Experimental Analysis and Validation of Catalytic Converter in IC Engine

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Abstract

The motivation behind this paper is to develop a low-cost three way catalytic converter. The catalytic converter is a device which converts harmful exhaust gases from internal combustion engine into harmless gases. Harmful gases like NOX, CO; unburned HC etc. are converted into N_2, CO_2, H_2O respectively. The catalytic converter was developed based on catalyst materials consisting of metal oxides such as cobalt nitrate, Co $(NO_3)_2$, and copper sulphate, $CuSO_4.5H_2O$, with alumina substrate. Both of the catalyst materials such as Co $(NO_3)_2$ and $CuSO_4.5H_2O$ are inexpensive in comparison with conventional catalysts such as palladium or platinum. In addition, the noble metals such as platinum group metals are now identified as human health risk due to their rapid emissions in the environment from various resources like conventional catalytic converter, jewelers and other medical usages. The conventional catalytic converter was based on noble metal catalyst with honeycomb ceramic substrate.

KEYWORDS: Catalytic Converter, Exhaust emission, C.I.Engine, Performance, Air injection.

I. Introduction

Pollution can take the form of chemical substances or energy, such as noise, heat or light. Pollutants, the components of pollution, can be either foreign substances/energies or naturally occurring contaminants. Pollution may be defined as "an unwanted/undesirable foreign matter added to environment in other words, Pollution may be defined as "the excessive discharge or addition of undesirable substances or unwanted foreign matter into the environment, thereby adversely altering the natural quality of the environment, and causing damage to human, plant and animal life or it may be unreasonable interference with the comfortable enjoyment of life or the conduct of business". The term environment includes air, water and land.

Air pollution may be defined as any atmospheric condition in which certain substances are present in such concentrations that they can produce undesirable effects on man and his environment.

These substances include gases (sulphur oxides, nitrogen-oxides, carbon monoxide, hydrocarbons etc), particulate matter (smoke, dust, fumes, aerosols etc) and radioactive materials and may others. Most of these substances are naturally present in the atmospheric in low (background) concentrations and are usually considered to be harmless.

Air is polluted by dust, cement, coal and some gases. An individual inhales about 16 kg of air in a day. If the air is polluted it causes many ill-effects on human beings. Polluted air also affects plant life, promotes corrosion, blocks out day-light, and causes deterioration of rubber, paints etc. Pollution has become a major source of problem during the last 25 years. It is harmful to natural resources and human health. Automobile contributes 25% of the air pollution. Government has proposed various emission control norms in order to prevent the air pollution from automobiles.

I.I. Major sources of pollution from automobiles

The major sources of pollution from automobiles are:

- Primary pollution.
- Secondary pollution.

Primary pollution contributes emission of harmful carbon monoxide (CO), unburned hydrocarbon (UHC), and oxides of nitrogen (NOx) and particulate matter, where as secondary pollution contributes the green house effect.

Carbon monoxide is formed due to incomplete combustion in combustion chamber. Unburned hydrocarbon is due to the evaporation of fuel from the fuel tank and also due to formation of unburned gases in the exhaust oxides of nitrogen (NOx) and particulate matter is formed due to improper combustion and formation of NOx increases with increase in temperature at the exhaust.

For diesel vehicles, the major challenge of exhaust emission control is particulate removal and control of NOx. Because of excess air in the engine, there are lower level of CO and unburned gaseous hydrocarbons (UBF) when compared with the emission of petrol engines. However, the particulate, which are minute particles of unburned carbon, may be coated with carcinogenic poly aromatic hydrocarbons and sulphates resulting from the combustion of sulphur in the fuel or lubricator. Today, NOx emissions are controlled by engine design and calibration, often at the expense of increased particulate emission. It also can be reduced with the help of reduction catalytic converters. An effective three-way catalytic converter reduces HC, CO and NOx.

Fortunately though it has not been recognized widely, automobile exhaust is known enemy since this is signalled by the emission of visible smoke as encountered in a over loaded vehicle or the fuel is adulterated. First job is to screen vehicle by visual inspection, send those discharging excessive visible smoke to mobile or stationary workshop for smoke meter testing and subsequent maintenance. Recording petrol engines it may be fitted with catalytic converter. It is also necessary to use the SCR to reduce NOx, CO and unburnt HC coming from the engine. It has been seen that pure gasoline or oxygenated fuel used in the engine could not satisfy the emission norms proposed by the government. Therefore it is also necessary to use an SCR to reduce the level of pollutants.

II. Literature review

GRIGORIOS C. KOLTSAKIS et al (1997) researched the potential of catalytic systems in automobile emission control were discussed in "CATALYTIC AUTOMOTIVE EXHAUST AFTERTREATMENT" The catalyst technology applicable in each case, the operating principles and performance characteristics, durability aspects and considerations regarding the interactions between catalyst performance and engine management. The concise presentation of related mathematical model equations provides insight into the catalytic mechanisms and the physical phenomena involved. Further reductions of catalytically controlled automobile emissions may be attained by developing improved and more durable catalysts, by applying a systems approach in designing optimized engine-exhaust after treatment configurations, as well as by efficient control of in-use catalytic systems through inspection, maintenance and on-board diagnostics.

IMRAN SYAKIR MOHAMAD et al (2009), analysed Tin (IV) oxide has been recognized as an alternative catalyst for carbon monoxide gas treatment generated from vehicular and industrial activities were investigated in “Development of tin (IV) oxide based catalyst for carbon monoxide emission control” tin (IV) oxide was used as a catalyst with the addition of cobalt (II) oxide and nickel (II) oxide as dopants, prepared by modification of sol-gel method. The catalytic ability was tested towards the oxidation of carbon monoxide using continuous fixed bed reactor (SELOX) instrument. Two catalysts, ECAT1-400 calcined at 400oC and ECAT2-600 calcined at 600oC gave a promising catalytic ability towards carbon monoxide oxidation. Both catalysts completed the carbon monoxide oxidation to carbon dioxide at 215oC and 200oC. Several techniques were used in this research to characterize the physical and chemical properties of the catalyst materials.
M.A. KALAM et al (2009), developed characteristics of a new catalytic converter (catco) to be used for natural gas fuelled engine in “Development and test of a new catalytic converter for natural gas fuelled engine” The catco were developed based on catalyst materials consisting of metal oxides such as titanium dioxide (TiO_2) and cobalt oxide (CoO) with wire mesh substrate.

WATHANYU AMATAYAKUL et al (2001) analysed the life cycle assessment of a typical ceramic three-way catalytic converter were discussed “Life cycle assessment of a catalytic converter for passenger cars”. The environmental impacts occurring in the life cycle of a catalytic converter, encompassing the extraction of raw materials,

XAVIER COURTOIS et al (2000) modified the three-way catalytic activity of a 4.7% Cu: Al_2O_3 catalyst modified by addition of small amounts of rhodium (from 100 to 2000 ppm) was measured up to 550°C, in steady state or oscillatory conditions (0.1 Hz), using a synthetic gas containing N_2, O_2, CO, C_3H_6 and NO in “Three-way catalytic activity of alumina-supported copper catalysts modified by rhodium” No synergetic effect in the catalytic properties has been observed between Cu and Rh, as the CO, NO and C_3H_6 conversions at low temperature increase with rhodium concentration. At high temperature, the use of copper which exhibits oxygen storage properties improves the CO and NO conversion by moving up the limitations observed in the conversion under oscillatory conditions.

The study of Cu, Rh: alumina catalysts have evidenced no synergetic effect between Cu and Rh for the activity in three-way catalysis. For each reaction, the conversion at low temperature increases with the rhodium concentration. However, compared to rhodium alone, the CO and C3H6 oxidation begins at lower temperature in presence of copper. When the catalytic tests are performed under oscillatory conditions, differences are observed at high conversions between the catalysts of different composition.

III. Objective of the project

The objective of the project is to research on engine exhaust after treatment control by using alternate source of material like alumina for doing oxidizing reaction in catalytic converter to make cost effective solution.
In the scope of the project two combination of wash coat technology is under experimentation research.

i. Cobalt nitrate ii. Copper sulfate.

Based on the result best wash coat technology will be selected

III.I Methodology

In an existing catalytic converter the precious metals like platinum, palladium, are normally used. To overcome from the cost and usage of precious metals, it was an effort to identify by project experiment results by using alternate source of material like alumina. The alumina is selected in the ball type construction and tipped into the cobalt nitrate and copper sulfate solution in the wash coat technology. Wash coat assist in oxidation process to reduce the CO, HC emission. The new trials will prove the concept of alternate material comparison over precious metals employed in recent trends, and will enhance the feasibility of cost effective solution.

IV. Catalytic Converter

A catalytic converter is an after treatment device that reduce the pollutants from automobiles to exhaust to very low emission levels. Nitrogen oxide can be reduced in the presence of some reducing agents. UN burnt HC; CO can be oxidized using oxidant. HC/CO can be oxidized to completion in the presence of certain catalysts with secondary air injection in front of catalyst bed.

IV.I. Major types of catalytic converter

Two-Way Catalytic Converter

A two-way catalytic converter has two simultaneous tasks

Oxidation of carbon monoxide to carbon dioxide

$2CO + O_2 \rightarrow 2CO_2$

Oxidation of un burnt hydrocarbons (un burnt and partially-burnt fuel
To carbon dioxide and water:

$C_XH_{2X+2} + [(3x+1)/2]\ O_2 \rightarrow xCO_2 + (x+1)\ H_2O$ (a combustion reaction)

This type of catalytic converter is widely used on diesel to reduce hydrocarbon and carbon monoxide emissions. They were also used on spark ignition (gasoline) engines in USA market automobiles through 1981, when the two-way converter’s inability to control NOx led to its supersession by three-way converters.

Three Way Catalytic Converter

Since 1981, three-way catalytic converters have been used in vehicle emission control systems in North America and many other countries on road going vehicles. A three-way catalytic converter has three simultaneous tasks.
Reduction of nitrogen oxides to nitrogen and oxygen:

$$2NO_x \rightarrow xO_2 + N_2$$

Oxidation of carbon monoxides to carbon dioxide:

$$2CO + O_2 \rightarrow 2CO_2$$

Oxidation of Unburnt hydrocarbons (HC) to carbon dioxide and water:

$$C_xH_{2x+2} + [(3x+1)/2]\ O_2 \rightarrow xCO_2 + (x+1)H_2O$$

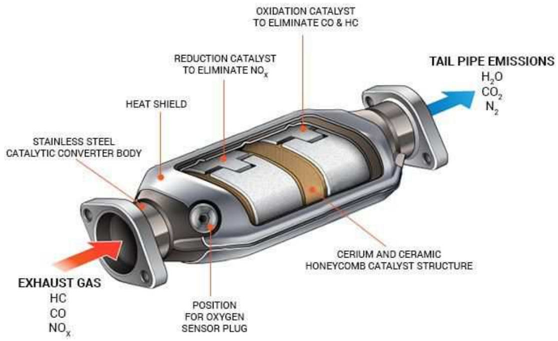


Fig.4.0. Catalytic Converter

These three reactions occurs most efficiency when the catalytic converter receives exhaust from an engine running slightly above the stoichiometric point. This is between 14.6 and 14.8 parts air to1 part fuel, by weight, for gasoline. The ratio for LPG, natural gas and ethanol fuels is slightly different, requiring modified fuel system settings when using those fuels. Generally, engines fitted with 3-way catalytic converters are equipped with a computerized closed-loop feedback fuel injection system employing one are more oxygen sensors, though early in the deployment of 3-way converters, carburetors equipped for feedback mixture control were used. While a 3-way catalyst can be used in an open-loop system, NOx reduction efficiency is low.
Within a narrow fuel/air ratio band surrounding stoichiometric, conversion of all three pollutants is nearly complete. However, outside of that band, conversion efficiency falls of very rapidly. When there is more oxygen then required, then the system is in oxidizing condition. In that case, the converter's two oxidizing reaction (oxidation of CO and hydrocarbons) are favored, at the expense of the reducing reaction. When there is excessive fuel, then the engines is running rich. The reduction of NOx is favored, at the expense of CO and HC oxidation.

V. Experimental / test set up

V.I. Catalyst and substrate preparation
Material selection for catalyst:

In this study, several stock solutions with different aqueous molar ratios and weight ratios were used. Cobalt nitrate and copper sulfate were used as a metal oxide catalyst. The cobalt nitrate and copper sulfate used as the oxidizing agent. Its inertness to sulphate formation and surface properties makes it preferred carrier in selective catalytic reduction of CO and HC from the stationary pollution sources.

V.II. Catalyst preparation
Cobalt (ii) nitrate catalyst
Alumina powder and ammonia hydroxide solution were used in wash coat material to increase the

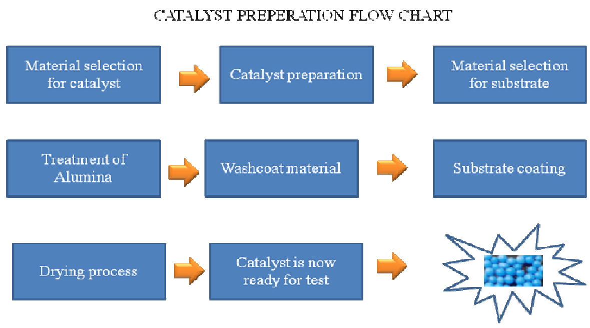


Fig.5.0 Catalyst preparation flow chart

coating strength to surface of alumina balls substrate. 200 ml of water was added into 20.0 gram Co $(NO_3)_2$. One gram of alumina powder and 100ml of Ammonia hydroxide were gradually added. To ensure homogenization, the solution was then stirred at 500 rpm for two hour

Copper (II) Sulfate Catalyst

Alumina powder and ammonia hydroxide solution were used in wash coat material to increase the coating strength to surface of alumina balls substrate. 200 ml of water was added into 20.0 gram $CuSO_4 \cdot 5H_2O$. One gram of alumina powder and 100 ml of Ammonia hydroxide were gradually added. To ensure homogenization, the solution was then stirred at 500 rpm for two hour.

Fig.5.1. Magnetic stirrer

V.III. Material selection for substrate

The substrate material is aluminum oxide, as it is widely used in the automotive exhaust system not only due to its advantages in mechanical and physical properties but also low-cost. The aluminum oxide was selected as ball shape to catalyst coating. Figure 5.7 shows the Alumina balls substrates.

Fig.5.2. Alumina Balls

Fig.5.3 Alumina balls coated with cobalt (II) nitrate

Fig.5.4 Alumina balls coated with copper(II) sulfate

V.IV. Construction of catalytic converter

The exhaust gas after treatment device construction is having following phases

1. Drawing or layout preparation.
2. Drawing consists of assembly drawing and detailed drawing of individual components.
3. The selection of material.
4. Fabrication of catalytic converter outer casing.
5. Preparation of other sub components like cone and flanges.

Drawing or layout preparation

The alumina catalysts are filled into the catalytic converter. The preparation of catalytic converter and its benchmarking observations are shown below,

The bench marking study shows following shapes,

- Cylindrical
- Oval construction

Out of these, cylindrical shape is selected because it has following advantages.

- easy manufacturing feasibility,
- uniform shape and structure formation,
- the manufacturing cost is less,

Purpose of cones fitment in the catalytic converter is to increase the gas velocity and to have uniform index and diffusion of pollutant to come in contact with alumina catalyst for better oxidation reaction. The connecting of coupling flanges is made for connecting the exhaust gas line with catalytic converter at suitable locations.The purpose of inner shell is to hold the alumina catalyst in the gas path. The outer cylindrical shell is an external construction to protect and hold the whole internal catalyst construction.

Preparation of sub components

List of sub components are as follows,

1. Inner shell
2. Outer shell
3. Cone
4. Flanges
5. Support rings

Fabrication

Assembly of all sub components along with filled wash coat catalyst will make the all new alumina catalytic converter ready for testing

V.V. Catalytic converter fabrication flow chart

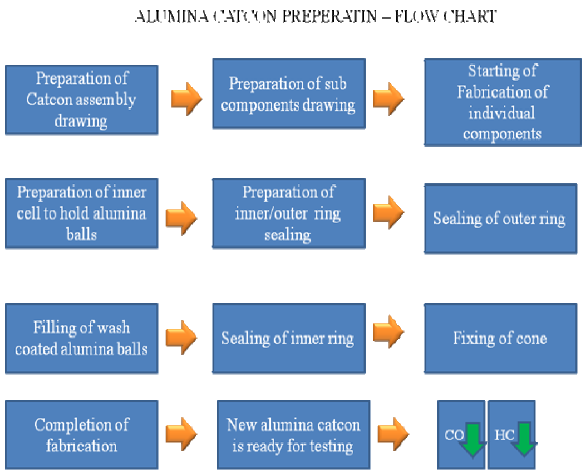


Fig.5.5. Alumina catalytic converter fabrication flow chart

V.VI. Catalytic converter detailed drawing

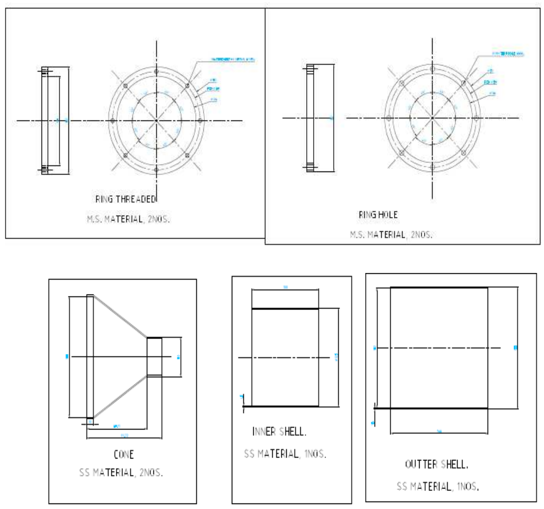


Fig.5.6. Catalytic converter of detailed drawing

V.VII. Catalytic converter assembly drawing

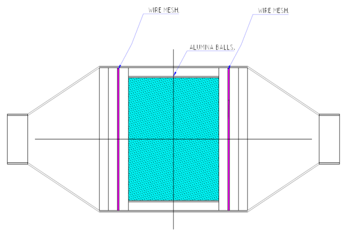


Fig.5.7. Catalytic converter assembly drawing

V.VIII. Catalytic converter chamber

The fabrication of catalytic converter consists of few components, namely the inner shell, outer shell, cone and wire mesh. The catalytic converter casing and inner chamber remain as same as typical catalytic converter installed in the vehicle system. The same outer dimensions were purposely fixed in order to avoid redesign of the existing exhaust system, which then required further thermal optimization and design validation studies. The alumina balls were then coated with metal catalyst before arranged onto a catalytic converter. Catalytic converter 1litre capacity is selected for the experiment

Fig.5.8. Alumina catalytic converter

VI. *Experiment results – base readings*

The experimental engine is of 1.5L SI engine. Before taking the catalytic converter efficiency, the base engine emission readings are acquired by using 5gas analyzer. The details of 5 gas analyzer is shown below,

Technical details:

Voltage	11-22 V DC
Power Consumption	25 W
Warm up time	7 min
Response time	< 15 s
Operating temperature	5-45ºc
Relative humidity	≤ 95% non-condensing

Before taking the emission test, a leak check has to be conducted in the digital gas analyzer. The leak check is conducted by closing the probe's nozzle manually. The purpose of leak check is to discharge the residual gases through the gas analyzer's exhaust tube. The components present in the exhaust gas such as hydrocarbon, NO_x in parts per million and carbon monoxide, carbon dioxide, oxygen in percentage volume will be displayed in the digital gas analyzer.

Fig.6.0 Avl 5 gas analyser

A K-type thermocouple in conjunction with a digital temperature indicator was used to measure the exhaust gas temperature. The thermocouple was inserted in the exhaust pipe nearer to the engine exhaust manifold. An orifice meter connected to a surge tank was used to measure the air consumption with the help of tube manometer. The surge tank fixed on the inlet side of the engine maintains a constant airflow through the orifice meter. Exhaust emission from the engine were measured with a AVL Five Gas 444 gas analyzer. In the 5 gas analyser system uses following measurement principle

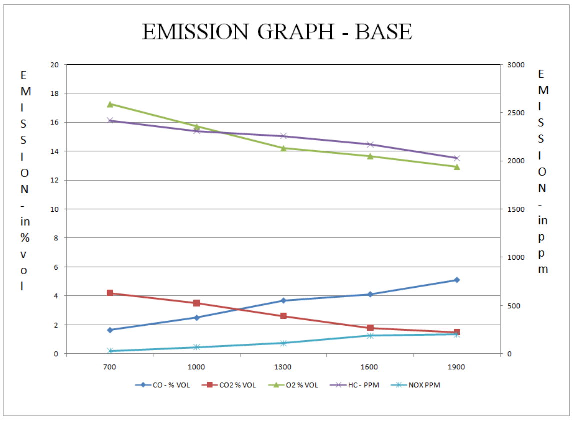
- CO, CO_2 Analyser uses NDIR principle
- HC analyser uses HFID principle
- NO_X analyser uses CLD principle

All the experiment was carried out after thorough inspection and calibration of the engine and measuring instruments. At each load, all reading was taken five times for repeatability and the average of these reading taken for final analysis. the experiment results are shown below,

Table 6.0 Emissions result-base

SPEED N	CO % vol	HC ppm	CO2 %vol	O2 %vol	Nox ppm
700	1.66	2420	4.2	17.27	32
1000	2.51	2310	3.5	15.72	72
1300	3.7	2260	2.6	14.22	112
1600	4.13	2170	1.80	13.69	187
1900	5.12	2030	1.5	12.94	201

Emission Graphs



Graph.6.0. Emission graph Base

The emission readings and graphs are measured from low idle rpm to full speed with the specified speed intervals of 300rpm. The observed readings are going to be compared with new developed catalyst experiments in second phase. Based on the converter efficiency and catalyst performance recommendations and conclusions will be suggested.

Emission analysis: The objective is to see the effect of the 500gms coated catalyst in the catalytic converter reaction. Following catalyst are prepared for experiment

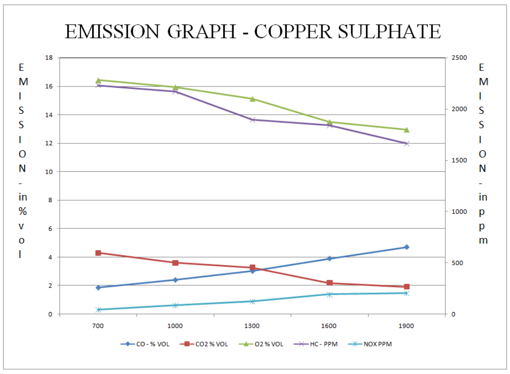
a) Cobalt nitrate b) Copper sulphate

The experiment emission results were compared for CO, HC, NOx emission, as there is no particulate emission from the SI engine. The main emission reductions from the experiment results are only the oxidation reaction as these two catalysts were capable to assist only on oxidation reaction. Hence the main focus in this substrate selection is based on % reductions of CO, HC emissions.The emission values are compared with base readings, copper sulphate, and cobalt nitrate. The evaluation is given in the conclusion based on oxidation reduction efficiency.

VI.I. Emission – copper sulphate

Table 6.1 Emissions result-copper

EMISSION - RESULT - COPPER SULPHATE					
SPEED N	CO % vol	HC ppm	CO2 %vol	O2 %vol	Nox ppm
700	1.86	2230	4.3	16.43	45
1000	2.4	2170	3.61	15.93	87
1300	3.02	1894	3.28	15.11	123
1600	3.9	1840	2.2	13.48	192
1900	4.7	1662	1.92	12.94	204

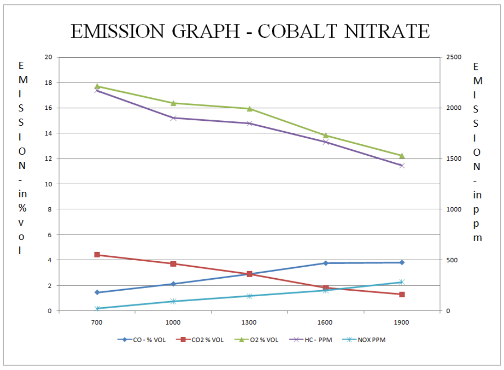


Graph. 6.1 Emission Graph – Copper Sulphate

VI.II. Emissions – cobalt nitrate

Table 6.2. Emission – cobalt nitrate

EMISSION - RESULT - COBALT NITRATE					
SPEED N	CO % vol	HC ppm	CO2 %vol	O2 %vol	Nox ppm
700	1.45	2170	4.41	17.72	23
1000	2.12	1899	3.7	16.37	95
1300	2.93	1845	2.9	15.93	147
1600	3.76	1665	1.8	13.84	201
1900	3.82	1432	1.3	12.23	284



Graph. 6.2 Emission Graph – Cobalt Nitrate

VI.III. Results Discussion

Conclusion: Based on the emission results conducted on the experimental engine, the proto type catalytic converter was utilised in 2 different test followed by each substrate. After completion of test results were analysed and compared with base readings in graphical form as shown above. The graphical representation clearly indicates that cobalt nitrate catalyst was superior in performance, Good in % reduction of CO, HC emission. And the cobalt nitrate catalyst has the similar properties of the platinum and palladium precious metals. The effective pre selection of this substrate has proved the lowest emission results with highest performance with comparable low cost. These analyses are totally a new concept and development of alternate source to meet the need of 2 way oxidation catalytic converter efficiency requirements. It is strongly proposed for upcoming future automobile segments for Vehicle and Engine level emission reduction purpose.

VII.Conclusion

Due to increase in air pollution, the government agency started introducing the stringent emission norms to control the engine out emission from automobiles. The stringent emission norms started a new drive on development of low or ultra low emission engines by using the latest trend of technology like multi valving, CRDI, Variable valve lift, VGT turbo charger, camless valve gearing, hybrid or alternate sources of fuels. But the new development of engine can have tend this latest trend on engine technology, but what about the existing engines and its overhead infrastructure involved in making the assembly and production. Hence it was a great solution to use the exhaust after treatment devices to control the existing engine out emission and passing the required current emission norms and certifications. The current catalytic converters are using the oxidation process by employing the precious coat metal like platinum and palladium. To overcome from cost and reducing the rare metal usage the project made the drive to develop an alternate source of oxidation catalyst for oxidation reaction and thus reduces the CO and HC emissions. The substrate selected in this project is Alumina balls and the wash coat technology employed by using the cobalt nitrate and copper sulphate. The catalytic converter is constructed with inner/outer shell construction supported with two cones and flanges. The initial emission readings are conducted in the experimental project engine. The alumina substrate with wash coat completed in the first phase, In Catalyst (Cobalt nitrate, Copper sulphate) made ready for the canning process inside the catalytic converter. In second phase , the prototype catalytic converter loaded with catalyst and experiments carried out for emission, The experiment emission results were compared for CO, HC, NOx emission, as there is no particulate emission from the SI engine. The main emission reductions from the experiment results are only the oxidation reaction as these two catalysts were capable to assist only on oxidation reaction. Hence the main focus in this substrate selection is based on % reductions of CO, HC emissions.

In the experimental result analysis and graphical study, the emission values are compared with base readings, copper sulphate, and cobalt nitrate. From result discussion, it was concluded that, the cobalt nitrate is selected as the based oxidation reduction catalyst based on its efficiency.

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