*CHE59700 – Process Safety*

# Explosive Potential of Fertilizers: Historical Incidents, Chemical Causes, and Regulatory Response

*Sollecito, Matteo; Mosala, Sohan Joshua; Harmancilar, Orhun; Hussain, Rayhan*

*Graduate Group: G1*

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## Executive Summary

This paper explored the duality of fertilizers such as ammonium nitrate and urea, which are essential for enhancing crop yields, but have unfortunately been involved in some of the most catastrophic industrial accidents globally. The accidents analyzed in this report are the 2013 explosion at the West Fertilizer Company in Texas, the 1992 Lake Charles reactor mishap in Louisiana, and the 2020 Beirut port disaster in Lebanon. Each of these incidents underscores critical gaps in safety protocols, storage practices, and regulatory enforcement.

Analysis revealed that improper storage methods, inadequate maintenance, and lax regulatory oversight are recurring factors contributing to such disasters. Thus, the studied incidents highlight the need for stringent safety measures, including fire-resistant storage facilities, robust inspection routines, and the use of materials that withstand corrosive or hazardous environments. The analysis also examined the regulatory frameworks, such as OSHA standards, the EPA's Risk Management Program, and the Chemical Facility Anti-Terrorism Standards (CFATS), which have all been implemented in response to these disasters. Despite improvements, gaps remain in ensuring compliance, particularly in high-risk environments.

This paper ends by recommending adopting advanced monitoring systems, improving public and industry awareness, and enforcing zoning laws to keep hazardous facilities away from populated areas. It is also highlighted that international collaboration is also essential to harmonize safety standards and promote best practices worldwide, not just regionally.

By applying rigorous engineering principles, proactive risk mitigation strategies, and robust regulatory measures, the devastating consequences of fertilizer-related incidents can be minimized. This approach is essential for ensuring that society can outweigh the risks of fertilizers with the amount of benefits they can bring to the agricultural sector.

## Introduction

Agriculture, a foundation of human civilization and sustenance, has continuously adapted to scientific and technological advancements throughout history. Among the most transformative developments, the introduction of chemical fertilizers in the early 19th century completely revolutionized the way crops are produced. These fertilizers dramatically increased crop yields, supported the rapid expansion of industrial agriculture and played a critical role in addressing global food security challenges. To be concise, what they essentially allowed crop cultivators to do, was grow more food on the same amount of land. Fertilizers are either derived from natural sources, such as animal waste or plant materials or they are chemically synthesized.

No matter their benefits fertilizers have also demonstrated a more devastating potential. Many, particularly those containing high levels of nitrogen, such as ammonium nitrate and urea, possess chemical properties that make them not only beneficial for crop growth but also volatile and potentially explosive under specific conditions. Under safe and controlled use and storage these dangerous compounds can be contained, however, when they are exposed to heat, pressure, or ignition sources they can become extremely hazardous. Additionally, the same attributes that make these chemicals powerful agricultural tools can also render them attractive for misuse in terrorist attacks, by having the ability to be repurposed into explosive devices. This dual-use nature has highlighted the need for vigilant management, regulation, and safety measures.

Over the past century, the world has witnessed numerous tragic incidents involving fertilizers. These events have resulted in catastrophic loss of life, environmental devastation, and extensive property damage. Notable examples include the 1947 Texas City disaster in the United States, the 2013 explosion in West, Texas, and international incidents such as the 2020 Beirut port explosion in Lebanon, among others. What this all underscores is the importance of

understanding the risks associated with these substances. These disasters have required for regulatory agencies to enforce stricter mandates, improve safety protocols, and ensure that the greater public is aware of the inherent risks when handling these materials.

To that end what this paper hopes to provide is a comprehensive overview of significant fertilizer-related explosions around the world, analyzing the specific chemicals involved, their chemical properties, and the root causes of these incidents. By examining these cases, this paper aims to uncover patterns and common factors that contribute to such disasters. Furthermore, this paper will explore the regulatory frameworks, particularly in the United States, designed to minimize the likelihood of similar occurrences. By doing this the paper will ultimately create an understanding these incidents and the lessons they offer as they are crucial for preventing future tragedies from such important agricultural components.

## Objective:

The problem at hand lies in the dual-edged nature of fertilizers, which, while indispensable for modern agriculture, pose significant safety risks due to their hazardous chemical properties. The objective is to analyze key incidents involving fertilizers, identify the chemical and logistical factors contributing to these events, and evaluate the effectiveness of U.S. regulations aimed at mitigating such risks. To be more specific, this paper will focus on the chemical properties of ammonium nitrate and urea. In addition, the analysis will investigate why these chemicals are so explosive under certain hazardous chemical conditions, and the mechanisms by which these chemicals become explosive. The significant worldwide incidents that this report will outline is the 2013 West Fertilizer Company explosion in Texas, the 1992 Lake Charles Urea HP Reactor Explosion and the 2020 Beirut Explosion. Specific attention will be brought to identify any

common factors leading to fertilizers explosions including poor storage conditions, lack of regulation enforcement, inadequate safety protocols, and accidental ignition sources. Reviewing U.S. regulations such as CFATS and OSHA guidelines will also be important in this report.

## Literature Review

Ammonium nitrate is the most common chemical widely used in fertilizer industry. Normally it is an oxidizer but when exposed to heat, shock, or contamination with combustible materials, it can undergo rapid decomposition, leading to violent explosions [1]. Improper storage and handling can exacerbate these risks, as seen in catastrophic incidents like the Beirut port explosion in 2020 and West Fertilizer explosion in Texas in 2013. Consequently, strict safety protocols and regulations are essential to mitigate its dangers.

As previously mentioned, the accident that occurred in 2013 at the West Fertilizer facility in Texas was one of the deadliest accidents which has ever occurred in the chemical industry. According to the CSB (Chemical Safety Board), the catastrophic blast claimed the lives of 12 emergency responders and 3 civilians. Over 260 people are injured, many needing long treatment and hospitalization [2]. The West Fertilizer facility was destroyed and eventually proclaimed bankruptcy. Many, nearby community buildings were also decimated, and many other residences took irreparable damage. In the incident, ammonium nitrate exploded because of the intense heating caused by the fire started in the facility. The exact reason why the fire started is still unknown. Emergency responders quickly arrived at the location but were mostly unaware of the explosion hazard. Eventually, according to the literature, 40 to 60 tons of ammonium nitrate exploded, causing all the consequences [2]. Following investigation, the CSB found many issues with the regulations ranging from population settling near a fertilizer plant and lack of

emergency response training [2]. OSHA and EPA introduced many new regulations following this accident. The CSB showed that by an executive order from the President (Barack Obama) at the time and collective actions from various regulatory agency sources, many new updates that have impacted the national and local levels were made, such as the establishment of the RAGAGEP [2,3].

Another, more recent deadly accident was also researched, where the focus was on the improper storage and handling of ammonium nitrate. The Beirut explosion occurred in Port Beirut in Lebanon, on the 4th of August 2020. In the accident, the literature reported that more than 218 people died and more than 6500 people were injured [4]. Many of the nearby buildings were completely ruined and approximately 300,000 people become homeless. The Accident occurred due to the detonation of nearly 2750 tons of ammonium nitrate that was confiscated from a ship and stored in the port approximately for 6 years. It was also stated in the literature that in storage there were 15 tons of fireworks nearby, and several other hazardous chemicals [4]. These events together with the poor emergency response to the initial fire, caused maybe one of the most fatal plant accidents in the industry. [4]

The other dangerous chemicals that are used in fertilizer industry and researched in for this paper is urea. It is mostly used as a nitrogen fertilizer, having the highest nitrogen concentration compared to the other nitrogen fertilizers, making it a very low cost and appealing fertilizer. Being an explosive chemical and produced from ammonia and $CO_2$ under very high pressure, the production process is a high-risk safety concern. Literature research found that there are at least 100 incidents in the last 25 years with consequences ranging from near misses to fatalities [5,6]. In addition, the literature showed that most of these incidents are related to

leaks caused by the high-pressure nature of the process, corrosivity of ammonia, ammonium carbamate (an intermediate in the production of urea) and human error [5][6].

The final disaster researched for this project focused on a Urea focused tragedy. On July 28th of 1992 in a plant located in Lake Charles, Louisiana and owned by Arcadian's Corporation an explosion injured 6 Arcadian and 4 nearby other company employees and resulted in the destruction of the facility. The root cause of the explosion was found to be various leaks which occurred in the corrosion-resistant stainless-steel liner of the reactor. As a result, the reactor exploded during the normal operation [7].

The final literature review that was conducted was one on the safety regulations in place due to the various concerns around ammonium nitrate and urea. As a results of these incidents, OSHA has now regulated ammonium nitrate manufacturing and storage conditions under 29 CFR 1910.119 and 29 CFR 1910.109 (also 27 CFR 555.220 for bulk storage). Manufacturing and storage regulations now give details such as the upper temperature that shouldn't be exceeded during the handling (170°C) and chemicals that chemicals it should be kept away from. The literature also explained the proper emergency procedures under 29 CFR 1910.120 [8]. When conducting research under CFATS, it was found that CISA requires companies to make reports to them if they have stored ammonium nitrate with 0.2 percent combustible substances at quantities higher than 400 lbs. (for theft risk) or 5000 lbs. (for release risk) at any concentrations. If it stores solid ammonium nitrate with nitrogen concentrations higher than 23%, at quantities higher than 2000 lbs., at concentrations higher than 33% (ammonium nitrate concentrations, not nitrogen), it was found that CISA also requires companies to report this due the improvised explosive risk [9,10]. For urea, however, there is not any specific OSHA regulations, and it is not

present in Appendix A of CFATS regulation since urea is generally considered as low hazardous chemical. In this case, it was found that urea is regulated through 29 CPR 1910 [11].

## Analysis:

Fertilizers, especially those with ammonium nitrate, have been linked to multiple devastating explosions globally. These events highlight the urgent necessity for strict safety protocols and rules regarding the handling and storage of these materials. This study reviews three major events: the 2013 explosion at West Fertilizer Company in Texas, the 1992 Lake Charles Urea HP reactor blast, and the Beirut explosion in 2020. Every instance is examined to understand the core reasons, engineering concepts at play, pertinent safety protocols, and applicable U.S. regulations designed to avert similar events.

### 2013 Texas Explosion at West Fertilizer Company

***Incident Summary:***

On April 17, 2013, a blaze at the West Fertilizer Company in West, Texas, caused a massive explosion that involved around 30 tons of fertilizer-grade ammonium nitrate (FGAN). The explosion led to 15 deaths, more than 260 injuries, and significant destruction in the neighboring area. [2]

***Chemicals Involved:***

The main chemical present was ammonium nitrate.

***Root Causes:***

Ammonium nitrate was kept in wooden containers inside a wooden building, resulting in a very combustible setting. The lack of fireproof barriers greatly increased the likelihood of an explosion [12]. Investigations also indicated that the quick advancement of the fire into the

storage region was mainly caused by the flammable materials adjacent to the ammonium nitrate. What's more is that the site's position close to dense populations greatly intensified the disaster's effects [2]. Finally, it was also found that there were inadequate inspections and obsolete safety protocols which revealed deep-rooted regulatory shortcomings.

***Engineering principles and lessons:***

From this incident it was learned that it is essential to prevent the storage of ammonium nitrate alongside combustible or reactive substances. In addition, storage buildings must be built using non-flammable materials and installed with strong fire suppression systems. Finally, locations that manage hazardous substances should be placed at a significant distance from residential and public spaces to reduce the chance of accidents [12].

***Post-Incident Regulatory Changes:***

OSHA's Process Safety Management (PSM) regulations for fertilizer-grade ammonium nitrate were enhanced. In addition, there was an enforcement of a more rigorous EPA Risk Management Plan (RMP) regulations to guarantee proactive hazard control.

***Main takeaways identified:***

What these enhanced regulations highlight is the significance of hazard assessment, mechanical integrity, and emergency response planning to avert comparable occurrences.

**1992 Explosion of Urea HP Reactor in Lake Charles**

***Incident Summary:***

On December 19, 1992, an explosion occurred in a high-pressure (HP) urea reactor at the IMC-Agrico facility in Lake Charles, Louisiana, causing major property damage and the discharge of dangerous chemicals [7,13].

***Chemicals Involved:***

The reactor housed ammonium carbamate, a urea production intermediate, noted for its high corrosiveness and functioning at elevated pressure and temperature.

***Root Causes:***

The first root cause identified is what sources have called Stress Corrosion Cracking (SCC). Essentially what this describes is the dual effect of a corrosive environment, which the ammonium carbamate provided and sustained tensile stress which the process conditions provided, leading to potential structural failure [7]. As it pertains to the 1992 incident, the reactor's pressure shell underwent SCC because of extended contact with ammonium carbamate at high temperatures. Additionally, there were an inspection shortcoming, as regular non-destructive testing (NDT) might have identified the initial signs of cracking. However in the case of this incident, it was found that many of these ests were conducted poorly, and did not represent the impending danger [7]. On top of all these failures, it was also unfortunately found that the materials used in the reactor did not have adequate resistance to the chemical environment [7].

***Engineering principles and lessons:***

Routine and effectively conducted NDTs, including ultrasonic and radiographic tests, must be required for high-pressure machinery. Furthermore, it must be imperative for companies to opt for corrosion-resistant alloys or coatings to endure harsh chemical conditions, such as the ones presented by ammonium carbamate. Finally, pressure vessels must be engineered with safety margins to account for deterioration over time or have maintenance cycles which address any material decline from repeated use [14].

***Regulatory actions and improvements:***

Even though the PSM standard was created in 1992 (the year of the incident), the Lake Charles explosion emphasized the necessity for provisions. In fact, this incident is often cited as the one of the main catalysts for the creation of an industry standard that could be followed by any manufacturer of hazardous fertilizers [7,14]. Apart from that, facilities managing extremely dangerous chemicals were also mandated to perform comprehensive Process Hazard Analyses (PHA) to recognize and reduce risks and establish strong Mechanical Integrity (MI) programs that involve regular inspections of essential equipment like pressure vessels and reactors.

***Main takeaways identified:***

This explosion incident highlighted the urgent requirement for rigorous inspection, maintenance, and design regulations in chemical processing plants, especially those dealing with high-pressure machinery and corrosive materials.

**2020 Beirut Explosion**

***Incident Summary:***

On August 4, 2020, a devastating blast shook the Port of Beirut, resulting in more than 200 fatalities, injuring many people, and leading to significant destruction of property. The main reason for this disaster was the careless storage of ammonium nitrate in significant amounts without any safety measures implemented. The ammonium nitrate was kept in a fireproofed warehouse with inadequate ventilation and no separation from flammable substances [4,15]. The precise reason for the explosion is still unknown, but the nearby presence of fireworks and

welding work probably initiated the event. Furthermore, the urban design of the storage facility, situated close to heavily populated regions, intensified the disaster's effects [4,15,16].

***Chemicals Involved:***

Ammonium nitrate, kept in significant amounts without adequate safety precautions, was the main material implicated.

***Regulatory actions and improvements:***

Chemical Facility Anti-Terrorism Standards (CFATS) regulated by the Department of Homeland Security (DHS) vigilanced on stopping unauthorized entry to ammonium nitrate storage locations and now require that companies provide precise documentation of ammonium nitrate amounts and sites if stored.

In addition, after the Beirut explosion, the EPA assessed and deemed that there needed to be more distancing of ammonium nitrate from sources of ignition, a serious adoption of secure storage methods, including keeping conditions cool, dry, and properly ventilated, and increased transparency with the surrounding community about the storage of hazardous materials [15.16].

OSHA reiterated its Explosives and Blasting Agents Standard (29 CFR 1910.109) regarding the storage of ammonium nitrate. These recommendations highlight the importance of using non-combustible materials and ensuring distance from heat or ignition sources. Inspections oversee contamination levels and temperature regulation to avoid spoilage and self-heating [4,15,16].

The National Fire Protection Association (NFPA) broadened its guidelines for ammonium nitrate within NFPA 400, incorporating more rigorous zoning, storage separation, and designs for fire-resistant storage facilities. NFPA also requires first responders to be trained on the risks associated with ammonium nitrate [15].

Finally, the federal Aviation Administration (FAA) and maritime regulations enacted steps to improve safety. The IMDG Code oversees the maritime transport of ammonium nitrate in the U.S., whereas the FAA improved air shipping regulations. These actions affected state policies, resulting in updated hazardous material zoning regulations for facilities in prominent agricultural regions such as Texas and Oklahoma [15,16].

***Key Lessons Learned:***

This tragedy stands as a clear reminder of the significance of following engineering principles and lessons. To begin with, dangerous materials like ammonium nitrate must not be kept in proximity to other reactive items or sources of ignition. Additionally, facilities need to comply with stringent fire safety regulations, which encompass adequate ventilation, fire resistance, and temperature management procedures. Finally, officials need to establish strong emergency protocols for the safe disposal of hazardous or outdated substances.

**Common Trends Found:**

In each of the three incidents, improper or hazardous storage methods were a common element. Regulatory shortcomings, such as inadequate enforcement or the lack of safety standards, intensified these dangers. Moreover, the closeness of facilities to densely populated regions intensified the effects of the disaster. To tackle these challenges, safety measures encompass regulatory alignment, the incorporation of sophisticated monitoring systems for early risk identification and educating the public along with training on managing hazardous substances. In summary, the reviewed cases highlight the disastrous risks of poorly managed fertilizers and their related chemicals. Engineering fundamentals, alongside strong regulations and proactive risk mitigation are vital for averting future disasters.

## Recommendations:

Incidents related to fertilizers, including the 2013 West Fertilizer explosion, the 1992 Lake Charles reactor mishap, and the 2020 Beirut explosion, highlight the urgent necessity for rigorous safety protocols in the management, storage, and manufacturing of dangerous substances such as ammonium nitrate and urea. These disasters highlight shared problems, such as inadequate storage conditions, insufficient equipment upkeep, and deficiencies in regulatory supervision.

To mitigate these risks, secure storage methods are essential. Facilities should be required to utilize fire-resistant materials, store ammonium nitrate separately from reactive substances, and ensure a cool, dry, and adequately ventilated atmosphere. Sophisticated monitoring systems and rigorous adherence to safety standards such as OSHA's 29 CFR 1910.109 and NFPA 400 are also essential for reducing potential risks. Consistent inspections and upkeep, including non-destructive testing and employing corrosion-resistant materials, can aid in preventing severe equipment breakdowns. Integrating safety buffers in equipment design also guarantees durability.

An effective emergency response strategy must also be at the forefront of this conversation. This must comprise of staff training, fire control systems, and regular drills that facilitate efficient accident management. Regulatory frameworks such as CFATS and the EPA's RMP Rule should be applied consistently, accompanied by regular audits and updates that reflect new discoveries. Zoning regulations must be equally adhered to, so that it is guaranted that high-risk facilities are situated away from densely populated regions.

The lessons from each incident also emphasize the significance of international collaboration to synchronize safety standards and policies. Adhering to global regulations, such as the UN’s Dangerous Goods Code, can enhance the safe transport and storage of hazardous

substances. By emphasizing strong engineering standards, implementing rigorous regulations, and cultivating a safety-oriented culture, future disasters related to fertilizers can be prevented, safeguarding individuals, assets, and ecosystems.

## Conclusions:

It has been mentioned various times in this report however it cannot be understated, fertilizers a double-edged sword. They are essential for sustaining global agriculture but also poses significant safety risks due to their hazardous chemical properties. This analysis highlighted how key incidents, like 2013 West Fertilizer explosion in Texas, the 1992 Lake Charles reactor mishap, and the 2020 Beirut explosion, reveal critical vulnerabilities in the storage, handling, and regulation of fertilizers like ammonium nitrate and urea. These disasters underline recurring themes of inadequate storage conditions, insufficient regulatory enforcement, and the lack of public and industry awareness regarding the potential hazards.

The lessons learned from each of these events emphasized the importance of rigorous adherence to engineering principles, such as designing fire-resistant storage facilities, ensuring proper ventilation, and employing materials resistant to corrosion. In addition, consistent application of safety protocols, advanced monitoring technologies, and systematic inspections are crucial as they can significantly reduce the likelihood of such catastrophic incidents and mitigate the consequences if they occur. Lastly, strong regulatory frameworks, like OSHA, NFPA, CFATS, and EPA, coupled with effective emergency response strategies were also found to be critical for mitigating risks.

The recommendations mentioned are not possible without strong international collaboration and harmonizing safety standards globally. With that cooperation, it is possible for

agricultural and industrial sectors to create a more robust framework for managing hazardous substances. What this comprehensive approach would not only safeguard human lives and infrastructure but also protect ecosystems, ensuring the safe and sustainable use of fertilizers in modern agriculture. These efforts are vital for striking that balance between the good and bad that come from using and synthesizing commercial fertilizers.

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