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Experimental Studies on the Performance and Emission Characteristics of a Electrically Heated Catalytic Convertor fitted S.I.Engine

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ABSTRACT

The rapid growth in the energy consumption at individual level has given rise to a dramatic increase in both air and water pollution problems. The automobile is probably the most notorious source of atmospheric air pollution on a total mass basis. Under the Indian Conditions two and four wheelers have become the most popular mode of transport. In the present work catalytic converter was chosen for SI engine emission control, to reduce CO, HC and NOx emission. A catalytic converter has to be designed and introduced in the exhaust line of the SI engine. In the present work Maruthi omni engine is chosen for emission control study using an electrically heated catalytic converter. The objective of the electrically heated catalytic converter is to reduce the cold start emission of CO, HC and NOx in the exhaust gas of the engine. The catalytic converter is made of stainless steel plate. The plate is coated with copper, Nickel and Chromium catalytic materials. These emission levels will be measured using the AVL exhaust gas analyzer and the results will be analyzed.

Introduction

Air pollution is not a new phenomenon. Starting in the fourteenth century with the growing use of coal and accelerating with the industrial revolution, air pollution from combustion became a serious problem and consequently several serious episodes occurred. The worst of these was in London, in 1952. A week of intense fog and smoke resulted in over 4000 deaths. In a United States the most alarming episode occurred during a four-day period in 1948 in Donora, Pennsylvania, when 20 deaths and almost 6000 illnesses were linked to air pollution. These air pollution episodes were caused almost entirely by combustion of coal, in stationary sources such as power plants and smelters. The high concentration of sulphur oxides and particulate matter in the smoke and fog caused industrial smog or sulphurous smog. In contrast, the smog in Los Angeles basin was primarily the result of automobile emissions of unburned hydrocarbons and oxides of nitrogen. This type of smog is known as photochemical smog. The world's population is becoming ever more urbanized and consequently the quality of air is deterioration in many of the most rapidly growing cities. In most mega cities the principal source of air pollution is motor vehicles. Controlling emissions from these vehicles is a very difficult problem because

i) Motor vehicle is small and therefore rarely serviced properly;

ii)It is operated accelerating and decelerating under various conditions of loads and speeds;

iii) It has millions of prototypes on the highways.

The pollution is caused by the incomplete combustion of the fuel inside the combustion chamber. It occurs due to insufficient supply of oxygen or due to improper design of the engine cylinder. In order to control the emission from road vehicles, the western countries have implemented laws that strict the emission from a vehicle. These regulations have been put forth for every year to control the emission form automobiles.

In India these regulation started off in road vehicles from the year 1995. In our country through we started late towards this process we approach in an hard and strict manner to reach the present day Euro norms which are in about five years in advance to the present India norms. The Indian government is proceeding with its best efficiency to reach out this problem. In this process many bills have been passed to control emission in India. Many modifications have been brought throughout the automobile industries to control emission. It is shown in the table 1.

Table 1: Emission norms for the year 2005 and above

Vehicle	Pollutants, g/km	Year 2005		Preferably from Year 2008	
		Bharat Stage II		Bharat Stage III	
		Norms	DF*	Norms	DF
2 Wheelers	CO	1.5	1.2	1.0	1.2
	HC + NOx	1.5	1.2	1.0	1.2
3 Wheelers (petrol)	CO	2.25	1.2	1.25	1.2
	HC + NOx	2.00	1.2	1.25	1.2
3 Wheelers (Diesel)	CO	1.00	1.1	0.5	1.1
	HC + NOx	0.85	1.0	0.5	1.0
	PM	0.10	1.2	0.05	1.2

* Deterioration factor to account for deterioration of devices like catalytic converter

The objective of this work is to use the electrically heated catalytic converter in petrol engines and to reduce the cold start emission of engine exhaust. In addition to this, it also develops a new and innovative technology in the field of substrate geometry for catalytic converters. The metallic substrate posses the higher durability, faster light off temperature and there is less thermal shock stress resulting in long life to the converter. An effect of electrically heated metal substrate catalytic converter is employed to reduce the cold start emissions.

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Literature Survey

General

Exhaust emission requirements have become increasingly more stringent in the past decade with the introduction of LEV and ULEV standards. These regulations have forced improved combustion control and after treatment of exhaust. It is well known that to achieve these very low emission standards by the control on Hydrocarbon and Carbon monoxide emission during cold start. Lot of works have been reported in the literature on the cold start emission control on SI engines by sing include electrically heated catalyst, hydrocarbon storage devices.

Whittern Berger and Kubsh (1991) have studied emission performance of an electrically heater catalytic converter – for both low mileage tests and after exhaust aging. They have observed that the aged EHC system using a 300 hour engine schedule impacted cold start HC and CO emission on par with low mileage EHC system. It has been reported that the aged EHC system reduced HC emission by 76% and CO emission by 92% during first 140 seconds of the FTP cycle when compared to that with the aged converter without heating. **Louis Socha et al** (1992) have reported that an extruded metal electrically heated catalyst (EHC) in combination with a traditional main converter can achieve the Low and Ultra-low emission standards. They have reported that non-methane hydrocarbon (NHMC) emissions range from 0.15 to 0.3 g/mile for such systems. They have concluded that emission and energy and when the EHC system is located close to the engine.

J.C. Summers et al (1993) explored the use of close-coupled catalysts in conjunction with conventional under floor converters for achieving California LEV standards. They identified catalytic formulations for both converters to optimize engine system performance. They studied the benefits of double wall exhaust pipe connecting the two converters and thin walled substrate for the light-off catalyst .**Takehisa Yaegashi et al** (1994) have developed a new heating strategy for electrically heated catalysts to reduce power consumption while achieving the desired hydrocarbon conversion. They have also developed a relationship between catalyst volume and power consumption. They have concluded that the front face beating of the catalyst reduced power level and achieved light off quickly. This (EHC impact on Extended Hot Soak Periods **Kubsh et al** (1996) primarily deals with the evaluation and emission performance of a vehicle fitted with EHC for a vehicle soak period that is ranging from 30 to 180 minutes. For soak periods of 30 and 60 min the EHC showed poor conversion efficiency. But with secondary air injection, the EHC showed better emission performance, i.e., significant reduc6tion in both NMHC & CO emissions.

Pfalzgraf et al (1996) have investigated the performance of close coupled catalytic converters complemented by engine-related catalyst heating measures and secondary air injection in Audi A4 and V6, 2.8 litres and five valve engines. It has been reported that the emission results were below half of the maximum emission allowable as per LEV standards. **Kubshand Brunsox** (1996) have studied the performance of the EHC with low and high cell density (160 cpsi Vs 400 cpsi), non-straight flux channel geometry and several low-power zoned heating strategies (all with 160 cpsi) in a V6 test engine. They have concluded that hydrocarbon emission for the aged low cell density; high cell density and anon-straight channel designs were significant during cold start with full face heating strategies.

Yuichi Shimasaki et al (1997) have reported that an EHC system using extruded Altimeter Powered Electrically Heated, catalyst (APEHC) and thin wall light off substrate achieved ULEV standards. They have also studied the durability of the APEHC with hot vibration testing, water quenching, thermal cycling, corrosion, electrical cycling test, steady state temperature test and electrical load dump test.

Naomi Noda et al (1998) have studied the cold start emission performance of passive inline hydrocarbon absorber. They have also studied the effect of the centre hole on the absorber BZA. They have found that the absorber BZA with a 25 mm diameter centre hole reduces30% lower FTP NMHC emission when compared to a system with no centre hole adsorbent BZA.

Design of Converter

The important parameter to be considered in the design of catalytic converter is the volume of the converter. The design criteria for fixing the volume of the converter are space velocity which is defined as follows:

$$\text{Space velocity} = \frac{\text{Volume flow rate of exhaust gas in } \frac{m^3}{hr}.}{\text{Convertor volume in } m^3}$$

The reciprocal of the space velocity will be the residence time generally the rage of space velocity is 15000 to 100000 h-1. An average space velocity suitable for the engine is to be selected. At the maximum load and rated speed, the mass flow rate of air (ma) entering the engine is determined by using an orifice meter and the mass flow rate of the fuel (mf) is determined by noting the time for the consumption of known volume of fuel using a burette fitted to the fuel tank. The sum of these two (Ma + mf), gives the mass flow rate of the exhaust gas, which is converted into volume flow rate by dividing it by the density of exhaust gas.

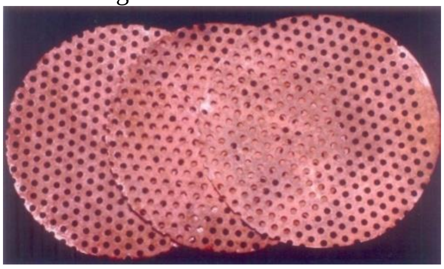

Figure 1 Cu coated plate

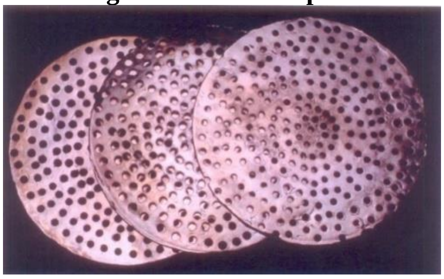

Figure 2 Cr coated plate

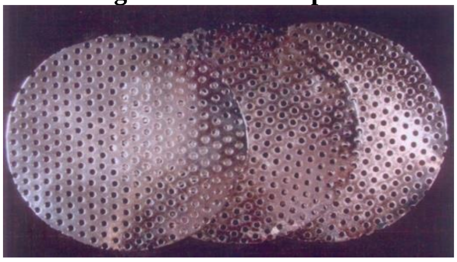

Figure 3 Ni coated plate

For the engine considered in this study, the maximum volume flow rate of exhaust gas was found to be 140.66/40000 hr-1 was selected. Hence the converter volume was obtained as 140.66/40000 = 3516 cm^3. Choosing an axial flow, single bed converter of circular cross section, a bed diameter of 122 mm and bed length of 300 mm were selected for the converter. Mild steel plate of 1.2 mm thickness was used to fabricate the catalytic converter. The entry and exit of the converter was made smooth by providing converging and diverging sections at angles 30° and 65° respectively. In the present work metal plate of 0.1 mm thickness has been used as substrate. The substrate plate was providing small holes about 2.5 mm diameter. The substrate was coated with different catalyst material by electro plating process. Figures [1, 2 and 3] show the photograph views of coated plates. The plug was provided in the housing of the catalytic converter. The heater plug was connected to battery.

Methodology

Electric heated catalytic converter is reducing the cold start exhaust emission. The easiest way to preheat the converter is to use of electrical heater plug. Three number of 15 Ams heater plug should be used in catalytic converter. Two heater plugs are provided before converter bed one heater plug was placed after catalytic converter. Before starting the engine the catalytic converter bed should be preheated by using 12V battery supply through the heater plug. The effect of heating reduces the CO and HC emissions the results are compared with and without heating of catalytic converter.

Experimental procedure

- Check the fuel level in fuel tank
- Before starting the engine, heat the plates inside catalyst converter to 50°C with the help of heater plugs.
- Start the engine properly
- catalytic converter was provided, with chromium coated MS plates, copper coated MS plates and Nickel coated MS plates for three trials
- Take the fuel consumption for 3 minutes with the help of stop watch and level indicator in the fuel tank
- With help of AVL di-gas analyser, CO, CO_2, HC and NOx were measured before and after catalytic converter. AVL di-gas analyser is shown in figure 4.
- Take the exhaust temperature before and after catalytic converter.
- Repeat the above procedure for 1800, 2200, 2600 and 3000 rpm and the readings are tabulated.
- The above procedure is taken for two trials.

Figure 4. Photographic view of AVL di-gas analyzer

Experimental set-up

Experimental investigation was carried out on Maruthi Omni four stroke petrol engines. Catalytic converter was designed, fabricated and introduced in the exhaust line of the engine. The catalytic converter housing is made of stainless steel. The sectional view of catalytic converter is shown in figure 5. Exhaust gas analyzer (NDIR) was used to measure the CO, HC and NOx emissions. The bed temperature was measured by digital thermometer using thermocouple. The engine was run at constant brake power by varying the speed. The emission concentrations of HC, CO, NOx and fuel consumption were noted. Before starting the engine the heater is switched on for the purpose of raising the bed temperature. When the bed temperature reaches 60°C the electrical unit automatically disconnected the power source. The heating arrangement lowers the cold start emission and improves the life of the converter. The temperature is an important parameter for better chemical reaction. The concentrations of CO, HC and NOx were measured before and after the catalytic converter for different speed conditions. The photographic view of experimental setup is shown in figure 6. The conversion efficiency of the catalytic converter at different speed was determined using the expression. The photographic view of catalytic converter is shown in figure 7.

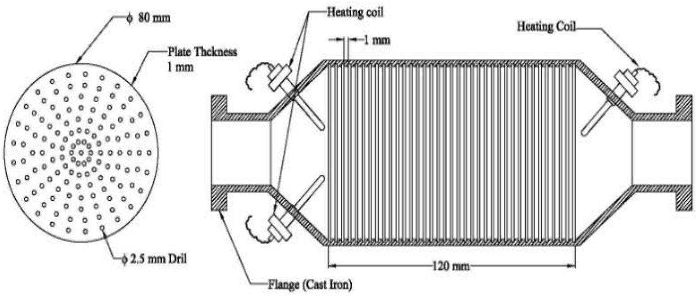

Figure 5. Sectional view of electrically heated catalytic converter

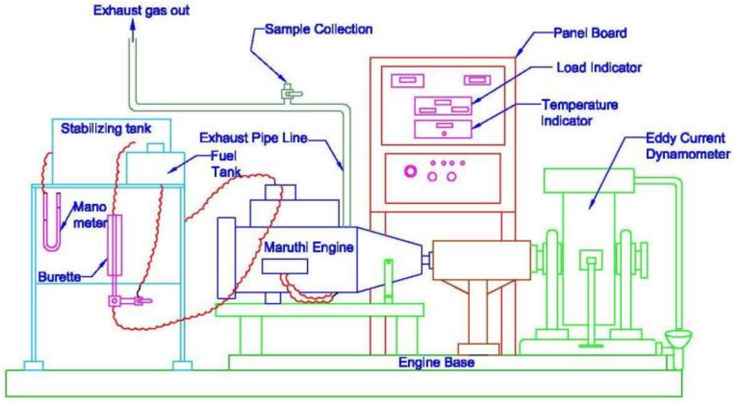

Figure 6. Experimental setup

Engine Specification

Type	Maruthi Omni
Stroke length	72 mm
Engine power	37 HP @ 5000 rpm
Compression ratio	8.7:1
Displacement	796 cc
No. of cylinder	3 cylinder
Firing order	1 – 3 – 2
Cooling system	Water Cooled
Lubrication system	Pressurized 324.5 kg/cm^2 @ 3000 rpm

Results and discussion

Figure 9 shows the variation of CO emission with different speed of the engine without heating the catalytic converter. Without catalytic converter (WOCC) the CO emissions are varying from 6.3% by volume at 1400 rpm to by 4.89% by volume at 3000 rpm. By using Cu coated catalytic converter 2.75% by volume of CO emission decreases at 1400 rpm. At higher speed CO emission further reduced 3.4% by volume.

This is due to high bed temperature of the catalytic converter. Among the catalytic materials used in the converter the Nickel coated catalytic converter shows maximum reduction of CO emission. In the Nickel coated catalytic converter 3.9% CO reduction achieved at 1400 rpm. Figure 10 shows the CO emission with varying speed of the engine with catalytic converter (WCC).

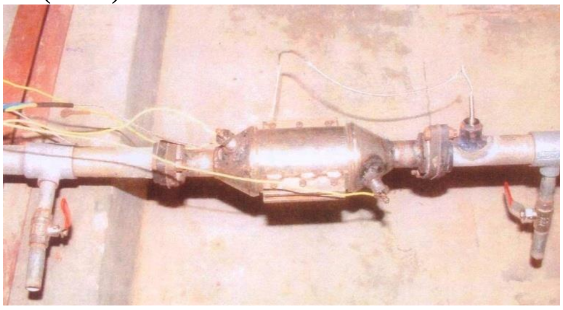

Figure 7. Photographic view of Catalytic converter

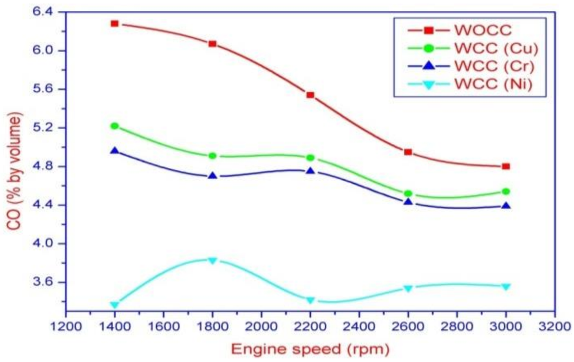

Figure 9. CO against engine speed (Without heating)

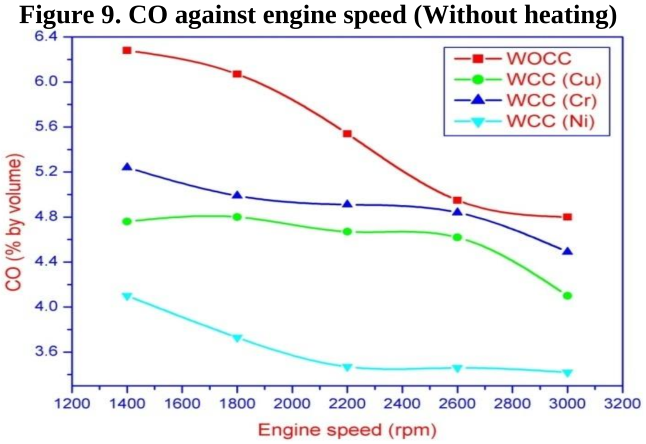

Figure 10. CO against engine speed (With heating)

Without catalytic converter CO emission varies from 6.3% by volume at 1400 rpm to is 4.89% by volume at 3000 rpm.Due to heating of the catalytic converter the bed temperature raises about 60°C the faster light off temperature take place. It is found from the graph due to electrical heating maximum reduction of emission for all the catalytic converter. Figure 11 shows the variation of exhaust gas temperature with varying speed of the engine without heating of catalytic converter. At 1400 rpm the exhaust gas temperature is 450°C without catalytic converter and 580°C at 3000rpm. The effect of catalytic converter Copper, Chromium and Nickel the exhaust gas temperature is 430°C, 400°C and 380°C respectively at various speed conditions. Among the catalytic materials there are no appreciable changes in exhaust gas temperature at maximum speed of the engine. Similarly with heating of catalytic converter marginal changes in exhaust gas temperature is shown in figure 12.

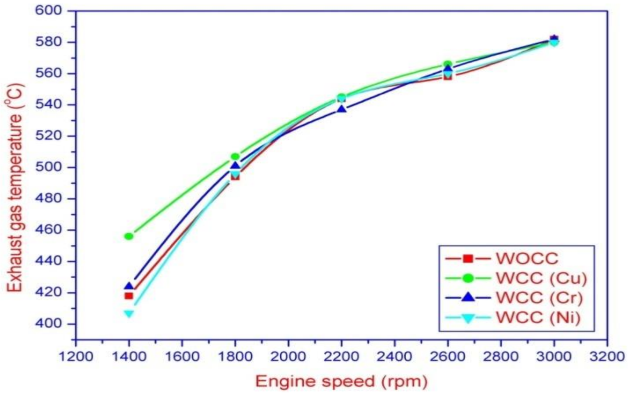

Figure 11. Exhaust gas temperatures against engine speed (Without heating)

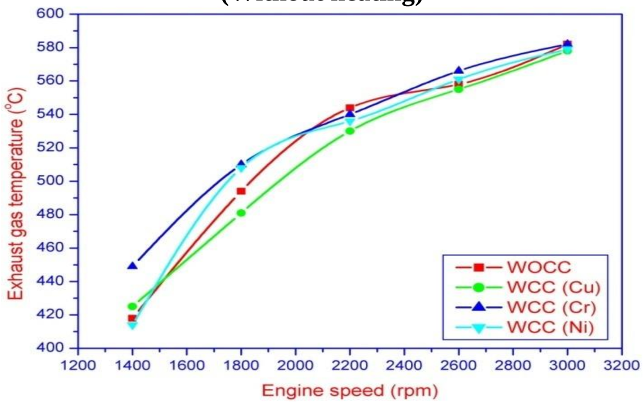

Figure 12. Exhaust gas temperatures against engine speed (With heating)

Figure 13 shows the variation of HC emission without heating the catalytic converter with different speed of the engine. The HC emission gradually decreases when the engine speed increases for all the cases. Among the three catalytic converters the Copper coated converter shows maximum reduction of HC emission about 300 ppm. The reason is the Copper coated catalytic converter having higher oxygen reaction that leads to faster oxidation process. The figure 14 shows variation of HC emission with heating the catalytic converter for different catalytic materials. The HC level varies from 500 ppm at 1400 rpm to 300 ppm at during maximum speed of the engine without catalytic converter. With heating the use of catalytic converter at lower speeds faster light off temperature achieved. Hence the HC emission significantly reduced for heating of catalytic converter.

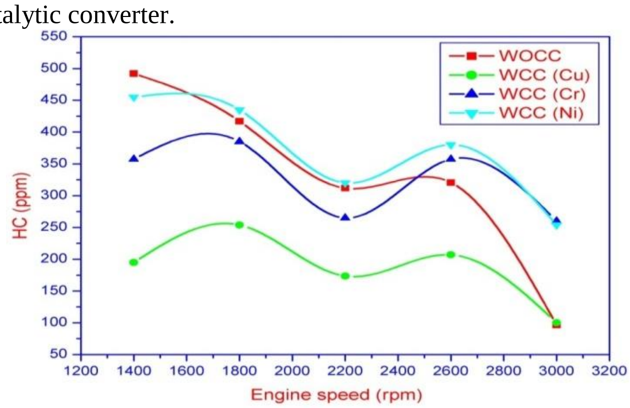

Figure 13. HC against engine speed (Without heating)

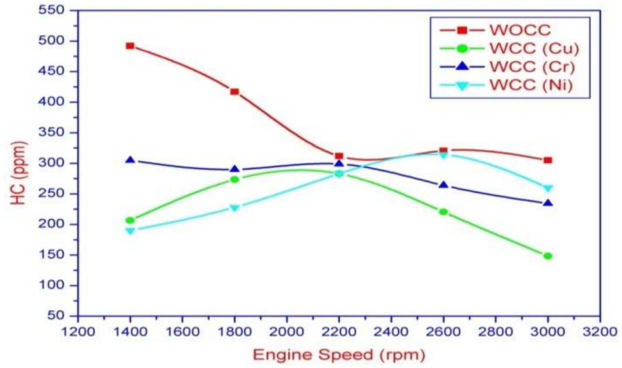

Figure 14. HC against engine speed (With heating)

Figure 15 shows the NOx emission with different engine speed with different coated materials without heating. At lower speed NOx emission is 550 ppm and gradually increases at part speed and beyond that the emission level gradually decreases. For all the catalytic converters the NOx emission significantly reduced. The Copper coated catalytic converter reduces the maximum level of NOx emission than other materials.

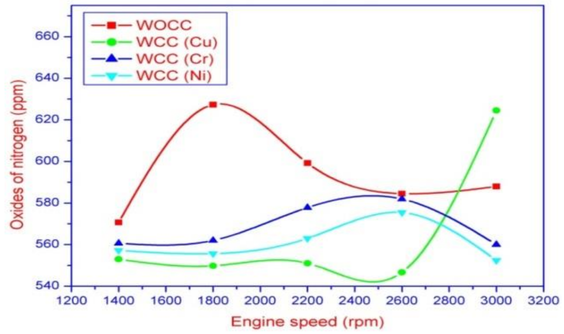

Figure 15. Oxides of nitrogen against engine speed (Without heating)

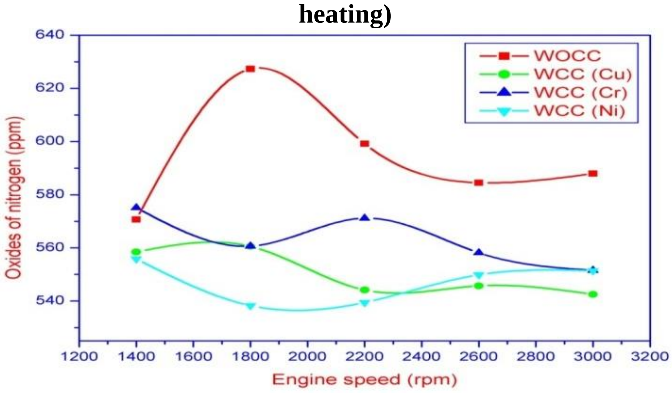

Figure 16. Oxides of nitrogen against engine speed (With heating)

Figure 16 shows the NOx emission for coated catalytic converter with heating. Due to heating of catalytic converter the Copper coated catalytic converter are reducing the NOx emission significantly when compared to without heating.

Conclusion

From the experimental investigations following observation were made

- The experiments are conducted with varying speed with constant load by using different materials i.e. Copper, Nickel and Chromium coated plates.
- There is marginal reduction of CO emission for copper and Chromium catalytic material without heating.
- Using copper as catalytic converter HC emission gradually reduces when compared to other materials.
- NOx emissions for copper coated catalytic materials have lower NOx emission when compared to Chromium and Nickel.
- By using copper as a catalytic material with heating having less CO emission
- By using copper as a catalytic material with heating having less HC emission
- By using copper as a catalytic material with heating having less NOx emission

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