Incident

Risk and safety management of ammonium nitrate fertilizers: keeping the memory of disasters alive

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This paper is aimed at keeping the memory of disasters alive, assuming that risk awareness and implementation of safety measures are facilitated by case histories. There have been several accidents and a few disasters in the ammonium nitrate fertilizer industry, and it is worthwhile to review these from time to time, beyond the regulation and practice changes which they triggered.

BASF plant, Oppau, 1921

On 21 September in 1921, two consecutive explosions occurred in a silo in the BASF plant in Oppau, Germany, creating a 20m deep, 90x125m large crater. The entire area was covered by dark green smoke and there were several additional fires and small explosions. At the time of the event 4500 tonnes of ammonium sulphate nitrate compound fertilizer (ASN) were stored in the silo. The explosion killed 507 people and injured 1917. The plant and approximately 700 houses nearby were destroyed[21].

The introduction of a new, spray drying process was one of the reasons for the explosion. This particular process modified some physical parameters of the ASN such as the density, the crystalline structure and humidity. Therefore the ASN, dried with the new process had fractions with higher ammonium nitrate (AN) content and this inhomogeneous mass was stored together with the ASN that was dried with the old process. Due to higher AN content, lower density, lower water content (reduction from 4% to 2% with the new technique) and changed crystalline structure, the accumulated fine fraction was explosive. In addition, the operational issue was that the storage in large quantity lead to caking. The anti-caking procedure at that time was to use dynamite! It was repeated over 20,000 times with no large explosion before that day. Similar risky procedures were at the origin of other accidents in Kriewald in Germany in 1921 (26 July)[25] and Tessenderlo in Belgium in 1942 (29 April)[26].

Texas City disaster, Texas, 1947

Another tragic accident, involving two ships loaded with thousands of tonnes of ammonium nitrate and sulphur, occurred on 16 April in 1947, on the ship SS Grandcamp docked in Texas City, Texas, USA[2]. In that event, 500 people died and 3500 people were injured, which was 25% of Texas City's population at the time. Also, serious damage was caused in the nearby refineries, ripping open pipes and tanks of flammable liquids and starting numerous fires. The blast

Figure 1: Oppau – The consequences of the explosion[1]

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occurred when a small fire, perhaps caused by a cigarette, broke out on the Grandcamp. There were two additional factors that worsened the situation of the first explosion. First of all, in the ensuing chaos, nobody payed attention to the ship docked about 200m away (SS High Flyer) which was also loaded with sulphur and thousands of tonnes of ammonium nitrate and exploded sixteen hours after the first explosion on the Grandcamp. The first explosion ignited the High Flyer. However attempts to release the ship from its moorings and thus reduce potential damage in the event of an explosion failed. The second factor that contributed to the high number of fatalities was the fact that large numbers of people were allowed to stay in the close vicinity of the fire and therefore could not escape from the subsequent explosion.

Another ship accident occurred in the French port Brest in 1947 (28 July) — an explosion occurred after a large fire, killing 26 people and injured 500[20].

AZF site, Toulouse, 2001

Exactly 80 years to the day after Oppau, a severe explosion occurred in a temporary storage for off-specification and downgraded ammonium nitrates at 10.17 a.m. on 21 September in 2001 at the AZF industrial site in Toulouse, France. The detonation, felt several kilometres away, corresponded to a magnitude of 3.4 on the Richter scale. A 7m deep crater (65x45m) was observed outside the plant and a large cloud of dust and red smoke drifted to the north-west. The accident resulted in 30 fatalities, with up to 10,000 people injured and 14,000 people receiving therapy for acute post-traumatic stress. The cost was estimated by insurers to be in the region of 1.5 billion Euro[3].

The direct causes of the explosion of the storage of roughly 400 tonnes of off-specification ammonium nitrate (AN used for technical and fertilizer grade) in the plant have still not been officially established. Investigators, representing the company and the legal authorities, have not yet agreed on the origins of the accident. An appeal has been made and the trial will be reopened in 2017. However, the final legal expert report concluded that the explosion occurred due to an accidental combination of sodium dichloro-isocyanurate and downgraded ammonium nitrate. The key controversial element is the ignition source of the stored AN. Investigations showed that its origin was neither a fire nor an initial explosion followed by the mass explosion[4].

Figure 2: The area affected by the explosion (Source: Archives Grande Paroisse[17])

Regardless of these uncertainties, the following important findings could be recognised[5]:

- The safety report of the AZF factory did not take into account the off-specification and downgraded ammonium nitrate waste storage since it was not regulated (no Seveso classification). Their higher sensitivity was not recognised, and their waste status did not help.
- Although the explosion risk of AN was known, fire risk was considered more probable in open storage operations, and as the reference scenario by the industry. The safety report did not describe each possible accident scenario.
- Urbanisation had spread out considerably near the site since the launching of the chemical activities after World War One. At the time of the accident, the chemical site was surrounded by business parks, hospitals, and dwellings[6].
- Twenty-five subcontracting companies worked continuously on the site. Three different subcontracting companies worked in the warehouse (the downgraded AN was picked up, unloaded and removed by them) and another subcontractor carried out the maintenance of this warehouse. The legal expert assumption is that the waste of some chlorinated compounds manufactured in the other part of the plant was inadvertently mixed with other AN waste and poured on the AN waste storage.
- The storage building involved in the accident did not have nitrogen oxide detectors although other facilities were equipped with such sensors around the facility.

West Fertilizer Company, West, 2013

More than 60 years after the Texas City disaster, a significant explosion of fertilizers shook the inhabitants of Texas again. On the evening of 17 April 2013, a fire of undetermined origin broke out at the West Fertilizer Company in West, Texas, USA. After their arrival, firefighters started to fight the fire when a detonation occurred. Although the firefighters were aware of the hazard from the tanks of anhydrous ammonia, they were not informed of the explosion hazard from the 30 tonnes of fertilizer grade ammonium nitrate with a 34 percent total nitrogen content, which was stored in bulk granular form in a 7 m high bin inside the wooden warehouse[7]. As a consequence of the explosion, the shock wave crushed buildings, flattened walls, and shattered windows. Twelve firefighters and emergency responders were killed along with three members of the public who were volunteer firefighters. The accident also resulted in more than 260 injured victims, including emergency responders and members of the public, and more than 150 buildings were damaged or destroyed in the accident. The cause of the initial fire remains unknown; nonetheless, the US Chemicals Safety Board investigated the factors that likely contributed to the intensity of the fire and detonation of the ammonium nitrate fertilizer. They found two possible scenarios as following:

- contamination of ammonium nitrate with materials that

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served as fuel;
- the nature of the heat buildup and ventilation of the storage place.

The scenarios are presented in the final investigation report with further analysis on the detonation[12].

A similar accident occurred in a smaller facility (an agricultural storage building with 3-5 tons of AN fertilizer in a big-bag) in 2003 in Saint-Romain en Jarez (ARIA No. 25669) with 23 firefighters injured.

In the light of the facts above, the common pitfalls are:

- initial lack of knowledge and remaining low awareness about the hazardous characteristics of fertilizers (inherent explosive risk);
- no hazard identification and poor risk assessment (use of explosives for anti-caking procedures, contamination with organic materials, off-specification and downgraded higher sensitivity);
- inadequate risk management for storage and transportation of ammonium nitrate;
- deficiencies in the emergency response planning and management;
- deficiencies in the learning from past accidents;
- pitfalls in the regulation;
- lack of adequate land-use planning restrictions.

Based on the findings and the causes of the accidents, the following recommendations can be identified:

BASF, Oppau

- The assumption that past successes will work again in the future takes no account of the consequences of failure. Safety is more than reliability. Risk management scope should be enlarged and usual practices should be questioned from different perspectives.
- Although the incident occurred in 1921, it highlights management of change issues. For example, the influence of the change on the sensitivity of the product had not been realised. Hazard identification and risk assessment should be carried out before making changes in the process or the physical properties of the handled substances.
- There was lack of knowledge of the characteristics of the ASN fertilizer. Overall knowledge of the dangerous substances used in the facility is crucial. This knowledge should be updated by monitoring scientific work. The safety behaviour of materials should be studied beyond the product quality knowledge.

Figure 3: West explosion aerial photo (Source: Shane Torgerson)

Texas City disaster

- Adoption and implementation of procedures and instructions for safe operation is crucial.
- Lack of concern with failure or disaster was a big problem in this case, as no risk was estimated. Also, no-one seemed to be aware that the fertilizer was hazardous[22]. The scientific opinion about fertilizer was that it was inert and could not catch fire.
- Large numbers of people were gathering around the dock to see what was happening, which highlights the poor knowledge of the nature of the fertilizer and the fire and explosive risk. Information to the public is an emergency management and educational tool that can help in preventing more severe consequences in case of an accident. The issue with controlling the public at major emergencies and the role of social media is a new version of this problem.
- Even though risk zones were formed around the dock, the effect of a potential accident was underestimated. Apparently 20% of the industrial area was estimated to be exposed to a fire, meanwhile the two explosions and resulting fires inflicted damage to 90% of the area. It is imperative to maintain appropriate safety distances between establishments and the residential area to prevent major accidents or mitigate the consequences.
- Safety culture as a concept was not around in 1947 and employers and their workers also in the neighbouring refineries and chemical factories had only basic knowledge of the hazards.
- Texas City was a boomtown in those years and the priority appears to have been economic growth over safety. Appropriate balance should be created between economic development and process safety. Also, land-use planning was not considered as a priority.

AZF, Toulouse accident

- Given the variety of ways in which ammonium nitrate can cause an accident, there are many accident scenarios that operators must consider. The site risk assessment should include all possible major accident scenarios including low probability high consequence ones. It should address domino effects relating to the dangerous substances stored, transported or produced on-site.
- Operators should have full knowledge of the inherent hazards associated with the handling and storage of ammonium nitrate fertilizer, especially off-specification and downgraded fertilizers and technical grade, and regularly review operating procedures to ensure they are being followed.

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- The ammonium nitrate storage facilities were not directly managed by the AZF company employees but by subcontractors, whose knowledge of the products and the site could sometimes be incomplete. When contracting out a technical process to a third-party the operator should ensure that all risks in the area and associated with the contractor's work have been identified and controlled[8, 9].
- In order to cause as low impact as possible on the population, land-use planning or urban development control zone limits should be applied, even retroactively.

West, Texas

- The only scenario which was considered as dangerous in the storage facility was the accidental release of anhydrous ammonia. Conducting comprehensive hazard identification, analysis and risk assessment where hazardous substances are stored or handled is a basic requirement when operating dangerous establishments. For small and medium enterprises lacking expertise, stricter regulation should be applied and enforced.
- Separation of combustible materials from organic substances is needed to reduce potential conflagration and explosion once an ammonium nitrate fire has started.
- It is unacceptable for a site storing ammonium nitrate in bulk quantities to operate without proper fire prevention, protection and mitigation measures.
- Development should be restricted around sites that handle or store ammonium nitrate, and in the case of existing development in close proximity to the site, appropriate prevention and protection measures should be in place to reduce the risk as much as possible.
- Local authorities should be aware of the dangers associated with ammonium nitrate hazards and oversee the sites in their jurisdiction as appropriate to the level of risk. Even sites with relatively small quantities can be significant risks if they are in close proximity to human development[4].
- Local responders should also be aware of all ammonium nitrate storage sites in the area and the maximum quantities that might be present. They should be trained on how to fight ammonium nitrate fires in accordance with the current best practice.

Changes in the legislative system following these events

1. After the accident at BASF in Oppau, use of explosives to loosen solidified salt was forbidden. Treatment of ASN with anti-caking additives to prevent caking is required.
2. After Texas City disaster the following recommendations[1] were made:
   Anyone dealing with or handling ammonium nitrate should be fully advised of the hazardous nature of the chemical and of the proper methods of storage and handling. Also, these materials should be stored only in brick or fireproof sprinklered buildings on skids or pallets on concrete floors with at least one foot clearance from walls. Storage should preferably be in separate fire divisions from highly combustible commodities or well-segregated. Spilled material from broken bags must be re-sacked immediately and, to avoid contamination to the contents, must not include floor sweepings.
3. Following the AZF accident, a significant modification in the Seveso II Directive[18] was introduced and the categories of fertilizers were extended under this legislation to cover off-specification and downgraded AN fertilizer and technical grade. Furthermore, in France, the accident itself initiated a review of the safety studies to better address low probability high consequence scenarios[10]. It also lead to the development of a new land-use planning approach and the implementation of governance tools at the level of company (involvement of workers and subcontractors) and at the level of the territory (involvement of stakeholders such as neighbours, public parties)[11].
4. West, Texas
   The investigation was completed and the final investigation report with a list of recommendations was published on 28 January 2016 by the US Chemical Safety Board[12]. In the aftermath of the accident, President Barack Obama issued EO 13650 (Executive Order), "Improving Chemical Facility Safety and Security"[23]. By the second anniversary of the accident, in April 2015, three bills regulating storage and inspection of ammonium nitrate and a fourth bill to create a state-wide notification system alerting the public about any hazardous chemical leak at a manufacturing facility were introduced in the Texas Legislature. Also, the NFPA 400 Hazardous Materials Code was reviewed after the accident[19]. Furthermore, in December 2014 the OSHA Directorate of Enforcement Programs issued investigatory and citation guidance on elements of the OSHA standard 29 CFR 1910.109(i) on explosives and blasting agents[24]. Because the current version of 1910.109(i) has limited enforcement in some areas – and because NFPA 400 (2016 Edition) includes updated provisions, the US Chemical Safety Board states in the investigation report that OSHA should update 1910.109(i) to include requirements similar to provisions in NFPA 400 (2016 Edition). In total, ten organisations made recommendations on the accident. These recommendations were published in the investigation report on the US Chemical Safety Board website.

Conclusion

It is a common practice that, following a major accident, a thorough investigation is carried out with great involvement of experts in the field, creating reports and listing recommendations and lessons learned. Yet, history shows that there are difficulties in learning those lessons, in discovering the hidden remaining risk to anticipate some atypical scenarios[13] or the next accident, or take on board the recommendations. Therefore, similar accidents reoccur from time to time with similar, but also new recommendations. However, some of the new recommendations in accident investigation reports do not take into account lessons learned or recommendations made from past accidents. Whatever the technical scenario involving AN[16], some flaws are found in safety management, regulation, oversight and land use planning. The legislation may be modified and some standards are changed over the years but they are not implemented everywhere with the same pace and enforcement. The

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inherent risks of AN fertilizer are still high[14] which require further regulation especially for small and medium enterprises. It may be a solution to introduce more hazard than risk based standards on the storage of AN fertilizers to prevent further accidents. This should then allow the storage of, for example, off-spec material and accidental contamination to be included in the requirements.

After an accident, the memory fades and people tend to forget some lessons or the momentum to implement corrective actions. As repeatedly stated by Trevor Kletz[15], "organisations have no memory, only people have", it is therefore imperative that process safety experts have memory and remember these major events. Similar or new triggering initiators can happen everywhere, and therefore, learning from past mistakes remains a requisite to avoid a recurrence or the next disaster. Reducing exposure by reducing risk at source and vulnerability by using land use planning approaches remain parts of a global strategy.

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