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Lessons to be learned from an analysis of ammonium nitrate disasters in the last 100 years

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HIGHLIGHTS

- Root causes and contributing factors from ammonium nitrate incidents are categorized into 10 lessons.
- The lessons learned from the past 100 years of ammonium nitrate incidents can be used to improve design, operation, and maintenance procedures.
- Improving organizational memory to help improve safety performance.
- Combating and changing organizational cultures.

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ABSTRACT

Process safety, as well as the safe storage and transportation of hazardous or reactive chemicals, has been a topic of increasing interest in the last few decades. The increased interest in improving the safety of operations has been driven largely by a series of recent catastrophes that have occurred in the United States and the rest of the world. A continuous review of past incidents and disasters to look for common causes and lessons is an essential component to any process safety and loss prevention program. While analyzing the causes of an accident cannot prevent that accident from occurring, learning from it can help to prevent future incidents. The objective of this article is to review a selection of major incidents involving ammonium nitrate in the last century to identify common causes and lessons that can be gleaned from these incidents in the hopes of preventing future disasters. Ammonium nitrate has been involved in dozens of major incidents in the last century, so a subset of major incidents were chosen for discussion for the sake of brevity. Twelve incidents are reviewed and ten lessons from these incidents are discussed.

1. Lessons learned

Ammonium nitrate (AN) has been a chemical of particular interest in the wake of the explosion in West, Texas in 2013. However, the explosion in West is far from an isolated incident. AN has been involved in dozens of incidents in the last century with varying contributing factors and consequences. Incidents involving AN have occurred all over the world during all supply train stages including transportation, production, and storage of the material.

AN is usually used as either a fertilizer or an explosive material [1]. Fertilizer-grade AN has lower porosity and higher density as compared to AN intended for use as an explosive [1]. As an explosive, AN is usually mixed with fuel oil, called ammonium nitrate fuel-oil (ANFO) [2]. As a fertilizer, AN is an excellent source of nitrogen for all crops as it is one of the most concentrated forms of nitrogen fertilizer (35% N) [3]. Nearly all the nitrogen that plants use is in the form of ammonia or nitrate compounds. AN fertilizer is popular because it is very soluble in water and therefore in the soil. The nitrate can move deep into the root zone under wet conditions. Furthermore, AN and AN-based fertilizers are relatively inexpensive.

At atmospheric temperatures, AN is not considered flammable or combustible [2,3]. However, it becomes a strong oxidizing agent that can detonate under certain conditions including, but not limited to, elevated temperature, presence of impurities, and confinement [4,5]. The primary hazards associated with AN [2] can

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be classified as explosive, fire (as an oxidizer), and self-sustained decomposition (SSD) [6] hazards.

Researchers have studied the thermal decomposition of AN through the use of various techniques such as Differential Scanning Calorimetry (DSC) [7], Setaram C80 Heat Flux Calorimetry (C80) [8], Accelerating Rate Calorimetry (ARC) [8], Thermogravimetric Analysis (TGA) [9], and Adiabatic Dewar Calorimetry (ADC) [10]. Due to the variety of testing methods and equipment accuracy, there are slight differences in values reported in the literature. It has been reported that the decomposition of AN occurs at 210 °C [4], 200 °C [11,12], and 190 °C. [10]

Different decomposition mechanisms of AN have been reported in literature [9,11,13,14]. An endothermic reversible reaction can occur at relatively low temperatures, such as around 170 °C, producing nitric acid and ammonia with a heat of reaction of $-176\ \mathrm{kJ\,mol^{-1}}$ [14]. At higher temperatures, between 170 and 280 °C, exothermic irreversible reactions can occur, generating nitrous oxide and water with a heat of reaction of $59\ \mathrm{kJ\,mol^{-1}}$ [14]. If the material is suddenly heated up, explosive decomposition reactions might occur [14], generating nitrogen, oxygen, water, and nitrogen oxides.

Incidents involving AN were identified using a review of literature, google searches, and checking reports by news media. A review of these past incidents involving AN has produced a list of 12 major and illustrative incidents which were used to generate a list of 10 lessons discussed in this paper. The twelve major historical incidents are summarized in Table 1. Because the material makes for a highly effective, cheap explosive, it has been exploited at times for terrorist attacks and deliberate destruction. These incidents pertain more to chemical security than process safety, so this work will focus on incidents with non-deliberate causation.

Incidents involving AN, both accidental and deliberate, continue to occur and will continue to occur unless practices are improved at facilities across the country and the world. The two train derailments that occurred in Traskwood, Arkansas three years apart in the 1960s clearly demonstrate the potential for events to reoccur, even in the same location, if past incidents are not studied and learned from.

2. Improve zoning and city planning to create buffer zones between sites storing explosives and critical infrastructure

Explosions that involve AN frequently have a devastating impact on the nearby populations. This has occurred partially because of a lack of zoning or city planning which allowed the construction of important infrastructure like schools, hospitals, and nursing homes near facilities that handle/store AN and other hazardous chemicals. The need for such zoning and planning is exemplified by the incident in West, the final and most recent incident listed in Table 1. Local governments should work to create more robust city plans wherein "safe-distances" and "exclusion zones" are established, based on existing federal regulation and industry guidance, to prevent placing critical infrastructure near high-risk facilities. This is not however the responsibility of the local government alone. If a company realizes that there is a plan to construct a sensitive facility like a nursing home near an existing chemical facility, it should inform the local authorities of the possible risks and consequences. Regulations in the United States, Australia and other countries provide recommendations for minimum separation distances between AN stockpiles and other sensitive infrastructure, like schools, hospitals, highways, and the like. The regulations in the United States are covered under 29 CFR 1910.109, the explosives and blasting agents regulation.

3. Improve coordination and planning between facilities and local authorities to improve incident response and safety

It is imperative that a channel of communication between AN facilities, local authorities, and emergency response teams is always open and active. This can be done by incorporating a more active Local Emergency Planning Committee (LEPC) that has the potential to act as a facilitator between facilities and the community. In some cases first responders and members of the effected communities have claimed that they either had no knowledge that a facility existed, or that they were unaware of the hazards posed by the facility [15]. Communication will help members of the community respond and make informed decisions when responding to incidents at nearby facilities. Improved communication will also help the facility to determine whether or not they are in compliance with state and federal regulation, inform the community of relevant hazards, and share information on the facility's risk management systems. Moreover, it is recommended that facilities stay in constant communication with the local emergency responders. Companies should invite emergency responders and local governmental authorities to visit the facility to improve understanding of the company's operations and needs. This will allow the emergency responders to become familiar with the facility, identify the quantities and locations of chemicals handled by the facility, and help in identifying appropriate first response actions in the event of an incident.

4. Do not allow the public to help with or observe first response activities at HAZMAT incidents

HAZMAT incidents involve chemicals that are able to harm people and/or the environment. In most cases only personnel with special training and proper knowledge about that particular chemical know how to handle the chemical. As such, the public should not be allowed to help with or observe the response activities. As much as possible, members of the public should be required to evacuate the area once a HAZMAT situation is identified. The public usually does not have adequate knowledge of the potential hazards of the incidents, and is therefore not able to safely help respond to HAZMAT incidents. The situation may deteriorate at any time for a variety of reasons. People without training may be injured if they try to help or get too close. The approach of first responders may also be hindered by the need to get through crowds of people. Therefore it is best for the public to stay away from all HAZMAT incidents. On a practical level, it may be difficult to prevent crowds from gathering, as the public has a tendency to flock to accidents. However the attempt should be made to keep the public at a distance. Police should exercise appropriate authority in support of fire and health personnel to remove people from the scene to a safe distance.

5. Do not use steam to suffocate an AN fire

Fighting an AN has to be done with large volumes of water [15]. If smaller volumes of water are used, most of the water will vaporize to form steam. The nitrate itself can supply sufficient oxygen to sustain an AN fire; therefore, steam cannot suffocate an AN fire. The steam will increase the risk of an explosion as the temperature in the fire increases. Lees [16] states that sprinklers, fog nozzles, and fire extinguishers tend to be ineffective against AN fires. The report from the incident that occurred in Texas City involving AN in 1947, the second incident in Table 1, also states that "*Fire departments combating ammonium nitrate fires should use only water in large quantities (applied gently so as not to scatter the material)*" [15]. In an enclosed space vaporizing water may also cause an increase in pressure, which could in turn make an explosion worse.