CHAPTER 1

1.0 INTRODUCTION

1.1 BACKGROUND

Since the beginning of time, mankind has appreciated the value of air, that invisible thing which sustains life when breathed. Now, with advances in science, much more uses of air have been discovered and its importance increased tenfold. Apart from being breathed, atmospheric air warms the surface of the Earth, is necessary for photosynthesis in plants, compressed air is used to store energy, in braking systems, and in buoyancy devices.

However, air is composed of many different gases mixed in a very precise ratio. The balance of the atmospheric elements in air gives it its special qualities, and if there should be even a slight change in the quantities, events of such magnitude would follow that life itself may be threatened. An increase in the percentage of Oxygen would prove poisonous to animals who breathe it, an increase in the percentage of Carbon (IV) oxide would mean excess heat retained in the atmosphere. Too high inert gas levels would result in air difficult to breathe in. High toxic gas levels would cause living organism's tremendous pain, or kill them off.

Thus, life itself depends on the balance of the atmospheric gases that make up air. Other components of air include: water vapour, the trace gases (ozone, nitrous oxide, methane), aerosols (dust, pollen, spores), and, in some areas, trace amounts of volcanic gases (sulfur dioxide, hydrogen sulfide, carbon monoxide).

1.2 SIGNIFICANCE OF WORK

The Nigerian society has become industry-based. Of the industries currently existent, the petroleum industry is arguably the backbone of the Nigerian economy. However one of the costs of this is bound to be the pollution of the environment due to emission from vehicle using their petroleum fuel. It is therefore necessary for there to less pollution by developing means to handle and convert vehicular emissions into useful resources for mankind. Conversion of vehicular emission in turn, minimizes harm to the environment into which they are discharged and potentially safe enough for reuse. This work explores basically two means of catalytic conversion.

1.3 SCOPE OF WORK

This work involves obtaining data and using theoretical approach and deduction reasoning to compare two catalytically convertors. Conventional catalytic converter and

multi-component catalytic convertors are used in this work to show how harmful vehicular emission can be converted into harmless gases. Limitations of these two methods were also discussed.

1.4 LIMITATION

- The multi component catalytic converter solves a lot of standing problem, but it still has its limitations.
- The converter does not solve the problem of carbon dioxide emissions from motor vehicles and so the current Greenhouse Effect continues to increase, causing more global warming and damage to the upper atmosphere.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 AIR POLLUTION

Air pollution is the introduction of chemicals, particulates or other harmful materials into the Earth's atmosphere, causing damage to living systems and the natural or built environment. Although the subject of air pollution has been very much publicized in recent times, it was not always so. For many years, man was unconcerned by the substances he released arbitrarily into the atmosphere and was unaware of the dangers they would pose when their concentrations in the air exceed certain thresholds. And so, many polluting activities went unchecked. The result was the progressive worsening of air in such areas.

Air pollution, though present before, increased exponentially in the industrial age because of the proliferation of factories and chemical plants in industrial cities. Due to lack of awareness, these factories let off their gaseous wastes without restraint. It was common for these cities to be covered in smog, so common in fact that no one felt threatened by this man-caused mixture of smoke and fog and went about their daily activities whenever it occurred. This went on until the Great Smog of '52 rolled over

London, leaving over 12,000 deaths and 100,000 more illness casualties in its wake, and man learned the dangers inherent in air pollution.

Since then, restrictions have been placed on gaseous and particulate emissions by national environmental protection agencies. In Nigeria, the Federal Environmental Protection Agency (FEPA) monitors such regulations. However, air quality in the country is still very low. The 2014 EPI (Environmental Performance Index) rates Nigeria 123rd out of 134 countries with respect to air quality, giving her a score of 72.7 out of 100.

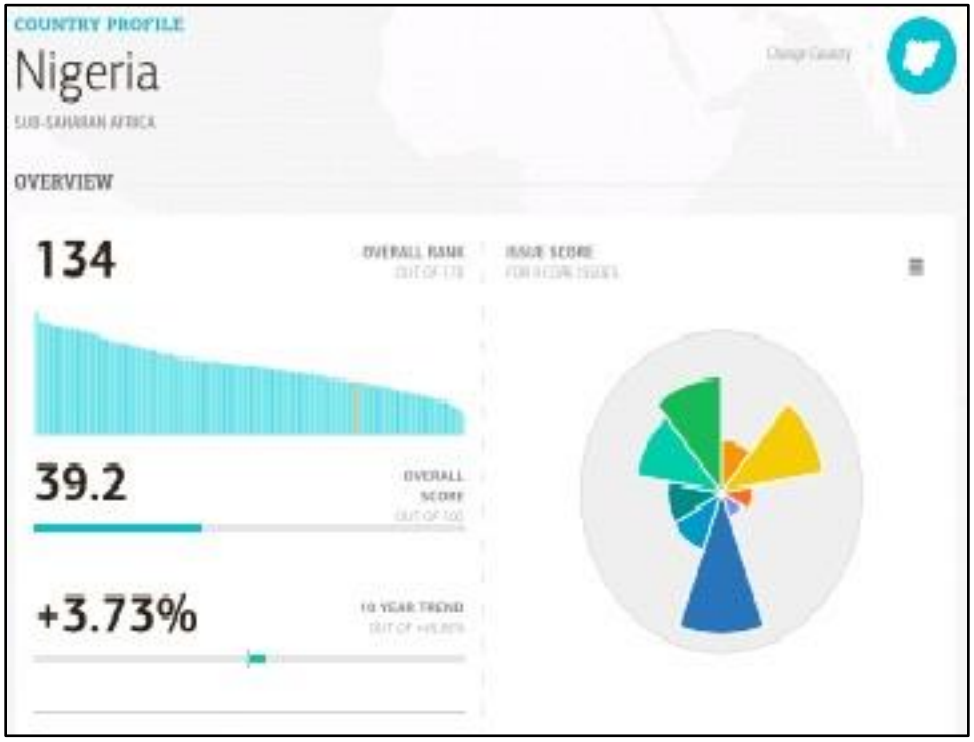


FIGURE 2.1 -NIGERIA'S 2014 EPI RATING

2.2 CHEMICAL ENGINEERING AND AIR POLLUTION

Since its inception, the field of chemical engineering has been wrongfully vilified as the perpetrator of polluting activities. This is not true, because the problem of air pollution was present even before Chemical Engineering's inception in 1887. However, as most pollutions are results of chemical processes, the Chemical Engineer has a greater role to play in battling them, because his broad training makes it possible to harness the basic principles of Chemical, physical, and even biological conversions to reduce the volume and toxicity of existing pollutions, and to design or redesign processes inherently less polluting than their historical counterparts. (AIChE, 2009)

2.3 SOURCES OF AIR POLLUTION

Air pollution stems from many sources, both natural and anthropogenic. Some of the natural sources are:

I. Volcanic ash, containing SO_2 and CO,

II. Decomposition of organic matter,

III. Dust

Anthropogenic sources are:

I. Vehicular Emissions (Transport air pollution)

II. Natural gas flaring

III. Industrial waste solid disposal/ Factory emissions

IV. Forest fire agricultural burning

V. Solid waste decomposition.

The sources, their content, and their relative contribution to the overall air pollution are shown in the table below.

	Source	CO	SP	SO_2	HC	NO_2	Total
A	Transport	3.5	0.07	0.045	0.039	0.455	4.415
B	Fuel combustion (power heating)	0.05	0.07	0.95	0.01	0.53	1.665
C	Industrial process solid waste disposal	0.029	0.165	0.19	0.54	0.035	1.24
D	Forest fire agricultural burning	0.31	0.045	0	0.12	0.01	0.485
Total		4.27	0.39	1.185	1.09	1.035	7.97

Table 2.1 –Source and content of pollutant

2.4 TRANSPORT POLLUTION

Transport pollution is the pollution caused by the incomplete combustion of fuel in the internal combustion engines of motor vehicles. It is listed as the highest source of air pollution in the world.

When gasoline or diesel burns in the internal combustion engine of a vehicle, the hydrocarbons are expected to react to form Carbon (IV) oxide and water vapour.

$$C_nH_m + (m/4+n)\ O_2 \rightarrow nCO_2 + (m/2)\ H_2O$$

However, due to lack of sufficient oxygen in the engine, some of the hydrocarbons go unburned, and CO is formed instead of CO_2. In addition to this, Nitrogen in the internal air of the engine is forced to react with oxygen in the heat, forming nitrogen oxides (NO_x) which are harmful to the environment. Carbon black (soot) is also produced as particulate. The combination of these four pollutants and the immense number of people who have grown to rely on road vehicles gives rise to a level of mass air pollution impossible to control once it leaves the vehicles.

Various methods have been tried to reduce these emissions, but most of the affect the vehicles power so much that they are considered non-pragmatic. Fortunately, some of these methods do work, and one of them, the Catalytic Converter, is discussed fully in the next section.

2.5 THE CONVENTIONAL CATALYTIC CONVERTER

FIGURE 2.2 – EXTERNAL VIEW OF A CATALYTIC CONVERTER

A catalytic converter is a device that converts the toxic mixture of gases that constitute a vehicle's exhaust stream to a less toxic mixture by catalyzing a redox reaction. Thus, the pollutants are converted even before they leave the tailpipe of the vehicle.

The conventional catalytic converter is made up of an outer heat shield, a shell which holds its attachments to the underside of the vehicle, the washcoat, and inside, held in place by hear resistant materials, a porous ceramic brick called a monolith, made of a magnesium oxide-alumina-silica compound called cordierite, and coated with precious metals such as Palladium, Rhodium, and Platinum. As seen above, the converter is found before the tailpipe of a vehicle and opens at both ends for the entrance and exit of the exhaust stream. At the entrance, the exhaust stream is a mixture of CO, NO_x, unburned hydrocarbons, and particulate matter, but when it exits, it has become a mixture of CO_2, water vapour, and Nitrogen gas only.

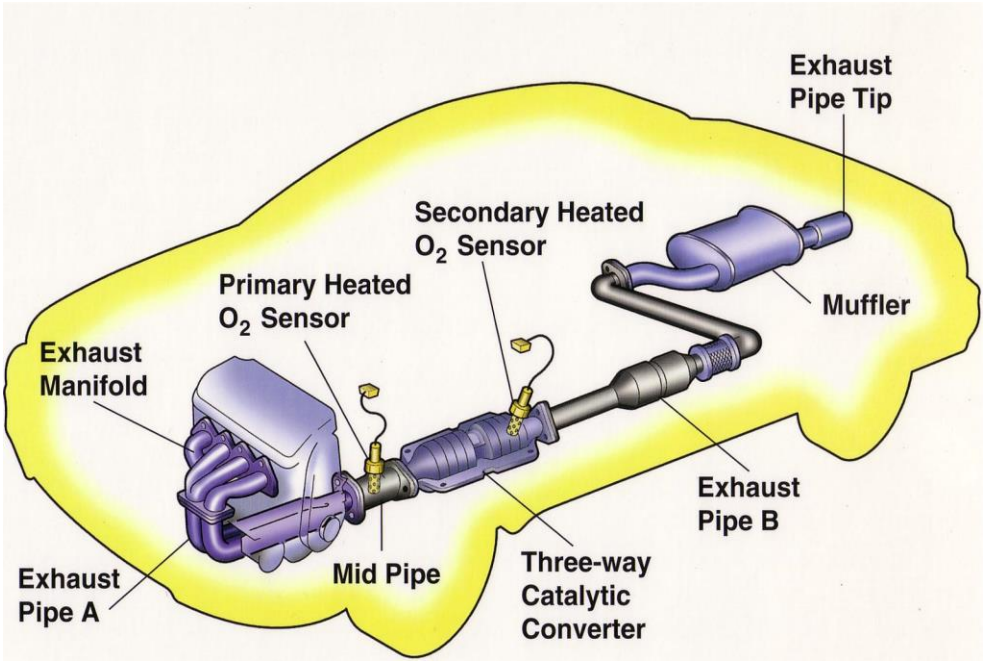


FIGURE 2.3 –THE POSITION OF A CATALYTIC CONVERTER IN A VEHICLE

2.6 HOW IT WORKS

Basically, a catalytic converter provides excess oxygen for reaction with the unburned hydrocarbons and Carbon monoxide (CO) in the presence of the precious metals catalyst and at a high temperature of about $300^{o}C$ to $750^{o}C$, while also reducing the nitrogen oxides (NO_x). When the hot exhaust gas enters the catalyst, it is brought into contact with the catalyst covered cordierite and gaseous oxygen trapped in the porous brick. At high temperatures, the unburned hydrocarbons are forced to react with Oxygen before it leaves the brick.

$$C_nH_{2n+2} + ((3n+1)/2)O_2 \rightarrow nCO_2 + (n+1)H_2O$$

The carbon monoxide is oxidized to carbon dioxide,

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

Carbon black particles are at first trapped in the brick, and then slowly oxidized to CO_2.

$$C + O_2 \rightarrow CO_2$$

And the NO_x is reduced to Nitrogen and Oxygen.

$$2NO_x \rightarrow N_2 + xO_2$$

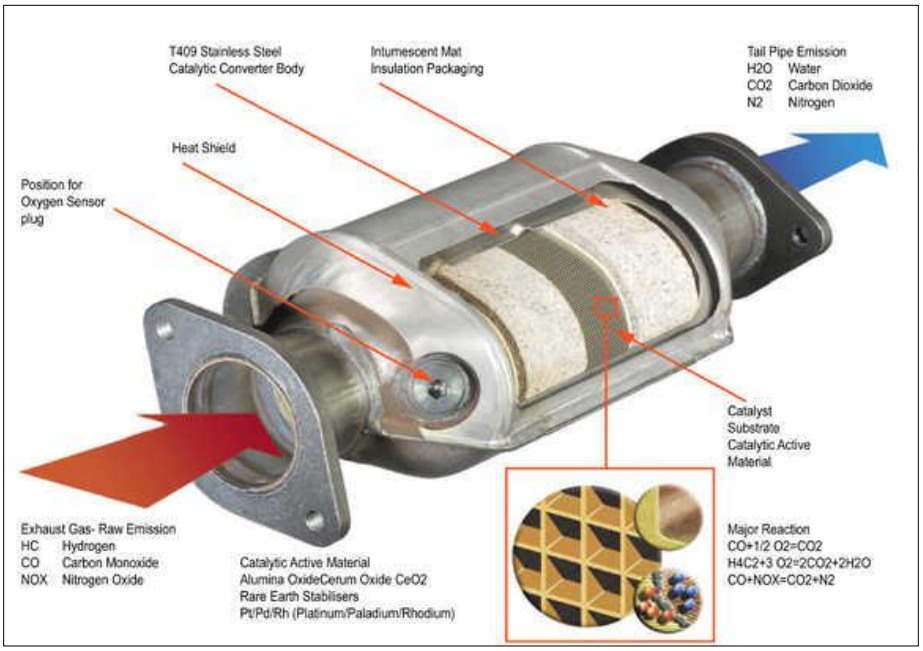


FIGURE 2.4 –CROSS SECTION OF A CATALYTIC CONVERTER

2.7 PROBLEMS WITH THE CONVENTIONAL CATALYTIC CONVERTER

Although the conventional catalytic converter solved most of the emission problems, it has some limitations which have greatly affected its performance.

2.7.1 INCOMPLETE NO_X REDUCTION

NO_X is not completely reduced as it's supposed to be especially in lean burn engines, due to the fact that the oxygen present is in orders-of-magnitude more than the NO_X, and therefore, the relatively small amount of NO_X molecules have to fight for reaction partners and catalytic sites. This problem is commonly called the lean-NO_X problem.

2.7.2 UNWANTED REACTIONS

Unwanted reactions can occur in the 3-way catalyst, such as the formation of odoriferous H_2S and NH_3, though this is now rare due to the use of Nickel and/or Manganese in the washcoat.

2.7.3 WARM-UP PERIOD

Vehicles emit most of their pollution during the first five minutes of engine operation before the catalytic converter has warmed up enough to be active.

2.7.4 ESCAPE OF PARTICLES

Because the particulates are delayed in being oxidized, most of them end up escaping the cordierite brick before the reaction can take place.

2.7.5 EASY REMOVAL

Due to the external location of the converter, it is very easy to remove. Thus, motorists looking for an increase in their engine's horsepower can easily uninstall it from the exhaust. Also, thieves poaching for spare car parts or for the precious metals used in it can easily saw it off, causing damage to other components of the car.

CHAPTER 3

3.0 METHODOLOGY

3.1 THE MULTI-COMPONENT CATALYTIC CONVERTER

To solve the problems encountered by the conventional catalytic converter, a new type of converter called the multi-component catalytic converter has been developed. Unlike the former, the multi-component converter passes the exhaust gas through a 3-step process that ensures complete conversion of the pollutants to harmless gases. Because of this, the multi-component catalytic converter is a long tube incorporated into the vehicle's exhaust tail pipe itself, which, considering the easy-removal problem of the conventional catalytic converter is an added advantage. Also, as shown in the

next section, a brand new system of NO_X removal is employed, successfully ending the lean-NO_X problem and a whole compartment is dedicated to the oxidation of carbon black particles, enabling its complete conversion.

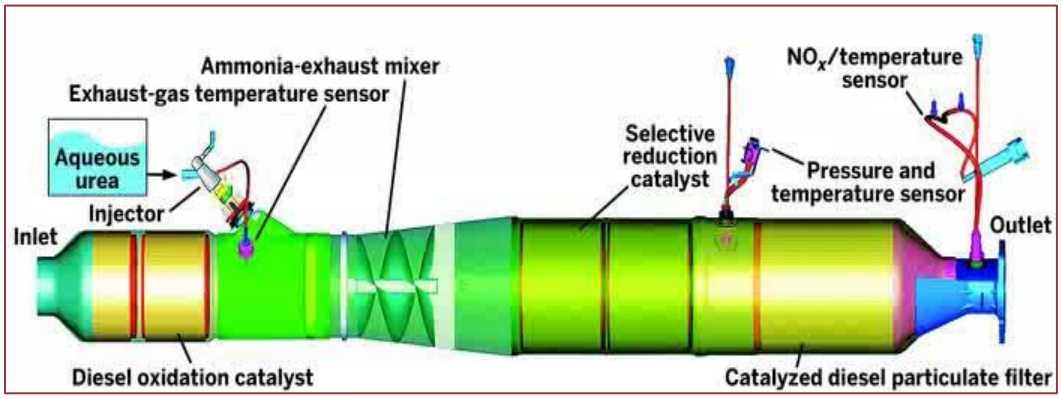
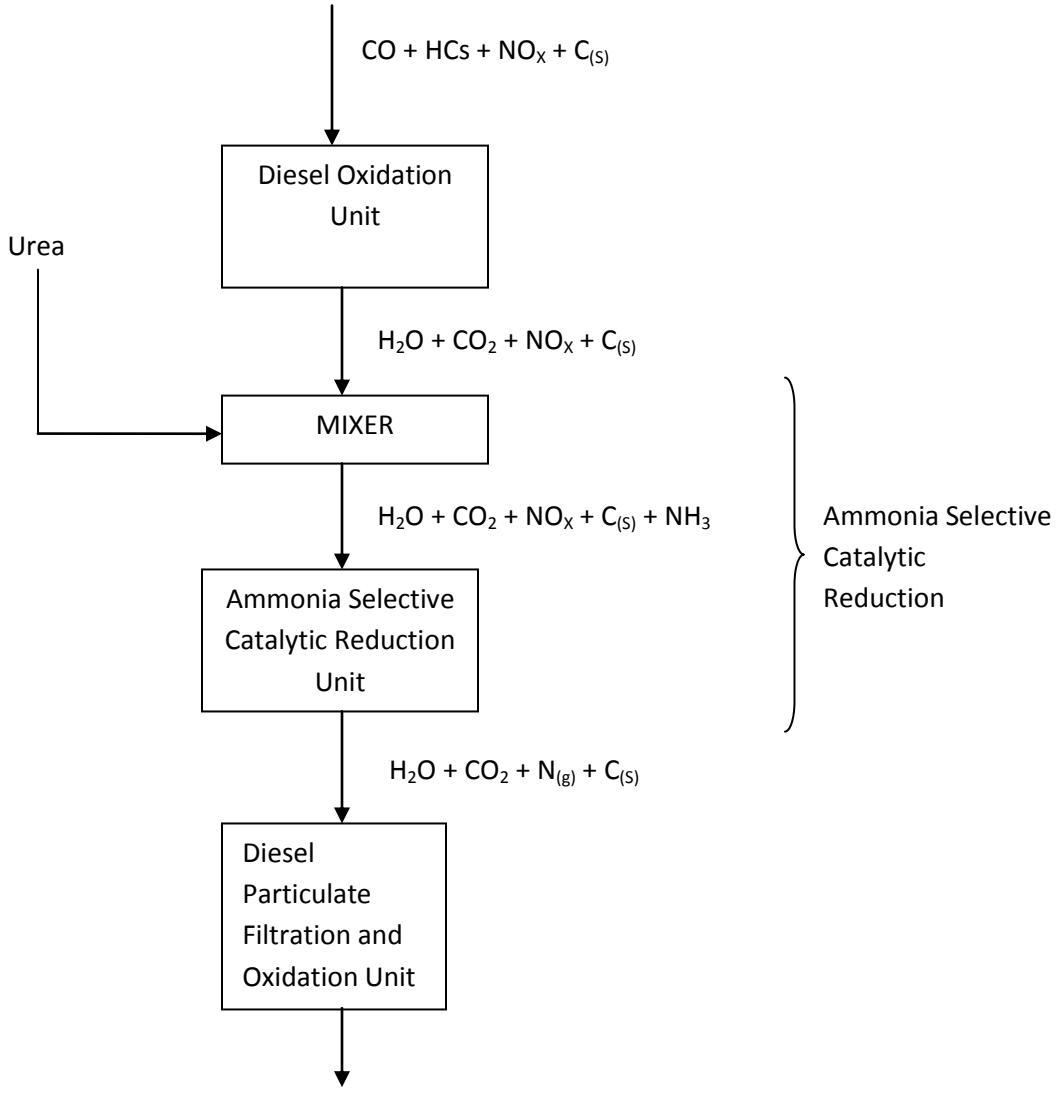


FIGURE 3.1 –THE MULTI-COMPONENT CATALYTIC CONVERTER

3.2 THE CATALYTIC PROCESSES

As mentioned above, the multi-component converter passes the exhaust gas through a 3-step process, the first dedicated to oxidizing carbon monoxide (CO) and unburned hydrocarbons, the second to reducing NO_X completely, and the third to oxidizing carbon black or soot to carbon (IV) oxide. Apart from this breakdown into different processing units and the use of a different method of reducing NO_X, the multi-component catalytic converter is very similar to the conventional catalytic converter. As it still uses catalyst coated cordierite bricks to catalyze the reactions.

Another major difference is the multi-component converter's reliance on sensors, especially during the NO_X reduction process, and its use of zeolites in addition to different catalysts for each section. The size of the cordierite bricks also vary depending on application and position in the process flow sequence. In the order of the sequence, the converter segments are: Diesel oxidation, Ammonia selective catalytic reduction (SCR), and Diesel particulate filtration and oxidation.



$H_2O + CO_2 + N_{(g)}$

Figure 3.2 - Schematic description of Diesel Particulate Filtration and Oxidation Unit

3.2.1 DIESEL OXIDATION

The diesel oxidation reactor works in exactly the same way as the conventional catalytic converter. The cordierite brick is coated with Palladium or Platinum, and carbon monoxide (CO) and unburned hydrocarbons reacts with oxygen in it presence to form CO_2 and Water vapour. However, the cordierite brick is more porous (i.e. it contains larger pores) than the conventional catalytic converter. This is to enable the free passage of carbon black particles as they are not to be oxidized at this stage. Still, if any should be trapped in the brick, it would be oxidized without much delay due to the relatively small amount present.

$$C_nH_{2n+2} + (\frac{(3n+1)}{2})\ O_2 \rightarrow nCO_2 + (n+1)\ H_2O$$

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

3.2.2 AMMONIA SELECTIVE CATALYTIC REDUCTION

The ammonia SCR section is divided into two processes: the mixing, and the catalytic reduction. The stream leaving the Diesel Oxidation unit is joined with a urea stream and sent into a mixer where the two streams are mixed effectively and as much NO_X comes into contact with Ammonia as possible.

The mixed stream is then sent into the SCR unit where the cordierite bricks are coated with Copper Chabazite, an ion-treated zeolite. The Cu-Chabazite catalyzes the reaction of Ammonia and NO_X to form Nitrogen and Water:

$$NO_X + NH_3 \rightarrow N_{2(g)} + H_2O$$

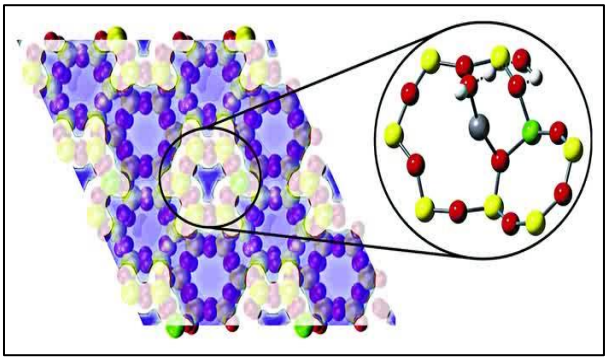


FIGURE 3.3 –STRUCTURE OF COPPER CHABAZITE

Copper Chabazite is a stable two-fold compound with coordinated bonding arrangement for partially hydrated Copper. In the diagram, Cu is gray, Si is yellow, Al is green, O is red, and H is white.

Note that the urea solution in this section is a consumable that must be replenished periodically, just like the vehicle's oil.

3.2.3 DIESEL PARTICULATE FILTRATION AND OXIDATION

This section, just like the first uses the same principles as the conventional converter. However it is expected that by this point in the process, the only pollutant left is the particulate carbon black or soot. This gives the Carbon black plenty of room for oxidation as there is no other compound competing for the oxygen. The cordierite brick here is not as porous as that of the conventional catalytic converter to trap the particles even longer and allow for complete conversion. It is recommended that the brick is even larger than the rest so there's no chance of any unreacted soot passing through.

Also, if by any chance some CO has escaped the Diesel Oxidation unit, it is oxidized in the Diesel Particulate Filtration and Oxidation Unit.

CHAPTER 4

4.0 RESULTS AND FINDINGS

4.1 ADVANTAGES

The multi-component catalytic converter solves most of the problems encountered by the conventional converter.

4.1.1 COMPLETE REACTIONS

All reactions are completed and no pollutant is left since the three sections pay specific attention to each of them. Thus, the lean-NO_X problem is also solved, as is the case of escaping particulates.

4.1.2 NO WARM-UP PERIOD REQUIRED

The warm-up period problem is also solved, as the zeolite layer on the cordierite brick absorbs the cold gases till the catalytic converter is sufficiently heated up. This was not possible in the conventional converter because of the small size of cordierite used.

4.1.3 NOT EASILY REMOVABLE

Because of its size and the fact that it is incorporated into the tailpipe, the multi-component catalytic converter cannot be easily removed. The effort involved is enough to ward away potential thieves and incorrigible motorists.

4.2 LIMITATIONS

The multi component catalytic converter solves a lot of standing problem, but it still has its limitations.

4.2.1 CO_2 EMISSIONS

The converter does not solve the problem of carbon dioxide emissions from motor vehicles and so the current Greenhouse Effect continues to increase, causing more global warming and damage to the upper atmosphere.

4.2.2 NO SMALL SIZE

As of present, this converter can be used only for medium and heavy duty trucks due to its size. Smaller vehicles are still stuck with the conventional catalytic converter.

4.2.3 COST

The materials used as catalysts are expensive and not as easily acquirable as our everyday metals.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In conclusion, the multi-component catalytic converter is much better than the conventional converter in preventing vehicular emissions air pollution, even considering its limitations. The advantages outweigh the disadvantages by a very high value.

5.2 RECOMMENDATION

As a country where there is a lot of use of both medium and heavy duty trucks, the government should see to it that those used are installed with this type of catalytic converter as this would very much help to reduce the amount of smog and pollution we see in our cities and highways. In the meantime, engineers should work to make a cheaper but working multi-component catalytic converter for smaller vehicles as these make up the bulk of road transportation users.

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