Consequence Modeling of Chlorine Release from Water Treatment Plant

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ABSTRACT

In the recent years, world has seen a wide range of major accidents with a number of fatalities, economic losses, and damage to the environment. These accidents can lead to serious danger to human health and the environment which can be occurred inside or outside the establishment. Consequence assessment is very important to predict and prevent deleterious effects of these events. Chlorine is a toxic material that is used in Water Treatment Plants as disinfectants. The aim of this study is to determine and identify the locations with high risk near the water treatment plant of Rasht, in the north of Iran. In this paper the modeling of chlorine release has been investigated for water treatment plant by using PHAST (Process Hazard Analysis Software Tool) software. According to the result of modeling the rupture of chlorine vessel in F stability class is the worst possible Release scenario because it has been affected more distance than other scenarios. The probability of fatality is %100 in each 3 stability class for the point located at 100 meter downwind. Thus the surrounding land of this plant is non-residential for this distance and the suitable recommendation should be considered to decrees risk of chlorine release.

Keywords: Consequence assessment; Rupture; Chlorine; Release.
1. INTRODUCTION

Great quantities of dangerous chemicals are handled and kept for intermediate temporary storage in docks, marshalling yards and port areas for further transport. Thus, many incidents have occurred in chemical storage sites during the past few years with considerable consequences to neighboring populations [1, 2]. As a result, a large number of studies have been carried out to assess the level of risk and the probable impact to the surroundings for certain port areas [3-6].

The science of risk assessment, which has emerged in recent years with ever-increasing importance is defined as “a process, which includes both qualitative and quantitative determination of risks and their social evaluation” [7]. Risk assessment in chemical process industry is a very important issue for safeguarding human and the ecosystem from damages caused to them. Consequence assessment is an integral part of risk assessment [8]. Risk consequence is the outcome of an event or situation expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gains. Consequence analysis plays an important part in Chemical Process Quantitative Risk Analysis (CPQRA). Consequence analysis is also useful for many other purposes than CPQRA [9]. For example, consequence analysis is used for the following purposes:

- Determining the acceptability of a site, or an optimum location on plant property.
- Determining equipment design parameters i.e. stack height, water deluge requirements, etc.
- Comparative analysis, such as in equipment design option selection.
- Identification of potential impacts on adjacent facilities, communities and populations.

In 1960, the national aeronautics and space administration (NASA) used from consequence assessment. Then other organization used this method. Consequence analysis has been done for different chemical materials including toxic, flammable and explosion materials [10]. Environmental risks posed by such geographical distribution of chemical plants have emerged gradually with the soaring environmental pollution incidents. For example, about 150,000 people were evacuated during the chlorine leaking accident on 16 April 2004 in the Tianyuan Chemical Plant in Chongqing City in southeast China [11]. Chlorine is a toxic material that has many applications in Water Treatment Plants. Disinfection of drinking-water is one of the main achievements of our time in the protection of public health. The use of chlorine for the destruction of microbiological pathogens is essential to protect the public from outbreaks of waterborne disease [12]. Chlorine, as well as other disinfectants, produces a variety of chemical by-products recently Because of population growth, Construction of water treatment plant has increased. Thus consequence assessment is more important to predict and prevent deleterious effects of chlorine release.

Various software has been used for consequence analysis of risk, such as SLAB, ALOHA, PHAST, etc [13]. Required information for this software is wind speed, atmospheric stability, height of the release above the ground, momentum of the material released and buoyancy, surface roughness, Also the type of population distribution have important role around the desired industrial unit [9]. PHAST presented the best model for dispersion of gas in the environment. PHAST is a comprehensive consequence analysis tool. It examines the process of a potential incident from the initial release to far field dispersion, including modeling of pool vaporization and evaporation, and flammable and toxic effects. PHAST is
able to simulate various release scenarios such as leaks, line ruptures, long pipeline releases and tank roof collapse in pressurized/ unpressurised vessels or pipes [14].

In addition to standard wind-rose information on wind speed and direction, the dispersion of release is dependent on the atmospheric stability or weather category. The available data should be analyzed. The detailed wind-rose data should be given and the overall proportions for day and night. The atmospheric conditions are normally classified according to six Pasquill stability classes (denoted by the letters A through F). The stability classes are correlated to wind speed and the quantity of sunlight. During the day, increased wind speed results in greater atmospheric stability, while at night the reverse is true [9]. This is due to a change in vertical temperature profiles from day to night. Within the stability classes, A represents the least stable conditions while F represents the most stable.

In order to calculate the consequence of risk created by the different failure cases, a consequence assessment requires information about the local population distribution. The populations are defined separately as day and night distribution for range buildings and locations [15]. The population group that are most exposed to potential releases are on-site and off-site, so the consequence results will be most sensitive to the concerned facility population assumptions.

The aim of this study is to determine and identify the locations with high risk near the water treatment plant of Rasht. The PHAST software has been used in this paper to modeling of chlorine release. All of possible scenario is considered for real chlorine plant and the result presented to evaluate risk consequence of water treatment plant.

2. METHODOLOGY

2.1 Water Treatment Plant of Rasht

Water treatment plant of Rasht provides drinking water of Rasht, Lahijan and Langarud and uses from water of “SEFIDROOD” River. Because of Rasht has a lot of agricultural land, water in most rivers is including agricultural pesticides mostly in the spring and summer seasons. According to these reasons, it is essential to establish water treatment plant in Rasht, capital city of Gilan province. This unit is located in a populated area, where has about more than 50000 population. There are 2 chlorination lines in chlorination building that each line has four chlorine cylinders. In this study, 6 scenarios have been defined including rupture and leakage of vessel and pipeline. 5 and 25 mm of hole diameter has been selected in leakage scenario. Required information for this software including operational condition, geometrical data for vessels, phase of chlorine, IDLH factor and climate information is shown in Table 1 and Table 2 respectively. IDLH, immediately dangerous to life and health is concentration limit for toxic gaseous compound or vapors. These levels have been established by NIOSH (The National Institute for Occupational Safety and Health) as the concentrations from which one could escape within 30 min without any escape-impairing symptoms or any irreversible health effects [16]. This concentration for chlorine is presented about 30 ppm by NIOSH.
3. RESULT AND DISCUSSION

Chlorine has been used for disinfection of drinking-water in this plant. Because chlorine is a toxic material so its dispersion is very dangerous for human health. Here the PHAST software has been used to modeling of chlorine release. After running of this software with available data, 16 diagrams including maximum concentration footprint, probit versus distance and probability of fatality were obtained for each scenario which some of them has been compared together. Fig. 1 and Fig. 2 show the maximum concentration footprint versus cloud width (m) and distance downwind (m) for rupture of chlorine vessel and pipeline in F stability class. In these figures locations with red, yellow, green and blue color respectively shows the areas with 300 ppm, 150 ppm, 60 ppm and 30 ppm of concentration of chlorine. Fig. 1 shows that the cloud of chlorine with concentration up to 30 ppm would arrive to the point located at 1200 meter downwind for rupture of chlorine vessel in F stability class. Fig. 2 shows that the cloud of chlorine with concentration up to 30 ppm would arrive to the point located at 114 meter downwind for rupture of chlorine pipeline in F stability class.

**Table 1. Operational Data of Chlorine and Plant**

|                      | Volume(m³) | Temperature(°C) | State of Chlorine | IDLH(ppm) |
|----------------------|------------|-----------------|-------------------|-----------|
| Chlorine Vessel      | 0.84       | 21.3            | Saturated liquid  | 30        |
| Chlorine pipeline    | 0.00251    | 21.3            | Saturated liquid  | 30        |

**Table 2. Climate Information**

| Atmospheric Stability Class | Population Density(/m²) | Wind Speed(m/s) |
|-----------------------------|-------------------------|-----------------|
| Day                         | C                       | 0.25            | 8               |
|                             | D                       | 0.25            | 16              |
| Night                       | F                       | 0.18            | 1.5             |

![Fig. 1. Maximum concentration footprint for rupture of chlorine vessel in F stability class](image1)

![Fig. 2. Maximum concentration footprint for rupture of chlorine pipeline in F stability class](image2)
Fig. 3 and Fig. 4 show the maximum concentration footprint versus cloud width (m) and distance downwind (m). In these figure, the area that is limited by the blue and green curve respectively shows maximum concentration footprint for leakage of chlorine vessel with hole diameter of 25mm in C and D stability class. Fig. 3 shows that the cloud of chlorine would arrive to the point located at 290 meter downwind in C stability class for leakage of chlorine vessel with hole diameter of 25mm and would arrive to the point located at 2400 meter downwind in D stability class for leakage of chlorine vessel with hole diameter of 25mm. Fig. 4 shows that the cloud of chlorine would arrive to the point located at 220 meter downwind in D stability class for leakage of chlorine vessel with hole diameter of 25 mm and would arrive to the point located at 200 meter downwind in C stability class for leakage of chlorine vessel with hole diameter of 25mm. The results of consequence modeling are outlined below in Table 3.

![Fig. 3. Maximum concentration footprint for leakage of chlorine vessel with hole diameter of 25 mm in C and D stability class.](image1)

![Fig. 4. Maximum concentration footprint for leakage of chlorine pipeline with hole diameter of 25 mm in C and D stability class.](image2)

In Fig. 5, blue and green curve respectively shows the probability of fatality for rupture of chlorine vessel versus distance downwind (m) at outdoor and indoor release in F stability class. In Fig. 6, blue and yellow curve respectively shows the probability of fatality for rupture of chlorine vessel versus distance downwind (m) at outdoor release in C and D stability class, also green and red curve respectively shows the probability of fatality versus distance downwind(m) at indoor release in C and D stability class. Fig. 5 shows the probability of fatality for rupture of chlorine vessel is 1 at outdoor release in F stability class for the point located at 110 meter downwind. Fig. 6 shows that the probability of fatality for rupture of chlorine vessel is 1 at outdoor release in C and D stability class for the point located at 100 meter downwind. Due to the above issues, it is recommended that the land around the unit to be haunted by a distance of 1800 meters. It was also proposed that chlorine cylinders placed between the walls. Doing so, it does not reduce the risk of accidents, but also reduces the risks of accident.
Table 3. The Results of Consequence Modeling

| Scenario       | Stabilility class | Hole size (mm) | Distance for cloud of chlorine with concentration up to 30 ppm (m) | Location point for 100% fatality in outdoor release (m) |
|----------------|-------------------|----------------|-----------------------------------------------------------------|-------------------------------------------------------|
| Rupture of vessel | F                 | 1200           | 110                                                             |                                                       |
|                 | C                 | 1134           | 100                                                             |                                                       |
|                 | D                 | 1834           | 100                                                             |                                                       |
| Rupture of pipeline | F             | 114            | Not exist                                                     |                                                       |
|                 | C                 | 102            | Not exist                                                     |                                                       |
|                 | D                 | 126            | Not exist                                                     |                                                       |
| Leakage of vessel | F              | 5              | 1245                                                           | 55                                                    |
|                 | 25                | 1590           | 60                                                             |                                                       |
|                 | C                 | 5              | 158                                                           | 25                                                    |
|                 | 25                | 290            | 30                                                             |                                                       |
|                 | D                 | 5              | 144                                                           | Not exist                                            |
|                 | 25                | 242            | Not exist                                                     |                                                       |
| Leakage of pipeline | F            | 5              | 135                                                           | 25                                                    |
|                 | 25                | 168            | 25                                                             |                                                       |
|                 | C                 | 5              | 162                                                           | Not exist                                            |
|                 | 25                | 200            | 25                                                             |                                                       |
|                 | D                 | 5              | 143                                                           | Not exist                                            |
|                 | 25                | 220            | Not exist                                                     |                                                       |

Fig. 5. Probability of fatality for rupture of chlorine vessel in F stability class.

Fig. 6. Probability of fatality for rupture of chlorine vessel in C and D stability class.

4. CONCLUSION

Chlorine and its consequences have a far more reaching effect in society that one may have imagined. The PHAST software has been used in this paper to modeling of chlorine release. All of possible scenario is considered for real chlorine plant and the result presented to evaluate risk consequence of water treatment plant. According to the result of modeling the rupture of chlorine vessel in F stability class is the worst possible Release scenario because it has been affected more distance than other scenarios. The probability of fatality is 100%.
in each 3 stability class for the point located at 100 meter downwind. Thus the surrounding
land of this plant is non-residential for this distance and the suitable recommendation should
be considered to decrees risk of chlorine release. Therefore suggested that the land around
the unit to be haunted by a distance of 1800 meters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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