Case Study

Investigating the Challenges of Ammonia Emission in Firuzabad Sodium Carbonate Factory Incident: A Case Study

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ABSTRACT

Background: An ammonia gas explosion poses immediate health hazards such as respiratory tract burns, skin and eye irritation, and potential death within seconds. It also causes long-term negative impacts on biodiversity, affecting aquatic life and vegetation. An explosion in the Firuzabad sodium carbonate factory in Iran led to massive ammonia gas leakage and the poisoning of several employees. This study evaluates the risks of ammonia gas release caused by the explosion and the rescue team's response in the same factory.

Materials and Methods: This study was conducted in 2020 in Firuzabad City, Iran. The investigation was based on case reports and data analysis obtained via field observations, document reviews, interviews, and experiments. Technical and specialized information on explosion were analyzed by ALOHA software.

Results: Based on data analysis, red, orange, and yellow zones around the explosion area were identified. The red zone had an ammonia emission range of 1.2 km with an explosive power of 10 kW, causing potential death in 60 seconds. Orange zone had a range of about 1.7 km, an explosive power of 5 kW, and the potential for second-degree burns and respiratory damage within 60 seconds of release. The yellow zone covered an area of about 3.3 km. Interviews and field observations provided information on the risk-based response process, response equipment, medical treatment, hazardous materials, handling and response equipment, personal protective equipment, mutual aid, and resource typing.

Conclusion: The results of this study show that the immediate evacuation of the area, employment of the rapid warning system, the triage of the injured, the presence of an emergency operation plan to control hazardous and toxic materials disasters, the performance of the rapid response team and multi-specialty teams were among the existing challenges of the operation team. Background of this study confirms the potential hazards associated with ammonia gas emissions from explosions in sodium carbonate plants.

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Introduction

Industrial accidents encompass various incidents depending on the industry involved and the workplace. Still, one of the most common industrial accidents worldwide is burns and explosions in chemical factories. Workers in chemical factories or oil refineries are at risk of burns and explosions due to working on dangerous materials and equipment [1].

Like many countries, Iran has experienced industrial accidents in the past. Accidents can occur in industries such as mining, petrochemicals, and factories. These incidents have resulted in injuries, fatalities, and environmental damages [2]. One of Iran's most prominent industrial accidents occurred in Azarab Industries factory in 2014. The explosion in the factory killed at least 15 workers and injured many others. This factory manufactured equipment for the oil and gas industry and the explosion was caused by a gas leak. In 2020, a gas leak occurred in a petrochemical plant southwest of Mahshahr City, killing two workers and injuring dozens [3].

In Iran, one of the well-known industries is glass and crystal, which is dependent on the production of sodium carbonate. In this industry, ammonia is one of the important raw materials in the production process. The gas is stored and maintained in special tanks in glass and crystal factories. Kaveh, Maragheh, Firuzabad, and Semnan factories manufacture sodium carbonate with different methods. The raw materials used in this process are ammonia, carbon monoxide, and concentrated saltwater solutions. The most recent explosion of an ammonia gas tank in Iran occurred in 2022 in Hormozgan Province in an ice factory, as a result of which 7 people got injured. The recorded accidents by the explosion of ammonia tanks in Iran are few, and there is no detailed report of the challenges and evaluation [4]. Ammonia is produced as a raw material in the sodium carbonate factory and enters the production line in special tanks. Exposure to high concentrations of ammonia gas may damage skin and internal organs [5].

Nitrogen and hydrogen in ammonia are decomposed at 450°C to 500°C. The presence of oil or flammable materials can increase the risk of ammonia, making it a potential hazard in sodium carbonate plants. Ammonia emissions are harmful to both factory workers and the environment. They can alkalize air and water, which irreparably damages the ecosystem. People should be aware of possible dangers in their vicinity [6].

Two types of explosions can occur in ammonia deposits. The shock-to-explosion transfer mechanism causes the first type. It can be initiated by releasing an explosive charge into the mass, detonating a projectile thrown into it, or detonating an explosive mixture in contact with the mass. This explosion happened in Kriewald, Morgan, Oppau, Tessenderlo, and Traskwood. The second type of explosion is caused by a fire that spreads within the ammonium nitrate alone or a mixture of ammonium nitrate with combustible materials. This type of explosion happened in Texas City, Brest, Tianjin, and Beirut [7-9].

This study investigated the risks of ammonia gas release caused by an explosion in a sodium carbonate factory in Iran. Our research aims to discover the challenges caused by the explosion, the operational team performance, and the potential environmental effects caused by the ammonia release.

Materials and Methods

This study was conducted in 2022 in Firuzabad City, Fars Province, Iran. The study data were collected through field observations, document analysis, interviews, and experiments. The explosion occurred around 17:00 on Monday, June 14, in the sodium carbonate factory located in Firuzabad, Iran. The bursting of the pipe connected to the ammonia tank of the factory triggered the explosion. After the accident, the research team thoroughly assessed the spread of chemical pollutants in the environment, identified environmental hazards, and obtained meteorological, geographical, site characteristics, chemical information, and source power from trustworthy sources (Table 1). Following the factory policy, the recorded data were available to the research team in the shortest possible time. The data included the technical details of the tank explosion and recorded videos and photos. The documents were highly reliable and correct as they were supposed to be submitted to the legal authorities; other available information was obtained through interviews and field observations. The operational team of the incident blocked all roads leading to the factory in a radius of 45 kilometers, and vehicles were not permitted for several hours after the incident. The explosion at the carbonate factory injured approximately 149 people, all of whom received immediate treatment, and 23 were hospitalized. Fortunately, there was no loss of life.

Results

After analyzing the data, three zones were identified: Red, orange, and yellow. In the red zone, ammonia was released up to a range of 1.2 km (0.7 miles), with an ex-

Table 1. Technical and specialized information of explosion

Classification of Technical Data	Description of information
Location data	Location: Firuzabad, Iran Building air exchanges per hour: 0.59 Time: June 14, 2022, 17:02 hours ST
Atmospheric data	Wind: 6.3 m/s from NW at 10 m Ground roughness: Open country Cloud cover: 0 tenths Air temperature: 35°C No inversion height Relative humidity: 24%
Chemical data	Chemical name: Ammonia CAS[1] number: 7664-41-7 Molecular weight: 17.03 g/mol AEGL[2]-1 (60 min): 30 ppm AEGL-2 (60 min): 160 ppm AEGL-3 (60 min): 1100 ppm IDLH[3]: 300 ppm LEL: 1500 ppm Ambient boiling point: -35.0° F Vapor pressure at ambient temperature: greater than 1 atm
Source power	BLEVE[4] of flammable liquid in horizontal cylindrical tank Tank diameter: 50.5 m Tank length: 10 meters Tank v volume: 2000000 L Tank contains liquid Internal storage temperature: 35°C Chemical mass in the tank: 500000 kg Tank is 42% full Percentage of tank mass in fireball: 100% Fireball diameter: 1085 yards Burn duration: 43 s

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[1]Chemical abstracts service, [2]Acute exposure guideline levels, [3]Immediately dangerous to life or health, [4]Boiling liquid expanding vapor explosion.

plosion power of 10 kW. Any person within that range may die within 60 seconds after ammonia release. The orange zone, with an explosion strength of 5 kW, has a range of about 1.3 km (1.1 miles) and the possibility of second-degree burns and respiratory damage up to 60 seconds after the release. The yellow zone occupies an area of about 3.3 km (2.1 miles) and can cause injuries and surface burns up to 60 seconds after the explosion. The incident resulted in 149 injuries, with 34% of the injured working in the orange zone and 66% in the yellow zone. Others were quickly discharged from the hospital after treatment and suffered from post-accident shock and superficial trauma. No residents were injured because there was no residential area around the factory. The output data from Marplot software and Google Earth confirmed the absence of residential areas near the factory. The roads leading to the explosion site were closed immediately after the incident, and traffic around the factory was completely suspended. The only possible concern was the Dalkey River at the extreme of the yellow zone [10].

The pipeline warning and monitoring system automatically blocked the available gas flow. After further investigations and based on records, the tank's explosion was caused by the damage and bursting of one of the pipes connected to the main tanker. The high-pressure gas release from the leaking pipes had caused the explosion of the main tank. The rescue team was sent to the scene by the regional emergency. Field triage was performed by more experienced personnel before the arrival of the medical operation team, and the injured in the emergency group were immediately transported to the nearest hospital by ambulance. In response to this incident, especially in healthcare and incident command, challenges and effective factors were identified based on the standard response checklist in the hazardous and toxic materials (HAZ-MAT) incident. This information was collected from interviews and field observations of experts. The presence and operation of the early warning system made the siren sound after a few seconds, and most workers realized the danger from the sound of the explosion and the siren. An emergency operation plan

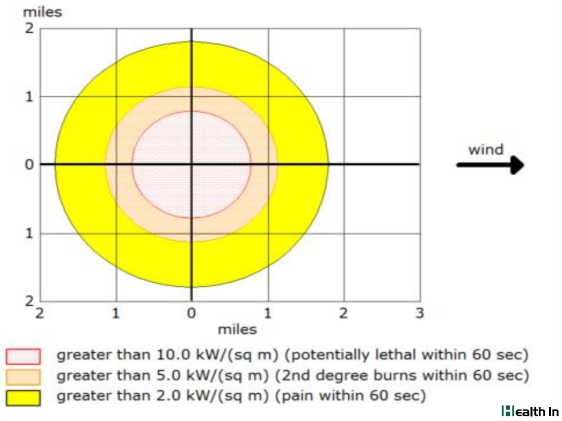

Figure 1. The amount of ammonia gas released in the environment and the analysis of life risks after the explosion based on the ALOHA analyzer software

(EOP) to control HAZ-MAT disasters was in effect in the factory, but personnel were barely aware of it.

Various measures were to be taken in the red, orange, and yellow areas, and information was extracted through interviews, field observations, and access to recorded data. Access was not restricted in the red area, representing the highest threat level and the most dangerous area. The responders had entered the red zone to contain and control the leakage or release of hazardous chemicals. According to the available information of the warning system, they had taken action to cut off the current. The orange zone warns of a medium threat level. Measures, such as anti-pollution methods and the conception of protective barriers, have not been carried out in this incident. In the yellow zone, air monitoring, immediate evacuation, and closing the roads to the factory were implemented. Of course, the zoning was implemented after the accident was simulated, and the operation team could not practically do something separately. There was triage of the injured in all zones, and rescue teams had free access to all zones.

The commander of the rapid response team and multi-specialty teams cannot be evaluated through interviews. However, according to the reports, they were active in the incident. Thirty minutes after the explosion, the incoming roads were closed by the police and the security team of the factory (Figure 1).

In the triage area, the injured were triaged by the factory's medical team until the arrival of the emergency team. Due to the possibility of water pollution in the Dalkey River, sampling was done from the river, but a few hours had passed since the explosion. Based on field and technical evaluations, contamination was not found in other areas, and the possibility of contamination

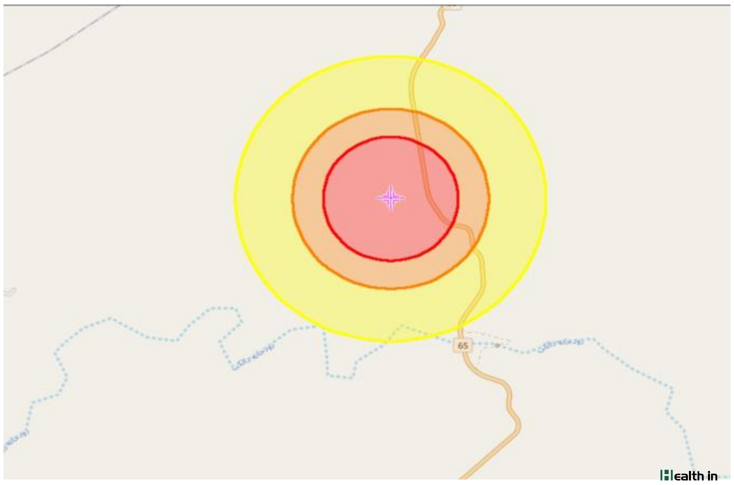

Figure 2. Topography of the amount and strength of ammonia gas emission using Marplot software

Figure 3. Aerial photograph of the location of the factory recorded in the Google Map

1) The road leading to the factory, 2) The location of the explosion, 3) Dalkey river

spreading to other regions was expected to be very low. These evaluations are plotted in Figures 2 and 3.

No effective measures were taken to decontaminate the factory and the surrounding environment because there was no dosimeter to determine the contamination and specialized system for this task. The damage assessment team carried out technical and engineering inspections.

Although there was a low possibility of ammonia in the river due to its insignificant concentration in the yellow zone and its diffusion, the research team collected water samples from several points along the river's path. The Fenat method and spectrophotometric colorimetric tests were used to check the ammonia concentration, which had an average value of less than 0.1 mg/L in water samples [11].

Discussion

During the Firuzabad incident, the average concentration of ammonia released into the environment was 1500 ppm. Exposure to such levels of ammonia can cause respiratory and eye damage according to standard measures. Personnel in the red zone and close to the explosion site were hospitalized with breathing difficulties, and ammonia concentration in this area was estimated to be around 1100 ppm [12].

A 2016 study analyzing the risk associated with ammonia tanks in Iran concluded that the lethal dose of ammonia concentration is 1000 ppm with a lethality percentage of 0.4 at a distance of 500 m from the leakage point. Fortunately, the explosion during the Firuzabad incident had no human casualties, thanks to the appropriate placement of the control room located within a safe distance from the explosion site [13].

A study by Inanloo et al. evaluated the effects of an ammonia transportation explosion through ALOHA analyses. This study concluded that wind speed and time of day play a crucial role in determining the release of ammonia into the environment. A 66.4% increase in ammonia release rate was predicted for a 2-ton tank at wind speed of 6.70 m/s. The explosion during the Firuzabad incident did not involve a tank of this size. However, with a tank capacity of 0.84 tons and a wind speed of 6.3 m/s in sunny weather, the rate of ammonia propagation was estimated to be 2 miles, consistent with Inanloo et al.'s study [10].

Another study evaluated the distribution of ammonia risks based on logistics subsystems and outcome types, indicating that 65.23% of the people involved in the production subsystems were injured, with a majority suffering from respiratory injuries. This finding aligns with the Firuzabad incident, where individuals working in the production systems sustained more injuries, and those requiring long-term hospitalization had respiratory system damage [14]. In the study by [15] Mokarram et al., the factors contributing to the concentration of ammonia in the Kor River in Iran were investigated. The study found that the amount of ammonia concentration in the air did not influence [15].

A study by Fukuoka concluded that universities should cooperate and develop research and analysis methods, rules for creating chemical accident reports, etc. They provide a place to share information so that the lessons learned from all kinds of accidents. In the current study, we could not offer a theory in the prevention phase with certainty because we lacked the standard tools, and according to the conditions, it was done by trial and error [16].

It is mentioned in the international rules of response to chemical accidents in 2022 that mandatory rules for effective response to similar accidents in all countries should be set domestically as well. Thus, if the dimensions of the Firozabad incident were larger, the response to fix the pipeline leak, the triage of the injured, and the emergency evacuation would face serious problems. The long-term recovery was not done as it should have been, and only the restoration of mechanical structures was observed. Laws should be set so that the dimensions of releasing chemical gases to the environment are carried out immediately after the incident, and all the existing scenarios are practiced and repeated several times [17].

One key factor that helped control the casualties and damages during the Firuzabad incident was the implementation of EOP for chemical hazards. Rapid response and multi-specialty teams reduced the incident's complexity and minimized the time interval from production stoppage to factory restart. According to a study by Sharma in India, training specialized teams, repetition of exercises, operational capability of research, and planning of organizations to control CBRNE (chemical, biological, radiological, nuclear, and explosive) risks have been proven effective [18]. These findings highlight the importance of having proper emergency response protocols to minimize such incidents' impact and ensure timely and effective disaster management.

Conclusion

This research shows that the ALOHA analysis was relatively consistent with the information collected from the explosion site. The software predicted the areas within a mile of the blast site where the probability of injury and death was higher, but fortunately, no one was present in these areas. The immediate evacuation of the place, the prompt closing of the roads leading to the factory, and the lack of residential areas near the factory have contributed to no casualties. However, the challenges extracted in the field of disaster management for the explosion of the ammonia tank of the Firuzabad factory included the existence and operation of the early warning system, immediate evacuation of the factory and personnel, EOP for HAZ-MAT disaster control, the fast and multi-specialty response teams, evacuation of the roads leading to the factory, triage of the injured, hospital emergency, the possibility of contamination of the Dalkey River and other areas, decontamination of the factory and the surrounding environment, technical and engineering investigations to fix the breakdown, system decontamination of casualties and legal proceedings for those responsible for the accident. These factors highlight the need for continuous evaluation and modification of safety protocols to improve emergency response methods and disaster management in the future for such incidents. It is important to work closely with local authorities and emergency response teams to coordinate relief and rescue efforts. The safety of the people should be the top priority, and all efforts should be made to provide immediate assistance to those affected by the explosion. In the reports of similar cases, there is a lack of information in the evaluation. It is suggested to design tools for future studies that can be used with the minimum available data. These tools provide appropriate lessons that must be approved by specialized experts. Considering the wide application of chemical accident simulation software, it is suggested that researchers in the field of health in disasters and emergencies acquire more information in this field and use it to validate their research.

Practical suggestions

If there has been an explosion of ammonia gas tanks, the priority should be to ensure the safety of the people in the surrounding areas. Here are some suggestions for relief and rescue efforts.

1. Evacuation: Immediately evacuate the people in the surrounding areas to a safe distance. The evacuation should be done quickly to prevent further injuries or casualties.

2. Medical assistance: Set up medical camps nearby to provide the affected people with first aid and medical assistance. Arrange for ambulances and other medical facilities to transport the injured to the nearest hospitals.

3. Search and rescue: Deploy trained personnel to search for people trapped under the debris or in the nearby buildings. Use specialized equipment like thermal imaging cameras and gas detectors to locate survivors or trapped individuals.

4. Provide shelter and food: Arrange for temporary shelters and food for the people who have been evacuated. This measure can be done in nearby community centers or schools.

5. Control the spread of gas: Use water sprays or foam blankets to control the spread of gas. This activity can help reduce the impact of the gas on the surrounding areas and prevent further damage.

6. Investigate the cause: Conduct an investigation to determine the cause of the explosion and take measures to prevent similar incidents.

Ethical Considerations

Compliance with ethical guidelines

This study has been collected as a case report from field reports and interviews. The investigation was approved after discussing and exchanging opinions in the Disaster Health Department of Aja University of Medical Sciences. Written consent was obtained from the study participants.

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There were no financial resources for this study, and the study was only conducted to share the lessons learned.

Authors' contributions

Data collection: Hossein Salehi; Data analyses: Simintaj Sharififar; Designing the study and writing the original draft: The both authors.

Conflict of interest

The authors declared no conflict of interest.

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