Design and Performance Analysis of a Three Way Catalytic Converter

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Abstract:- **The world is being aware of the pernicious effects of the unwanted and unavoidable parameter like exhaust emission from automobiles and the need to control them. Presently, Three-Way Catalytic Converter (TWC) is an important after treatment device to reduce damaging engine exhaust emissions. Platinum group metals well known as non-noble metals have shown greater pollution-control capability, but due to cost considerations, these metals are used in lesser quantities. This dissertation focuses on controlling the automobile emissions using the combination of nano-particles of non-noble metal i.e. Ruthenium Catalyst to better level. In recent years, use of nano technology in the field of energy, environment, medical and information technologies has been rapidly increased due to the interesting physical and chemical properties of the nano materials arising from the quantum size effect which is remarkably different from those in bulk samples. Numbers of experimentations have been made by many researchers using NPs of various catalyst materials and analyzed for their effect on the TWC and the results have reported remarkable enhancement in the performance of TWC. So it becomes important to review the various methods of NPs preparations synthesis and their effect on the properties of the materials and characterization of the NPs for evaluation of various properties of the same. The TWC model is developed for Tata Indica Four Stroke Four Cylinder Diesel Engine of 1405 cc capacity. Space velocity was found an important consideration while designing TWC. The use of non-noble metal catalysts for the developed model of TWC has shown 12.66 to 63.67 % control over CO emissions, 3.66 to 56.58 % over HC emissions and 12.35 to 29.64%over NO emissions.**

Keywords: **Carbon monoxide, Hydro-carbon, NOx, Catalyst, Emission, TWC.**

I. INTRODUCTION

The exhaust emissions from automobiles are unwanted and unavoidable parameters with which the world is seriously concerned. The efforts are being made in order to reduce the automotive exhaust emissions by various control technologies. Numbers of strategies have been incorporated to control automobile emissions like exhaust gas recirculation, selective catalyst reduction, low NOx burner, two way and three-way catalytic converter, engine optimization, etc. But the most effective technique was found to be Three-Way Catalytic Converter (TWC) [14]. Before the TWC, no other technique could control all the pollutants, i.e. Hydrocarbon (HC), Carbon Monoxide (CO) and Oxides of Nitrogen (NOx). So improvement in the TWC can lead to improve the emission control performance of the same.

The TWC works on all the three gaseous pollutants of concern: CO, unburned HC & NOx. TWC typically contains active catalytic materials, which promote oxidation of CO & unburned HC and reduction of NOx [15]. Pt (Platinum) and Pd (Palladium) are used as an oxidation catalyst while Rh (Rhodium) is used as reducing catalyst for NOx reduction [16]. Other than precious metal catalysts, cheaper combination based on copper, chromium, nickel, manganese, etc. have also been tried but could not achieve comparative efficiency [2,8,9,19]. In TWC, efficient diminutions of CO, unburned HC and NOx are simultaneously carried out on the same catalyst bed [15]. One of the current advancement in the TWC is the use of nano technology for the materials, i.e. nano-particles (NPs) of the materials [4,5,17,20]. In recent years, use of nano technology in the field of energy, environment, medical and information technologies has been rapidly increased due to the interesting physical and chemical properties of the nano materials arising from the quantum size effect which is remarkably different from those in bulk samples [21].

Number of experimentations have been made by many researchers using NPs of different catalyst materials and analyzed for their effect on the TWC and the results have reported remarkable enhancement in the performance of TWC [16, 24, 29, 30]. So it becomes important to review the various methods of NPs preparations & synthesis and their effect upon the properties of the materials and characterization of the NPs for evaluation of various properties of the same.

II. METHODOLOGY

Present work focuses on using catalyst materials of non-noble metals with nano-particles to study the emission performance of the engine at various loads and speeds. The developed model of TWC is designed for the passenger car up to 1400 cc capacity. The emission performance is tested by using five gas analyser.

Table 1 Specifications of Substrate

Particular	Specification
Type	Metallic Substrate
Diameter and Length	90 and 90 mm (Two halves)
Cell Density	400 CPSI
Wall Thickness of Substrate (t_s)	1.50 mm
Material for Substrate Wall	Stainless Steel
Meshing	Honeycomb Structure
Material	Alloys of Fe, Al and Cr
Grade	21 Cr Al 6
Wall Thickness of Mesh (t_m)	0.11 mm

In this work, Ruthenium catalyst is used in combination with Platinum. The preparation of Platinum Catalyst is done by using Multi-Wall Carbon nano-Tubes and Ruthenium Catalyst by Sol-Gel method under Argon using dry solvents. The substrates incorporated are metallic with cylindrical shape of diameter and lengths equal to 90 mm both. The specifications of the substrate are tabulated in Table 1. The insulating material used was carbon fibre. The developed model of TWC is to be tested on Multi Cylinder Diesel Engine Test Set-up with Computer Interface (Tata Indica Four Cylinder Diesel Engine). The specifications of the engine are given in Table 2. Figure 1 shows the test setup-Multi Cylinder Diesel Engine with Computer Interface and figure 2 shows the developed model of TWC.

Table 2 Specifications of Engine

Parameter	Specification
Make and Model	Tata; Model- Indica V2SL
Engine	Diesel Engine, 1.4 L
Cubic Capacity	1405 cc
Bore × Stroke	75 × 79.5 mm
No. of Cylinders	4
No. of Strokes	4
Maximum Power	48.1 bhp @ 5000 rpm
Maximum Torque	85 Nm @ 2500 rpm

Figure 1 Multi Cylinder Diesel Engine Test Set up with Computer interface

Figure 2 Developed Model of TWC fitted at the end of engine tailpipe

Preparation of Ruthenium Catalyst

The synthesis of Ruthenium was carried out by 20 wt % of Ru under Argon using dry solvents. In a 2 liters-two neck flask fitted with a dropping funnel and a vacuum adapter, maintained under a steady flow of argon, 2.868 g of anhydrous ruthenium chloride and 1 litre of dry THF needed to be introduced and sonicated for 15min to generate a uniform suspension of the salt. 5.6 g of vulcan XC 72 was added to the suspension and the mixture was stirred vigorously for 2 hrs at room temperature. The flask was then placed in an oil bath maintained at 50°C. 27.0 mL of 1.5MLiBet3H/THF solution was dripped over 2hr and the resulting mass was allowed to stir vigorously for 24 hr at 50°C. After stopping the stirring, flask was cooled to room temperature. Colorless and clear supernatant was pressed off and wash the precipitate twice with 150mL portions of THF and dry the same. The residue was conditioned at 200 °C using argon (5min) followed by hydrogen (30min) and argon (5 min) again. The sample tube can be allowed to cool to room temperature. This enables the formation of stable, 20 wt% Ru/C catalyst.

III. RESULTS AND DISCUSSIONS

HC, CO and NO Emissions

The exhaust emissions of the engine were measured by using AVL 5 Gas Analyzer. At the start, the engine was run for some time before starting the test. The emissions were measured at different loads and speeds. By considering the rated power, the maximum load carrying capacity was calculated and it was found to be 36 kg. Accordingly, engine was loaded for 0% load, 25% load (9kg), 50% load (18 kg), 75% load (27 kg) and full load. Various engine parameters were considered for the testing like load, RPM, torque, mechanical efficiency, BSFC and MEP. These parameters were readily recorded by the interfacing computer. Various conditions of load and speed were applied to the engine to know the emission performance of the TWC model at those conditions.

The comparison of the emissions is shown by graphs.

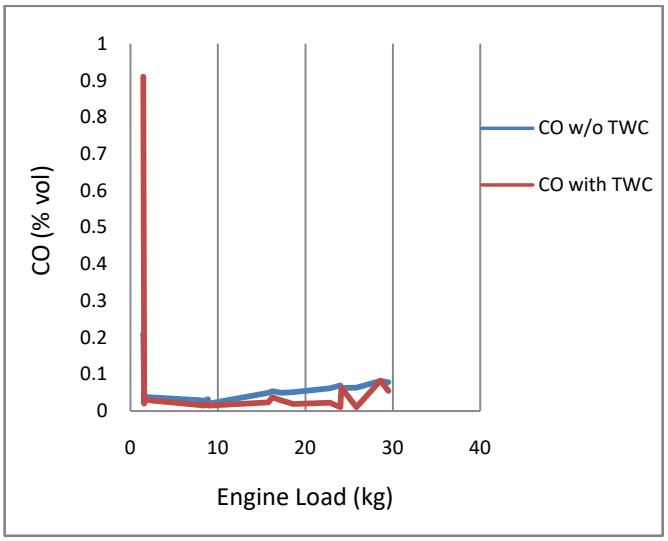

Figure 4. Engine Load v/s CO Emissions

Figure 4 compares CO emissions with and without TWC from load 0 to 30 kg. The graph clearly shows lack of control over CO emissions at the start. It indicates either cold start of the engine or light off period of the TWC. The control over CO emissions starts after 1.59 kg. Initially the control looks very poor that upto 9 kg of load. The remarkable reduction in the CO emissions is seen after 18 kg of load. The CO emissions are well controlled before the full load but it goes on decreasing as it comes to full load. The maximum reduction in the CO emissions is found to be 0.06 % vol., i.e. 85% reduction at the load of 24 kg and 1000 rpm.

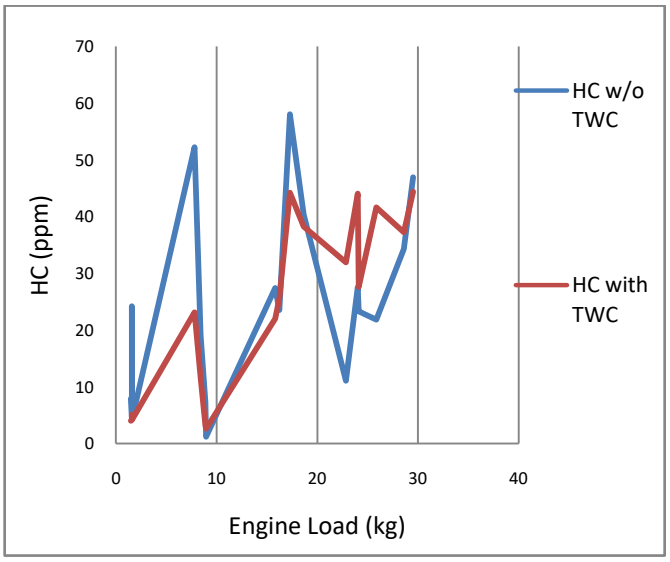

Figure 5. Engine Load v/s HC Emissions

Figure 5 compares HC emissions with load applied. A tremendous reduction in the HC emissions is found at till the load of 9 kg at highest rpm. Moderate control can be observed over HC till the approximate load of 18 kg. No reduction is seen after the half load till the full load. Maximum control over HC is found to be 78.9% at the load of 9 kg and 4000 rpm (reduction in HC by 19.09 ppm) and minimum control is 3.66% (reduction in HC by 0.16 ppm) at the initial stages.

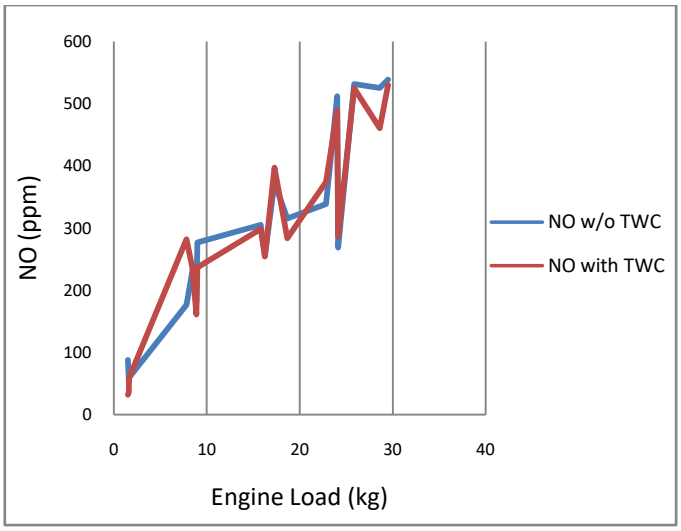

Figure 6. Engine Load v/s NO Emissions

The comparison in figure 6 of load v/s NO clearly indicates the failure of TWC model over NO emissions with increasing load. In the cold start phase, TWC model completely fails to control NO emissions. Good control can be observed in the range of 9 kg till half load. Maximum reduction in the NO is 56 ppm in the starting phase of loading. After the half load to full load, no significant reduction is observed continuously. This comparison concludes lack of control over NO emissions as load increases. Some control over NO can be seen in the region of highest loads. The graph claims the Ruthenium catalyst to be a poor reduction catalyst material and the economic range of load with controlled NO emissions is as 10 to 20 kg.

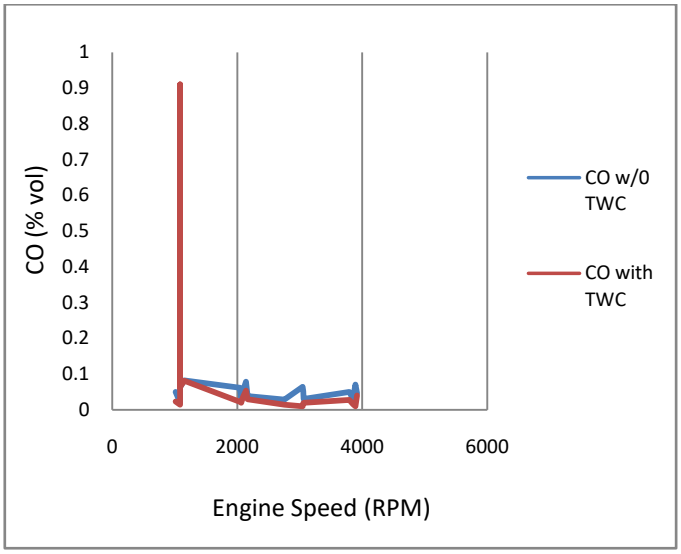

Figure 7. Engine Speed v/s CO Emissions

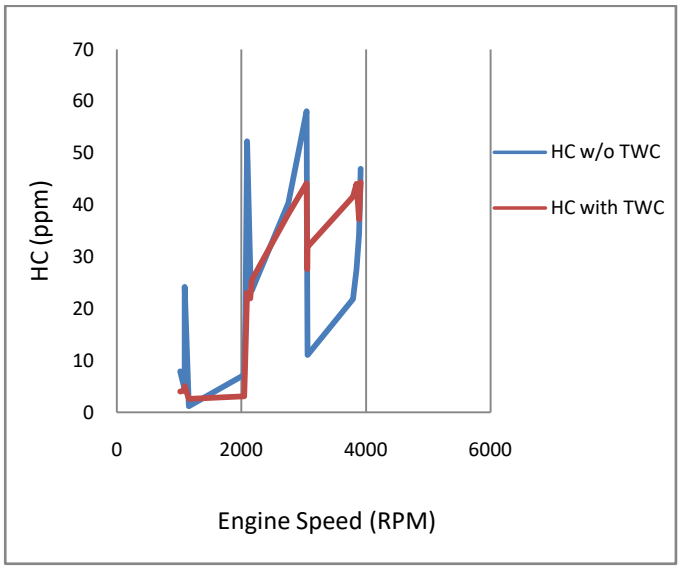

Figure 8. Engine Speed v/s HC Emissions

The TWC model fails to control the CO emissions in the initial stages of speed (Figure 7). But as the speed increases further, the moderate control can be observed until the end. The emissions are controlled till the highest speed is achieved. The last intersection of the graph indicates no further reduction is possible if engine is run at more speed. Figure 8, shows good control at start and tremendous control over HC from 2000 till 3000 rpm except some minor regions. The graph clearly indicates no control offered by the TWC model over HC emissions after 3000 rpm. The maximum speed of the engine has to be 3000 rpm as per the interpretation of the graph.

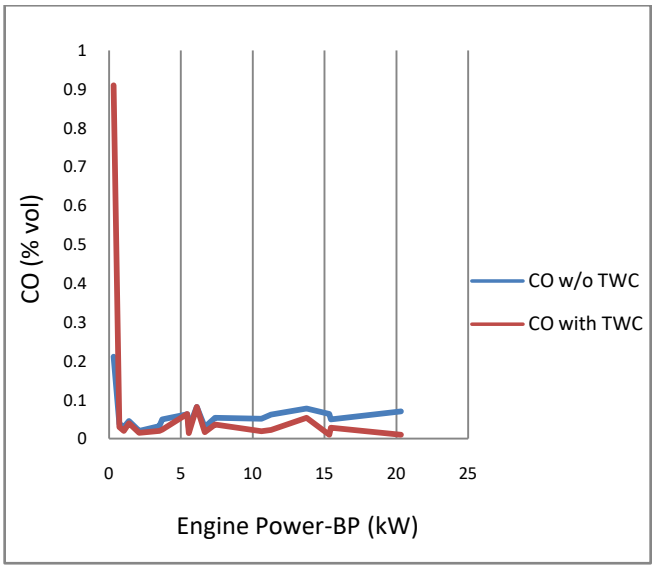

Figure 9. Brake Power v/s CO Emissions

Figure 9 shows graph plotted as brake power in kW v/s CO emissions in % vol. approximately upto 6 to 7 kW of brake power, CO is reduced by small amount. Major reduction in CO can be noted after the BP of 7 kW. Control offered over CO is appreciable and the control is maintained even in the highest values of brake power. Hence the developed TWC can be used for engine with maximum brake power of 20 kW and more.

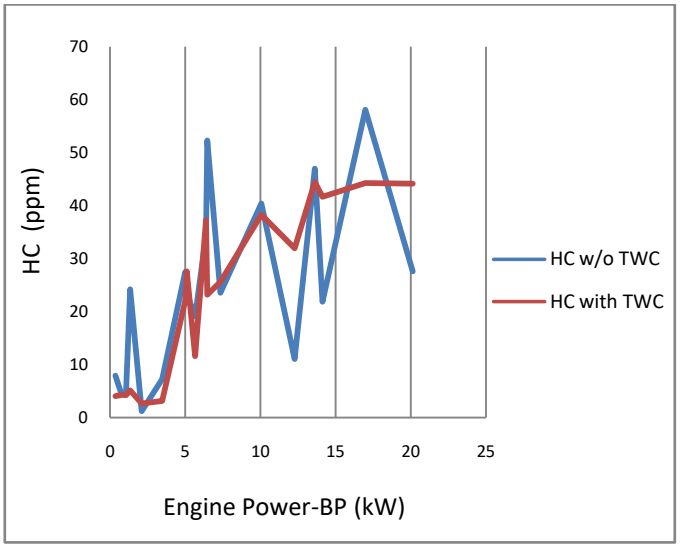

Figure 10. Brake Power v/s HC Emissions

The graph in fig. 10 represents comparison between brake power and HC emissions. It is clear that HC emissions are well controlled upto brake power of 10 kW. After 10 kW, no control is observed. Maximum reduction id found at brake power about 6 kW. Then the reduction seems to be faded rapidly. Hence it can be concluded from the graph that the TWC model is well suited for the vehicles with maximum brake power of 10 to 11 kW as long as HC emissions are concerned.

IV. CONCLUSION

In the research work, an attempt has been made to use nano particles of Ruthenium metal as a catalyst in TWC for automotive exhaust emission control. From the results, it is clear that the Ruthenium catalyst is quite good as an oxidation catalyst as it has shown moderate control over the HC and CO emissions. The HC emissions are reduced by 3.66 to 56.58% and CO emissions by12.66 to 63.67 %. The developed model has completely failed to control the NO emissions. The maximum reduction in the NO emissions is 12.35 to 29.64%. As long as cold start problem is considered, the TWC model is effective only for HC emissions. The catalyst material is needed to be characterized for finding their catalyst activity at higher temperatures.

Hence it is concluded that the Ru Catalyst proves to be a good oxidation catalyst suitable only for the HC and CO emissions. It can be used with other reduction catalyst in the TWC in order to get control over NO emissions.

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Definitions/Abbreviations

TWC	Three Way Catalytic Converter
HSU	Hartridge Smoke Unit
NPs	Nano-Particles
CPSI	Channel per Square Inch
HC	Hydrocarbons
CO	Carbon Monoxides
NO_x	Oxides of Nitrogen
NO	Nitrous Oxide