Catalytic Converters in Automobiles for Pollution Control

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Introduction

In the last few years, the topic of pollution control has assumed prime importance. Pollution from automobiles, today, has escalated to reach alarming levels. In an effort to control vehicular pollution, a major step has been taken. April 1st 1995 signalled the launch of UNLEADED PETROL and new cars in the metro cities of Delhi, Bombay, Calcutta and Madras would come fitted with an emission control device- THE CATALYTIC CONVERTER.

Lead which is added to automobile fuel as an anti-knocking agent prevented the use of catalytic converters as even a small amount of lead in exhaust fumes would destroy the catalyst. Unleaded petrol, as the name implies, contains no lead and hence allows the use of these devices to control emission. This device converts the harmful carbon monoxide and hydrocarbons in exhaust fumes to harmless carbon di oxide and water. To prevent damage to catalyst due to accidental filling of leaded petrol, cars with catalytic converters will have narrower fuel fill pipes which can accommodate only the narrow nozzles of unleaded petrol pumps. So while normal petrol is still available, hopefully, unleaded petrol will go a long way in emission control from vehicles and provide a much needed breath of fresh air on our roads.

Catalytic Converter and Its Need

A catalytic converter is a part of the exhaust system fitted between the exhaust manifold and the silencer. The principal function of this device is to convert the harmful products formed as a result of combustion of automobile fuels into harmless products. We know that combustion of automobile fuels, viz, petrol and diesel, leads to the formation of a number of products like CO, CO_2, SO_2, nitrogen oxides(NO_x) (NO_x is an oxide of nitrogen where x can take values 1, 2, 3, etc), hydrocarbons (HC), polycyclic aromatic aromatic compounds (PAH) and water. Except CO_2 and water, all the products named above are pollutants and hence, there exists the need to control their emission (refer table 1). A catalytic converter converts all these pollutants into harmless components. In fact, it is heartening to know that the use of a catalytic converter can reduce automobile emissions by as much as 90% .

Table 1: Permissible pollutant emission levels (g / kW - hr)

POLLUTANT	1992-96 EURO 1* (EXISTING)	1996-2000 EURO 2 (NEW REGULATIONS)	1992-96 INDIAN
1 NO_x	8.0	7.0	17.0
2 CO	4.5	4.0	14.0
3 HC	1.1	1.1	3.5
PARTICULATE	0.61	0.15	

* EURO = Regulations in Europe.

Products of Combustion of Automobile Fuels

Petrol engines are spark ignition engines and diesel engines are combustion ignition engines. These engines give rise to a distinct composition of polluting products.

Petrol Engines : A petrol engine is operated by using a mixture of air and petrol. During most part of its operation, the air-fuel ratio is low (i.e. rich mixture is used). Rich mixture implies a high CO and unburnt hydrocarbon (UBHC) content in exhaust. But the concentration of NOx is low due to low compression ratio.

Diesel Engines : In diesel engines, diesel is sprayed into the engine cylinder after compression of air. During most part of its operation cycle, lean mixture is used (high-air fuel ratio). Lean mixture implies high oxygen content and so the concentration of CO and UBHC is low. Also, the compression ratio in diesel engines is high. So the peak temperature is high and hence NOx content is also high. The fine diesel droplets may not burn completely and the unburnt fuel can undergo thermal cracking due to high temperature in engine to form particulate matter called diesel soot.

So the exhaust treatment must be based mainly on oxidation in the case of petrol engines (CO and UBHC) and on reduction in the case of diesel engines (NO_x). Diesel engines in addition may require particulate filters. But some Diesel engines (like those designed by TELCO) are such that NO_x is controlled and hence the treatment is based on oxidation.

Principle of A Catalytic Converter

As stated above, the catalytic converter basically works by catalysing the oxidation of combustion products. The catalyst must be chosen such that the CO and hydrocarbons are oxidised but not the SO_2 and NO_x. (Fig.1 illustrates the principle.) The following oxidation reactions are involved -

$$CO + \tfrac{1}{2} O_2 \longrightarrow CO_2$$

$$HC + O_2 \longrightarrow CO_2 + H_2O$$

$$PAH^1 + O_2 \longrightarrow CO_2 + H_2O$$

$$ALDEHYDES + O_2 \longrightarrow CO_2 + H_2O$$

The SO_2 in the exhaust fumes is converted to sulphate ions(SO_4^{2-}) which then reacts with water. The NO_x is reduced to N_2 and O_2.

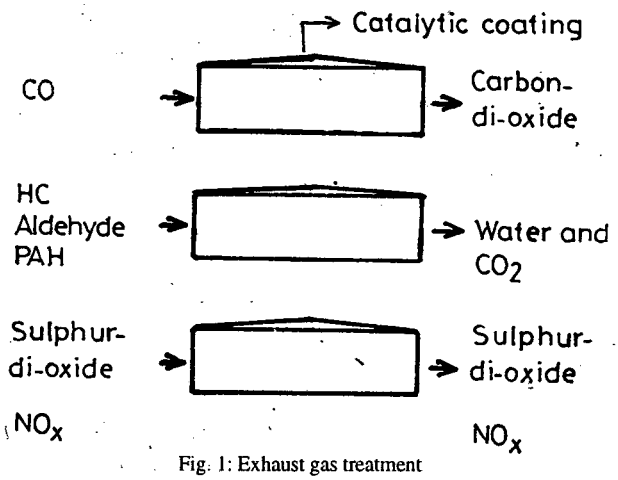

Fig. 1: Exhaust gas treatment

Design and construction of a catalytic converter

The design of a catalytic converter is limited by a few factors. The factors affecting the design of a catalytic converter are -

1. Lead Content : In India, lead is added to fuels as an anti-knocking agent in the form of lead tetra ethyl. This is not the case in foreign countries where the knocking tendency is much less compared to India because Indian vehicles operate at a higher compression ratio (8.5) as compared to 5-6 in foreign countries. It is found that even traces of lead in exhaust fumes destroy the catalytic activity of the catalyst. So a catalytic converter can be used with unleaded petrol only.

2. Temperature : Very high temperature destroys catalytic activity, which is low at low temperatures. So an optimum temperature is required for catalytic efficiency. Catalytic activity is maximum at around 700°C.

Structure of A Catalytic Converter

The catalytic converter consists of an active coating of catalyst on a suitable substrate. The substrate may be made of ceramic or metal. The catalysts used are generally the transition metal elements like platinum, palladium, rhodium or a suitable composition of all these. Sometimes base metal oxides are also used. The catalyst is impregnated on either silica or alumina (these compounds are called washcoats). The washcoat is applied on the substrate. Sometimes promoters are also used to increase the catalytic activity of the catalyst. The substrate is designed to have maximum surface area. A typical catalytic converter exposes an area equal to, roughly, that of a football field. The entire arrangement is housed in a metallic 'can'. This simple arrangement works as a catalytic converter. Fig.2 shows a section of the catalytic converter.

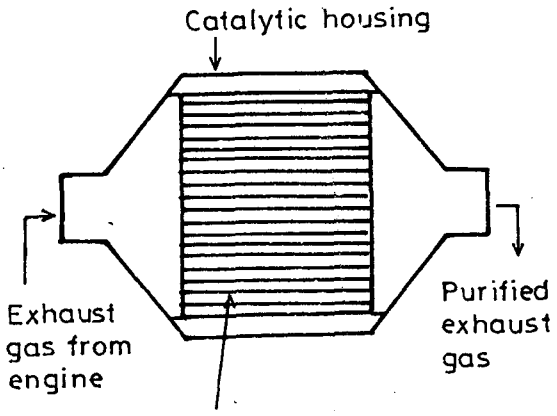

Fig.2 A section of the catalytic converter.

Design Parameters

Catalyst : The catalyst should possess the following properties for efficient working -

1. Specific activity/ Conversion efficiency

This is the activity per unit area of the catalyst.The specific activity must be high in order to reduce the amount of catalyst used.

2. Temperature Sensitiveness: The catalyst should allow a certain range of temperature for maximum efficiency. It is found that catalytic efficiency is maximum at around 700°C. But ideally, the catalyst in a catalytic converter should maintain its efficiency upto ± 200°C from the above value.

3. Deactivation Period : Over a period of time, the catalytic activity reduces due to deposition of particles on the catalytic surface and other factors. Therefore, the deactivation period of the catalyst used must be sufficiently long.

It is found that the transition metals have the above mentioned properties and hence are preferred over base metal oxides. As mentioned earlier, sometimes a mixture of transition elements is used as catalyst. The composition decides whether the catalyst helps in oxidation or reduction or both. For CO and UBHC oxidation, platinum or palladium is preferred and for NOx reduction, rhodium is preferred. As an example a DEGUSSA (a German company which manufactures catalytic converters) three way catalyst system uses 2-5 gram of metal (a 7:3 ratio of Pt and Rh). The three way catalyst system is described elsewhere in this paper. Though noble metals are advantageous over basic metal oxides, they have a disadvantage- they sinter at high temperature (around 900°C)

Substrate

1.Surface Area - Volume ratio : For high catalytic efficiency, the catalyst should have maximum surface area even while having low volume, that is, the substrate must

have a high surface area - volume ratio.

2. **Porosity** : The substrate must have high porosity to minimise pressure drop across the catalytic converter.The pressure drop must be lower than 100 m-bar (a tenth of the atmospheric pressure).

The substrate may be made of metal or ceramic. There is no reason for one to be preferred over the other as each has its own advantages and limitations.

Advantages of ceramic substrate

1. Withstands higher temperature than metal (upto 1400°C)
2. More porous and can be designed for higher surface area/volume ratio easily.
3. It has longer life than metal substrate.

Advantage of metal substrate

The advantage of metal substrate is that the time taken to reach the optimum temperature (700°C) is less.

Washcoat

It is applied over the substrate and then the catalyst is deposited on it. The washcoat should be inert to prevent sintering. Silica and alumina are widely used as washcoats.

Types of Catalytic Converters

The support material or substrate determines the types of catalytic converters. At present there are two designs. They are monolith type and spherical pellet type.

Monolith type catalytic converter Or Monolith Configuration

It consists of a single unit with parallel passages (30-60 per cm^2) through which exhaust gases flow in one direction. The substrate may be a metal or a honey-comb structure of ceramic. The catalyst is impregnated on alumina washcoat and an approximately 0.2 mm thick layer is applied on the substrate. The passage

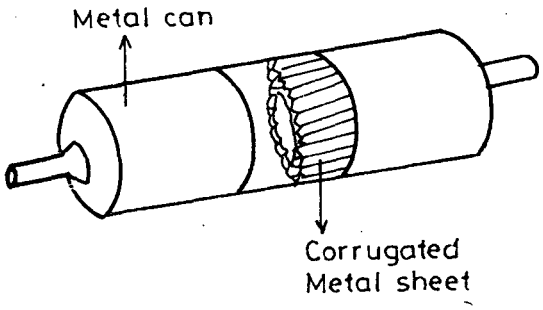

Fig. 3 : Catalytic Converter with metal substrate (monolith configuration)

ways are generally square in cross-section (because square cross section has more surface area than circular cross-section for same volume). The flow of gases is laminar and hence the mass transfer is less. Fig.3 shows a monolith type of catalytic converter with metal substrate.

Pellet type catalytic converter Or Pellet configuration

In this case, the substrate consists of alumina beads. It exposes larger surface area than monolith configuration. Pellets must have abrasion resistance as the flow of exhaust fumes is turbulent. Hence greater mass transfer takes place. This type of catalytic converter is widely used in the U.S.A., especially in heavy vehicles. A catalytic converter with pellet configuration is shown in Fig.4

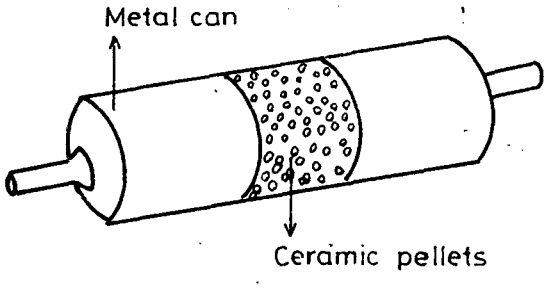

Fig. 4 : Pellet type of catalytic converter.

6.0 Three Way Catalytic System

The three way catalytic system (Fig.5)

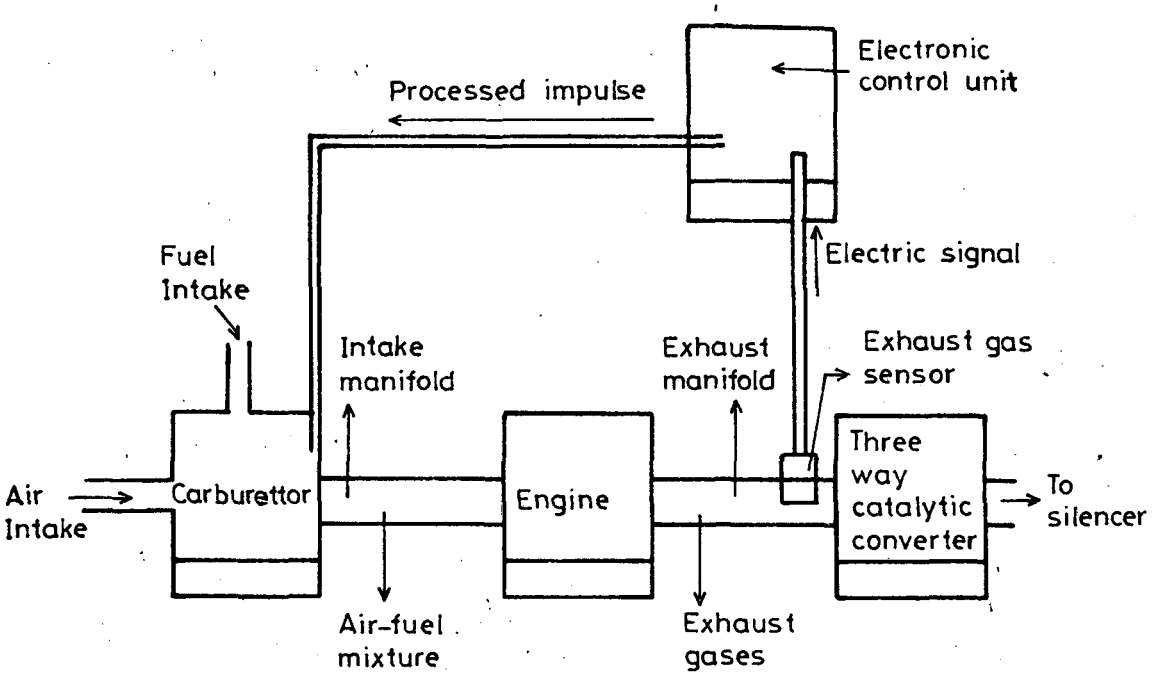

Fig. 5 : Schematic representation of a three way catalytic converter.

is a complete emission control system which consists of the following :

1. **A Converter** : It simultaneously oxidises CO and UBHC, and reduces NOx.

2. **An Exhaust gas sensor or Lambda sensor** : The exhaust gas sensor indicates the air-fuel ratio (rich or lean). It is placed in the exhaust stream and is made up of a platinum coated zirconium element, which has a metal housing to prevent abrasion by exhaust gases. The Zirconium-Platinum combination acts as an electrochemical cell when heated. From the voltage of the cell, the composition of mixture is found. If the mixture is rich, the temperature attained in the cylinder is also high. Hence the cell has high voltage. Similarly, when the mixture is lean, the temperature attained is low and hence the voltage of the cell is also low. The use of this sensor is essential because the catalytic converter functions efficiently only at a particular air-fuel ratio (Fig.6)

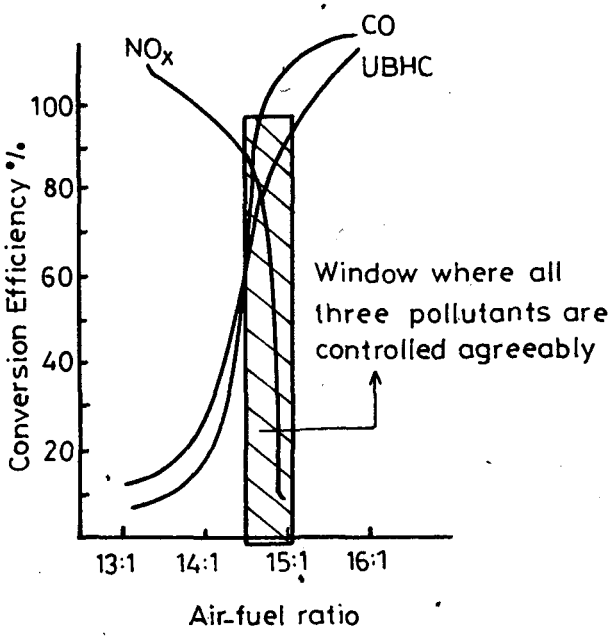

Fig. 6 : Characteristic Conversion efficiency of a three way catalyst

Electronic Control Unit (ECU)

It processes signals from the EGS and accordingly sends signals to the carburettor.

Closed loop carburettor

Based on the signals received from the ECU, it controls the air - fuel ratio to the desired level.

Applications and advantages of catalytic converters

Applications

Apart from their use in automobiles like cars,jeeps, heavy vehicles, etc., it is being planned to use this device in stationary engines like construction machines and generators and in special purpose vehicles like fork-lift truck, tractors, etc.

Advantages

It oxisises CO and UBHC and reduces exhaust gas odour and particulate emission like diesel soot in diesel engines. Emission of aldehyde and polycyclic aromatic hydrocarbons is reduced.

Limitations and possible solutions

Life

As mentioned, over a period of time, the catalyst gets deactivated. At present the catalytic life is long enough for the vehicle to run about 80,000 kilometres, but effort is on to double this deactivation period.

Availability of unleaded petrol in India

At present, unleaded petrol is available only in selected outlets in four metro cities. So the vehicles in these cities are restricted from going out, as unleaded petrol is not available outside these metros. Hence it requires carrying large amounts offuel, which is difficult and also dangerous. One suggestion is to by-pass the converter. But then, in spite of having a catalytic converter, it cannot be put to use. Hence, the solution is to make unleaded petrol available throughout the country.

Cost

At present, a catalytic converter costs around twenty thousand rupees. This is so high because we are currently importing it. Hence, there is a need to make the production indigenous. It is encouraging that a few Indian companies have already started work in this direction. Hence its cost will be brought down soon. Also, the cost is higher due to the use of noble metals like Pt, Pd, Rh, etc. Research can be done to eliminate the use of these expensive metals and to find economic alternatives, even while maintaining catalytic efficiency. The ceramic extrusion method used for making substrates is also expensive. Hence alternate technology is needed for the same.

Engine Design

As mentioned earlier, 'Indian made' vehicles operate at a high compression ratio and so the temperature produced in the cylinder is also high. Hence, the knocking tendencies are more in Indian vehicles. To avoid knocking, lead is added to petrol. Now, with catalytic converters, leaded petrol cannot be used. But the same engines are used with unleaded petrol and hence knocking can occur. To avoid this, it is necessary to modify the engines to work at lower compression ratios.

Conclusion

Contribution to air pollution comes from two major sources, viz, automobiles and industries. A study in Bombay has shown that nearly 70% of the toxic gases are spewn out by automobiles and only the remaining 30% are from industries. It has already been mentioned that, that a catalytic converter can reduce emission by upto 90%. So is it not logical to think that reduction in automobile emission can control air pollution as a whole? Catalytic converters have already been made mandatory in vehicles manufactured after April 1, 1995 in the metros. With this sort of legal enforcement, one hopes that air pollution is controlled considerably and that there is a breath of fresh air everywhere.

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