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Causes of Ammonium Nitrate Explosions and Handling Mechanisms – Case Study of the 2020 Beirut Lebanon Explosion

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Abstract

Ammonium nitrate (AN) is a chemical that is widely used in industry, for example as fertilizer in agriculture, explosives in military and civilian applications (for example in mining) or as a basic ingredient in solid propellants. However, as a dangerous chemical, storing ammonium nitrate can cause problems if not properly. The characteristics of AN have been studied extensively that pure AN is stable at room temperature but can explode when mixed with impurities in a closed space or in the presence of a heat/flame source nearby. This was proven in the explosion disaster at the Port of Beirut, Lebanon in 2020. This article was written using a systematic literature review (SLR) approach, where the data used came from articles published on Google Scholar, DOAJ, Emerald, Springer, and Science Direct with relevant keywords according to the topic. This article aims to evaluate and find out the causes of the ammonium nitrate explosion disaster in Beirut, as well as provide an analysis of suggestions for handling mechanisms so that a similar incident does not happen again. Evaluation of the cause of the explosion at the Port of Beirut, with fire/heat burning down part of the warehouse. An that was stored in a port warehouse mixed with other goods caused a large explosion which was started by a small fire in the warehouse. The explosion caused the death of 220 people, injured 6,500 people, formed a crater 140 meters deep and an earthquake measuring 3.3 on the Richter scale. This explosion is classified as the third most destructive urban explosion of all time, after the atomic bombs on Hiroshima and Nagasaki at the end of World War II. As a precaution, proper handling and storage of AN is required in accordance with international regulations. To reduce the potential danger of explosions without causing significant risks, this is done through an appropriate disposal mechanism.NH_4NO_3.

Keywords: Beirut Explosion; Explosion Evaluation; Ammonium Nitrate; Handling And Storage Of Ammonium Nitrate; Disposal Of Ammonium Nitrate

INTRODUCTION

In the Middle East region, Beirut is one of the oldest cities. Its civilization has existed for more than 5,000 years. Beirut is the center of the Lebanese government and plays a very important role in the economy, with most of its activities in the Badaro District, Rue Verdun, Hamra, Ryad el Soleh Street, and Achrafieh. Based on the 2007 population census, the population of Beirut reached 2.2 million, making it the fifteenth largest city in the Arab world. So there are lots of public facilities in the city, for example ports, airports and industry.

Beirut Port is located on the peninsula at the midpoint of Lebanon's Mediterranean coast which is the most important logistics center in the eastern Mediterranean region, this port is a strategic link between continents. For Lebanon, the Port of Beirut is an economic lifeline, in the form of the largest shipping and logistics inspection point, handling 82 percent of imports and exports and absorbing 98 percent of all container activity in Lebanon.

On August 4 2020, there was an explosion at the Port of Beirut in Lebanon which resulted in a major disaster and civilian casualties. The explosion caused a tragedy with enormous loss of life and infrastructure, disrupting all functional aspects of the affected communities. The explosion in Beirut is categorized as the third most powerful urban explosion of all time after the Hiroshima and Nagasaki nuclear bombs at the end of World War II. The explosion created a 140 m wide crater and an earthquake measuring 3.3 on the Richter scale on the surface, destroying everything nearby, which can be observed through satellite images before and after the explosion (figure 1). The impact of this incident killed around 220 people and injured more than 6,500 people in a short time, besides causing more than 300,000 people to lose their homes. This major disaster also damaged hospital buildings, damaged schools, commercial centers, museums and other important buildings. The economic burden caused by the explosion is estimated to exceed 6.7 billion US dollars.

This study provides the latest analysis based on a literature review after 3 years of the explosion incident at the Port of Beirut from 2020 until now and then provides an in-depth evaluation of the handling and storage of the chemical ammonium nitrate as an explosive material with a case study of the incident at the Port of Beirut, as well as suggesting actions and recommend strategies that can be used so that similar incidents do not happen again.

Figure 1. Satellite image before and after the explosion at the Port of Beirut

RESEARCH METHODS

Study area

The literature review was carried out by searching and collecting data according to the keywords: Beirut Explosion; Explosion evaluation; Ammonium nitrate; Handling and storage of ammonium nitrate; Disposal of ammonium nitrate. The sources used are articles published in Google Scholar, DOAJ, Emerald, Springer, and Science Direct within a period of 3 years (2020-2023). Reference sources from the articles obtained were then filtered to find additional studies through appropriate official reports and relevant book sources.

Procedure

This literature review uses a Systematic Literature Review (SLR) approach. This approach involves identifying, assessing and interpreting all findings related to the topic of discussion from various sources. Systematic review is a term used to refer to mixed research methodology because it uses a variety of sources, both qualitative sources and quantitative sources. In its development, it is carried out to search, collect, and then evaluate research related to a particular topic focus.

The stages of the SLR approach are broadly divided into 3 stages, namely: 1) Planning, in writing it refers to the problem formulation that has been described in the introduction section, the data used in this research is secondary data, secondary data can be obtained through literature studies, books, and related scientific articles; 2) Implementation, application of the SLR method can help source search. At the stage of searching for reference sources as a review of relevant literature, because it uses case studies of global events, we look for articles that use English (international scientific articles); 3) Reporting, the final stage in the SLR approach where

analyzing the results of the reference articles that have been searched will be made in written form which is then continued in a discussion of the literature review.
Data analysis

This literature review analyzed and identified 76 articles, excluding duplicates. Furthermore, articles related to the Beirut explosion, explosion evaluation, handling and storage, characteristics, and disposal mechanisms of ammonium nitrate are summarized to describe the explosion mechanism, analyze the causes of the explosion, evaluate the handling and storage of ammonium nitrate, as well as provide advice and provide recommendations for anticipatory follow-up actions. events that can be repeated. Articles used in this review included case reports, theoretical studies, and reviews as deemed appropriate. A total of 32 articles were deemed relevant for review.

RESULT AND DISCUSSION

Figure 2. The location of Warehouse 12 at the Port of Beirut was the point of the explosion

Beirut explosion

Based on reports, the explosion at the Port of Beirut that occurred on August 4 2020 was caused by a fire that triggered an explosion of ammonium nitrate in Warehouse 12 (Figure 2). Based on port data, the warehouse contained 2,750 tons of ammonium nitrate, which is equivalent to 1,100 tons of trinitrotoluene (TNT), which is a highly explosive chemical that is generally used as a base for fertilizer. According to records, the chemical has been stored for six years and has been neglected, the ammonium nitrate was confiscated from a ship's cargo which experienced problems with port administration payments. The cause of the fire was triggered by welding work being carried out in the Warehouse 12 area. A port employee confirmed that maintenance was being carried out on the warehouse doors before the explosion occurred, the process generating a heat source. At 17:45 local time (15:00 GMT), the Warehouse 12 area located in the port of Beirut was first reported on fire. A bag of fireworks was also in the warehouse as the first point of fire so that the heat radiation/open flame was the main factor in accelerating the spread of fire quickly throughout the warehouse that stored AN. At 6:00 p.m., the roof of the warehouse caught fire and there was a large initial explosion, followed by a series of smaller explosions that some witnesses said sounded like fireworks going off. Unfortunately, the fire started by AN eventually spread throughout the warehouse and sparked dozens of explosions and two consecutive explosions. In particular, the second explosion caused the most serious explosion. During the firefighting, the first explosion occurred at 18:07 and a second, larger explosion occurred 35 seconds later causing a colossal explosion that sent a mushroom cloud into the air and a supersonic blast wave that spread throughout the city as in figure 3.

Figure 3. Explosions at 17.55 (initial explosion) and 18.08 (orange and mushroom cloud) in Beirut port

The explosion at the Port of Beirut was also felt in neighboring countries such as Turkey, Syria, Israel and Cyprus, which are more than 250 km across the Mediterranean Sea. The impact of the explosion, apart from the loss of life of around 220 people and the injury of around 6,500 people, is that more than 70% of the buildings in Beirut were affected. At least 70,000 houses were damaged, many of them uninhabitable. Based on calculations, the magnitude of the explosion impulse was strong, causing damage to building layers up to at least a radius of 5 km from the center of the explosion (figure 4a), with different levels, which can be categorized into explosion areas and damage areas (figure 4b). The shock wave from the explosion mechanism shattered windows and collapsed the suspended ceiling at the passenger terminal of Beirut International Airport, which is 9 km south of the port.

(a) (b)

Figure 4. View of the location after the explosion at the Port of Beirut; (a) Point of detonation of ammonium nitrate and (b) explosion impact radius.

The ammonium nitrate that occurred in the explosion in Beirut was of the Nitropril type which was stored in bags. Based on the manufacturer's technical data sheet, this product is classified as a safety sensitive material consisting of white to off-white low density porous ammonium nitrate (AN), consisting of 99% AN, with a total mass of nitrogen contained of 34% specially designed for use as an oxidizer. According to the material safety data sheet (MSDS), storage requirements for Nitropril include storage that must be kept dry, away from sources of fire or heat, and preferably stored in a well-ventilated place. In the case that occurred, the lack of proper storage conditions combined with the long storage time (since 2013) in Warehouse 12 at the port of Beirut, worsened the storage conditions of the Nitropril bags. The manufacturer warns users that nearby explosions or large fires involve a risk. In MSDS, containment of ingredients can also result in explosions according to the product. Additionally, in the event of a fire, it is recommended by the manufacturer to open the storage area to provide maximum circulationNH_4NO_3

The Beirut Port explosion is believed to be the largest non-nuclear explosion in human history, destroying most of the city's residential area. However, in world history, quite a few similar events occurred due to AN explosions as shown in table 1.

Table 1. Characteristics for the 9 explosions with the highest amounts of ammonium nitrate globally.

City & Country	Year	Location	Quantity (Tons)	Reason	Die	Wound
Beirut, Lebanon	2020	Harbor	2,750	The flames are out of control	220	6,500
Texas, USA	1947	Boat	2,086	The flames are out of control	581	5,000
Tianjin, China	2015	Port	800	The flames are out of control	173	798
Faversham, England	1916	Factory	700	The flames are out of control	115	-
Oppau, Germany	1921	Factory	450	Explosive contamination	561	1,952
New Brunswick, Canada	1947	Factory	400	The flames are out of control	0	0
Toulouse, France	2001	Fertilizer	200	Chlorite contamination	30	2,242
Tessenderlo, Belgium	1942	Factory	150	Explosive contamination	189	900
Wayandra, Australia	2014	Transport	56	Traffic accident	0	8

The table above describes the explosion cases involving AN with the largest number of tonnes. It is known that the explosion that occurred at the port was the largest explosion case, but even though it caused many victims, the case that occurred in Texas was the case with the most deaths. When looking at the location of the incident, the factors caused by storage are the most numerous.

The Texas City explosion, USA, in 1947 caused around 581 people to die, 5,000 people were injured, 500 houses were destroyed. A fire broke out on the French ship SS Grandcamp docked in Texas City, and exploded its cargo containing about 2,000 tons of ammonium nitrate. This set off a chain reaction of fires and explosions on other ships and nearby oil storage facilities.

Then the explosion in Tianjin, China, in 2015 caused 173 people to die, 798 people were injured. A factory, at a container storage station at the port, stored flammable chemicals with ammonium nitrate. The investigation concluded that an overheated container of dry nitrocellulose that had not been stored properly was the cause of the initial explosion. The subsequent explosion likely involved 800 tons of ammonium nitrate, (about 256 tons of TNT equivalent), and 700 tons of sodium cyanide, as well as dozens of other compounds. The explosion caused damage worth $1.1 billion dollars, and there are many more explosions related to AN as in table 1 above[18].

Before around 1950, AN as a fertilizer product experienced severe clumping problems. Remedial measures then taken such as the use of AN oxidizer to break down the hardened mass or the application of a layer of wax on the granules led to major accidents with hundreds of fatalities, for example the tragedy at a factory in Oppau Germany (in 1921) and the ship disaster in Texas City (in 1947). In the first accident, it occurred during the process of breaking down hardened fertilizer using heat and in the second accident it involved fertilizer coated with wax in a paper bag. So several evaluations regarding the development of safer products and the implementation of safer practices were then carried out, which substantially improved safety and provided a major boost to the AN fertilizer industry, with production of over one billion tons of AN as fertilizer in the following years. Unfortunately, during this period, several accidents with AN continued to occur, some of them quite large.

It is important to realize that fire incidents involving AN do not actually easily escalate to cause an explosion. Furthermore, there are many fire incidents that do not develop into explosions, where they burn to the ground without escalation or being controlled.

Ammonium Nitrate (AN)

AN is a colorless crystal salt that is very soluble in water. Even though it is hygroscopic, it does not form hydrates. AN is also soluble in alcohol, acetic acid, and nitric acid. AN dissolves in liquid ammonia to form what is known as Divers' solution and can be used to remove ammonia from gases. AN has a negative heat of solution in water therefore it can be used to prepare frozen mixtures. The chemical reactivity of AN has been well documented by Mellor. The boiling point of the pure material is about 210°C at 11 mmHg and it filters without decomposition. It decomposes around 230°C at 760 mmHg, and above 325°C it will deflate. If restricted, AN may explode between 260°C and 300°C. Data on solubility, vapor pressure, boiling point, specific heat of aqueous AN solutions, and many other properties, especially relevant to their use as components of explosive mixtures, are well documented (table 2).

Ammonium nitrate is often combined with fuel oil to make explosives used in the mining and construction industries. In other cases, militants have made bombs with this material in the past. Examples of the use of ammonium nitrate-based explosives were used in the 1995 Oklahoma City bombing, the 2011 Delhi bombing, the 2011 Oslo bombing, the 1992 and 1993 City of London bombings, and the 1996 Manchester bombing.

Ammonium nitrate is an interesting molecular ionic crystal that has been studied using many of the scientific techniques available today. AN exhibits a series of temperature-dependent phases at atmospheric pressure characterized by increasingly greater freedom of movement of and ions. Three of these phases (commonly referred to as phases VII, V, and IV) occur in the temperature range 258 to 27°C with transition points (V to VII) around 178°C and (IV to V) at 27°C. The highest temperature phase (phase I) is analogous to the plastic phase observed in many molecular crystals because large reorientations of the and ions occur$NH_4^+ NO_3^- T_o NH_4^+ NO_3^-$.

TABLE 2. Characteristic properties of Ammonium Nitrate

Characteristic	Mark
Molecular formula	NH_4NO_3
Molecular weight	80
Heat of combustion	1,447.7 J/g
Heat of formation	4,594 J/g
Heat of explosion	1,447.7 J/g
Heat of fusion	76.7 J/g
Density	1,725g/cm^3
Color	Colorless
Melting point	169.6°C
Specific volume	0.580 /gcm^3
Solubility in water (20°C)	66 g - 100 g
Oxygen content	60%
Available oxygen	20%
Flame temperature	1,500°C

Explosive speed	1,250 – 4,650 m/s
Thermal expansion coefficient	9.82x %/10^{-4}°C
Specific heat (0-31°C)	1.72 J/mol
Vapor pressure at 205°C	7.4 mmHg

Under normal handling and storage conditions, ammonium nitrate is not hazardous. However, if there is a large amount of material lying around for a long time, it begins to decompose and hydroscopically absorbs water vapor from the atmosphere and eventually turns into lumps, making it more dangerous, because if there is a heat source, the chemical reaction will be much stronger. The speed of the explosion that occurs increases with density so that the force of the explosion is greater in solid form compared to powder because the heat and gases from decomposition cannot escape as easily as they can from dispersed granules, a free-flowing pile of fine particles.

Explosion Mechanism

AN can cause an explosion through rapid decomposition, causing an increase in pressure, or detonation. However, AN-based fertilizers are difficult to detonate because they are made with high resistance to explosions and thus require very energetic shocks. In addition, the critical charge diameter is large, making it difficult to achieve sustained detonation in practice. Neither flames, sparks, nor friction can cause an explosion. If not handled properly, a number of factors can decrease this resistance including contamination with incompatible substances, reduced particle size, increased temperature and thermal cycling (which increases porosity and causes damage to the prill or grain structure). In practice, most products contain additional ingredients to provide good anti-caking properties and thermal stability.

Based on the known causes of accidents with AN and related investigations, the primary mechanism for initiating an explosion in an AN can be identified as the deflagration to detonation transition: This is known as the deflagration to detonation transition (DDT). Deflagration is the ignition of a flame that propagates and moves subsonically (the speed of the flame is less than the speed of sound) in a mixture of fuel and oxidizer. Meanwhile, detonation is a supersonic combustion wave. Explosions in gases propagate at speeds ranging between 5 to 7 times the speed of sound in reactants where the detonation speed of ammonium nitrate ranges from 2 to 5 km/sec, depending on the density while in explosions.

During deflagration, chemical reaction zones move from one particle of a substance to another through thermal conduction and convection. In detonation, the propagation is by hydrodynamic shocks, which if strong enough can heat the material and cause a very fast reaction. Under certain conditions, rapid deflagration can become supersonic and thus can develop into an explosion.

Evaluate the incident

Evaluation of the explosion at the port of Beirut in 2020 can involve several aspects, including causes, security and regulatory management, humanitarian impact, as well as steps taken to prevent similar events from occurring in the future. The following are some evaluation aspects that can be considered:

1. The evaluation includes an in-depth investigation into the cause of the explosion, including any safety and risk management failures that may have occurred. This can include improper storage analysis of ammonium nitrate (figure 5) and lack of regulatory compliance. Some of the evaluations include: Lack of knowledge of human resources regarding risk management, work safety, and anticipating the worst, resulting in neglected standard operating procedures.
2. The extent to which safety management and regulations regarding the storage of hazardous materials, such as ammonium nitrate, have been followed and implemented must be evaluated. If there are violations, corrective measures must be identified. Some of the

regulatory security management that occurred in Lebanon before the incident, including: Weak monitoring and enforcement of regulations by the relevant authorities, legal instrumentsThe available texts and articles do not have texts and articles relevant to chemical safety issues related to import, storage and use control, the available texts on chemical safety do not cover comprehensive measures and protocols, the absence of administrative texts relevant to national classification chemical material
3. The evaluation should include recommendations and concrete steps that can be taken to prevent similar events from occurring in the future. This includes improvements in security management, regulations and safety procedures. Some of the evaluations include: Lack of understanding regarding the safety of ammonium nitrate chemicals, failure to carry out safety audit inspections, lack of security technology, weak international cooperation with relevant authorities, absence of emergency management related to storage, and low openness and transparency of authorities.

Figure 5. Inappropriate storage location

To prevent ammonium nitrate explosions from occurring again, a holistic approach is needed that involves strict regulations, effective risk management, and implementation of best practices in the storage and handling of hazardous chemicals. Here are some steps you can take:
1. Regulatory Monitoring and Enforcement: The government must have strict regulations regarding the storage, handling and transportation of ammonium nitrate. It is important to ensure consistent implementation and enforcement of these regulations.Monitoring should only be carried out by suitably qualified personnel, with the necessary detailed information before starting operations.
2. Routine Inspections and Security Audits: Facilities storing ammonium nitrate must undergo regular inspections by security authorities and audit checks to ensure compliance with security standards. These inspections may include storage infrastructure, security procedures, and clear labeling.Storage facilities and buildings must be made of non-combustible materials and must ensure that flammable materials are kept away from the cargo.
3. Education and Training: Workers involved in storing and handling ammonium nitrate must receive appropriate training regarding safety procedures, handling hazardous chemicals, and emergency response.Provide knowledge to workers that is communicated in safety data sheets for materials to be stored, and store these sheets in an easily accessible place.
4. Safe and Proper Storage:Storage options include closed/open space, separation from other materials to avoid mixing, adequate infrastructure. Ammonium nitrate must be stored in safe conditions and in accordance with safety guidelines resulting in the use of storage facilities designed to withstand explosions.
5. Risk Management: Facilities storing ammonium nitrate must have a comprehensive risk management plan. This includes identification of potential risks, evaluation of impacts, and implementation of risk control measures.Risk analysis according to the nature and level of

danger of the materials to be stored (classification in categories established in international standards).

6. Technology and Security Systems:Installation and continuous monitoring of necessary security systems.The application of modern security technologies and systems, such as gas detection sensors, automatic fire suppression systems and smart security systems, can improve monitoring and detection of potential problems.
7. International Cooperation: Countries that produce, import, or store ammonium nitrate need to share information and best practices through international cooperation. This can help improve safety standards globally.
8. Alternative Use or Substitution: When possible, consider using less risky chemical alternatives or substitutions to reduce potential harm.Once contamination occurs in AN, prompt disposal, separation and disposal are in accordance with regulations
9. Emergency Management and Response: Facilities storing ammonium nitrate must have a clear emergency response plan and be tested regularly. This involves regular training and simulations to increase preparedness.
10. Openness and Transparency: Governments and facility owners need to encourage openness and transparency in reporting on security and risk management. This involves sharing information with the public and relevant interested parties.

The 2020 explosion at the Port of Beirut marked a serious regulatory failure. Explosions of AN-based products are most likely to occur when storage conditions deteriorate: material containment, impurity contamination, or sources of heat or ignition. Hazardous reactions between AN and other products include chlorinated compounds, organic materials, and heavy metals, especially when exposed to liquid AN[20]. Investigations of previous AN disasters in different parts of the world guide AN management and safety policies (Table 1). The explosion at the Port of Beirut highlights the importance of national institutions regulating chemicals to monitor and implement chemical safety measures and adopt prevention strategies from/for the entire country. In addition, local port administrations and other relevant authorities need stronger support that has the credentials to ensure a high level of security to improve management of chemical storage facilities, ensure safe storage and handling of chemicals, and develop effective emergency response plans.

There is an urgent need to adopt and enforce regulatory standards and safety procedures, especially in the transport and storage of hazardous materials. Governments should introduce safety measures to ensure storage of these materials at an appropriate distance from population centers and residential areas. For example, after the explosion in West, Texas, President Obama in the United States created a working group, to improve the security and safety of chemical facilities co-chaired by the department of homeland security, the environmental protection agency, and the department of labor.

The Lebanese government could consider recruiting stakeholders including practitioners and academics to identify best practices as part of an executive oversight committee or working group, or as part of an existing chemical and biological nuclear incident preparedness program. Similar steps would likely improve operational coordination, improve information sharing between different government agencies, and modernize policies and regulations on chemical safety. The proposed committee would coordinate activities across government agencies involved in managing chemicals (e.g., Ministries of Defense, Agriculture, Environment, Public Health, etc.), to address safety and security issues and reduce risks associated with hazardous chemicals for officers, operators and the wider community.

Handling and Storage of Ammonium Nitrate

Handling and storing ammonium nitrate must be done with extreme care to avoid the risk of accidents or explosions. Ammonium nitrate is a chemical compound that can become an explosive if not managed properly. Here are some general guidelines for safe handling and storage of ammonium nitrate:

Handling of ammonium nitrate:

1. Use protection and safety equipment, the procedure is to always wear protection, such as safety glasses, face shield, chemical gloves, and protective clothing when handling ammonium nitrate.
2. Good ventilation, ensuring that handling is carried out in a well-ventilated area to avoid the buildup of dangerous gases.
3. Avoid contact with substances that form dangerous mixtures, avoid direct or indirect contact of ammonium nitrate with substances such as acids, organic materials, or metals that can form mixtures that can cause an explosion.
4. Avoid high temperatures and humidity, keep ammonium nitrate away from heat sources, high temperatures and high humidity. Storage in a cool and dry place is recommended.
5. The correct layout, arrangement and storage of ammonium nitrate must comply with applicable safety guidelines and regulations. Storage facilities must be designed to prevent accidents.

Ammonium Nitrate Storage:

1. Closed and Locked Storage Area, ammonium nitrate must be stored in a closed and locked storage area to prevent unauthorized access and reduce the risk of theft or misuse.
2. Separation from other materials, ammonium nitrate must be separated from materials that can cause dangerous reactions, including separation from fuel, organic materials and flammable materials, which is important to reduce the risk of explosion.
3. Warning signs: Ammonium nitrate storage areas must be clearly marked with warning signs and information about the associated hazards.
4. Fire extinguishing system, ammonium nitrate storage facilities must be equipped with an effective and reliable fire extinguishing system.
5. Regular monitoring and inspections, carrying out routine monitoring and inspections of storage facilities to ensure good security conditions.
6. Safety training and awareness, ensuring that all persons involved in handling and storing ammonium nitrate have received adequate safety training and have a high level of awareness of the associated hazards.
7. Emergency response procedures: establish clear emergency response procedures and communicate with all workers involved in handling and storing ammonium nitrate.
8. Compliance with regulations and guidelines: ensure that the storage and handling of ammonium nitrate always complies with the regulations and safety guidelines applicable in the local region or country.

Several leading organizations on an international scale, which study and issue regulations on chemical safety issues, provide guidance on conditions that must be avoided or strictly controlled when handling and storing AN-based materials. A summary of these guidelines is presented in Table 3.

Table 3. Conditions to avoid or control for the production, trade, storage and transportation of AN

Topic	Conditions according		
	SAFEX	**IME**	**NFPA**
Heat/fire	Construction is made of non-flammable materials. There are no flammable materials nearby	Buildings must be made of non-flammable materials. If flammable materials are used, a sprinkler fire extinguishing system is still required. Facilities must implement a program called Hot Works to ensure safety.	Buildings must be made of non-flammable materials. If flammable construction materials are used, a fire protection system must be provided. Flammable and combustible Flammable and combustible materials must be separated from AN.
Pollution	Incompatible materials should be strictly separated from AN-based fertilizers.	Incompatible organic and inorganic materials should be kept away from AN	Organic chemicals, acids, self-igniting materials, fuels, etc. must be separated from AN.
Mechanical stimulation	Dedicated storage space. Adequate separation from potentially explosive atmospheres.	In the case of storage with explosives, it is mandatory to maintain the safe distance required by law	Explosive and blasting materials must not be stored in AN

Note: SAFEX International; IME (Institute of Makers of Explosives); NFPA (National Fire Protection Association)

Ammonium Nitrate Disposal

Decomposition of ammonium nitrate can be done to prevent explosions, which will be further exacerbated by improper storage procedures and long storage periods. Some safe decomposition methods can be undertaken with caution and only by trained personnel. Although, keep in mind that for most cases, handling of ammonium nitrate and its decomposition methods should be carried out by experts and with the right equipment. Here are some methods to consider:

1. Mixing with Other Substances: Ammonium nitrate can be mixed with other substances which can reduce its stability, making it more difficult to explode. For example, sawdust, clay, or other inert materials can be used.
2. Controlled Heating: A controlled heating process under strict conditions can reduce ammonium nitrate to a more stable compound without causing an explosion. Warming up can be done carefully and under expert supervision.
3. Mixing with Oxygen Reducing Compounds: Mixing ammonium nitrate with oxygen reducing compounds can reduce the potential explosion hazard. Examples of these compounds include substances containing metals.
4. Reactions with Metals: The reaction of ammonium nitrate with certain metals can form more stable compounds.
5. Use of Inhibitors: Use of certain inhibitors or stabilizing compounds can help reduce the reactivity of ammonium nitrate.
6. Dissolution: Ammonium nitrate is soluble in water. In some cases, dissolution of ammonium nitrate can be considered as a method to reduce its concentration.

It is important to remember that the application of safe decomposition methods for

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ammonium nitrate must take into account many factors, including environmental conditions, the amount of ammonium nitrate involved, and the technical capabilities of the personnel involved. Any action must comply with applicable safety and environmental regulations and must be carried out by trained experts. In industrial or large-scale storage contexts, regulatory authorities and safety experts should be involved in evaluating and implementing safe decomposition methods.

One of the AN disposal processes can be through thermal decomposition to break down ammonium nitrate intonitrogen oxide gas), water), and nitrogen(NO_x(H_2O(N_2). Although AN is stable at room temperature during storage, a small portion of the ammonia will undergo changes. Due to its application as an explosive component which is an energetic material, the thermolysis of AN depends on various factors such as pressure and temperature, where no single mechanism can explain all aspects of its decomposition characteristics. Several possible decomposition pathways can be seen in Table 4. Where the thermal decomposition process is initiated by an endothermic proton transfer reaction as shown in reaction 1 (Table 2). When heated from 200 to 230°C, exothermic decomposition occurs in reaction 6. This reaction is rapid but controllable and is the basis for the commercial manufacture of nitrous oxide in reaction 2. Above 230°C, decomposition follows reaction 3. The reaction pathway is reported follows reaction 4 during detonation, and reaction 5 has been suggested when AN undergoes an explosion. Most mechanisms aimed at the decomposition of AN assume the production of ammonia and nitric acid and their subsequent oxidation by decomposition products. Roser et al., assumed a known equilibrium reaction for that leading to the oxidizing species and described its formation and water as the main product as in reaction 2 (Table 4).$NH_3HNO_3HNO_3NO_2^-(N_2O)$

TABLE 4. AN thermal decomposition mode

Reaction	Heat Evolution (cal/g)	Gas Volume (ml/g)	Temperature (°C)
(1)$NH_4NO_3 \rightarrow NH_3(g) + HNO_3(g)$	-521		
(2)$NH_4NO_3 \rightarrow N_2O + 2H_2O$	108	840	320
(3)$NH_4NO_3 \rightarrow 3/4N_2 + 1/2NO_2 + 2H_2O$	316	910	860
(4) +$NH_4NO_3 \rightarrow N_2 + 2H_2O\ 1/2O_2$	354	980	950
(5) $8NH_4NO_3 \rightarrow 5N_2 + 4NO + 2NO_2 + 16H_2O$	201	945	560
(6)$NH_4NO_3 \rightarrow 1/2N_2 + NO + 2H_2O$	86	980	260

Disposal or disposal of ammonium nitrate must be done with extreme care and in accordance with safety and environmental guidelines. Ammonium nitrate is a compound that can cause an explosion if not processed properly. Some safe methods for the thermal decomposition process include: Slow and controlled heating of ammonium nitrate can induce thermal decomposition; The use of closed reactors can help control the thermal decomposition process and prevent the leakage of harmful gases into the environment. Closed reactors may include fire suppression systems and temperature control facilities; The addition of a heat conductor, such as a metal, to the ammonium nitrate mixture can help increase the heat conductivity and reduce the temperature required for decomposition; Controlling humidity around ammonium nitrate can help prevent dissolution which can increase the risk of decomposition; Several compounds or materials may be added to help initiate or control the thermal decomposition of ammonium nitrate; and Monitoring and control of gases produced during thermal decomposition is essential. Monitoring and control systems must be designed to detect and respond to releases of potentially hazardous gases.

CONCLUSION

Comparison of maritime defense strategies can be observed in the fact that Indonesia is a non-claimant state, while Malaysia, along with the Philippines, Brunei, and Vietnam, is a claimant state. However, despite this difference, Indonesia and Malaysia share similarities in addressing threats in the South China Sea. Both countries employ a soft power maritime defense diplomacy approach as a government effort to resolve ongoing conflicts, where soft power diplomacy is a concept describing a country's ability to engage in cooperation with other nations without resorting to military means. The choice of soft power diplomacy is influenced, among other factors, by the fact that China is a significant trading partner for both countries. Therefore, it can be concluded that Indonesia and Malaysia are implementing track 3 of the multi-track diplomacy advocated by Diamond and McDonald. Through the established business cooperation relationships, there is potential to build peace between these countries.

In adopting soft power maritime defense diplomacy, Indonesia and Malaysia recognize the importance of fostering collaboration and understanding rather than resorting to confrontation. The emphasis on economic cooperation and business relationships in this strategy aligns with the idea that interconnected economies can contribute to regional stability. Both nations aim to leverage their economic ties, not only to enhance their own security but also to promote a broader atmosphere of cooperation and peaceful coexistence in the South China Sea. Furthermore, the implementation of track 3 in multi-track diplomacy suggests that the engagement between Indonesia, Malaysia, and China goes beyond traditional state-level interactions. It involves various non-state actors, particularly those in the business sector, who play a pivotal role in creating mutual understanding and shared interests. By recognizing the potential of economic collaboration to serve as a catalyst for peace, Indonesia and Malaysia are navigating a diplomatic path that prioritizes dialogue, economic interdependence, and shared prosperity as essential components of regional stability in the South China Sea.

REFERENCES

Berger, “Evaluation of the Experience of International Accidents Related to the Storage and Handling of Ammonium Nitrate Fertilisers,”*Hadmernok*, vol. 17, no. 2, pp. 129–145, 2022, doi: 10.32567/hm.2022.2.9.

A. Farahat, N. El-Kork, RP Singh, and F. Jing, “Possible Overestimation of Nitrogen Dioxide Outgassing during the Beirut 2020 Explosion,”*Remote Sens.*, vol. 14, no. 24, 2022, doi: 10.3390/rs14246377.

A. J. Hassel, M. Hagenlocher, and J. O. Connor, “Beirut Explosion,” pp. 1–26, 2021.

A. Kerbage, SF Haddad, M. Zoghbi, T. Souaid, E. Haroun, and A. Zoghbi, “Beirut Blast 2020: Cries and Bloodshed at the Busiest Hospital,”*Disaster Med. Public Health Prep.*, vol. 17, no. December, 2023, doi: 10.1017/dmp.2021.350.

AM Djerdjev, P. Priyananda, J. Gore, JK Beattie, C. Neto, and BS Hawkett, "The mechanism of the spontaneous detonation of ammonium nitrate in reactive grounds,"*J Environ. Chem. Eng.*, vol. 6, no. 1, pp. 281–288, 2018, doi: 10.1016/j.jece.2017.12.003.

A. Shakoor, SM Shahzad, TH Farooq, and F. Ashraf, “Future of ammonium nitrate after Beirut (Lebanon) explosion,”*Environ. Pollut.*, vol. 267, no. 3, p. 115615, 2020, doi: 10.1016/j.envpol.2020.115615.

AMT Thomé, LF Scavarda, and AJ Scavarda, “Conducting systematic literature review in operations management,”*Prod. Plans. Controls*, vol. 27, no. 5, pp. 408–420, 2016, doi:

10.1080/09537287.2015.1129464.

A.V. Jensen,*Hazards of Chemical Rockets and Propellants Handbook: Vol. 2. Solid Rocket Propellant Processing, Handling, Storage and Transportation*, Vol 2. Springfield, VA: National Technical Information Services, U S. Department of Commerce, 1972.

B. Kitchenham, O. Pearl Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman, “Systematic literature reviews in software engineering - A systematic literature review,”*Inf. Softw. Technol.*, vol. 51, no. 1, pp. 7–15, 2009, doi: 10.1016/j.infsof.2008.09.009.

BT Fedroff,*Encyclopedia of Explosives and Related Items*, Vol 1. Picatinny Arsenal: Dover, NJ, 1960.

C. Okoli, “A guide to conducting a standalone systematic literature review,”*Commun. Assoc. Inf. Syst.*, vol. 37, no. 1, pp. 879–910, 2015, doi: 10.17705/1cais.03743.

ET Rother, "Systematic literature review X narrative review,"*ACTA Paul. Enferm.*, vol. 20, no. 2, pp. 7–8, 2007, doi: 10.1590/s0103-21002007000200001.

F. Malak, A. Rifai, R. Baydoun, B. Nsouli, and D. Dimitrov, “Chemical safety and security after Beirut Port explosion: Part1 - State of the art of legal framework and authorization policy,”*Saf. Sci.*, vol. 144, no. August, p. 105456, 2021, doi: 10.1016/j.ssci.2021.105456.

G. Yu*et al.*, “Comprehensive study on the catastrophic explosion of ammonium nitrate stored in the warehouse of Beirut port,” Process Saf. Environ. Prot., vol. 152, pp. 201–219, 2021, doi: 10.1016/j.psep.2021.05.030.

G. Valsamos, M. Larcher, and F. Casadei, “Beirut explosion 2020: A case study for a large-scale urban blast simulation,”*Saf. Sci.*, vol. 137, no. February, p. 105190, 2021, doi: 10.1016/j.ssci.2021.105190.

J. Szczygielska and M. Frączak, “Good practices in managing the risks associated with the storage, handling and transportation of ammonium nitrate (V) in the light of the Beirut explosion in 2020 w 2020 roku,” no. V, pp. 50–57, 2022, doi: 10.22211/matwys/0223.

J. W. Mellor,*A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, 2nd ed. London: Longmans Green, 1992.

K. Dysz, B. Poszwald, A. Kwak, and A. Dylong, “Thermal Stability of Ammonium Nitrate in Two-Component Mixtures with Powdered and Fine-Grained Materials,”*Mater. Res. Proc.*, vol. 34, pp. 127–138, 2023, doi: 10.21741/9781644902691-16.

KD Shah, “Ammonium nitrate — decomposition, fire and explosive behavior,” no. October, pp. 2–6, 2018.

M. Tian, P. Deng, Y. Zhang, and MP Salmador, “How does culture influence innovation? A systematic literature review,"*Manag. Decis.*, vol. 56, no. 5, pp. 1088–1107, 2018, doi: 10.1108/MD-05-2017-0462.

MK Linnenluecke, M. Marrone, and AK Singh, “Conducting systematic literature reviews and bibliometric analyses,”*Aust. J. Manag.*, vol. 45, no. 2, pp. 175–194, 2020, doi: 10.1177/0312896219877678.

MS Hajjar, GM Atallah, H. Faysal, B. Atiyeh, J. Bakhach, and AE Ibrahim, “the 2020 Beirut Explosion: a Healthcare Perspective,”*Ann. Burns Fire Disasters*, vol. 34, no. 4, pp. 293–300, 2021.

N. Hsu and F. Doux, “There are several projects to manufacture ¨green ammonia¨ where hydrogen is obtained via hydrolysis of water and the hydrocarbons´ reforming is not required. In such a process, especially if electricity used comes from renewable energy, ammonia synthesis," 2020.

N. Souaiby and M. El-Hussein, “Beirut Explosion, the full story,”*Mediterr. J. Emerg. Med.*, vol. 28, no. November 2020, pp. 4–7, 2020, doi: 10.26738/MJEM.2017/MJEM28.2020/MH.EAE.100820.

PCP & C. of AGI David Moore, “Port of Beirut Explosion – Analysis and Impacts,” no. May, 2022, [Online]. Available: https://engineering.purdue.edu/P2SAC/news/events/2022-spring-p2sac-conference/Port of Beirut Explosion - Analysis and Impacts - David Moore.pdf

Q. Wang, L. Zhang, L. Wang, and L. Bu, "A practical method for predicting and analyzing the consequences of ammonium nitrate explosion accidents adjacent to densely populated areas,"*Heliyon*, vol. 9, no. 5, p. e15616, 2023, doi: 10.1016/j.heliyon.2023.e15616.

S. Al-Hajj, HR Dhaini, S. Mondello, H. Kaafarani, F. Kobeissy, and RG DePalma, "Beirut Ammonium Nitrate. Blast: Analysis, Review, and Recommendations,"*Front. Public Heal.*, vol. 9, no. June, pp. 1–11, 2021, doi: 10.3389/fpubh.2021.657996.

S. Cagnina, P. Rotureau, and C. Adamo, "Study of incompatibility of ammonium nitrate and its mechanism of decomposition by theoretical approach,"*Chem. Eng. Trans.*, vol. 31, pp. 823–828, 2013, doi: 10.3303/CET1331138.

S. Chaturvedi and PN Dave, "Review on Thermal Decomposition of Ammonium Nitrate,"*J. Energ. Mater.*, vol. 31, no. 1, pp. 1–26, 2013, doi: 10.1080/07370652.2011.573523.

S. ur Rehman*et al.*, "Ammonium nitrate is a risk for the environment: A case study of Beirut (Lebanon) chemical explosion and the effects on the environment," Ecotoxicol. Environ. Saf., vol. 210, no. December 2020, p. 111834, 2021, doi: 10.1016/j.ecoenv.2020.111834.

V. Babrauskas, "Explosions of ammonium nitrate fertilizer in storage or transportation are preventable accidents,"*J Hazard. Mater.*, vol. 304, pp. 134–149, 2016, doi: 10.1016/j.jhazmat.2015.10.040.

WK and R. Ince, "4-august-2020-beirut-ammonium-nitrate-explosion-damage-overview-final-report.pdf."

W. Pittman*et al.*, "Lessons to be learned from an analysis of ammonium nitrate disasters in the last 100 years," J. Hazard. Mater., vol. 280, pp. 472–477, 2014, doi: 10.1016/j.jhazmat.2014.08.037.

Y. Xiao and M. Watson, "Guidance on Conducting a Systematic Literature Review,"*J. Plan. Educ. Res.*, vol. 39, no. 1, pp. 93–112, 2019, doi: 10.1177/0739456X17723971.