were found in accordance with the findings of the Alfeiris [41].
Table 3. Various properties of test fuels.

| Properties                          | ASTM method | Gasoline | E10  | IB5  | IB10 |
|-------------------------------------|-------------|----------|------|------|------|
| Lower Heating Value (MJ/kg)         | ASTM D240   | 44.108   | 43.09| 42.73| 41.89|
| Kinematic Viscosity @ 40°C (mm²/s) | ASTM D445   | 0.54     | 0.87 | 0.99 | 1.02 |
| Density @ 15°C (g/cm³)              | ASTM D4052  | 0.747    | 0.755| 0.761| 0.764|

3. Preparation of the Catalyst

Commercially purchased H-ZSM5 (Zeolyst International, USA) was converted to Cu-ZSM5 by the ion exchange process. In this process, the H-ZSM5 was poured into an aqueous solution at 50°C contains 20M of Copper (II) acetate monohydrate in the proportion of 8g/L and kept for about 2 hours for the ion exchange process to happen. After this process, the obtained Cu-ZSM5 product was washed twice with the deionized water and dried at 120°C in a furnace for about 6 hours. Then the product was calcined in a closed type furnace at a temperature increase of 50°C/min until it reaches of 550°C and then it was kept in the furnace for about 6 hours. This process was done to increase the bonding of the Cu in the ZSM5 to withstand the high working temperature of the exhaust gas [42-45]. The image showing the various chemical compositions of H-ZSM5 and Cu-ZSM5 was shown in table 4. From the table it is clear that the Na2O was reduced from the H-ZSM5 to Cu-ZSM5, this is because of the ion exchange of the Na+ with that of the Cu+ ions. The SEM image of the H-ZSM5 and Cu-ZSM5 were shown in figure 1 and figure 2. From the figures 1 & 2, it can be observed that the particle size of the Cu-ZSM5 zeolite was slightly bigger than that of the H-ZSM5, this is due to the distribution of the Cu over the H-ZSM5 particles.

Table 4. Chemical composition of H-ZSM5 and Cu-ZSM5.

| Composition | H-ZSM5 (%) | Cu-ZSM5 (%) |
|-------------|------------|-------------|
| SiO₂        | 88.372     | 87.012      |
| Al₂O₃       | 3.256      | 3.091       |
| Fe₂O₃       | 0.114      | 0.110       |
| CaO         | 0.014      | 0.014       |
| MgO         | 1.150      | 1.050       |
| SO₃         | 0.134      | 0.126       |
| Na₂O        | 7.001      | 1.515       |
| K₂O         | 0.00       | 0.00        |
| CuO         | 0.00       | 5.012       |
| P₂O₅        | 0.00       | 0.00        |
| TiO₂        | 0.025      | 0.22        |
| BaO         | 0.00       | 0.00        |
| LOi         | 0.00       | 0.00        |

After the preparation, The Cu-ZSM5 catalysts have to be deposited in the inner walls of the blank monolith. Both the blank and oxidation monolith having a cell density of 400cpsi, 0.17mm wall thickness and 90mm length and diameter were purchased commercially (Bocent Advanced Ceramics Co Ltd, China). Initially, the weight of the blank monolith was measured by a weighing machine. Cu-ZSM5 was mixed with a binder (colloidal silica purchased from Technico, India) in the ratio of 1:10 and the formed slurry was stirred for about 2 hours. Then the blank monolith was dipped into the slurry for about 2 to 3 times and for each dip the excess slurry in the monolith was removed by blowing the compressed air in the inner channels. Then the monolith was weighed to find out the
increase in the weight due to the addition of the slurry. This process of dipping and the blowing the compressed air is continued until the weight of the monolith reaches 14% more than its initial weight. After the 14% increment in the weight, the monolith is calcined at 500°C in a closed type furnace for about 2 hours [46-48]. Then the oxidation monolith and the Cu-ZSM5 coated monolith were packed in a steel case as shown in figure.3 for the testing in the engine.

**Figure 1.** SEM image of purchased H-ZSM5.

**Figure 2.** SEM image of prepared Cu-ZSM5.

**Figure 3.** Photograph of experimental setup.

4. **Experimental Setup**
The tests were carried out in a Gasoline Direct Injection engine, which specifications were given in table.5. The engine was mounted on a test rig and is connected to an eddy current dynamometer for loading. The fuel consumption by the engine was measured with the help of the stopwatch. The AVL 444 gas analyzer (5 gas analyzer) is used for the measurement of harmful exhaust gas. The schematic view of the experimental setup was shown in Figure.4.
Initially, the engine was made to start with Gasoline test fuel, and the performance and emissions characteristics readings were taken for three different speeds of the engine namely 2000rpm, 3000rpm, and 4000rpm. Then the engine was fitted with the commercially purchased catalytic converter (tata nano, India) and the emission characteristics were measured for the different speeds as mentioned above. Finally, the fabricated zeolite coated catalytic converter was connected with the engine and emissions characters were measured for the same three rpm’s mentioned above. In all the test conditions the throttle was kept halfway wide open and all these tests were conducted three times in order to minimize the error and maintain the accuracy of the measured values. The same procedure was conducted for all the remaining test fuels (E10, IB5, and IB10) for finding the performance and emission characters.

| Make                  | Tata Nano Engine                        |
|-----------------------|-----------------------------------------|
| No. of Cylinders      | 2 (In-line)                             |
| Cubic Capacity        | 624cc                                   |
| Fuel Injection        | Multi Point fuel Injection (MPFI)       |
| Max Power             | 27.56 kW @ 5000rpm                     |
| Max Torque            | 51Nm@3000rpm                            |
| Compression ratio     | 9.5:1                                   |
| Dynamometer Constant  | 9549.5                                  |
| Fuel type             | Gasoline                                |
| Cooling               | Water cooling                           |

**Error Analysis**

Error Analysis is needed to find the difference between the actual value and the measured value. This difference may be due to human error or machine error. The collected data may have some percentage of variation than the actual data. This variation can be found out with the help of the error analysis. The error analysis was carried out by the Comparative standard error (CSE), as in equation 1.
Where UE is the usual error and \( \overline{\theta} \) is the total average of the collected data. The Usual error was calculated on the basis of the following equation.2.

\[
UE = \frac{\alpha}{\sqrt{n}}
\]

Where \( \alpha \) is the standard deviation of the group of selected data and \( n \) is the total number of data. Each parameter was collected for three times by repeating the test. Based upon the Comparative standard error method the percentage of error of the all parameters was shown from the table.6 to table.10.

**Table 6. CSE for BTE of test fuels.**

| Engine Speed | Gasoline | E10  | IB5  | IB10 |
|-------------|---------|------|------|------|
| 2000rpm     | 1.01%   | 1.22%| 1.07%| 1.25%|
| 3000rpm     | 1.15%   | 0.94%| 1.15%| 1.24%|
| 4000rpm     | 0.84%   | 1.08%| 1.06%| 0.87%|

**Table 7. CSE for SFC of test fuels.**

| Engine Speed | Gasoline | E10  | IB5  | IB10 |
|-------------|---------|------|------|------|
| 2000rpm     | 1.19%   | 0.69%| 1.02%| 0.98%|
| 3000rpm     | 0.77%   | 0.89%| 0.87%| 0.92%|
| 4000rpm     | 1.92%   | 1.45%| 0.91%| 1.22%|

**Table 8. CSE for CO emissions of test fuels.**

| Engine Speed | Gasoline | E10  | IB5  | IB10 |
|-------------|---------|------|------|------|
| 2000rpm     | 0.32%   | 0.29%| 0.34%| 0.29%|
| 3000rpm     | 0.34%   | 0.29%| 0.40%| 0.30%|
| 4000rpm     | 0.24%   | 0.17%| 0.37%| 0.36%|

**Table 9. CSE for HC emissions of test fuels.**

| Engine Speed | GASOLINE | E10  | IB5  | IB10 |
|-------------|----------|------|------|------|
| 2000rpm     | 1.24%    | 0.74%| 0.89%| 1.02%|
| 3000rpm     | 1.01%    | 0.50%| 0.88%| 1.05%|
| 4000rpm     | 1.17%    | 0.72%| 0.92%| 0.98%|

**Table 10. CSE for NOX emissions of test fuels.**

| Engine Speed | Gasoline | E10  | IB5  | IB10 |
|-------------|---------|------|------|------|
| 2000rpm     | 1.09%   | 1.72%| 0.69%| 0.88%|
| 3000rpm     | 0.99%   | 1.27%| 1.04%| 0.68%|
| 4000rpm     | 1.43%   | 0.94%| 0.90%| 0.87%|

5. Results and Discussions

5.1. Specific fuel consumption

The SFC the Figure.5 shows the variation in the SFC of various test fuels with respect to that of the engine speed. It can be observed from the figure that the SFC of the engine decreases with an increase in the engine speed. The average SFC for E10 the blend is 2.6% less than the average SFC of gasoline and the average SFC of IB5 and IB10 were 3.9% and 5% less than that of the average SFC of the gasoline. This shows the leaner mixture is required for the combustion operation of the engine when the alcohol content is increased. Also, the high octane number of ethanol and iso-butanol will affect the SFC. The results of SFC found to be matching with the research outcomes of H.Bayraktar [49].
The reduction in the SFC of the engine is due to the increase in the density and the kinematic viscosity of the alcohol added fuels. Even the energy content of the fuel gets decreased with the addition of the alcohol, the total mass of the fuel intake was more in case of the alcohol added fuel which will fulfil the energy of the engine [50].

![Figure 5. SFC against engine speed.](image1)

![Figure 6. Brake Thermal efficiency against engine speed.](image2)

5.2. Brake thermal efficiency
Brake Thermal Efficiency of all test fuels was increased with increase in the engine speed, the minimum value was obtained for 2000rpm and the maximum value was obtained for 4000rpm. As the engine speed increases the flame velocity will increase and this will make use of the cleaner air-fuel mixture and gives the higher brake power results in high BTE. Figure 6 shows the corresponding graph between the BTE and engine speed. The E10 fuel produced the higher BTE in all the engine speed conditions and the average BTE of E10 fuel is 7.0% more than that of the average BTE of pure gasoline. The average BTE of IB5 and IB10 fuels were 12.4% and 17.8% more than that of the average BTE of the gasoline. The presence of the oxygen content in the alcohol is also one of the main reasons for the complete combustion and the increase of the BTE. The previous research findings of alcohol added gasoline also show similar results [51, 52].

5.3. HC Emissions
The HC, CO, and NOX emissions were measured for all the test fuels by fitting the commercial catalytic convertor in the exhaust followed by the fabricated zeolite catalytic convertor using AVL 444 gas analyzer. The HC emissions were found to be decreasing in nature with the increase in the engine speed. Also, the addition of alcohol has also reduced the formation of the HC emission. Figure 7 shows the HC emissions recorded for all the fuels under commercial catalytic convertor conditions. The average emission of the E10 fuel was 5.5% less than that of the average HC emissions of gasoline fuel. The average HC emissions of IB5 and IB10 were 7.9% and 13.2% less than that of the average HC emissions of gasoline fuel. The emission values obtained were found in accordance with the research findings of I. Gravalos et al. Because of the improved combustion characters of alcohol blended gasoline is the reason for the decrement of HC emissions with an increase in the alcohol blend [53].
Figure 7. HC emission formation against engine speed for commercial catalytic convertor.

Figure 8. HC emission formation against engine speed for Cu-ZSM5 catalytic convertor.

The HC emissions observed during the zeolite coated catalytic convertor fitted in the exhaust was shown in figure.8. It is seen from the figure that the HC emission from the zeolite coated catalytic convertor is decreased further more than the commercial catalytic convertor. The average HC emission values observed from the zeolite-based catalytic convertor is 26%, 33%, and 42% less than that of the average HC emission values from the commercial catalytic convertor for the engine speeds 2000rpm, 3000rpm and 4000rpm respectively. The presence of separate oxidation monolith will help the oxidation reaction of HC to H2O and CO2 even faster than that of the commercial catalytic convertor. Thus the Cu-ZSM5 coated zeolite was performed better than that of the commercial catalytic convertor.

5.4. CO Emissions

Figure.9 shows the variation of the CO emission with respect to the various engine speed when the engine was connected with commercial catalytic convertor. It is seen from the figure that the CO emissions keep on decreasing with the increase in the engine speed from 2000rpm to 4000rpm for all the fuels. The main reason for the formation of the CO emission is the deficiency of the oxygen in the air-fuel mixture, but the oxygen content of the alcohol blended gasoline fuel is more than that of the pure gasoline which results in the less formation of CO emissions [54]. The average emissions of CO for E10 fuel were 7.1% less than that of the average CO emissions of gasoline. The average CO emissions for IB5 and IB10 were 15.3% and 19.3% less than that of the average CO emissions of gasoline. This is due to the addition of the oxygen in the test fuel due to the addition of alcohol. Similar results have been obtained in the previous alcohol-gasoline blends experiments conducted by T.Topgul et al [55]. So, the addition of Iso-butanol as an additive in the ethanol-gasoline blends reduces the CO emission effectively than that of the simple ethanol-gasoline blends. As the engine is operating in the leaner mixture at higher engine speed the combustion was complete in nature. Thus the CO emission values were measured for the engine fitted with a commercial catalytic convertor for various test fuels.
When the Cu-ZSM5 catalytic convertor was fitted with the engine the average CO emission valves recorded for the various test fuels at different engine speed seems to be further decreasing. The average CO emissions recorded in the Cu-ZSM5 catalyst were 7%, 9%, and 11.5% less than the average CO emissions recorded in the commercial catalytic convertor. The reason for this increased activeness of oxidation is due to the presence of the separate oxidation and reduction monolith in the zeolite coated in house-made catalytic convertor whereas in the commercial catalytic convertor both the oxidation and the reduction reaction takes place in the single monolith. The Cu-ZSM5 catalyst was a better choice for oxidizing CO emissions from the alcohol gasoline blend.

5.5. NOX Emissions

Figure 11 shows the variation of NOX emission with respect to the variation of engine speed when commercial catalytic convertor. The formation of NOX emission depends upon the combustion chamber temperature and oxygen concentration. As the oxygen content of the fuel increases with an increase in the alcohol concentration, the formation of NOX emission will increase with the increase in the alcohol concentration due to the complete combustion reaction. It is clear from the figure that the NOX emission of the test fuel keeps on increasing with the engine speed and alcohol percentage. The average NOX emission of the E10 blended fuel is 8.9% more than that of the average NOX emissions of pure gasoline. Also, the average NOX emission of the IB5 and IB10 blended fuel is 11.5 and 15.7% more than that of the average NOX emissions of pure gasoline. A similar result for the alcohol-gasoline blended fuels on the NOX emission characteristics was observed in the previous researches[56]. As the flame speed increases the combustion is complete, which results in the high temperature inside the combustion chamber which contributes to the formation of more NOX emissions. When the test fuels were tested by fitting the zeolite coated catalytic convertor, the amount of NOX emission observed was less than that of the commercial catalytic convertor which is shown in figure.12. The Cu-ZSM5 coated the catalytic convertor has more active sites for the reduction of the NOX emissions to N2 and O2. The formed O2 from the zeolite coated monolith also helps in the oxidation of HC and CO. The average NOX emissions observed from the Cu-ZSM5 catalytic convertor was 6%, 8.3%, and 11.1% less than that of the average NOX emissions values observed from commercial catalytic convertor for the engine speeds 2000rpm, 3000rpm and 4000rpm respectively.
6. Conclusion
In this study, Cu-ZSM5 zeolite was prepared and tested to find its emission-reducing capacity on alcohol-gasoline blended fuels in an SI engine. The alcohols used for this study were Iso-butanol (as an additive) and ethanol (blended in gasoline) for the investigation of performance and emission characters. The Cu-ZSM5 zeolite was coated in a monolith and well placed along with an oxidation monolith in a well-designed catalytic convertor. Initially, all the fuels (gasoline, E10, IB5, and IB10) were tested in an SI engine fitted with a commercially purchased catalytic convertor, and the emission values were observed in the gas analyzer. Then the same engine was fitted with the Cu-ZSM5 zeolite coated catalytic convertor and the emission values were measured for all the test fuels. From the results, it has been found that the zeolite coated catalytic convertor reduces HC, CO, and NOX emissions by 33%, 9%, and 8.3% more than that of the commercial catalytic convertor for the 3000rpm engine speed. For the wide range of operations, the zeolite coated catalytic convertor was very effective than that of the commercial catalytic convertor for reducing the engine emission. Even after 100 hours of operation, the zeolite coated catalytic convertor does not malfunction in its performance.

7. References
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