NZASE article

Ammonium nitrate explosion

On August 4 2020, a powerful explosion at Beirut's port sent a huge orange fireball into the air, followed by a massive shock wave that caused severe damage across Lebanon's capital. Hundreds of people were killed, thousands injured and 300,000 were left homeless. Three city hospitals and the country's main grain silo were destroyed by a blast that was heard 200km away in Cyprus.

This type of explosion has caused death and destruction before – France and Texas (1947) and China (2015) saw comparable blasts, all at ports. The same compound was also used in the 1995 Oklahoma City bombing, and can be a component in improvised explosive devices (IEDs). NZASE Science Communicator Mike Stone outlines the chemistry.

The blast

Beirut observers saw a fire and a series of small explosions, followed by a massive blast. A large fireball became surrounded by a white spherical cloud spreading outwards, and a huge plume of red-orange smoke. Such observations can tell experts much about the cause.

The sparks and popping noises of the first fire are consistent with a fire in stored fireworks.

The shock wave of compressed air spread outward. Its damage and destruction extended at least several kilometres - windows were blown out at the airport 9km away. Germany's geosciences centre GFZ measured the force of the blast as equivalent to a 3.5 magnitude earthquake, making it one of the largest non-nuclear explosions in history.

Immediately behind the shock wave of such an explosion is an area of lower pressure that causes water in the humid air to condense into fine droplets, forming the round white cloud.

Reddish smoke is a signature of NO_2 gas, often produced from the incomplete decomposition of ammonium nitrate (NH_4NO_3). Residents were warned to stay inside and wear masks because of the toxic gas.

From video footage the detonation velocity was estimated to be around 3,000m/s, which is also an indicator of ammonium nitrate.

It became clear that this explosion was caused by 2,750 tonnes* of ammonium nitrate which had been stored for six years at a port warehouse, after being off-loaded from an unseaworthy ship. In the days following the blast soldiers found much more in 20 containers at the port, which they moved into safe storage.

Damage to port buildings after the 2020 Beirut explosion; Wikimedia.

**1 tonne = 1 million kg*

What is ammonium nitrate?

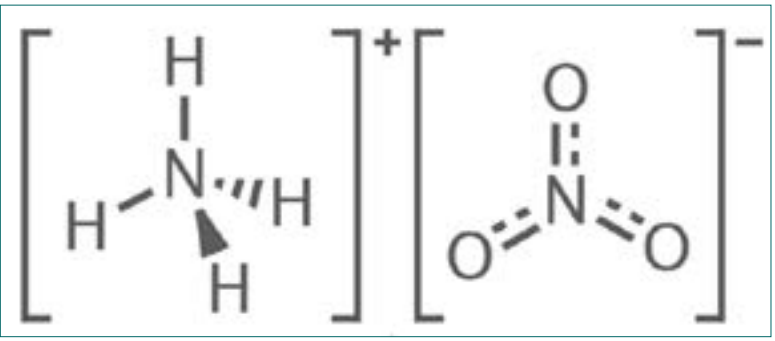
This soluble, white, crystalline salt is manufactured from ammonia and nitric acid as small porous pellets. It is mainly used as a fertiliser, providing nitrogen which plants need for growth. It can also be used as an explosive, but only if mixed with fuel oil and detonated by an explosive charge.

Ammonium nitrate pellets, loose and bagged.

Nitrogen in explosives

Many high explosives, e.g., TNT and RDX, contain nitrogen compounds. In these molecules, nitrogen atoms are bonded together using single or double covalent bonds. Energy is required to break these bonds but the reaction releases far more energy because of the formation of the extremely strong triple bond present in the N_2 product. The strength of this bond is why N_2 is such an unreactive gas, present as 78 percent of our atmosphere. N_2 reacts only under extreme conditions such as lightning, inside a car engine, or by using a catalyst such as those present in legume root nodules.

Ammonium nitrate is made up of two poly-atomic ions.



Fire first ..

It is still unclear what exactly ignited the fireworks that triggered the massive Beirut explosion. It may have been sparks from welding. Workers had been repairing a door and holes in the wall, but they had left for home an hour earlier.

Perhaps it was the heat – that sunny day Beirut reported a high of 30°C. Explosives experts say cheaply formulated explosives can ignite very easily in hot weather.

The fire may have been caused by ignition of other combustibles in the warehouse. Records show that the building storing ammonium nitrate also held kerosene, gas oil, blast fuses, and pain stripper solvents, as well as fireworks – a very dangerous mix.

The ammonium nitrate may have deteriorated in long-term storage. In humid Beirut, ammonium nitrate exposed to air would absorb a lot of water, over time causing the surface pellets to fuse into a crust. This could confine any gases formed, increasing the risk of an explosion once a source of heat was applied.

Whatever caused it, many factors had to come together in a tragic synchronicity.

The reddish smoke over Beirut, a signature of NO_2 gas.

.. then heat and confinement

Pure ammonium nitrate is inert, as long as it is stored properly in water-tight containers. The compound will only explode under certain conditions – if it is first triggered by fire.

If heated to 170°C by an adjacent fire, ammonium nitrate melts and flows like a liquid. If this river of molten ammonium nitrate meets a flammable material such as wood or cardboard, the fuel will ignite on contact, substantially accelerating the spread of the fire.

A sustained fire reaching 230°C will cause the ammonium nitrate to decompose. Pure ammonium nitrate decomposes completely into water, nitrogen and oxygen. This process will occur slowly naturally, but faster with heat.

It will not explode, however, until it is confined and heated further to 260-300°C. All the solid salt decomposes at once and the rapid production of huge volumes of gas creates the explosion shock wave. When this happens the decomposition products can also include nitrogen oxides (NO_2 and N_2O). The equation shows the increase in volume more clearly:

$2NH_4NO_3(s) \rightarrow 2N_2(g) + 4H_2O(g) + O_2(g)$

All combustion requires oxygen, usually from the air; with ammonium nitrate the oxygen comes from within the molecule. When a fire heats ammonium nitrate the molecule is no longer stable. Because ammonium nitrate – NH_4NO_3 – contains nitrogen in two different oxidation states, an exothermic reaction occurs between the two nitrogen species: the nitrate acts as an oxidant, while the ammonium acts as a reductant. Both nitrogen species react to form elemental nitrogen and the oxygen in the nitrate is also oxidised to elemental oxygen.

Contamination with oil or gasoline, even in small amounts is another factor making the ammonium nitrate more likely to detonate. For an accidental ammonium nitrate explosion to occur, a lot needs to go wrong – improper storage, confinement, contamination, lack of ventilation, and potential sources of ignition – all of which may have been involved in Beirut.

We know the factors that cause ammonium nitrate explosions. Safety consciousness has reduced accidents in manufacturing plants, but disasters continue to occur in transport and storage. Use of this compound is tightly regulated in most countries and the 2020 explosion in Beirut shows us just how important these regulations are.

Ngā Kupu

Ahi – Fire
Haukini pākawa ota – Ammonium nitrate
Hauota – Nitogen
Hononga hono - Covalent bond
Ngaru oro – Shock wave
Nga ngota – Atoms
Pakūtanga – Explosion
Pawa – Smoke
Rewa – To melt
Tākohu – Water vapour
Tote – Salt
Tauhohe putawera – Exothermic reaction

From Te Aka Maori Dictionary, Paekupu and Word Hippo

The reddish smoke in the Beirut explosion was followed by a huge white cloud of water droplets.

Sources

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