Conceptualization, designing, fabricating, and testing of unique three-way catalytic convertor-CuCA-Con

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ABSTRACT

The new concept known as "CuCA-Con" was developed to curb the emission levels of automobiles which are directly affecting the atmosphere at increasing alarming rates. It is the new three-way catalytic convertor which has peculiar mechanical and chemical design, which aims at oxidation of harmful Carbon monoxide gas and reduction of the oxides of Nitrogen and Hydrocarbons present in exhaust of vehicles to less harmful pollutants. It also ensures the entrapment of soot particles and removal of bad odor from exhaust gas. The CuCA-Con was conceptualized and designed keeping in mind the important aspect i.e. "Design for manufacturability" and at the same time attaining the prime goal of research i.e. "Reduction of emissions". Later, on the idea went through phases of modeling, fabrication and testing. The experimental results obtained from five way flue gas analyzer shows that the levels of oxides of Nitrogen, Carbon monoxide and Hydrocarbons in exhaust are reduced to such extent of satisfactory values that they satisfy Bharat stage-IV norms for four two wheelers, operating on gasoline and diesel. The low cost factor, effective catalysis of exhaust gas and versatile application of this catalytic convertor has made this unique invention. The idea and model was awarded overall second prize of Rs.40000 at SAE BAJA-2016, India. The award was solely sponsored by "Continental Group", the leading automotive giant.

Keyword: - *Ammonia slip, Chemical design, cost factor, CuCA-Con, Design for manufacturability, Mechanical design, MIG-Welding*

1. INTRODUCTION

What compelled Arvind Kejriwal, the Hon. Chief Minister of Delhi to enforce the Odd-Even formula? Why ministry of Road and Transport, Government of India has moved from Bharat stage IV to VI escaping Bharat stage V? Why stricter laws were formulated in G-7 Summit, 2015 held at Schloss Elmau, Germany in regards with air pollution.
The only one answer to all above questions is EMISSIONS!
There are billions of cars on the road, all over the globe and each one of them being source of air pollution and its effects are detrimental. All countries are trying to make their air clean by imposing stricter emission laws and all these decisions are putting peer pressure on mobility industries to develop the technology which would meet the new norms.
Our new unique concept-The "CuCA-Con" aims at lowering the emission levels by use of commonly available cheap resources like cupric oxide, Ammonia solution and Activated carbon filter cloth. The conjunction of these three has the potential to reduce carbon monoxide, hydrocarbons and oxides of nitrogen emissions considerably. Thus, it is the three-way catalytic convertor. It ensures the trapping of soot particle and removal of bad odor. The unique spiral design and direct injection aids in increasing catalysis activity. This research paper describes conceptualization, designing, fabrication, and testing of this unique catalytic convertor.
The low cost factor, Design for manufacturability, effective catalysis, versatile applications, and encountering the problem of ammonia slip are the main achievement of this research.

2. CHEMICAL DESIGN

2.1 Cupric oxide

Cupric oxide is the inorganic compound of copper which is black in color. It is considered as one of the major catalyst in field of chemistry for oxidation reaction [1]. Among all other catalyst like platinum, rhodium, palladium, cupric oxide has highest ability to carry out oxidation. The reaction has higher kinetic rates. It is one of the best catalysts for oxidation of carbon monoxide. It is for the same reason, many research are oriented towards production of copper oxide Nano particles. [1].The chemical reaction which takes place is as follows:

$$Cuo\ (cupric\ oxide) + Co\ (carbon\ monoxide) \rightarrow Cu\ (copper) + Co_2\ (carbon\ dioxide)$$

In this process, the carbon monoxides present in flue gas react with black cupric oxide powder to give less harmful carbon dioxide. It is insoluble in water and aqueous urea solution. It also does not react with ammonia, which is released during selective catalytic reduction. The non-inflammable property of cupric oxide made it suitable selection for catalytic convertor, as it can sustain high temperature [1]. It is easily available. This all factors altogether helped us to select cupric oxide as reducing agent to oxidize carbon monoxide present in exhaust.125 grams of cupric oxide powder was used which would get chemically exhausted, over period of three months.

2.2 Activated carbon cloth

Activated carbon is carbon that has been treated with oxygen to open up millions of tiny pores between the carbon atoms. It results in oxidation of Hydrocarbons and Carbon monoxide into water vapor and carbon dioxide [2]. It is obtained from coconut husk, which is very cheap and easily available. In this CuCA-Con, the filter cloth is used which is impregnated with activated carbon. It is easily available with industries dealing with treatment of water

Fig. 1 Black color cupric oxide powder

A gram of activated carbon can have a surface area in excess of 500 m^2, with 1500 m^2 being readily achievable. Therefore it's better adsorption and chemisorptions properties help us to entrap soot particles in its pores. It also has ability to remove odor [2]. The most important feature is that it is capable of absorbing ammonia and at same time act as substrate for selective catalytic reduction [2]. This is the main achievement of this research as problem of ammonia slip is encountered. It is the Vander Waals forces which hold down these all impurities. The cloth of size 100 $cm^{2,}$ with sieve size of 1 mm is used, due to which no back pressure is produced. It also has ability to sustain high temperature till 300 degree Celsius and exhaust pressure without tearing off. Its life is about 4-5 months. All these above features altogether reduce Hydrocarbon, Carbon monoxide, soot particles, and foul smell of exhaust [2].

2.3 Adhesive

The high temperature resistant adhesive known as 'LOCTITE' was used which has ability to sustain 300 degree Celsius. It was used to join cloth to metal plate. Its use is economical.

2.4 Urea spray

The concept of selective catalytic reduction was used to convert harmful oxides of nitrogen to diatomic nitrogen and water vapor. The aqueous urea solution known as Ad Blue which is 32.67% by weight is sprayed in catalytic chamber using direct injection technology under pressure and hence, it is added to stream of exhaust [3, 4]. The reaction took place is as follows:

$$4\,NH_3(ammonia) + 4\,NO(nitric\ oxide) + O_2(oxygen) \rightarrow 4\,N_2(nitrogen) + 6\,H_2O(water\ vapor)$$
$$6\,NO(nitric\ oxide) + 8\,NH_3(ammonia) \rightarrow 7\,N_2(diatomic\ nitrogen) + 12\,H_20(water\ vapor)$$

At high temperature this urea get dissociate into ammonia over length of travel and then this ammonia react with oxides of nitrogen of flue gas to give harmless diatomic nitrogen and water vapor.

Fig. 2 Activated carbon cloth.

This give us reduction of oxides of nitrogen by 90% which itself is great achievement. [3].The complete catalytic reaction take place at activated carbon filter cloth, which act as base material for selective catalytic reduction.[3]. Ad Blue is non-toxic, non-explosive and non-inflammable liquid. Hence, it is safe to handle. It is the upcoming Euro-VI technology [3, 4].

Fig. 3 Urea powder.

3. MECHANICAL DESIGN.

3.1 Material Selection

0.4 mm sheet of stainless steel is used to fabricate complete CuCA-Con's parts. The reason for the same is that it is corrosion resistant and can withstand high temperature.

3.2 Injection Unit

The Ad Blue is injected into catalytic chamber at particular location at angle of 45 degree with help of nozzle sprayer as shown inFig.4. The direct injection technology is used, because it ensures the proper catalytic activity by atomizing the aqueous Ad-Blue solution. It is the spray pattern which increases the catalysis rate. The angle of 45 degree was selected; because it was easier to weld the pipe for direct injection, with respect to complete structure at this angle and at same time achieve the required spray pattern in the direction of flow of flue gases. Due to this solution does not fall on walls of catalytic chamber and get properly mixed with flue gases.

Fig. 4 Direct injection through nozzle sprayer.

3.3 Fabrication

The idea was modeled in CATIA software. The laser cutting of the parts is done as shown below.

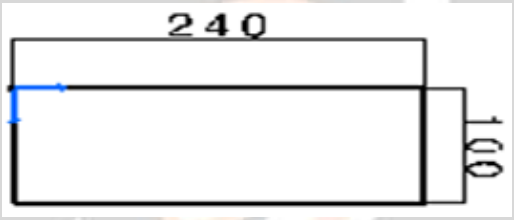

Fig. 5 Rectangular plate.

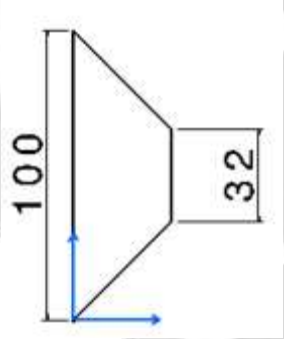

Fig.6.Trapezium

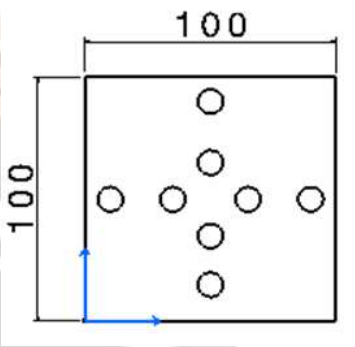

Fig.7. square plate

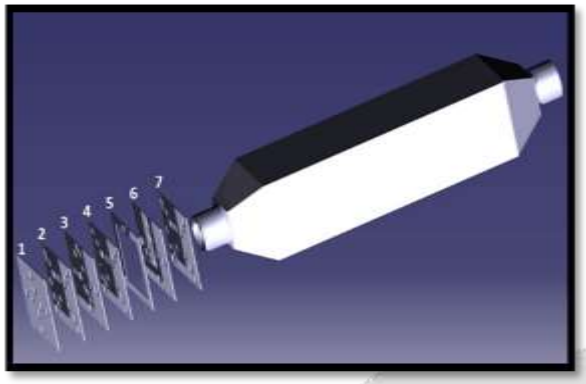

Fig.8.Exploded view of catalytic convertor

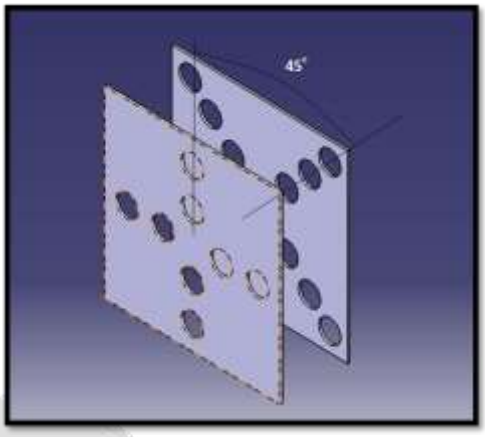

Fig.9. Spiral angle

These were altogether fabricated to obtain CuCA-Con. There are four rectangular plates and eight trapezoidal plates as shown above. Two circular pipes of shown diameter and length is welded on both sides of trapezoidal cage to make inlet and exit of catalytic convertor. The dimension of middle portion of catalytic convertor is as shown in above figure. These all dimensions were assumed and approximated so that it facilitates proper fabrication and at same time maintain the required pressure of gas, take enough time for travel so that catalysis take place and also the main design objective i.e. spiral flow is achieved. The laser cut square plate is having small holes of diameter 10 mm as shown in figure. These holes are arranged in circular fashion on square plate. Total there are 7 plates as shown in figure, which are numbered 1 to 7. Consecutive plate was arranged in such fashion that spiral angle of 45 degree was achieved. Both the values, 10 mm for hole diameter and 45 degree for spiral angle was assumed in order to obtain spiral flow, effective catalytic action and at same time zero back pressure. The distances between consecutive plates were 15 mm which is sufficient to create spiral flow. The thickness of plate is 0.45 mm. The plate number 5 is plate with no holes. It is the annular rectangular plate to hold the activated carbon cloth, with help of adhesive. The dimensions of square plate are as shown in figure. For the process of welding, MIG-Welding was used. By use of fixtures, the CuCA-Con was properly fabricated, so that no leakage of exhaust gas take place before the catalytic activity is done. This was ensured by complete seam weld. The fabrication process success completely depends upon the skill of welder. Only two operations were used 1. Laser cut 2. Welding

The nozzle is given at inlet end, so that sprayed urea goes under the required reaction throughout the length of catalytic convertor. The temperature at inlet end is high and hence this facilitates the faster conversion of urea to ammonia. Further in its journey it get subjected to spiral flow which helps in increasing the surface area and hence better catalysis. Finally, at plate 5 activated carbon cloth is placed so that, it would act as substrate for selective catalytic reduction. Cupric oxide is placed between plate 1,2,3,4 so that due to spiral flow and high pressure of exhaust the powder get into swirling action with gases and get reacted at that temperature.

4. TESTING, RESULTS AND DISCUSSION

The catalytic convertor is coupled to Briggs and Stratton 305 cc, 10 HP lawn mower engine whose emissions are eleven times more than ordinary vehicle. The values are as shown below:

CO: 1.2 g/km; HC: 0.13 g/km; NO_x: 0.06 g/km;

This value complies with Bharat stage IV norms. Hence this is the prime achievement of our research. This ensures that it can be implemented in near future in vehicles

5. CONCLUSIONS

(i) One can fit the Ad Blue injection unit, which is connected to compressor for purpose of injection.

The shaft of turbocharger will drive the shaft of compressor; hence no separate input energy is needed to drive the compressor.

(ii) When injection unit is accompanied with sensors, the injection can be electronically controlled i.e. injection will take place during exhaust stroke only.
(iii) The problem of ammonia slip is the major drawback of selective catalytic reduction technology. The chemiabsorption property of activated carbon cloth helps to absorb ammonia.
This is our major achievement.
(iv) Activated carbon is made from coconut. Hence, it is easily available and cheap.
(v) Direct injection helps in proper atomization of urea and help in faster catalysis.
(vi) Black color cupric powder is easily available and best suited for oxidation of carbon monoxide.
(vii) Only two manufacturing processes, laser cutting and welding are used. This makes the CuCA- Con cheaper.
Hence, three-way catalytic action is achieved at very cheaper rate.

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