Safety of Ammonium Nitrate

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Abstract

Ammonium nitrate (AN) is the main ingredient in most industrial explosives, but it is estimated that as much as 80-90% of the global annual production is used as fertilizer [14, 25]. Over the last years AN has been involved in several accidents and used in criminal bomb making. Therefore authorities and legislators worldwide have given it special attention. This paper is divided into three parts:

- The first part will focus on the accidents with AN that have occurred over the last years and possible scenarios based on official investigations.
- The second part covers safety and security related issues.
- The third part will summarize new legislation that is coming both within European Union (EU) and also on a global scale.

Focus now is not only on ammonium nitrate but also on all products containing high percentage of nitrates. Historically, when considering the huge quantities of AN and other nitrate based products that are used globally, the safety records have been quite good.

Reviews of past accidents that have led to an explosion have shown fire developing for some time prior to the detonation. However, this only happened in a small percentage of all fires. In most cases the AN just continued burning until all combustible material was consumed. In spite of lots of efforts spent on investigation, these mechanisms are not fully understood.

We all have a big challenge and responsibility in maintaining high standards within our industry to prevent accidents, theft and misuse of raw materials as well as explosives.
Introduction

Over the last years ammonium nitrate (AN) has gained increased attention from authorities. This is caused by various accidents and increased misuse of the product. In the past, the main concern has been on the safety of manufacture, transport, storage and use of ammonium nitrate. Today security issues are becoming more and more important and authorities are focusing on ways to prevent misuse of AN and other easily available products with high-risk potential.

The distribution of industrial grade AN is a “closed loop”, i.e. normally direct from the manufacturer to the user of the product, and therefore under good control from theft. Fertilizer grade AN however, will pass through a wide distribution network on its way to the farmer, and can more easily be stolen. There are currently regulatory and industry initiatives to improve the control of the distribution and storage of such fertilizers.

We all have big challenges in securing transport, storage and use not only of ammonium nitrate but also of all energetic materials used for blasting applications.

Accidents

As can be seen in Table 1, there have been several accidents involving ammonium nitrate. In addition to these, there have also been numerous fires in buildings containing AN, but they have not resulted in a detonation. However, these “normal” incidents do not make big headlines. The Internet makes information easily available and it is a question if there actually has been an increase in the number of accidents and incidents with AN during the last years.

Before 1950 there were numerous major accidents with ammonium nitrate (Kriewald, Oppau, Tessenderlo, Texas City, Brest), but AN in those days normally contained fairly large amounts of oil/wax as coating agent and were very different from the product we have today. In addition dynamite was often used to break up caked piles [8].

Table 1: Major accidents involving ammonium Nitrate 1950 – 2000 [8]

<table>
<thead>
<tr>
<th>Date/place/</th>
<th>Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960 Traskwood USA</td>
<td>AN Fertilizer</td>
<td>Rail transport. Wagons derailed → fire Hydrocarbons, concentrated nitric acid and AN involved. Explosion, No personnel injury</td>
</tr>
<tr>
<td>1963 Traskwood USA</td>
<td>AN Fertilizer</td>
<td>Rail transport. Wagons derailed → oil spill + fire. No explosion, No personnel injury</td>
</tr>
<tr>
<td>1966 USA Unknown location</td>
<td>AN Fertilizer</td>
<td>Storage. AN fertilizer, also pesticides and combustible materials. Fire. Smoke affected fire fighters. Explosion, No personnel injury</td>
</tr>
<tr>
<td>1967 USA Unknown location</td>
<td>AN Fertilizer</td>
<td>Rail Transport. 50 t AN in paper bags in wagons with wooden interior, fire, and left to burn out. No personnel injury</td>
</tr>
<tr>
<td>Year</td>
<td>Location</td>
<td>Type</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>------</td>
</tr>
<tr>
<td>1972</td>
<td>France, Unknown location</td>
<td>AN Solution</td>
</tr>
<tr>
<td>1973</td>
<td>USA, Unknown location</td>
<td>AN Fertilizer</td>
</tr>
<tr>
<td>1978</td>
<td>USA, AN Unknown location</td>
<td>Fertilizer</td>
</tr>
<tr>
<td>1982</td>
<td>UK</td>
<td>AN Fertilizer</td>
</tr>
<tr>
<td>1998</td>
<td>Kentucky, USA</td>
<td>Fertilizer</td>
</tr>
<tr>
<td>1997</td>
<td>Brazil, Unknown location</td>
<td>AN Technical</td>
</tr>
<tr>
<td>2000</td>
<td>Florida, USA</td>
<td>AN Fertilizer</td>
</tr>
</tbody>
</table>

From the accidents that occurred in the past, it appears that the explosions fall into two groups. The first group consists of explosions that were caused by a shock to detonation transition. The initiation of the explosion occurred by an explosive mass going off in the material, by the detonation of a shell thrown into the mass, or by the detonation of an explosive mixture in contact with the AN. Well-known examples of this type include Kriewald, Morgan, Oppau, Tessenderloo and Traskwood.

The second group consists of explosions that followed a fire that spread either to the ammonium nitrate or to nitrate that became mixed with combustible substances during the fire. With respect to this group it must be mentioned that there are numerous examples of fires in which the ammonium nitrate was impure but that did not led to an explosion. Some level of confinement appears to be an important boundary condition for the transition of a fire into an explosion.

Although fires and explosions with ammonium nitrate did occur in the past, the safety record (and the image) of the product remained at acceptable level. This changed within the EU with the explosion at Grande Paroisse, Toulouse, France on September 21, 2001. The explosion occurred in a warehouse that contained 200-300 tons of off-spec ammonium nitrate (both fertilizer and technical grade AN). In the explosion, 29 people were killed and nearly 2500 were wounded, 30 severely. The strength of the explosion caused severe damage to the plant and to the surroundings. What caused the AN to explode is still not fully understood [9] and to my knowledge no final official report has been issued.

More recently, the image of ammonium nitrate as a relatively safe product has been further damaged by a number of incidents in which AN has caught fire and subsequently exploded.

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Fire hazards

Ammonium nitrate itself does not burn but in contact with other combustible materials it increases the fire hazard. Because of its oxidizing properties, Ammonium nitrate facilitates the initiation of a fire and it intensifies fires in combustible materials. For this reason, the fire risk potential is generally considered higher than its explosive risk potential. Ammonium nitrate can support and intensify a fire even in the absence of air. Fires involving ammonium nitrate will release nitrogen oxides and ammonia. Until recently, the probability for an explosion of ammonium nitrate under fire conditions was considered to be very low. However recent accidents appear to justify reconsideration. In Table 2, a short summary on these accidents is given.

Table 2: Fire and subsequent explosions incidents 2003 - 2004

<table>
<thead>
<tr>
<th>Date/place</th>
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</tr>
</thead>
<tbody>
<tr>
<td>2 October 2003 St Romain en Jarez, France [19]</td>
<td>Explosion in farmer’s barn. The hay in a farmer’s barn caught fire. The barn also contained some 3-5000 kg fertilizer grade AN and about 3000 plastic (polyethylene) boxes in piles. Approximately one hour and fifteen minutes after the fire was notified, an explosion took place causing 26 injuries (including 18 fire-men) and structural damage to 82 houses of varying severity. Damage was observed as far as 650 meter from the warehouse.</td>
</tr>
<tr>
<td>18 February 2004 Neyshabur, Khorasan province Iran [20]</td>
<td>Railcar explosion. 51 run-away train wagons derailed, of which 7 wagons were loaded with 420 t fertilizer AN in bags, 7 with 390 t urea in bags, 17 with crushed-in-bulk sulphur, 10 with gasoline and fuel oil, and 10 with cotton lint. The AN exploded after catching fire from sulphur and petroleum products, causing 300 fatalities. 9 railway employees were charged for negligence: Emergency brakes and rail shoes (stoppers) had not been fully engaged.</td>
</tr>
<tr>
<td>9 March 2004 Castellon, Spain [21]</td>
<td>Truck explosion. A truck with 25 t of fertilizer AN in bulk (open truck, metal “bath-tube”) collided with a car and rolled over on its back, with spill of fuel and a fire started. About 20-30 minutes later an explosion occurred. Two people were killed (the car driver and a truck driver which was hit by a stone in the explosion) and 5 injuries. Pieces were thrown 200 meters away.</td>
</tr>
<tr>
<td>24 May 2004 Mihailesti, Romania [22]</td>
<td>Truck explosion. A truck with 23 t of fertilizer AN in bags skid off the road and turned over. The truck cabin started burning. An hour later the cargo exploded, just when a fire crew was about to start the water hoses. 20 people were killed and several houses in nearby village were damaged. Neither the truck nor the driver was qualified for dangerous goods transport. The fire crew was not informed of the dangerous properties of the cargo. No evacuation of people or road closure was initiated prior to the explosion.</td>
</tr>
<tr>
<td>22 April 2004 North Korea Ryongchon [23]</td>
<td>Railcar explosion. An oil road tanker was reported to have collided with two railcars loaded with AN and knocking down an electric pole. It is thought that electric sparks caused a fire and explosion of the AN, with 161 fatalities and 1300 injuries. Due to the size of the crater officials have questioned whether military explosives were involved instead of AN.</td>
</tr>
<tr>
<td>12 Sept. 2005, Shengangzhai China</td>
<td>A truck loaded with 18 t of ammonium nitrate exploded, destroying 17 village houses, killing at least 11 people and injuring 43. No more information available (Oct 2005)</td>
</tr>
</tbody>
</table>

These accidents all have one thing in common; some sort of contamination, fire over a period of time and then explosion.

In addition to the accidents listed above, the Walden accident in Canada should also be mentioned. This accident has no direct relevance to the ones described above, but the very extensive investigation
shows how difficult it is to actually find out the mechanisms involved when AN (or ANFO) is involved in a fire. In 1998 a tractor-trailer carrying approximately 18 tons of blasting explosives, including over 13 tons of ANFO, struck a rock face on the side of the road near the town of Walden, Ontario, Canada. Eyewitness of the incident state that there was an intense fire for approximately 30 minutes before the detonation. It was determined that only the ANFO had detonated as water gel and emulsion were recovered afterwards. In spite of extensive testing [4, 5, 6], the firm cause of the explosion has not been established, but it is still believed that the most likely cause of the detonation at Walden was a fragment impact. Earlier testing has demonstrated that ANFO cannot be heated to its critical (for detonation) temperature, by heat sources similar to a diesel fire, without heavy confinement. The mass of adjacent explosive appears to be insufficient confinement, that is, the explosives do not appear to be capable of self-confinement. Furthermore, no truck/explosive configuration can be realistically conceived of providing sufficient confinement. Conversely, it has been demonstrated that there are several fragment impact scenarios that realistically could lead to the detonation of molten ammonium nitrate. However, these scenarios are extremely difficult to recreate.

Lessons learned from past accidents:

- Under certain conditions AN can detonate as in case of a fire or when strongly impacted.
- The explosions have occurred when AN was contaminated by organics and/or when AN was heated in an enclosed space which caused pressure build-up.
- Very few, if any at all, accidental explosions have occurred involving AN fertilizer grade of EU quality and with high density.
- No accidental explosions have been reported for AN-based fertilizers with less than 80% AN.

Security

Theft and misuse

It is well known that AN, CAN and urea, in mixtures with other compounds like oil and sugar, etc., have detonation properties [3]. They have been used in several attacks all around the world. During the 1990’ies, these raw materials were used in several car bomb incidents in the UK and especially in London. During that same period, there were also numerous potential incidents that were discovered and stopped in time. The last known incident was in London in April 2004 where theft of 500 kg of fertilizer grade AN was discovered. The bag was found and kept under observation for several weeks and many people were arrested.

The trade of real explosives, UN Class 1, is well controlled and it is practically impossible to achieve large amounts of explosives for illegal actions. Less than 2 percent of the bombings in the United States involve commercially manufactured high explosives. Globally, AN is often the preferred compound to achieve an illegal explosion on a large scale.

The distribution of industrial grade AN is a “closed loop”, i.e. normally direct from the manufacturer to the user of the product, and therefore under good control from theft. AN fertilizer grade, however, will pass through a wide distribution network on its way to the farmer, and can more easily be stolen. There are currently regulatory and industry initiatives to improve the control of the distribution and storage of such fertilizers. If used for illegal applications, the fertilizers will have to be reworked to obtain an appropriate charge, depending on the properties of the material. The quality of the fertilizers made for
the European market is the most stringent, with special consideration for the inherent safety characteristics of the material.

Unfortunately, the knowledge for turning a chemical, including nitrate materials, into a bomb is available through many sources, especially on the Internet. Considerations about the critical diameter and sensitivity for ammonium nitrate are not a concern; there will always be ways to make a charge that can detonate. It will be more difficult if a large amount of inert material is added to the AN.

Taggants
Misuse of AN and explosives always raise concerns about what can be done to prevent these horrific events. Following such atrocities, there have been calls to require taggants in commercial explosives, even though most of the improvised explosive devices, which are the choice of criminals, were not made with commercial high explosives. Taggants can refer to two types of marking technologies.

- Detection taggants are used to detect explosives before detonation.
- Identification taggants are used to trace explosive materials to their source.

By International convention certain types of plastic explosives have to contain a small amount (0.1 to 0.5%) of an organic compound as detection taggants. Without detection agents, plastic explosives are difficult to detect. These taggants are organic substances and since they have to be added in amounts from 0.1 to 0.5% they cannot be added to ammonium nitrate without turning it into a Class 1 product [7]. While the technology of detection taggants has been successfully implemented in plastic explosives, a number of technical challenges remain to be resolved before identification – or post-blast – taggants can feasibly be deployed.

Identification taggant technology has consistently centered on the “Microtaggant,” which is a chip made of multiple layers of plastic and metal. These chips theoretically could be placed in AN and explosive products with the hope that investigators could find them at a bombing crime scene. The environmental impact resulting from the introduction of an estimated 1000 t (in USA) of plastic and metal taggants into the surroundings every year has yet to be evaluated. In fact, the addition of such particles to ammonium nitrate would disperse these gritty fragments throughout the environment.

A taggant from a criminal bomb would not be distinguishable from those taggants at the scene resulting from the legitimate use of explosives and from use at nearby farms. The finding of multiple taggants could complicate the investigation. So, until new and totally different taggant systems have been developed, the use of exiting taggant systems is of limited value.

In addition there is also ongoing work to develop suitable “sniffers” that can detect ammonium nitrate but to our knowledge this has not been successful.

Legislation, regulatory affairs

Today most inorganic nitrates are classified as Class 5.1 (Oxidizers). Due to availability, most focus from authorities is on fertilizer grade products. AN for technical applications (e.g. explosives) is better controlled in many countries. Regulatory updates are quite frequent and some examples are listed below.
UN
International Transportation Regulations for Dangerous Goods: ADR / RID / IMDG\(^1\)

Classification: of ammonium nitrate; 5.1 Oxidizing substances
- AN solid, non fertilizer: UN 1942
- AN fertilizer: UN 2067
- AN solution: UN 2426

Documents require: Bill of lading, emergency instruction, drivers training certificate

On the basis of the UN Recommendations on Transport of Dangerous Goods a new chapter has been added to ADR / RID / ADNR. This is valid from the 1st of January 2005 forward and begins at expiration of the usual six-month's transition period on 1.7.2005.

The new chapter of ADR / RID / ADNR contains special rules for dangerous goods with high hazard potential. This list of “high consequence dangerous goods” contains products such as explosives, toxic materials, flammable gases, other materials e.g. ammonium nitrate fertilizer in bulk above 3000kg. These High Consequence Dangerous Goods have the potential for misuse in illicit activities and may, as a result, produce serious consequences such as mass casualties or mass destruction.

Companies engaged in the transportation of High Consequence Dangerous Goods have to develop a security plan and to comply with a long list of special requirements.

Europe
EU [18]
Seveso II Directive has been revised:
- 5000 t / 10000 t: AN-based fertilizers that undergo self-sustaining decomposition
- 1250 t / 5000 t: AN fertilizer that satisfy the EU detonation test
- 350 t / 2500 t: Technical AN + AN solution above 80% concentration
- 10 t / 50 t: Reject AN material, returned from customers etc

CEFIC (European Chemical Industry Council) [17]
Has issued revised guidelines for transport of High consequence dangerous goods based on recommendations from UN.

EFMA (European Fertilizer Manufacturers Association) [13]
Has issued several new and/or revised recommendations relating to manufacture, storage and handling of nitrate containing products.
- Product stewardship program for fertilizers
- DO'S AND DONT'S. Safe Storage of Fertilizers Containing AN
- Guidance For Handling Non-Conforming Ammonium Nitrate Based Fertilizers in Distribution chain

France

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\(^1\) ADR; The European Agreement concerning the International Carriage of Dangerous Goods by Road
RID: European regulations on transport of dangerous goods by rail
AND: European regulations on transport of dangerous goods by inland waterways
Revision of storage permits, recalculation of separation distances, stack sizes etc.

UK
Safety: Recent measures sufficient (DEFRA), will defend AN as important fertilizer
Security: Will dilution of AN provide better security against terrorism?
For both security and safety:
  • All fertilizer grades AN on UK market must pass resistance to detonation test
  • Users of AN such as in mining and quarrying can apply for exemption certificates from the Health and Safety Executive
  • Proposal for new/revised guidelines for storage of AN for explosives

Germany
Safety of AN-products is not a major issue since AN Fertiliser with Nitrogen content above 28% is not allowed. CAN is considered safe, at least from a storage point of view.
In Germany, the storage regulations for AN has been very strict for many years:
  • Locked suitable building.
  • Minimum distances to buildings used regularly by humans and to public traffic routes.
  • Max. 25 t of bagged material in one stack/box.
  • Stacks/boxes have to be separated by concrete walls of 2,92 m thickness.

Spain
Very strict regulations for technical grade AN for many years (e.g. police escort required for transport).

Australia [16]
Definition: Security Sensitive Ammonium Nitrate consists of ammonium nitrate alone and/or ammonium nitrate mixed with other substances, such that the proportion of ammonium nitrate exceeds 45 per cent. Proposal also includes other security sensitive products (inorganic nitrates, emulsion matrix etc.) An ‘authority’ would be required to import, manufacture, store, transport, supply, export, use or dispose of SSAN.
Persons seeking an ‘authority’ will be required to:
  • Demonstrate a legitimate need for access to SSAN
  • Provide safe and secure storage and handling procedures
  • Report any loss, theft, attempted theft or un-explained discrepancy to the regulatory authority and police in each jurisdiction
  • Undergo background checking and be a minimum of 18 years of age and provide verifiable proof of identity, and if a company, details of the company

Background checking must include police and Australian Security Intelligence Organization (ASIO) checks.

Australian farmers use around 80,000 t of SSAN. On this basis, it can be assumed that the maximum cost of delivering the SSAN Compliance Grant Program (i.e.: Grants to all 18,000 farmers) would be in the order of A$99M.
5.4 USA

“Safe Explosives Act” [10]
Has been revised, and now much stricter regulations apply to those involved in purchase, handling, transportation and use of explosives. As the use of nitrate-based fertilizers is quite unregulated many believe these products should be even better controlled.
Congress enacted the Safe Explosives Act (“SEA”) on November 25, 2002 as part of the Homeland Security Act. The purpose of the SEA is to prevent terrorists and criminals from obtaining explosives. The SEA imposes a permitting, licensing and background clearance requirement on all users, manufacturers, dealers and importers of explosives. ATF is the agency responsible for enforcement of the SEA.

“Ammonium Nitrate Security Act”[11, 14]
A bill to prohibit the importation, manufacture, distribution, or storage of ammonium nitrate compound without a license, to prohibit the receipt of ammonium nitrate compound without a license or permit, and for other purposes.
- Sellers of detonable nitrate fertilizers to be licensed, and purchasers to obtain permits
- Facilities and individuals storing nitrate fertilizers to follow safety and security regulations promulgated by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)
- Immediate reporting to ATF of theft or loss from manufacturers, distributors or retailers

“Secure Handling of Ammonium Nitrate Act of 2005” [12, 14]
A bill to authorize the Secretary of the Department of Homeland Security to regulate the production, storage, sale, and distribution of ammonium nitrate on account of the prior use of ammonium nitrate to create explosives used in acts of terrorism and to prevent terrorists from acquiring ammonium nitrate to create explosives.
Congress finds the following:
(1) Although ammonium nitrate is an important fertilizer used in agricultural production, in the wrong hands, ammonium nitrate can be used to create explosives and was so used in terrorist attacks conducted in Oklahoma City, Bali, and Istanbul.
(2) The production, importation, storage, sale, and distribution of ammonium nitrate affect interstate and intrastate commerce.
(3) It is necessary for the Secretary of the Department of Homeland Security to regulate the production, storage, sale, and distribution of ammonium nitrate on account of the prior use of ammonium nitrate to create explosives used in acts of terrorism and to prevent terrorists from acquiring ammonium nitrate to create explosives.

South Carolina and Nevada are the only states that by March 2005 restrict the sale of ammonium nitrate. Oklahoma instituted ammonium nitrate regulations in April 2005.

The Fertilizer Institute’s (TFI) has launched “America’s Security Begins with You,” ammonium nitrate awareness campaign

IME has issued SLP-27, Security in Manufacturing, Transportation, Storage and Use of Commercial, Explosives. SLP-27 provides a comprehensive set of best practices for security in commercial explosives operations.
Conclusion

Over the last years ammonium nitrate (AN) has gained increased attention from authorities. This is caused because of various accidents, and increased misuse for bomb making

- Fires that have resulted in an explosion seem to have one thing in common: Some sort of contamination, fire over a period of time and then explosion
- Thermal tests with AN (and ANFO) have shown that they can not be heated to its critical (for detonation) temperature, by heat sources similar to a diesel fire, without heavy confinement
- It has been demonstrated in various reports that there are several fragment impact scenarios that realistically could lead to the detonation of molten explosives and most likely also molten AN. However, these scenarios are extremely difficult to recreate in real fire scenarios.
- In the past the main concern has been on the safety of manufacture, transport, storage and use of ammonium nitrate
- Today security issues are becoming more and more important, and authorities are focusing on ways to prevent misuse of AN and other easily available products with high risk potential
- UN has defined a list of high consequence dangerous goods that have been adopted by ADR/RID and revised regulations for transport of such materials have been issued.
- As a variety of materials can be misused, authorities are seeking ways either to safeguard the handling chain or to restrict their availability (Australia, USA, UK, others)
- Several countries have banned the use of ammonium nitrate as a fertilizer
- Other countries have introduced new ways of classification based on the risk potential and the ease by which a given product can be “treated” to make an explosive device.

References

1 Bauer, A., King, A. & Heater, R., 1982. “The explosion hazards of Ammonium Nitrate and Ammonium Nitrate based fertilizer compositions”, The Canadian Fertilizer Institute and Contributing Bodies, The Department of Mining Engineering, Queen’s University, Kingston, Ontario


10 Safe Explosives Act http://www.atf.treas.gov/explarson/safexpact/


13 European Fertilizer Manufacturers Association, EFMA. www.efma.org

14 The Fertilizer Institute, TFI, (USA). www.tfi.org

15 The Institute of Makers of Explosives, IME, (USA). Web site: www.ime.org


18 European Union, EU: http://europa.eu.int/index_en.htm

19 http://www.lci.fr/news/france/2003/0,,1394620-VU5WX0IEIDUy,00.html

20 http://news.bbc.co.uk/2/hi/middle_east/3498851.stm


22 http://static.highbeam.com/u/unitedpressinternational/may242004/romaniantruckexplosionkillsatleast16/

23 http://www.globalsecurity.org/military/world/dprk/ryongchon-imagery.htm
