9.3 Combustion products, pollutants and appropriate controls

Name: _____ Class: _____ Date: _____ **Total: 32 marks**

KEY WORDS incomplete combustion • acid rain • particulates

Objective

Predict products from fuel elements and conditions, then link each pollutant to its effects and suitable control. Original practice and authored marking guidance for 4.9.3.1–4.9.3.2, both tiers.

1 Key knowledge and worked examples

Complete combustion of a **pure hydrocarbon** with sufficient oxygen gives CO_2 and water. Limited oxygen can cause **incomplete combustion**, producing CO and carbon particles as well as some CO_2/water. **Particulates** also include unburned hydrocarbons. Sulfur in fuel burns to SO_2. High-temperature engines can form NO_x from nitrogen and oxygen in air, even with sulfur-free fuel.

CO is toxic, colourless and odourless: smell is not a test. SO_2/NO_x cause breathing problems and **acid rain**. Particles harm health and cause **global dimming** by reducing sunlight reaching the surface. This differs from greenhouse gases absorbing outgoing infrared.

Worked prediction. Pure hydrogen in oxygen forms water, not CO_2: the reactants contain no carbon. Replacing sulfur-containing petrol with sulfur-free petrol reduces SO_2 but not necessarily NO_x, because nitrogen can come from air.

Worked control. More complete combustion reduces CO/soot but still makes CO_2. Particle filters target particles; a gas can pass through. Exhaust treatment must match the pollutant and chemistry. With supplied calcium oxide, $CaO + SO_2 \rightarrow CaSO_3$; making sulfate also needs oxygen. A catalytic converter can reduce NO using CO, producing nitrogen and CO_2; it is not simply a universal gas filter.

2 Practice

2.1 Name the two products of complete combustion of a pure hydrocarbon in oxygen. [2]

2.2 Which pollutant causes acid rain together with NO_x? [1]

2.3 Give a harmful effect of carbon monoxide and explain why relying on smell is unsafe. [2]

2.4 Predict the combustion product of pure hydrogen in oxygen. Explain why no carbon dioxide forms. [2]

3 Exam-style questions

3.1 Explain why incomplete hydrocarbon combustion occurs. Give one gaseous and one solid pollutant it may produce, with one harmful effect of each. [5]

3.2 Explain how sulfur dioxide forms from a fuel. Exhaust is treated with calcium oxide. Complete the supplied reaction: $CaO + SO_2 \rightarrow$ _____. Explain why claiming $CaSO_4$ forms from only these two reactants is wrong. [4]

3.3 Oxides of nitrogen form in a high-temperature engine using pure fuel containing no nitrogen. Explain their source and formation, then give one health effect and one environmental effect. [4]

3.4 A town installs particle filters and switches to sulfur-free fuel. Evaluate "all breathing problems and climate effects from engines are now removed". Give two benefits and two remaining pollutant concerns, with reasons. [4]

3.5 Distinguish global dimming from greenhouse warming using the type/direction of radiation and the material responsible. [4]

3.6 A converter uses the supplied reaction $2CO + 2NO \rightarrow 2CO_2 + N_2$. Check atom conservation, name the two harmful gases removed, and explain why it does not remove all climate impact. [4]

Solutions

Authored marking guidance for these original questions.

2.1 Carbon dioxide and water. This is conditional on pure hydrocarbon and sufficient oxygen, not a claim about every fuel.

2.2 Sulfur dioxide.

2.3 Toxic/reduces blood oxygen transport; it is odourless, so absence of smell does not indicate absence of CO. It is also colourless.

2.4 Water; neither hydrogen nor oxygen contains carbon, so carbon dioxide cannot form from only these reactants. $2H_2 + O_2 \rightarrow 2H_2O$ conserves four H/two O atoms.

3.1 Limited oxygen prevents complete oxidation of the hydrocarbon; carbon monoxide, toxic/reduces oxygen transport; carbon particles/soot, respiratory/health problems or global dimming. Incomplete combustion is a condition, not a guarantee that every molecule makes CO rather than a mixture of products.

3.2 Sulfur impurities are present in fuel and oxidise/burn to sulfur dioxide. Product is calcium sulfite, $CaSO_3$. $CaO + SO_2$ supplies only three oxygen atoms per Ca/S, whereas $CaSO_4$ needs four; another oxygen source is required. Extra oxidation can make sulfate; do not change the supplied reactants silently.

3.3 Nitrogen and oxygen come from air; high temperature enables their reaction to nitrogen oxides; respiratory problems; acid rain/environmental damage. Sulfur-free or nitrogen-free fuel does not remove the atmospheric nitrogen source.

3.4 Filters reduce emitted particles and their health/dimming effects; sulfur-free fuel lowers SO_2 and its acid-rain/respiratory effects. Any two remaining concerns with reasons: CO_2 still comes from carbon-fuel combustion and is a greenhouse gas; CO can still form if combustion is incomplete and is toxic; NO_x can still form from hot nitrogen/oxygen in air and causes health/acid-rain effects. The two changes do not prove all emissions disappear.

3.5 Particulates reduce incoming sunlight reaching the surface, producing global dimming. Greenhouse gases absorb some outgoing longer-wavelength surface infrared and emit in all directions including back towards the surface, contributing to warming. Do not treat dimming as the same mechanism or assume it safely cancels warming.

3.6 Both sides contain two C, two N and four O atoms; CO and NO are removed. CO_2 is produced and remains a greenhouse gas, so this treatment does not eliminate climate impact. It transforms particular pollutants rather than removing all combustion products.