The Catalytic Converter

By

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Introduction

By-products of the operation of the gasoline engine include carbon monoxide, oxides of nitrogen, and hydrocarbons (unburned fuel compounds), each of which is a pollutant. To control the air pollution resulting from these emissions, governments establish quality standards and perform inspections to insure that standards are met. Standards have become progressively more stringent, and the equipment necessary to meet them has become more complex.

Positive crankcase ventilation was introduced in the United States in 1963, for the purpose of eliminating engine blow-by gas that formerly had been vented to the atmosphere as an emission source. This was achieved by routing the gas, along with crankcase-ventilation air, into the engine intake, where it could be recycled through the cylinders and properly burned. A small valve in the circuit was necessary to maintain the direction of flow.

Various engine modifications that alter emission characteristics have been successfully introduced. These include adjusted carburettor air-fuel ratios, lowered compression ratios; retarded spark timing, reduced combustion chamber surface-to-volume ratios, and closer production tolerances. To improve drivability of some arrangements, preheated air from a heat exchanger on the exhaust manifold is ducted to the air cleaner.

Sealing the gas tank and venting the tank through a liquid-vapour separator into a canister containing activated charcoal have controlled the undesired evaporation of gasoline hydrocarbons into the air. During engine operation these vapours are desorbed and burned in the engine.

Among emission-control devices developed in the 1970s were catalytic converters (devices to promote combustion of unburned hydrocarbons in the exhaust), exhaust-gas-re-circulation systems, manifold reactors, fuel injection, unitised ignition elements, and stratified charge combustion engines.

A catalytic converter consists of an insulated chamber containing a porous bed, or substrate, coated with catalytic material through which hot exhaust gas must pass before being discharged into the air. The catalyst is one of a variety of metal oxides, usually platinum or palladium, which are heated by exhaust gas to about 500º C (900º F, 737 K). At this temperature unburned hydrocarbons and carbon monoxide are further oxidized, while oxides of nitrogen are chemically reduced in a second chamber with a different catalyst. Problems with catalysts involve their intolerance for leaded fuels and the need to prevent overheating.

Exhaust-gas re-circulation is a technique to control oxides of nitrogen, which are formed by the chemical reaction of nitrogen and oxygen at high temperatures during combustion. Either reducing the concentrations of these elements or lowering peak cycle temperatures will reduce the amount of nitrogen oxides produced. To achieve this, exhaust gas is piped from the exhaust manifold to the intake manifold. This dilutes the incoming fuel-air mixture and effectively lowers combustion temperature. The amount of re-circulation is a function of throttle position but averages about 2 percent.

Manifold reactors are enlarged, insulated exhaust manifolds into which air is injected and in which exhaust gas continues to burn. The effectiveness of such units depends on the amount of heat generated and the length of time the gas is within the manifold. Stainless steel and ceramic materials are used to provide durability at high operating temperatures (approaching 1,300º C [about 2,300º F and 1537 K]).

Fuel injection, as a replacement for carburetion, is widely employed to reduce exhaust emissions. The precise metering of fuel for each cylinder provides a means of ensuring that the chemically correct air-to-fuel ratio is being burned in the engine. This eliminates cylinder-to-cylinder variations and the tendency of cylinders that are most remote from the carburettor to receive less fuel than is desired. A variety of metering and control systems are commercially available. Timed injection, in which a small quantity of gasoline is squirted into each cylinder or intake-valve port during the intake stroke of the piston, is employed on a number of cars.

In several timed-injection systems, individual pumps at each intake valve are regulated (timed) by a microprocessor that monitors intake vacuum, engine temperature, ambient-air temperature, and throttle position and adjusts the time and duration of injection accordingly.

Another approach is the stratified charge engine, a variation from conventional cylinder combustion. Fuel is injected into a combustion-chamber pocket, and the non-homogeneous, stratified charge is spark-ignited. Operation of the engine is possible at very lean air-to-fuel ratios, thus permitting high thermal efficiency at light engine loads. This provides excellent reductions in exhaust hydrocarbons, carbon monoxide, and oxides of nitrogen. The primary problem with the system is to make it function over a wide range of speeds and loads with good transient response.

The Catalytic Converter

A device incorporated into the exhaust system of an automobile that reduces the amount of pollutants in the automobile's exhaust gases.

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However because of the conversion of carbon monoxide to carbon dioxide it therefore causes an increase in greenhouse gases and in the process of removing toxic gases to less non-toxic gases it causes an increase in the greenhouse effect.

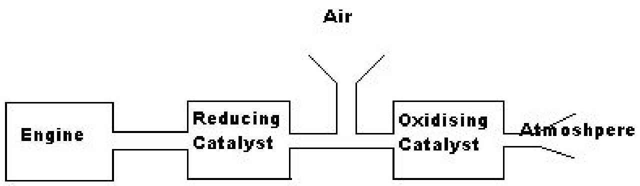
Reactions in converter

$HC + O_2 \rightarrow CO_2 + H_2O$ This reaction is oxidisation of the hydrocarbon.

$2CO + O_2 \rightarrow 2CO_2$ This reaction is oxidisation of Carbon monoxide.

$2NO \rightarrow N_2 + O_2$ This reaction is reduction of Nitrogen oxide.

By using both a reducing and oxidising catalytic converter, we can lower the activation energy for the HC, CO and NO so that they more quickly react to form less noxious products.



The reactions that occur in the catalytic converter are due to a catalyst. The catalyst is in a separate phase to the reactants is said to be heterogeneous, or contact catalyst. Contact catalysts are materials with the capability of adsorbing molecules of gases or liquids onto their surfaces.

Other Products

However due to the conversion of these oxides into dioxides it causes other pollutants to be emitted in the exhaust of the car. Though Nitrogen monoxide (a chemical which attacks the ozone layer and contributes to the formation of photochemical smog) and Carbon monoxide are extremely toxic since these are converted by reduction and oxidation into other gases, the Nitrogen monoxide is turned into harmless Nitrogen and Oxygen gas (N_2 O_2) so there is no problem with the conversion of Nitrogen monoxide but Carbon monoxide gives of a less toxic (to humans) product in the form of **Carbon dioxide (CO_2)** which is absorbed by plants in photosynthesis but this Carbon dioxide is a major cause of the greenhouse effect – where the greater the amount of Carbon dioxide molecules in the atmosphere the warmer the Earth gets. A prime example of what could happen if this type of exhaust conversion is used is the planet Venus; this has a runaway greenhouse effect and has a surface temperature of over 400^{o}C.

Along with these products from the catalytic converter there are other toxic products which are **Sulphur dioxide (SO_2)**, which is the cause of acid rain and **Hydrogen Sulphide (H_2S)** which is a very toxic (poisonous) chemical.

Effect of Temperature

The lowering the temperature causes the reactions of the Hydrocarbons and Carbon monoxide with Oxygen occur more often and would also stop the formation of Nitrogen monoxide from Oxygen and Nitrogen in the engine. This is however hard to do and so complicated cooling systems are applied to get the best performance of the fuel and the conversion of waste products.

Composition of exhaust.

Exhaust Component (%)	Driving Mode			
	Idling	***Cruising***	***Accelerating***	***Decelerating***
Carbon Monoxide	5.2	0.8	5.2	4.2
Hydrocarbons	0.075	0.03	0.04	0.4
Nitrogen monoxide	0.003	0.15	0.3	0.006

So at anyone mode of driving one of the exhausts is being produced faster than the other. On average the cruising mode would be probably the time when the least amount of gases is being produced.

Catalytic converter substrates

A substrate is a substance on which some other substance is absorbed or in which it is absorbed.

Catalytic converters are used to reduce the amounts of nitrogen oxides, carbon monoxide, and un-reacted hydrocarbons in automotive emissions. (Catalytic conversion requires a precisely balanced air-to-fuel ratio, hence the need for oxygen sensors such as those described in ***conductive ceramics: Oxygen sensors*** to aid in feedback control of fuel injection.) In dual-bed converter systems the exhaust gases are first reduced in order to eliminate the oxides of nitrogen; then they are oxidized with added air in order to eliminate carbon monoxide and unburned hydrocarbons. In more advanced three-way converters individual catalysts accomplish reduction of each species simultaneously.

Catalysts are either platinum-group metals or base metals such as chromium, nickel, and copper. Platinum-group metals or noble metals are any of several metallic chemical elements that have outstanding resistance to oxidation, even at high temperatures; the grouping is not strictly defined but usually is considered to include rhenium, ruthenium, rhodium, palladium, silver, osmium, iridium, platinum, and gold. Silver and gold, which with copper are often called the coinage metals, and platinum, iridium, and palladium comprise the so-called precious metals, which are used in jewellery.

In base-metal catalysts the active surfaces are actually ceramic oxides of the metals. Because platinum metals are extremely expensive, they are deposited on ceramic catalyst supports as salts and then reduced to finely divided metal particles.

For efficiency of conversion, extremely large surface areas are required. These are accomplished by ingenious micro-structural engineering of the ceramic support structure. Two types of structure are made pellets and honeycomb monoliths. The pellets are porous beads approximately 3 millimetres ($^1/_8$ inch) in diameter. With a single pellet having up to 10 square millimetres of internal pore surface area, one litre of pellets can have up to 500,000 square metres of support surface. The pellet material is often alumina (aluminium oxide, Al_2O_3). High internal porosity is achieved by carefully burning off the organic additives and by incomplete sintering. Honeycomb monoliths have 1,000 to 2,000 longitudinal pores approximately one millimetre in size separated by thin walls. The material is commonly cordierite, a magnesium aluminosilicate ($Mg_2Al_4Si_5O_{18}$) known for its low thermal expansion. The extruded cordierite structure is coated with a wash of alumina, which in turn supports the platinum catalyst particles. The surface area of the monolith is typically in the range of one square metre; however, this figure must be multiplied many times because of the porosity of the alumina on the surface.

Monolith supports are much more expensive than pellet supports, but they cause a smaller pressure drop in the exhaust system. Both types of catalyst support, because of their inherent friability, are susceptible to vibrational degradation. Containment of the supports is also difficult. A good seal must be achieved and maintained without imposing external stresses on the friable structure.

Conductive ceramics: Oxygen sensors.

Schematic diagram of a zirconia oxygen sensor used to monitor automobile exhaust gases. The sensor, approximately the size of a spark plug, is fitted into the exhaust manifold of an automobile engine. The thimble-shaped zirconia sensor, sandwiched between thin layers of porous platinum, is exposed on its interior to outside air and on its exterior to exhaust gas passing through slits in the sensor shield. The two platinum surfaces serve as electrodes, conducting a voltage across the zirconia that varies according to the difference in oxygen content between the exhaust gas and the outside air.