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Case Study

Investigation of Chlorine Gas Emission Hazards at ABFA Chlorination Plant at Abadan Station using Aloha and Marplot Software

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Abstract

Chlorine is a toxic and oxidizing gas used in Iran to purify drinking water, and failure to control the effects of a gas leak or tank explosion could cause irreparable harm to workers and residents around the station. There has been no research on this issue in the city of Abadan. This research investigated the release of chlorine gas from a 1000-liter tank at 1 tonne and 1.5 tonnes at the Abadan Chlorination Station. Aloha software was used to investigate the rate of diffusion, different risk areas, and the population at risk. The investigations show that the release of gas in the event of damage to the one-inch outlet valve of the tank can be lethal up to a radius of 2 km, effective up to a radius of 6.2 km, and felt up to 10 km. Considering the possibility of an accident and the location of the station in the direction of the wind, it is possible to harm a large number of citizens living within a 5 km radius of the station. Effective measures are therefore needed to inform the local population, raise awareness among employees and emergency services, install a suitable scrubber, and increase the safety level of the station.

Keywords: Danger zone; release rate; chlorine gas; Abadan station.

1. List of symptoms

PPM	Parts per million (measures the concentration of substances at very low concentrations)
AEGL	Acute exposure guideline values
ERPG	Emergency response planning, identification of downstream areas requiring effective control measures in the event of a chemical release (Emergency Response Planning Guidelines)
TLV-TWA	The lowest detectable concentration of pollutant (time-weighted average - limit values)
IDHL	Minimum concentration hazardous to health (air concentration immediately hazardous to life or health)
EPA	Environmental Protection Agency

2. Introduction

Chemical spills seriously threaten air quality and the safety of people living near the spill site. Despite the best efforts of factories and industries to manage chemicals safely, devastating and deadly accidents are always possible. In many cases, accidents cannot be predicted or prevented. Being prepared to respond to these crises at the time and place of occurrence requires knowledge and assessment of high-risk locations. An accident in a densely populated area will have a wider range of destructive effects on society. The initial impact of the accident is felt at the site and in the surrounding area. The damage caused by these incidents depends on their propagation, and properly responding to these conditions requires proper coordination of local people and institutions. This will be possible if society's awareness of the possibility of danger and the need to prepare for it is increased.

In Iran, due to the importance of the risks of exposure to chemical substances and their destructive effects, there is no written plan for responding to

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emergencies and assessing the level of risk and the extent of their release in the most effective way in the shortest possible time. Chlorine gas is one of the most harmful substances widely used in industry today. Many major industrial accidents in the last century have been linked to releasing this toxic gas into the environment. Chlorine is used to manufacture plastics and other materials, water and wastewater treatment, coolants and polishes, insecticides, medicines, disinfectants, bleaches, and other consumer products. One of the cases of chlorine gas release in Iran was in the city of Dezful in August 2016, when a gas leak from the cylinders of the Old Irrigation Company led to an accident. This accident injured 509 people. Therefore, ozone treatment should be used instead of chlorination, which is a safer and more effective modern method. Because of its special properties, ozone has been used as a drinking water disinfectant in European countries for almost a century. Ozone was first used in the Netherlands in 1893 in a treatment plant taking water from the Rhine. Today, over a thousand water treatment plants use ozone as chemical treatment, most in Western countries, especially France, Switzerland, and Canada. The largest ozone disinfection plants are in Paris and Montreal.

The release of chlorine into the environment can be caused by two unintentional factors: technical faults in the process, perforation of pressure vessels or mixing other chemicals with chlorine due to lack of knowledge of its properties, or deliberate acts of terrorism and sabotage. A solution must therefore be found to reduce these risks. One of the solutions is software modeling, which is a fast and accurate way of predicting the limits of material release and simulating its consequences. Since existing mathematical models for modeling consequences involve complex and time-consuming calculations, the use of simulation software becomes particularly important at this stage, and since assessing the consequences of risks such as the release of hazardous chemicals into the environment is one of the most necessary and important steps to increase the safety of existing or planned facilities, the importance of using software with more capabilities is doubled. The consequence assessment aims to determine the severity of risks and possible casualties caused by fire, explosion, and the spread of toxic substances.

Once the possible accidents in a process have been modeled, it is time to assess the effects and consequences of these accidents. These accidents can be divided into two categories: the consequences caused by the toxicity of substances released into the environment and the consequences caused by the explosion of these substances. One of the necessary pieces of information in evaluating the consequences of process accidents is the vulnerability criteria, which should be used after the scenario modeling stage to analyze the severity of the possible damage and compare each of the consequences with the standards expressing the severity of the damage.

3. Area

Given the location of the chlorine gas tank near the city of Abadan and its position in the wind direction of the cities, it is necessary to investigate the possibility of leakage of this highly toxic and dangerous gas. The chlorination of water is one of the most likely events, with the possibility of rupture and gas leakage from the pipes with a diameter of one inch of the outlet of the tank. The research examined the occurrence of this event during the winter season.

4. Background Research

In recent years there has been research in the area of publishing work. For example, Rama Brahman and Swaminathan (2000) researched a warehouse. A general model for the contingency plan was presented from the process risk study. The model presented was useful but general, and the emergency levels for different release scenarios were not specified [1].

Horeng et al. (2005) used consequence analysis in an article on some of the hazards of chlorine operations and their possible impacts on neighborhoods in central Taiwan. The results showed that multi-layered mitigation systems and operational restrictions should be implemented to provide more precise measures and protection. However, there was no specific regulation for chlorine plants in different locations, such as industrial parks or residential areas [2].

Adondriou et al. (2006) experimentally tested chlorine diffusion on a small scale and then modeled the results with three diffusion models, including two box models and a Gaussian model [3].

Mahoney et al. (2008) presented a model for determining emergency response zones, hot, hot, and cold zones, using the Arial Location of Hazardous (ALOH) software around the toxic gas emission area, based on guidelines for acute exposure levels [4].

In a study, Tseng et al. (2008) investigated the different phases of the emergency response plan and exposure to chlorine gas in process plants in Taiwan. Still, they did not use a process risk assessment method, specify the release scenarios, or determine the radius of chlorine damage during release to the environment [5].

Javad Adel et al. (2008) assessed the risk of chlorine gas leakage in drinking water chlorination plants in Tehran using the fault tree analysis method. This research showed that correcting the basic deficiencies of the stations or designing these stations based on standards significantly reduced the probability of an accident [6].

In an article, Salehi Artimani et al. (2019) addressed the modeling and assessment of the risk of chlorine gas release in water treatment plants. The results of this study showed that the best solution to reduce the

risk of release is proper siting and changing the water treatment method from chlorination to water purification. This is ozone [7].

Wones 1986 found that chlorinated drinking water can increase serum cholesterol, a major risk factor for atherosclerosis [8].

Bernard 2007 notes that exposure to chlorination products, such as those found in swimming pools and public recreation centers, may increase the risk of allergic diseases and respiratory disorders [9].

Achmad 2017 notes that hexavalent chromium, which may be found in dental instruments, is toxic and carcinogenic [10].

While Hattersley 2003 does not directly address the effects of chlorine on the human body, he suggests that chlorinated water may have negative health effects and that other water purification methods should be used [11].

Beach (1969) found that cough, dyspnea, and chest pains were common symptoms in workers exposed to chlorine gas and that chest radiographs showed congestion, consolidation, and nodules [12].

Ho (2010) reported that clinical manifestations of chlorine inhalation can range from mild upper airway irritation to life-threatening toxic effects, such as pulmonary edema/acute respiratory distress syndrome [13].

LoVecchio (2005) found that complaints included shortness of breath, eye irritation, nasal complaints, cough, and skin complaints and that hospital referral was rare [14].

Winder (2001) reported that exposure to chlorine gas can cause sensory irritation, irritation and bronchospasm, cellular changes to bronchioles and alveoli, and the development of pulmonary disease. Treatment of chlorine exposure is essentially symptomatic, with the efficacy of some treatments (such as corticosteroid therapy) still not well established [15].

The review of previous research revealed that no research had been conducted on the hazards of chlorine gas emission in the city of Abadan; therefore, this study attempted to collect relevant data using Aloha and Marplot software and investigate the risks of chlorine gas emission from the water chlorination plant in the city of Abadan.

5. Research Scope

This research is in the city of Abadan; the geographical location of this city is 48 degrees and 17 minutes longitude and 30 degrees and 20 minutes latitude, with a height of 3 meters above sea level and a width of 2,796 square kilometers. The boundaries of Abadan from the north to Shadgan, from the east and south to the Gulf of Pars, from the southwest and west to the country of Iraq, which forms the natural border between the Arvand River and is limited to Khorramshahr from the northwest.

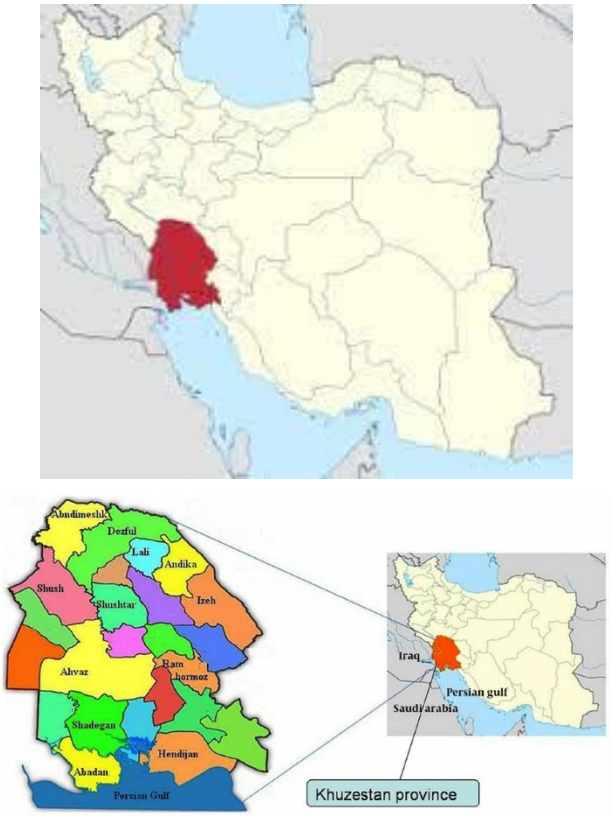

Figure 1. Geographical location of Abadan City

Abadan is located in the plain, and due to its neighborhood with large and burning deserts such as the Great Desert of Arabia and Iraq, it generally has hot and desert weather. Its minimum temperature during the year is 17.7 degrees Celsius. Its freezing days are a maximum of nine days a year. The cold winds that blow from the north, especially in the winter, sometimes bring the temperature to zero, and sometimes the northwesterly winds, together with the Mediterranean humidity, cause a relatively large amount of precipitation. The maximum heat in Abadan is more than 50 degrees, and its intensity is from July to the end of September. The temperature difference between day and night is 25 to 30 degrees Celsius, and the weather is variable and unpredictable.

The southernmost point of Khuzestan is seven degrees higher than the orbit of Ras al-Sartan, so it has a climate similar to tropical regions. Khuzestan has been known for its hot weather since ancient times, and Abadan, one of the southern cities of Khuzestan, has enjoyed this feature like other southern cities of the province. Some books mention it as a city with no winter, and even some sources consider Abadan to have only two seasons, summer and autumn. Muhammad bin Ahmad Shamsuddin al-Maqdisi in Ahsan al-Taqasim described it as having a "tropical climate." But the fact is that Abadan has very hot summers and mild winters due to its location on the Arvandrud, Bahmanshir, and Karun rivers and is generally close to the Persian Gulf.

Air pressure distribution in Abadan during the year is in two distinct seasonal forms. In late autumn and early winter (November, January, February), when the

temperature is low, the air pressure reaches its maximum, and in summer (June, July, August), when the temperature is high, the air pressure drops to its minimum.

According to the 2010 census, the current population of the city of Abadan is 220,000 people, and the population of the city is 300,000 people [16].

Materials and methods to investigate the risks of chlorine gas release and to calculate the release method, dispersion rate, and damage radius, to collect data including the physical and chemical properties of chlorine gas, the climate of the region, information on the storage location and the use of the tank type gas. The storage form, size, and capacity of the tank are required. First, the weather information of the region was extracted from the statistical yearbook of the Meteorological Organisation, and then, by referring to the location, the information on the location of the storage tank and its type was collected. Simulation software becomes particularly important at this stage because the existing mathematical models for result modeling involve complex and time-consuming calculations. ALOHA is one of the software packages used to study the release of contaminants into the environment. The US Environmental Protection Agency has approved this software to model accidents caused by releasing toxic and explosive materials or fires and explosions and their consequences. The software has a very rich database of more than a thousand chemical substances and a simple environment to prevent user errors. Among other features, it can be linked to other software, such as Google Earth GIS, and provides quick access to chemical information on substances and standard instructions. He showed how to deal with critical situations caused by releasing different substances. This useful and practical software was then used to model the speed of propagation, the rate of dispersion, and the impact radius. It provided a quick and accurate way of predicting the spread of a material release and simulating its consequences.

6. Information On the Location of Gas Storage and Use Stations

The station is located in a small room in an environment without buildings or trees. The diameter of the capsule is 0.8 meters, and its length is 1.8 meters, which is in the form of a cylinder. This capsule contains 1 tonne and 1.5 tonnes of chlorine in liquid form and is kept at room temperature. The leak in the tank's outlet pipe has a diameter of one inch and is forty centimeters from the bottom.

7. Criteria for Measuring the Severity of the Risk of Contact with Dangerous Substances

Contact with chlorine gas at a concentration of 12-14 PPM for half an hour to an hour is dangerous to humans, and a concentration of 100 PPM cannot be tolerated for more than one minute. In a normal situation, releasing 10 tonnes of chlorine into the air will produce a concentration of 140 PPM within 2 kilometers of the source and 15 PPM within 2 kilometers. The depth of the disaster is clear. Various criteria have been defined to determine an accurate criterion for the risk of different substances, including AEGL and ERPG. In this research, the severity of the risk was measured using the AEGL criterion. The AEGL is a critical exposure guideline used by planners and responders around the world to manage chemicals that have the potential to be released and cause human health effects and is divided into three different levels. The EPA organization has defined this criterion in three levels and according to the duration of exposure.

Level 1 AEGL: Airborne concentration of a chemical substance at which normal and susceptible people in the community are expected to experience discomfort, irritation, and non-sensory effects without specific symptoms when exposed above this concentration. These effects are not incapacitating, are transient, and disappear with interruption of exposure. For chlorine gas, this criterion is 5 PPM in 60 minutes.

The second level of AEGL is the airborne concentration of any substance that is expected to cause serious and long-term complications in normal and susceptible members of the community if they are exposed to more than this concentration and do not have the opportunity to escape. This standard for chlorine gas is 2 PPM in 60 minutes.

The third stage of the AEGL is the concentration of a substance in the air that is expected to cause serious and harmful effects in normal and susceptible population members if exposed to more than this concentration. This standard for chlorine gas is 20 PPM in 60 minutes.

8. Chemical Information of Chlorine Gas

Chemical name of chlorine

Molecular weight: 70.91 kg mol / kg

The lowest detectable concentration of pollutant PPM: TLV-TWA 0.5

Minimum dangerous concentration for health PPM: IDHL 10

Harmful concentration of FLC: 10 PPM

Boiling temperature: -34.03 degrees Celsius

Vapor pressure at ambient temperature is more than one atmosphere.

9. Discussion and Findings

As mentioned above, the most effective measure of the amount of gas emitted and dispersed is the wind speed and air temperature; therefore, according to the region's climatic conditions, calculations were made in the cold season.

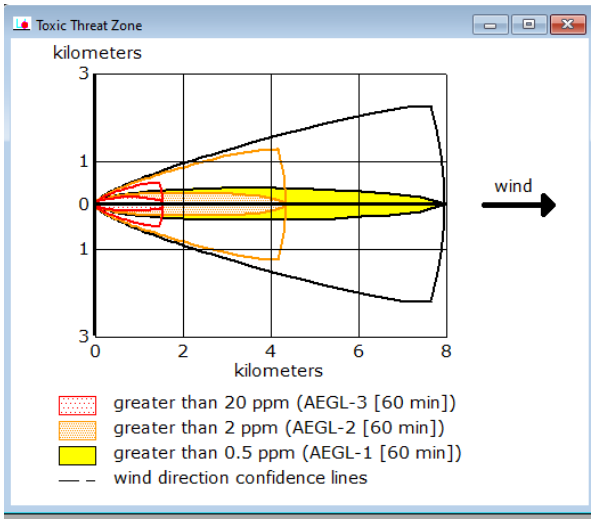

Figure 2. Radius of diffusion and chlorine gas concentration of 1 tonne

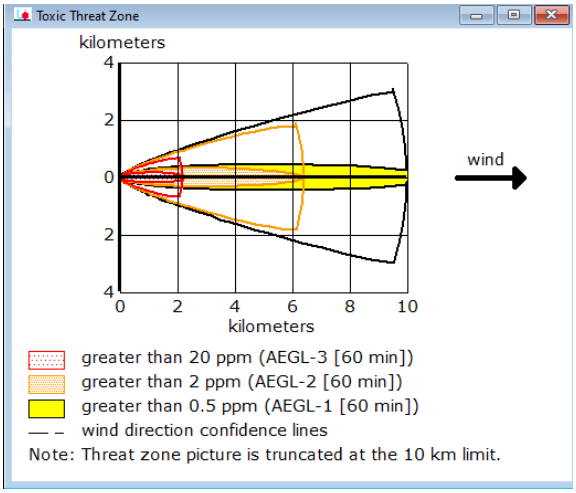

Figure 3. Radius of diffusion and chlorine gas concentration of 1.5 tonne

Figures 2 and 3 show chlorine gas's diffusion radius and concentration (source: Aloha software output).

Another software output is the radius of gas release and its concentration in 60 minutes. It shows the concentration in the cold season of the year if 1 ton of chlorine is released into the air within 1 km from the source of a high concentration of PPM 20 and within 3 km from the source a high concentration of PPM 2 will be created or if 1.53 tons (the tank is full) of chlorine is released into the air within a range of 2 km from the source of high concentration of PPM 20 and within a range of 6 km from the source of high concentration of PPM 2.

According to the information obtained, the data can be implemented on the city map based on the prevailing wind direction, as well as in general, regardless of the wind direction, to determine the area that may be affected by this event.

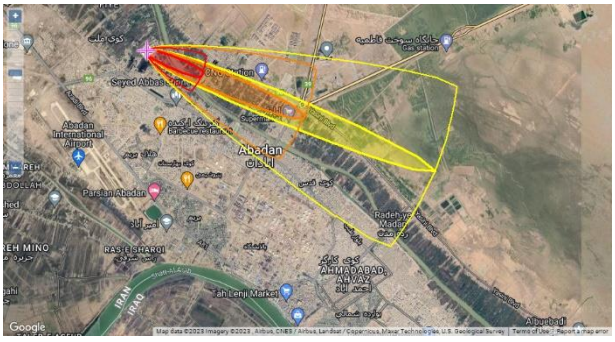

Figure 4. Radius of diffusion and chlorine gas concentration of 1 tonne

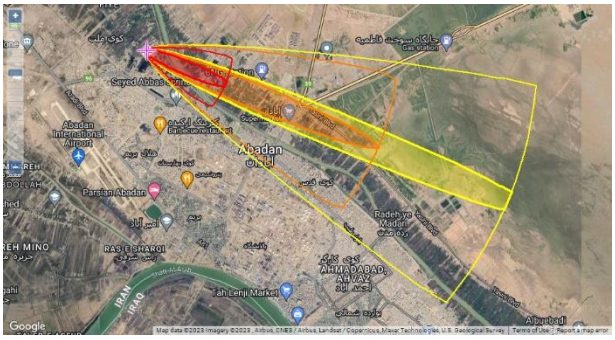

Figure 5. Radius of diffusion and chlorine gas concentration of 1.5 tonne

The emission radius and concentration of chlorine gas (source: MARPLOT software output) are shown in Figures 4 and 5.

10. Results and Suggestions

From the results of the research, it can be concluded that the release of chlorine gas in the event of damage to the outlet valve, given the location of the station in the direction of the prevailing wind and the range of release up to PPM 2, means that the entire area of the new city of Abadan is at risk of gas release and it is possible that a large number of citizens living within a 5 km radius of the station could be injured; Therefore, effective measures such as informing the population, raising the awareness of employees and emergency services, installing a suitable scrubber and improving the safety of the station are required. According to the calculations, diagrams, and maps, it is clear that within a radius of 2 kilometers, the situation is very dangerous and deadly. It will be, and up to a radius of 6 kilometers, there is a possibility of serious and long-term complications for people, depriving them of escape. Because of the high probability of such a crisis, the first step should be to install appropriate scrubbers in chlorination stations and to train station staff to deal with this situation. It is worth mentioning that due to the speed of release of substances such as chlorine gas, other rescue forces can't reach the place in time; therefore, the necessary equipment should be provided for the employees and guards at the place so that in case of a warning and a quick and appropriate response by them, it seems necessary to install warning systems for dangerous

areas and to teach people how to face such a situation Necessary measures after chlorine leakage control.

Once the leak has been controlled, the chlorine remaining in the tank must be removed from its hazardous state.

At this point, the safest of the following methods should be chosen, depending on the technical limitations:

- Use of chlorine in the damaged tank.
- Transfer of chlorine from the damaged tank to the healthy tank.
- Chlorine neutralization. In this case, the chlorine in the tank is neutralized using alkaline substances. As chlorine neutralization is an exothermic reaction, consideration should be given to increasing and controlling the temperature. Chlorine must be introduced into the neutralisation solution through a suitable pipe for neutralization. The solution and the depth of the neutralization vessel depend on the amount of chlorine available, the exit speed, and the number and size of the chlorine gas bubbles. With this method, it is possible to create a vacuum in the tank, which causes the neutralizing solution to return to the tank.
- The air stream must enter the tank to remove the vacuum to avoid this.
- The damaged chlorine container should never be immersed in the neutralization solution.
- The best condition for neutralization is to use a standard scrubber neutralizer.

11. Conclusion

This research investigated the release of chlorine gas from a 1000-liter tank at 1 tonne and 1.5 tonnes at the Abadan Chlorination Plant. Investigations using Aloha software for the rate of release and different risk and population at risk areas showed that the release of gas in the event of damage to the 1" outlet valve of the tank could be fatal up to a radius of 2 km, effective up to a radius of 6.2 km and could be felt up to 10 km away. Considering the possibility of an accident and the location of the station in the direction of the wind, it is possible to harm a large number of citizens living within a 5 km radius of the station. Therefore, effective measures such as informing the population, raising the awareness of employees and emergency services, installing a suitable scrubber, and increasing the safety level of the station are necessary:

1) The need to establish a national chemical information center and the presence of specialists and experts from all relevant and responsible organizations and institutions.
2) The need for specialization in the field of chemicals.
3) The need to pay attention and importance to human, animal, and environmental health.
4) There is a need to create a chemical table in the preventive and operational units of firefighting organisations throughout the country and appoint experts in the relevant positions.
5) Define research and appropriate expenditure.
6) Transferring chemical warehouses outside the cities or securing them completely.
7) Develop appropriate national legislation.
8) Identify the responsible organization and provide it with the necessary facilities.

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