Environmental Studies
FACT SHEET
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Number 094

Pollutants and their control: Sulphur dioxide

The UK and most other European countries have successfully reduced their sulphur dioxide emissions over the last 30 years (Fig 1a and b)

Fig 1a. SO_2 emissions and targets 1970 - 2010

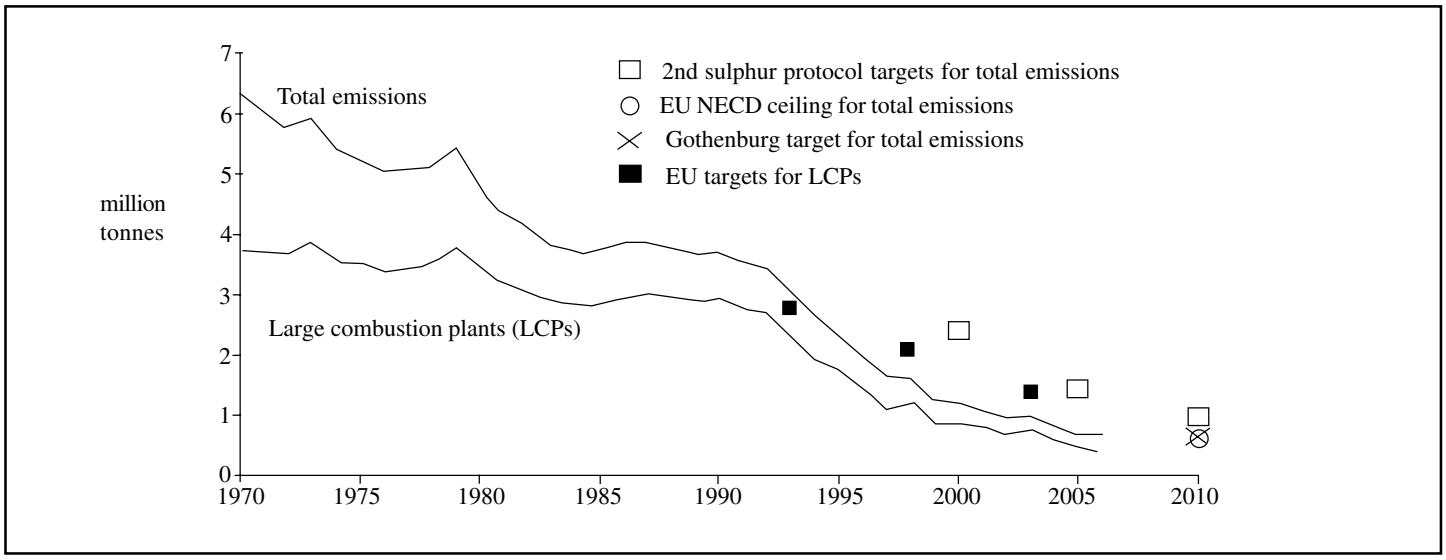
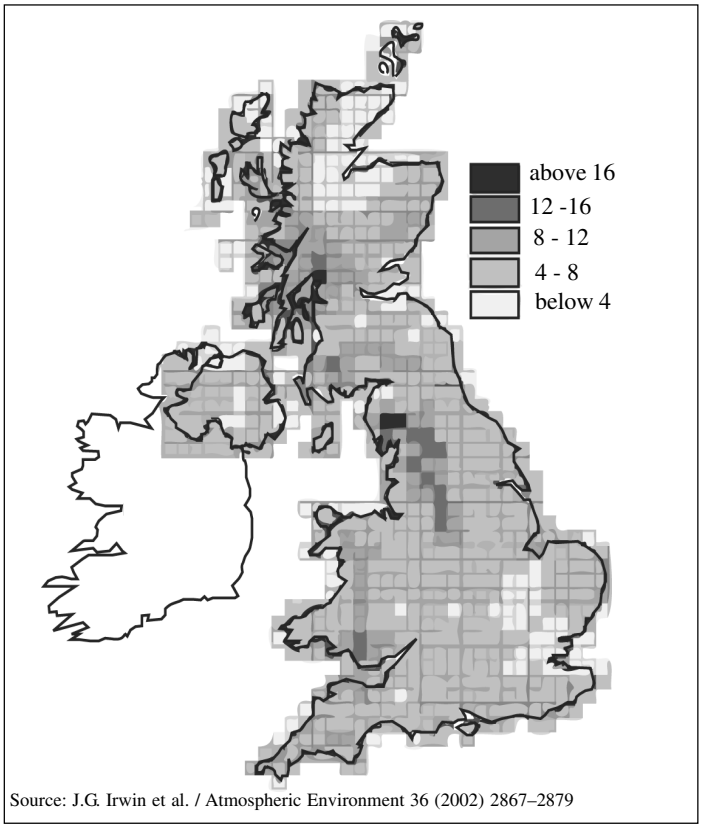


Fig 1b. Annual mean wet deposition of non-sea-salt sulphate (kg S ha^{-1} yr^{-1})



Source: J.G. Irwin et al. / Atmospheric Environment 36 (2002) 2867–2879

In the UK, total sulphur dioxide emissions fell by 82 per cent between 1990 and 2006 to 676 thousand tonnes. The greatest deposition occurs in high rainfall areas in the north and west of the country, particularly in Cumbria, the Pennines, west Central Highlands of Scotland and upland areas in Wales.

However, other countries continue to emit enormous amounts of both SO_2 and NO_2 and in some parts of the world acid rain remains a huge environmental problem.

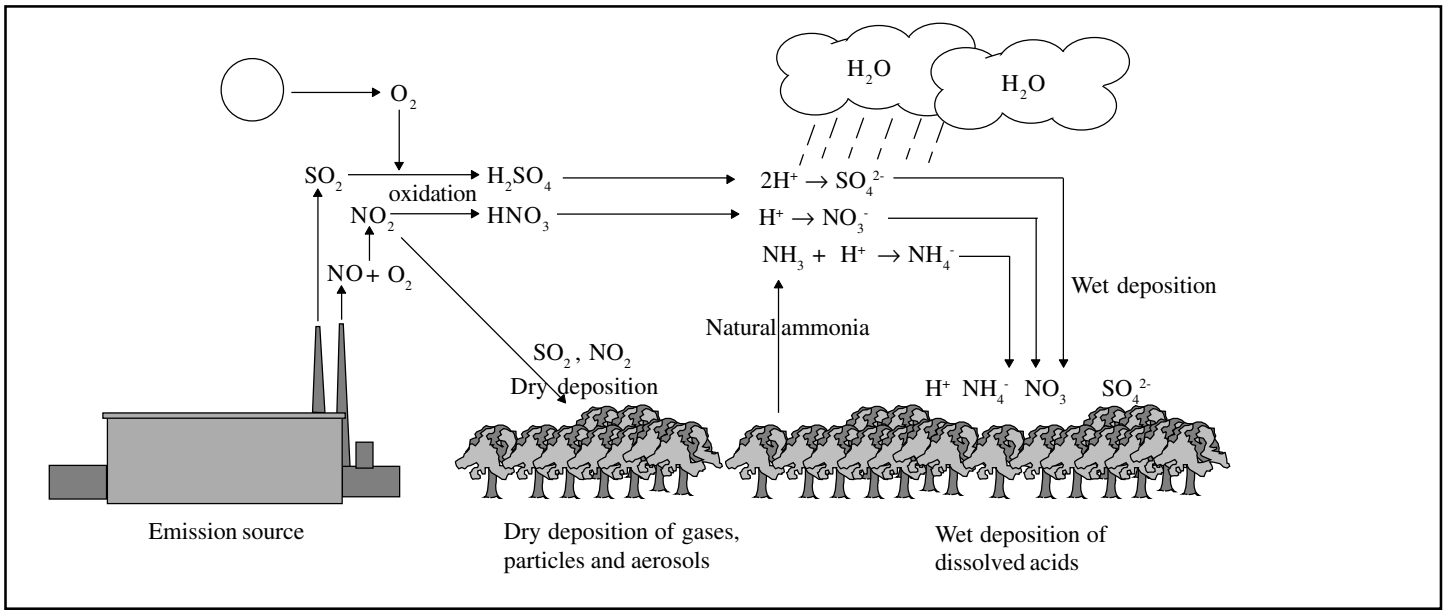
This Factsheet summarises:

- the problems caused by acid rain
- how SO_2 emissions can be reduced
- recent exam questions on the topic

Rain is naturally acid because CO_2, which is in the atmosphere. dissolves in moisture to form weak carbonic acid. Thus normal rain has a pH of about 6.5.

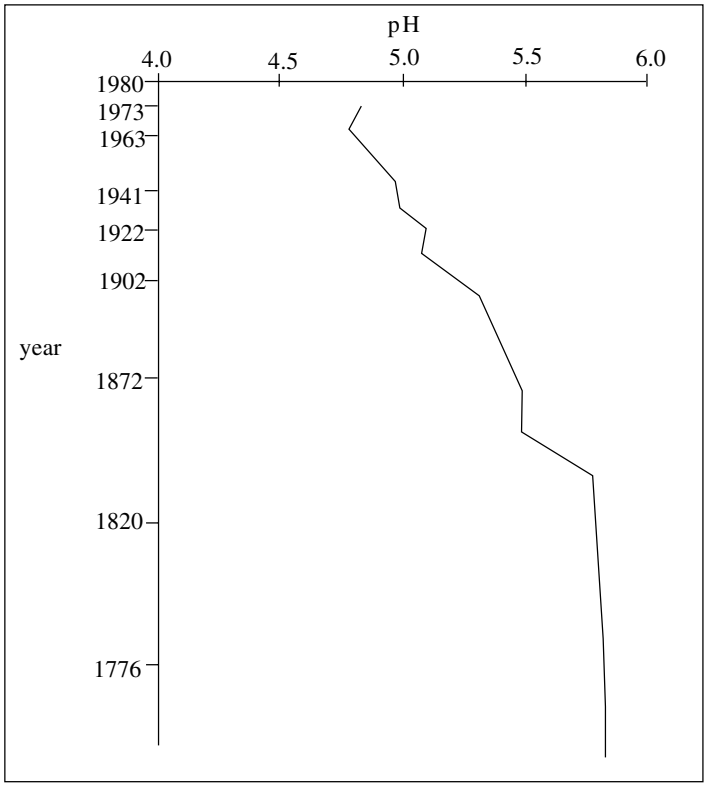
The emissions of SO_2 (from coal-burning power stations) and NO_2 (vehicle exhausts) created more acidic rain (Fig 2)

Fig 2. The emissions of SO_2 (from coal-burning power stations) and NO_2 (vehicle exhausts) created more acidic rain



Lakes and reservoirs from Scotland to Wales have been acidifying since the Industrial revolution (Fig 3)

Fig 3 Change in pH of a lake in Scotland.



How do we know what the pH of this lake was in 1880? By analysis of diatoms extracted from the sediments on the lake bed. Diatoms are microscopic algae which float around in the lakes. Their silica-rich skeletons are resistant to decay and dead diatoms sink and accumulate as sediment.

Different diatom species have different pH preferences - some thrive in alkaline waters, other species thrive in acidic waters.

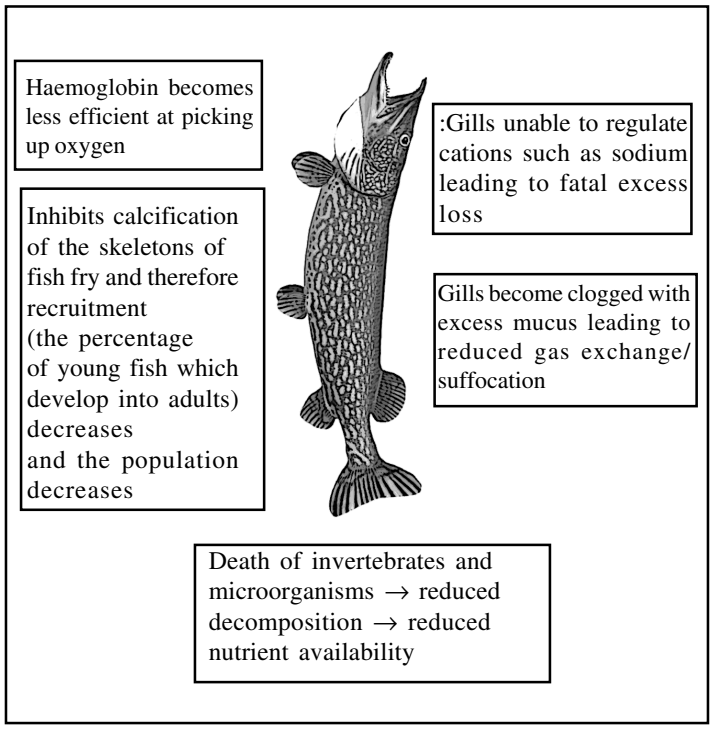
So by identifying the change in species composition of diatoms in sediment cores, we can track changes in the pH of the water. By dating the sediments using radiotracers, acidification can be correlated in time to events such as the Industrial Revolution and forest clearance.

Effects of acid rain

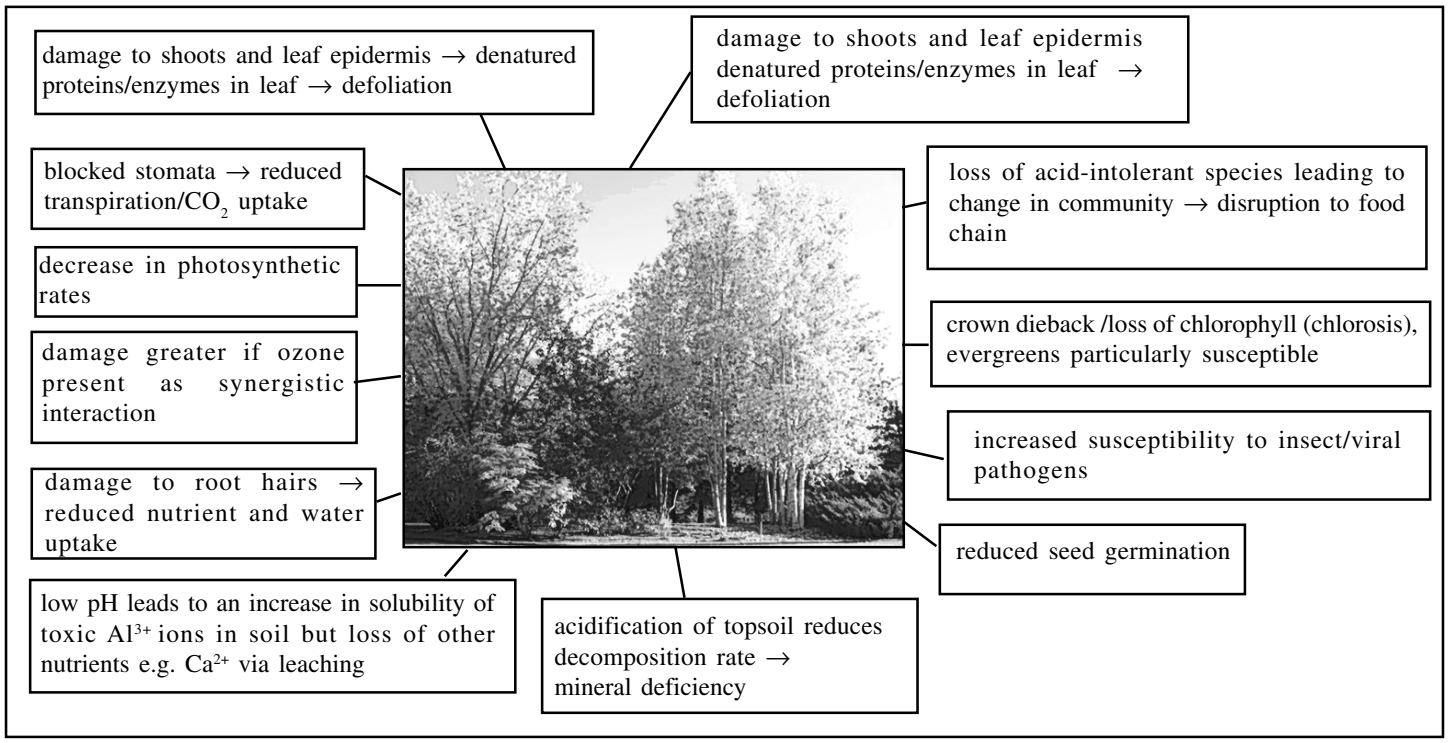
1. Aquatic fauna and flora

Sudden changes in water pH, as may result from the rapid influx of a snow melt, may be lethal to invertebrates and fish. When the pH of acidified soils falls below 4.2, aluminium becomes soluble and may enter aquatic ecosystems. High aluminium concentrations have several effects (Fig 4).

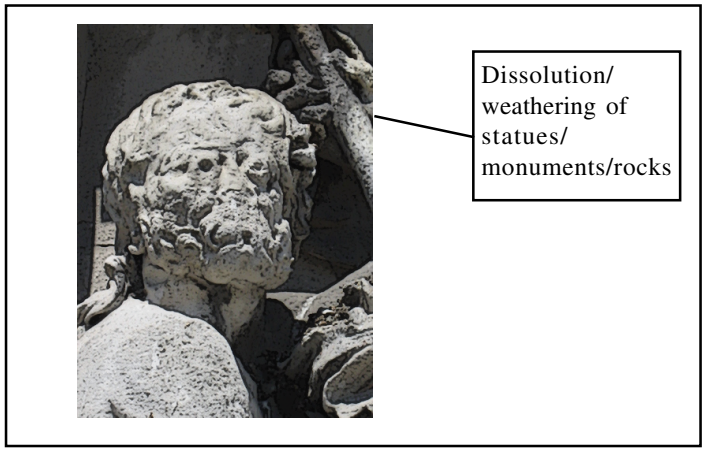
Fig 4. Effects of aluminium on aquatic life



2. Plants



3. Non-living objects



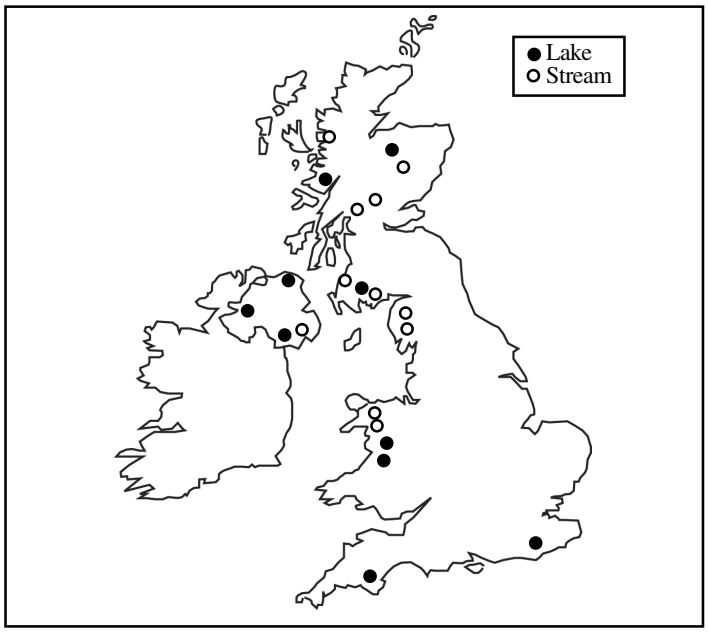
Ecosystem recovery

Anthropogenic acidification has clearly altered many ecosystems in the UK. The key questions we need to answer now are:

Should we take positive action to restore habitats to their pre-acidified status? and If we simply leave it to nature, how long will it take?

The most acidified sites in the Acid Waters Monitoring network (AWMN) are located in the Galloway region of south-west Scotland, north and central Wales and the English Lake District (Fig 4).

Fig 4. UK Acid Water Monitoring Network sites



These areas are severely acidified and are areas where the critical load has been exceeded. In each area, coniferous afforestation has contributed to this acidification.

Question . How can planting spruce trees increase the acidity of the soil?

Answer

1. Spruce, and most other conifers, keep their leaves (needles) all-year round. They are therefore more effective at filtering acidic particles in the wind and rain.
2. The trees selectively absorb base-cations from the soil, so leaving the soil more acidic.
3. The trees intercept rainfall which then evaporates before it reaches the soil. This effectively concentrates pollutants in the soil,and,via runoff, in surface-waters

Consequently, many ecologists are suggesting that, once the plantations are felled, they should not be replanted. This will greatly accelerate recovery of the habitats.

International pollutant

Acid rain is a transboundary pollutant – the acids can be transported hundreds of miles across national borders before falling as rain. In the 1970s, Norway flew the UK's then Prime Minister, Margaret Thatcher over Norwegian forest to show her the damage that was being done by UK acid rain emissions. SW winds had carried our power station emissions over to Norway.

Germany, Sweden, Poland and what was Czechoslovakia, all suffered serious forest damage. Forest dieback in the Swiss Alps caused concern because it increased the caused damage by avalanches.

Lichens as pollution monitors

Lichens may be used as biological indicators of atmospheric acid pollution:

- They are sensitive to sulphur;
- different species have different sensitivities;
- they are simple to use i.e we can simply measure their presence or absence, or size and they are static
- they can be used in long-term monitioring programmes.

Typical Exam Question

A student investigated whether the abundance of lichens on walls was influenced by the direction the wall faced. The student recorded the number of lichen colonies within a 50cm^2 quadrat, placed one metre above the ground on each of three walls. He used a chi-squared test to analyse his recordings.

(a) Suggest a suitable null hypothesis for this investigation (1).

(b) Complete the student's table (1).

	No. of colonies on wall facing		
	North	South	West
Observed	21	33	54
Expected			

(c) How many degrees of freedom were in this chi-squared test? (1)

(d) The student calculated a chi-squared value of 15.5 from these results. This chi-squared value has a probability of less than 0.001. Explain what this means (3)

Markscheme

(a) there is no difference between the number of lichens growing on the walls (facing different directions);

(b) 36, 36, 36;

(c) 2;

(d) p less than 0.05;

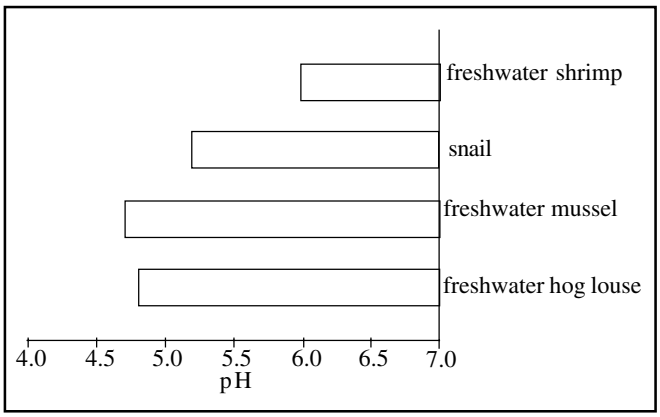
reject the null hypothesis;

the difference is not due to chance/significant difference;

the direction the wall faces does have an effect on the population of lichens;

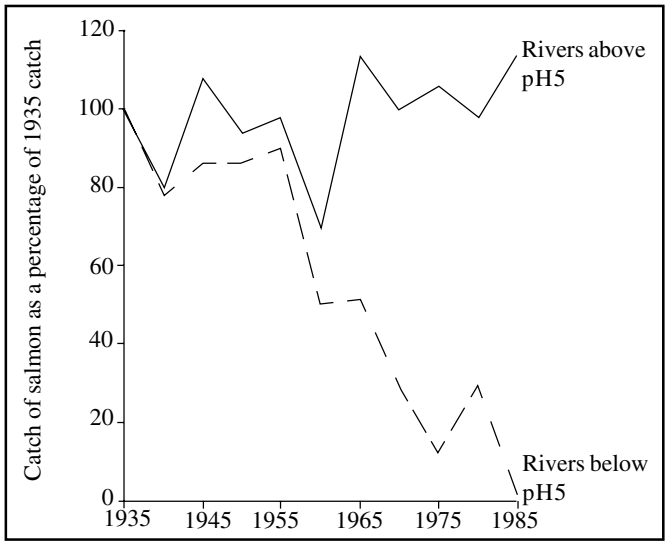
Aquatic organisms differ in their tolerance to water pH. The diagram shows the range of pH below a value of 7 tolerated by four common river invertebrates. (Fig 5)

Fig 5. pH range below pH 7 of four river invertebrates



(a) Suggest what might happen to the relative numbers of these invertebrates when a river of pH 6.3 is acidified to pH 5. (4)

The graph shows the changes in the annual catch of salmon from acidified rivers in Nova Scotia between 1935 and 1985 compared with rivers that were not acidified.



(b) Suggest an explanation for the data (4)

The Norwegian government has attempted to neutralize river acidity by the addition of lime in the form of calcium carbonate.

(c) Suggest why the addition of lime to lakes rather than rivers may be a more successful long-term measure. (2)

Markscheme

(a) Mussel and hog louse increase;

Able to {tolerate pH < 5;

Less competition / more food;

Fewer eaten / less predation;

Snail/shrimp decrease;

(b) Increased aluminium;

Death of eggs/fry;

Increased mucus production by gills;

Reduced oxygen uptake / suffocation;

Haemoglobin less effective;

Enzyme inhibition by newly-soluble heavy metals;

Food chain effect;

(c) Lake water slower/stationary;

How were emissions in Europe reduced?

1. Legislation

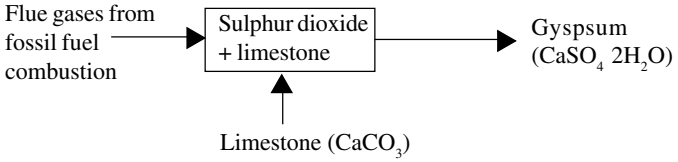
- SO_4/SO_2 monitoring networks were established within the European Monitoring and Evaluation Programme.
- In 1979, the Convention on Long Range Transboundary Air Pollution (LRTAP) was established to promote reductions in the emissions and deposition of anthropogenic sulphur and nitrogen throughout Europe.
- The convention adopted its first Sulphur Protocol, the '30% club', in 1985, with targets of reducing national emissions of SO_2 by 30%.
- in 1986, the UK was obliged by the EC directive for Large Combustion Plants to reduce sulphur emissions by 60% by 2003
- In June 1994, the Protocol on Further Reductions of Sulphur Emissions was signed by 28 countries.
- The agreed reduction for the UK involves a 70% reduction in sulphur emissions by 2005 and 80% by 2010. This is based upon the idea of critical loads. These reductions are calculated to protect 95% of ecosystem area.

2. Improved technology

- promotion and uptake of low-sulphur fuels instead of S-rich fuels e.g. from coal/oil to natural gas, nuclear power & renewables
- fluidised bed gasification
- removal of hydrogen sulphide from natural gas and oil
- wet and dry flue-gas desulphurisation

Typical Exam Question

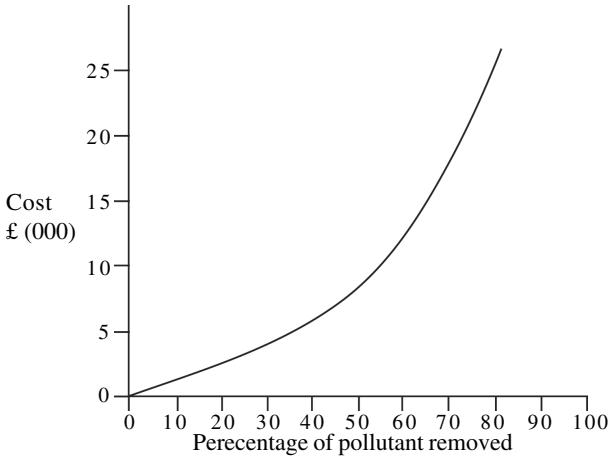
The diagram shows the process of flue gas desulphurisation at a coal-fired power station.



(a) Why do the flue gases contain sulphur dioxide? (2)

(b) Explain how flue gas desulphurisation may reduce the problem of acid rain (2).

(C) The graph shows the cost of removing sulphur from coal at a different plant. Suggest why the plant only aims to remove 90% of the sulphur. (2)



Markscheme

(a) Coal contains S; Which is oxidized during combustion;

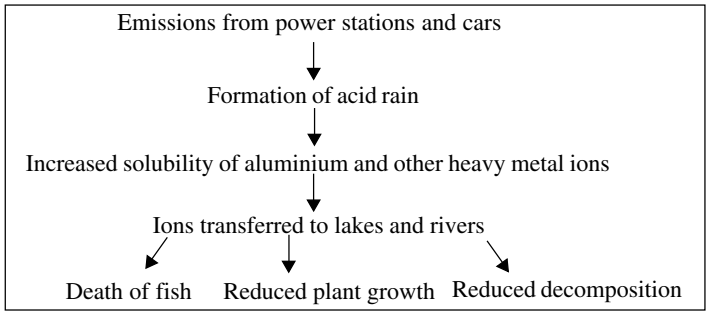
(b) Less SO_2 released; Less sulphurous/sulphuric acid formed;

(c) Too expensive; Small increase in extra S removal at huge expense;

Acknowledgments: This Factsheet was researched and written by kevin Byrne. *Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU* **1351-5136**

Practice Questions

1. The diagram shows some of the causes and consequences of pollution by acid rain



(a) Explain how emissions from power stations and cars contribute to the formation of acid rain (3)

(b) Outline the effects of acid rain on:

(i) forests (8)

(ii) lakes (4)

Refernces

IrwinJ.G, Campbell G, Vincent K (2002) Trends in sulphate and nitrate wet deposition over the United Kingdom: 1986–1999 Atmospheric Environment 36 (2002) 2867–2879

Markscheme

1. (a) sulphur dioxide combines with water to form sulphuric/ sulphurous acid;
nitrogen oxides combine with water to form nitric/nitrous acid;

(b) (i) crown dieback /loss of chlorophyll (chlorosis);
evergreens particularly susceptible;
damage to shoots and leaf epidermis;
denatured proteins/enzymes in leaf;
defoliation;
blocked stomata;
reduced transpiration/CO_2 uptake;
loss of acid-intolerant species leading to change in community;
disruption to food chain;
decrease in photosynthetic rates;
damage to root hairs;
reduced nutrient and water uptake;
increase in solubility of toxic Al^{3+} ions;
leaching/toxicity to invertebrates;
loss of Mg^{2+} / Ca^{2+} via leaching
decreased resistance to drought/ disease/ frost;
reduced decomposition;
mineral deficiency;
reduced seed germination;
increased susceptibility to insect/viral pathogens;

(ii) gills unable to regulate cations such as sodium;
osmotic imbalance;
gills clogged with excess mucus;
reduced gas exchange/ suffocation;
Inhibited calcium uptake;
death of fry/ reduced recruitment;
death of invertebrates and microorganisms;
food chains disrupted;
reduced decomposition;
reduced nutrient availability;