ChemFactsheet

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Catalytic Converters

To succeed in this topic you need to understand:
- how catalysts increase the rates of chemical reactions
- the environmental impact of the pollutants formed in internal combustion engines

After working through this Factsheet you will be able to:
- state which metals are used in catalytic converters
- explain 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	• Particles form soot 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 (Equation 1). Nitrogen is normally too inert to react with oxygen, but the electric spark used to ignite the fuel in the engine provides enough energy to allow nitrogen to react.

> ***Exam Hint:-*** *If you are asked to state the conditions in which the reaction between nitrogen and oxygen takes place, make sure you say that the engine has a* ***high*** *temperature, or quote a specific temperature. An acceptable answer is in the range 2500-4000°C. Alternatively, say that it is a* ***spark*** *which allows the reaction to take place.*

Equation 1 $N_2 + O_2 \rightarrow 2NO$

On further reaction with oxygen, nitrogen (II) oxide is oxidised to nitrogen (IV) oxide, NO_2 (Equation 2).

Equation 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, HNO_3, which is one of the acids in acid rain (Equation 3).

Equation 3 $2NO_2 + 2H_2O + O_2 \rightarrow 2HNO_3$

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 (Equation 4).

Equation 4 $C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$

But if sufficient oxygen is not present in the engine, then incomplete combustion takes place. This leads to the formation of carbon monoxide (Equation 5).

Equation 5 $C_8H_{18} + 8\frac{1}{2}O_2 \rightarrow 8CO + 9H_2O$

Incomplete combustion can also produce carbon, which forms particles of soot in the air, another atmospheric pollutant (Equation 6).

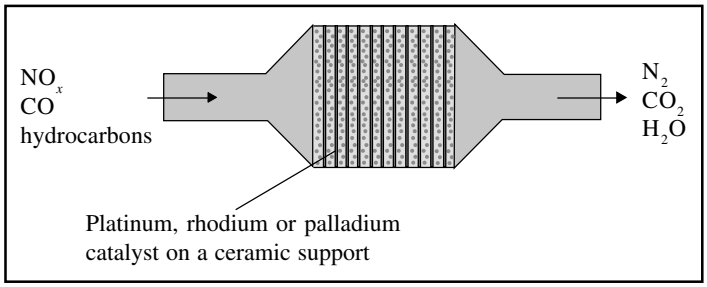
Equation 6 $C_8H_{18} + 4\frac{1}{2}O_2 \rightarrow 8C + 9H_2O$

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



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.

For more on catalysts, their action and other uses, see FactSheet 79 Catalysts.

How Does A Catalytic Converter Work?

The first reaction in a catalytic converters reduces the nitrogen oxides to nitrogen (Equation 7).

Equation 7 $2NO_2 \rightarrow N_2 + 2O_2$ and $2NO \rightarrow N_2 + O_2$

The second reaction uses the oxygen which is formed to convert carbon monoxide to carbon dioxide, and to convert any unreacted hydrocarbons to carbon dioxide and water (Equation 8).

Equation 8 $2CO + O_2 \rightarrow 2CO_2$ and $C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$

The catalyst also allows the direct reaction of nitrogen (II) oxide and carbon monoxide (Equation 9) to similarly produce carbon dioxide and water. The CO reduces the NO.

Equation 9 $2NO + 2CO \rightarrow N_2 + 2CO_2$

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, 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.

Practice Questions

1. Which three transition metals are commonly used in catalytic converters?
2. The three major constituents of exhaust gases are nitrogen, carbon dioxide and water vapour. Write an equation to show the formation of carbon dioxide and water from heptane, C_7H_{16}.
3. (a) What conditions lead to the formation of carbon monoxide in a car engine?
   (b) Write a balanced equation to show the formation of carbon monoxide and water vapour from the reaction of heptane with oxygen.
4. (a) What conditions lead to the reaction of nitrogen and oxygen to form nitrogen (II) oxide, NO?
   (b) Write an equation to show the formation of nitrogen (II) oxide, NO, from nitrogen and oxygen.
5. Write equations to show the following reactions, which take place in a catalytic converter:
   (a) the reduction of nitrogen (IV) oxide, NO_2, to form nitrogen and oxygen;
   (b) the oxidation of carbon monoxide with oxygen to form carbon dioxide;
   (c) the reaction between nitrogen (II) oxide, NO, and carbon monoxide to form nitrogen and carbon dioxide.
6. What is the effect of lead additives in petrol on catalytic converters?

Answers

1. Platinum, palladium and rhodium.
2. $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$
3. (a) Incomplete combustion, caused by insufficient oxygen.
   (b) $C_7H_{16} + 7½O_2 \rightarrow 7CO + 8H_2O$
4. (a) High temperatures, caused by the spark from the engine.
   (b) $N_2 + O_2 \rightarrow 2NO$
5. (a) $2NO_2 \rightarrow N_2 + 2O_2$
   (b) $2CO + O_2 \rightarrow 2CO_2$
   (c) $2NO + 2CO \rightarrow N_2 + 2CO_2$
6. Lead additives poison the catalysts. Particles of lead adsorb to the catalyst surface, thereby reducing its efficiency.

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