Environmental Studies
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Catalytic Converters

This Factsheet summarises:

- the environmental impact of the pollutants formed in internal combustion engines
- how catalytic converters reduce the formation of pollutants in internal combustion engines

Why do we need catalytic converters?

Internal combustion engines in cars and lorries burn hydrocarbon fuels. The major constituents of the exhaust gases from the engines are nitrogen from the air, and carbon dioxide and water vapour from combustion of the fuel. However, other substances are also contained in the exhaust gases, including nitrogen oxides, carbon monoxide and unreacted hydrocarbons (Table 1).

Table 1: Pollutants produced in internal combustion engines

Name of pollutant	Formula	How does it form?	Why is it a problem?
Nitrogen oxides	NO, NO_2. Collectively described as NO_x	By reaction of nitrogen and oxygen in the high temperatures of the working engine.	• Dissolve in atmospheric water to form acid rain containing HNO_3 • Contribute to smog
Carbon monoxide	CO	Incomplete combustion of the hydrocarbon fuel	• Highly toxic • Binds to haemoglobin, preventing red blood cells carrying oxygen
Carbon	C	Incomplete combustion of the hydrocarbon fuel	• Particulates and lead to respiratory problems
Unreacted hydrocarbons, such as heptane, octane and their isomers	C_7H_{16}, C_8H_{18}	Hydrocarbons pass through the engine without combustion	• Toxic • Contribute to smog

Nitrogen Oxides

Nitrogen (II) oxide, NO, is formed when nitrogen and oxygen react in the engine $N_2 + O_2 \rightarrow 2NO$. Nitrogen is normally too inert to react with oxygen but the high temperatures (2500-4000°C) and electric spark used to ignite the fuel in the engine provides enough energy to allow nitrogen to react.

On further reaction with oxygen, the NO is oxidised to nitrogen (IV) oxide NO_2 ($2NO + O_2 \rightarrow 2NO_2$).

After release from the engine's exhaust, nitrogen (IV) oxide may react with water and further oxygen to form nitric acid, HNO3, which is one of the acids in acid rain.

$$2NO_2 + 2H_2O + O_2 \rightarrow 2HNO_3.$$

Carbon Monoxide and Carbon

Carbon monoxide is formed by incomplete combustion of the hydrocarbon fuel. Complete combustion of a fuel produces carbon dioxide and water.

But if sufficient oxygen is not present in the engine, then incomplete combustion takes place. This leads to the formation of carbon monoxide.

Incomplete combustion can also produce carbon, which forms particles of soot in the air, another atmospheric pollutant

Unreacted Hydrocarbons

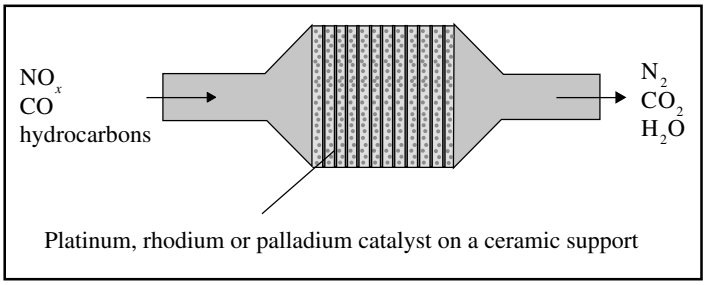
Unreacted hydrocarbons are released when the vapourised fuel passes straight through the engine without combustion, and is released in the exhaust gases. This tends to occur in badly maintained engines.

What is a Catalytic Converter?

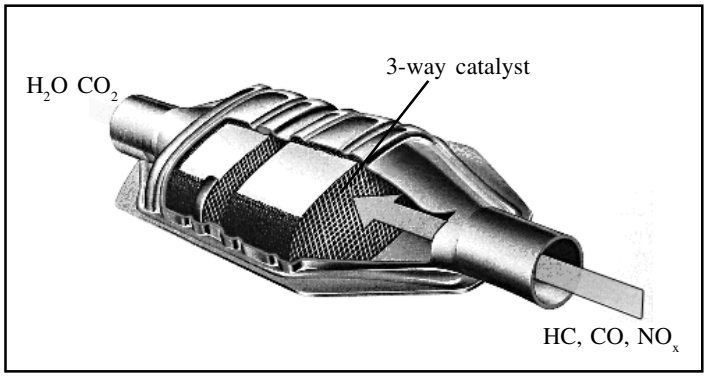
Catalytic converters limit (but do not completely eliminate) emissions of the pollutants described in Table 1.

Catalytic converters take in the exhaust gases from the engine and convert the pollutants into nitrogen, carbon dioxide and water vapour, which are then released with the other waste gases (Fig 1). The catalyst is made of alloys of platinum, rhodium or palladium, supported on a ceramic honeycomb-shaped mesh.

Fig 1. A Catalytic Converter (CAT)

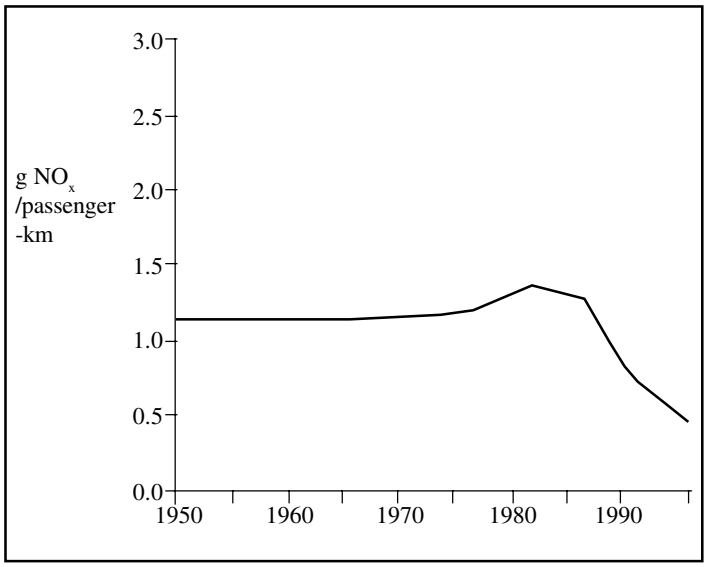


The ceramic support of the catalyst provides a large surface area for the waste gases to be adsorbed onto the heterogeneous catalyst. This maximises contact between the catalyst and the reactant gases, allowing as many particles as possible to react as they pass through. This is essential because the gases pass through at hundreds of kilometres per hour, allowing very little time for reaction to occur.



In Austria, where catalytic converters were made mandatory for passenger cars in the 1980s, the emissions of air pollutants (CO, NOx and NMVOC) from transport have fallen significantly during the past two decades (Fig.3).

Fig 3. NO_x car emissions 1950-2000 in Austria



Are There Any Problems With Catalytic Converters?

The first problem is the cost of the metals used in the catalyst. Platinum, rhodium and palladium are quite rare and this makes them relatively expensive. To reduce costs, the metals are spread thinly onto the ceramic support.

Secondly, catalytic converters only work effectively when hot. This means that on short car journeys - and 58% of car journeys in the UK are less than 8 km, they may not get hot enough to react efficiently with the nitrogen oxide and carbon monoxide emissions.

Most importantly, metal additives in the petrol can poison the catalyst. This means that other metals attach themselves preferentially to the catalyst surface.

This reduces its efficiency by preventing the reactants adsorbing onto it. Because lead is a very effective poison, catalytic converters can only be used in cars that run on unleaded petrol. Lead is no longer used as an additive but other additives which poison the catalyst include manganese and silicon.

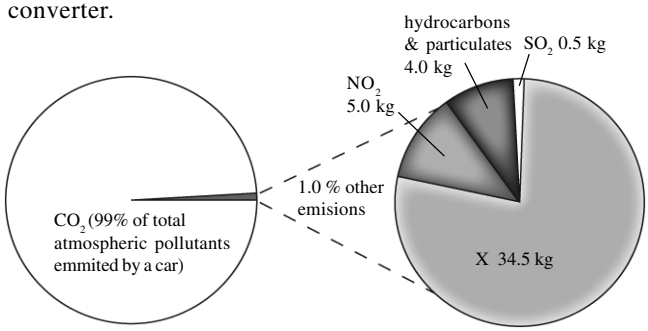
Unfortunately, catalytic converters, whilst decreasing carbon monoxide and hydrocarbon emissions, increase emissions of sulphate particles because they convert the minute amounts of sulphur oxides in petrol into sulphuric acid.

Why does pollution occur?

Overall, the environmental effects of CATS are mixed: fuel efficiency is decreased slightly, that is cars which have CATS will use more petrol. Thus, a finite resource will be exhausted more rapidly and all of the environmental problems which arise from oil extraction and refining and transport are, in a very small way, intensified. CO_2 emissions increase and therefore the effects of the enhanced greenhouse effect may increase. However, NO_2, CO and hydrocarbon emissions are reduced , thus decreasing the incidence of photochemical smog and acid rain. Finally, the use of rare metals in the catalyst means that mining of these precious metals increases, thus increasing air and water pollution and possibly, habitat destruction.

Practice Questions

1. (a) Which three transition metals are commonly used in catalytic converters?
   (b) What conditions lead to the formation of carbon monoxide in a car engine?
2. The pie charts show the relative proportions (by mass) of the atmospheric pollutants emitted by a car fitted with a catalytic converter.



(a) Identify gas X (1)
(b) Suggest two possible harmful effects of particulates (2)
(c) Explain how car emissions can contribute to acid rain (2)

Answers

1. (a) Platinum, palladium and rhodium;
   (b) Incomplete combustion, caused by insufficient oxygen;
2. (a) CO;
   (b) damage to respiratory tracts of animals bronchi/ asthma/ cancer;
   synergistic action with other pollutants to accelerate damage to respiratory system; reduced insolation/ reduced visibility;
   contributes to smogs/hazes; discolours buildings;
   deposite on leaves or in stomata reduce photosynthesis;
   act as condensation nuclei;
   (c) NO_2 dissolves in water vapour to form nitrous/nitric acid;
   SO_2 dissolves in water vapour to produce sulphurous/sulphuric acid;
   Particulates act as condensation nuclei;

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