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Atmospheric Chemistry

The Dark Side of Fireworks – The Chemistry of their Environmental Effects



By Andy Brunning — January 5, 2017

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THE CHEMISTRY OF FIREWORK POLLUTION

Fireworks displays can be spectacular, but they can also have some negative effects on the environment. Here we take a look at some of the issues.

PARTICULATE MATTER

PM₁₀ Particulate matter 10 micrometres or less in diameter

PM_{2.5} Particulate matter 2.5 micrometres or less in diameter

Fireworks produce a lot of very small particles, which can remain suspended in the air for some time after the display. This significantly increases the concentration of particulate matter in the air. Inhalation of these particles can have adverse effects on the respiratory and cardiovascular systems.

PERCHLORATE POLLUTION

Perchlorate concentration increase after a fireworks display in Albany, New York

PERCHLORATE ION

0.11 µg/L
↓
519 µg/L

Perchlorate compounds are used as oxidisers in some fireworks to aid the combustion reaction. These perchlorates can contaminate bodies of water near fireworks displays. Elevated concentrations of perchlorate in water can affect wildlife and it may also affect human health if it contaminates drinking water.

POLLUTING GASES

Fireworks lead to elevated levels of well-known polluting gases in the atmosphere. These gases include nitrogen dioxide and sulfur dioxide, which can cause respiratory problems, or exacerbate existing health problems such as asthma. They can also react in the atmosphere to form particulate matter.

METALS

Sr Ba Cu Pb Cr Sb
Ca Na Mg

Note: Lead (Pb) and chromium (Cr) are both banned in fireworks in the US and UK, but can still be found in some imported fireworks.

COLOURS OTHER METALS

Metal compounds give fireworks their vivid colours and can also be present in oxidiser or mixtures. These metals persist in the environment. Small particles of toxic metals such as lead, chromium and antimony show increases in atmospheric concentrations in the days after fireworks displays.

Click to enlarge

Many of us enjoyed watching spectacular fireworks displays to usher in the new year. However, the vibrant colours of fireworks belie the effects that they can have on the environment. With this graphic, we take a look at some of the issues that they can cause.

To an onlooker, it seems as if fireworks simply disappear without a trace after delivering their fiery payload to the skies. This isn't the case though – they leave behind billions of tiny particles, a complex chemical mix born from the various components that made up the firework. The particulate matter left behind after a firework's demise is one of the most significant polluting issues, and one that scientists

have looked into in some detail.

Of particular interest to those investigating environmental problems linked to fireworks are some of the smallest particles left behind, generally referred to as particulate matter (PM for short). Particulate matter is usually divided into two categories of interest: PM₁₀, which refers to particles with a diameter of 10 micrometres or less, and PM_{2.5}, which refers to particles with a diameter of 2.5 micrometres or less. For the purposes of comparison, a human hair has a diameter of 50-70 micrometres.

After a fireworks display, a number of studies have shown that the concentration of particulate matter in the local atmosphere is noticeably increased for days after the display. Just this week in Germany, [particulate levels reached 26 times the EU recommended limit](#) of 50 micrograms per cubic metre of air, with figures suggested that across the country over 4,000 tons of particulates were ejected into the atmosphere by fireworks displays. Meanwhile, [a study in the US](#) found that particulate concentrations increased by up to 370% in the 24 hours after an Independence Day firework display.

These higher levels of particulates can have effects on our health. The particles remain suspended in the air and can be breathed in. This can cause respiratory problems, or exacerbate conditions such as asthma. Long term exposure to particulate matter is associated with respiratory and cardiovascular disease.

It's not only the presence of these particles that can cause problems – the chemical nature of some of them can also have detrimental effects. [The colours of fireworks derive from compounds of different metals](#), and some metal compounds are also used as components in the explosive mixture. Small particles of these metals are dispersed by the fireworks' explosions; barium, compounds of which can be used to give green colours, is one such example.

Other metals have been banned from fireworks in some countries due to their toxicity – these include lead and chromium. However, imported fireworks from countries where these metals are not banned can still lead to them being released during fireworks displays, and [increased levels have been recorded in the local atmosphere after displays](#).

As well as the metals, another kind of compound can also cause problems. Perchlorate compounds are used in some fireworks as oxidisers – chemical compounds which release oxygen and help fuel the combustion reaction inside the firework. Perchlorate can contaminate water when it settles to earth after fireworks displays, and [studies have shown that perchlorate concentration in nearby bodies of water can increase significantly](#), in some cases [increasing by over 1000 times](#) the usual average value.

Perchlorate can pose a risk to aquatic organisms, but in some cases it may also pose a risk to us. There is concern that [ingestion of perchlorate might interfere with the production of thyroid hormones](#) if it gets into the body. After fireworks displays there is the possibility of perchlorate contaminating drinking water supplies.

Finally, pollutant gases we're already familiar with can also be produced by fireworks. These include gases such as nitrogen dioxide and sulfur dioxide, which can cause respiratory problems if their concentration in the local atmosphere is heightened. Whilst the levels of these compounds produced by fireworks pales in comparison to those produced by the burning of fossil fuels or the combustion of petrol in cars, it can still have an impact at a local level. Their effects were examined in a [previous post on atmospheric pollutants](#).

Scientists aren't idly sitting by in light of these problems. Efforts are being made to make 'greener' fireworks that have less of an impact on the environment. Recently, [compositions which reduce the need to use perchlorate compounds](#) in firework compositions have been developed, and other efforts have been made to [reduce the presence of harmful combustion products](#). That said, there's still plenty still to do to reduce the environmental effects further.

So next time you're at a fireworks display, do enjoy the colours – but bear in mind the environmental impact!

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CARBON DIOXIDE AND OCEAN ACIDIFICATION

Climate change is a much-discussed effect of rising carbon dioxide levels, but they can also affect our oceans. This graphic takes a look at the chemistry of ocean acidification.

THE BASICS

Microscopic carbon dioxide has increased by 40% from pre-industrial levels due to the burning of fossil fuels and deforestation. Ocean acidification occurs when atmospheric carbon dioxide dissolves in seawater.

Year	pH
1870	8.2
2013	8.1
2100	7.7

Acidity and alkalinity are measured on a logarithmic pH scale. A pH near 7 is neutral, below 7 is acidic. A change of one unit represents a tenfold change in acidity or alkalinity. Seawater is basic, but average ocean surface pH is expected to drop 0.2 units over industrial times, a 20% increase in acidity.

THE CHEMISTRY OF OCEAN ACIDIFICATION

Atmospheric carbon dioxide dissolves in seawater (S) and reacts with the water to form carbonic acid (C). Carbonic acid dissociates partly into bicarbonate ions (B) and hydrogen ions (H). Hydrogen ions produced by this dissociation increase acidity, lowering seawater pH. Increased atmospheric carbon dioxide ultimately produces more hydrogen ions, lowering pH further.

$$\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$$

Hydrogen ions can also react with dissolved carbonate ions to form carbonate ions (C) but this is less favored. Consequently hydrogencarbonate ions are the most abundant form of inorganic carbon in the oceans. Calcium carbonate can then react with dissolved carbon dioxide to however to form more hydrogen carbonate ions (B).

$$\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{Ca}^{2+} + 2\text{HCO}_3^-$$

THE EFFECTS OF OCEAN ACIDIFICATION

- EFFECT ON CALCIFYING ORGANISMS AND CORALS**

As ocean pH drops, hydrogen ions react with carbonate ions. Calcifying organisms such as corals, sponges and mollusks use the carbonate ions from seawater to form shells. When calcium carbonate is under-saturated in seawater, their shells can start dissolving. Coral skeletons can also be affected.

$\text{CaCO}_3 + \text{Ca}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$
- EFFECT ON FOOD WEBS AND FISHING**

Calcifying organisms are at the base of a number of marine food webs. Negative effects on their population could have a knock-on effect on species that feed on them, impacting fishing industries.
- EFFECTS ON ANIMAL CHEMICAL SIGNALING**

Many marine species use chemical signals for olfactory predators, settlement and reproduction. Ocean acidification is altering signaling molecules, which could in turn have potentially detrimental effects on a number of different species.

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REDUCING VEHICLE EMISSIONS WITH CHEMISTRY

Flaws of Volkswagen cars have been found to emit up to 40 times more nitrogen oxides in normal operation than they did during emissions testing, making the company in controversy. This graphic looks at the devices present in a vehicle to help reduce pollution, and how they work.

POLLUTING COMPOUNDS

NO_x NITROGEN OXIDES (A mix of nitric oxide and nitrogen dioxide)

CO CARBON MONOXIDE

HC UNBURNED HYDROCARBONS

THE 'DEFEAT DEVICE'

The 'defeat device' found in Volkswagen cars is an illegal device, built as part of software that detects if the car is being tested. When it detected this, it ran the engine's performance reducing the NO_x emitted in normal driving conditions they were much higher.

The car detects when it is in test conditions (generally by monitoring various other parameters like engine speed/acceleration)

CATALYTIC CONVERTERS

Rh Pt Pd

CO, HC → CO₂, H₂O, N₂

These catalytic converters are present in all petrol-powered cars and help remove carbon monoxide, unburnt hydrocarbons, and nitrogen oxides. The catalysts are made of platinum, palladium, and rhodium. These heavy metals can be used in other applications. Their use in catalytic converters makes them more expensive, but they are essential for reducing emissions.

SELECTIVE CATALYTIC REDUCTION

NO_x + 2CO → N₂ + 2CO₂

NO_x + 2H₂ → N₂ + 2H₂O

NO_x + 2C₂H₆ → N₂ + 2C₂H₄ + 2H₂O

These catalytic converters reduce NO_x emissions by NO_x reduction. The catalysts are made of platinum, palladium, and rhodium. These heavy metals can be used in other applications. Their use in catalytic converters makes them more expensive, but they are essential for reducing emissions.

NO_x ADSORBERS

NO_x + Pt → Pt-NO_x

NO_x + Pd → Pd-NO_x

NO_x + Rh → Rh-NO_x

NO_x adsorbers can also be used in diesel engines. The nitrogen oxides are stored on the adsorbent until the engine is idling, then released by the exhaust system. The NO_x adsorbent has the ability to store NO_x until the engine is idling, then released by the exhaust system. The NO_x adsorbent has the ability to store NO_x until the engine is idling, then released by the exhaust system.

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