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Modeling and Assessing Risk analysis of Chlorine Gas in Water Treatment Plants

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ABSTRACT

The necessity of confronting current incidents of the world has intensified the issue of safety observation and preparedness in critical conditions for societies. These incidents, which have been mostly related to industrial incidents, have been accompanied by serious environmental damages and many financial and life losses. Risk assessment includes management system to observe necessary requirements in order to reduce irreversible hazards. The desired option for risk assessment is based on economic analyses in most of the cases and any economic analysis requires optimization of financial resources. The goal of this study was to model and assess the risk resulting from the emission of chlorine gas in water treatment plants in order to protect environment and population against storage of this toxic substance. To model this process, Jalalieh Water Treatment Plant located between Fatemi Square and Fatemi Crossroad, which is one of the high density areas of city of Tehran, was studied.

Key words: Risk assessment, Safety, Water treatment plants, Chlorine, Crisis preparedness

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INTRODUCTION

Occurrence of incidents is not understandable, predictable and avoidable in many cases. Obtaining necessary preparedness for responding to these crises at the time and place of occurrence requires recognition and assessment of high-risk places. Occurrence of incidents in high density areas leads to more extensive destructive effects in society. The rate of damages resulting from these incidents depends on the expansion of the first reaction to the incident at the place of occurrence and its surroundings.

Proper response to these conditions requires suitable coordination between people and local institutions, which can be executed when the awareness level of society from risk possibility and the need for mutual preparedness for confrontation increases.

Goals

- Recognizing and specifying risks to the public, especially the personnel near the industrial compounds
- Recognizing and specifying the risks resulting from external factors and their harmful effects on the industrial unit
- Clarifying the accurate zone and extent of risk to be used optimally by the crisis management authorities to confront such an incident; assessing and testing the paths to remove or reduce risks
- Suggesting ways for risk reduction considering economic interests

Data and Information
Meteorological Information [3][4]

Emission of pollutant is a function of atmospheric stability and conditions in addition to the dependence on wind speed and direction. The available information should be analyzed and the information relating to stable conditions should be selected for investigating and assessing the maximum risk. In this study, the meteorological information related to city of Tehran was collected from two Golhak and Mehrabad Meteorological Stations. This information was analyzed for different times of year and atmospheric conditions relating to high stability were considered.

Population
In order to calculate social risk level resulting from pollutant emission, it is necessary to assess population density and distribution in the risky place. Population distribution is a function of two factors of time and place and is different during day or night time as well as public places and buildings. Also, in risk assessment, it is necessary to consider the population groups which are at different risk levels (on site and out of site) [10].

Local Information [3][8]
- Location: Dr. Fatemi St, Jalalieh Water Treatment Plant, Tehran
- Height above sea level: 1245-1260 m
- Air exchange rate per hour: 0.5
- Date: March 2012

Chemical Information [6]
- Chemical name: Chlorine
- Molecular weight: 70.91 kg mole/kg
- *TLV-TWA*[1]: 0.5 *ppm*[2]
- *IDHL*[3]: 10 ppm
- *FLC*[4]*: 10 ppm*
- *FLC*[5]*:10 ppm*
- Boiling temperature: -34.03°C
- Vapor pressure at ambient temperature: more than 1 *atm*[6]
- Saturation concentration in ambient conditions: 1000000 or 100% ppm

Meteorological Information [3][4]
- Wind: 1 m/s
- Stability level: E
- Air temperature: 15 °C
- Relative humidity: 40%
- Roughness level: urban zone

Information of Chlorine Gas Storage Tanks [2]
- Model of chlorine storage tanks : cylindrical
- Dimensions of tanks: length: 203 cm, width(diameter): 80cm, radius: 40 cm
- Mass of empty tanks: 550 kg
- Thickness of wall: 1cm
- Stored chlorine temperature: below -8°C
- Situation of the stored chlorine: liquid and gas
- Liquid level available in tank: 90%

[1] Threshold limit value-time weighted average: the minimum rate of the recognizable concentration of pollutant –average weight in terms of time for the pollutant
[2] divided by million (concentration unit equivalent to mg/m^3)
[3] Immediately Dangerous for Life and Health: minimum rate of concentration which is dangerous for life
[4] Footprint Level of Concern: is concentration rate of the pollutant in which harmful and dangerous effect is made evident.
[5] Footprint Level of Concern: is concentration rate of the pollutant in which harmful and dangerous effect is made evident.
[6] Pressure unit

- Pressure of each tank: 7 bar
- Height of pipe to tank joining place: 1 m below the tank
- Diameter of the pipe connected to tank: 1 inch

Simulation

The dispersion model used for estimating the range of chlorine emission was *ALOHA*[7].

ALOHA is an atmospheric dispersion model to assess emission of pollutant and predict rate of dispersion and has the following advantages:

- Determining distance of chemical emission using physical properties and toxicity rate of the substance
- Ability to perform calculation at due times
- Drawing the affected zones in terms of concentration of chemical substance
- Ability to predict concentration of the chemical indoors and outdoors during emission of the pollutant
- Drawing concentration of chlorine gas at specified points after 1 h of pollutant emission in terms of indoor concentration, concentration rate at ground level and concentration rate inside buildings

Water treatment process in Jalalieh Water Treatment Plant was of physical, chemical and microbial type. Thus, chlorine had a main role in water treatment according to traditional methods. Chlorination process was performed in two initial and final stages in order to remove and destroy undesirable and pathogenic organisms, relatively modify color, odor and flavor and do sterilization. Chlorine used in this treatment plant was stored in 4 tanks, the specifications of which were as follows [1].

1. The following information was obtained by stimulation:

- Used model: heavy gas
- The *LOC*[8] specified by the user: equal to (IDlH=10 ppm)
- Emission duration: 10 min
- Maximum mean rate of substance emission:150.14 min/kg
- Total emitted substance : 803.76 kg

2. Acute Exposure Guideline Levels (AEGL)

- Red lines: 1393 yard[9] (*20 ppm=AEGL-3(60 min))*
- Orange lines: 2.1 miles[10] (2 ppm=AEGL-2(60 min))
- Yellow lines: 3.9 miles[11] (0.5 ppm=AEGL-1(60 min))

Concetration Rate in Threatened Zones

This model presents concentration limit for critical concentration rate or level of concern (specified by the user as LOC concentration by being applied to the software (its rate for chorine was IDHL-10ppm using the handbook[12])) [16], maximum rate of outdoor concentration which was 1050000 ppm from the emission point and maximum rate of indoor concentration which was 4990 ppm.

Outdoor and indoor concentration rates of chlorine cloud are demonstrated in terms of time in different distances from the point of emission (Figure 2) and maximum rate of concentration is given in terms of time from the range of threatened zones during the emission of chlorine gas and also outdoor and indoor concentration rates of pollutant are shown in terms of different distances from the pollutant's emission place (Figures 3, 4 and 5).

[7]Areal Locations of Hazardous Atmospheres: is the software which has been designed by American Environmental Protection Agency for controlling and forecasting air pollution condition.

[8] Level of Concern

[9]AEGL-3: concentration rate of a substance in which people are exposed to serious life threatening hazards.

[10] AEGL-2: concentration rate of a substance in air with which the vulnerable people will suffer from serious irreversible and long term effects with inability to escape from the place.

[11] AEGL-1: concentration rate of a substance in air which is predicted to afflict the ordinary people including vulnerable , suffering from disease or external effects with disease. Anyway, these effects don't disable person and are transitional when they are exposed to it.

[12] Confidence lines: centerlines in diagram No. 1 which are dark black lines.

[13] Outdoor concentration: concentration in open space , indoor concentration: concentration in closed space downwind: off centerline:

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[12] *Environmental Data of Organic Chemicals*

The threatened zones can be observed in terms of distance (Figure 1):

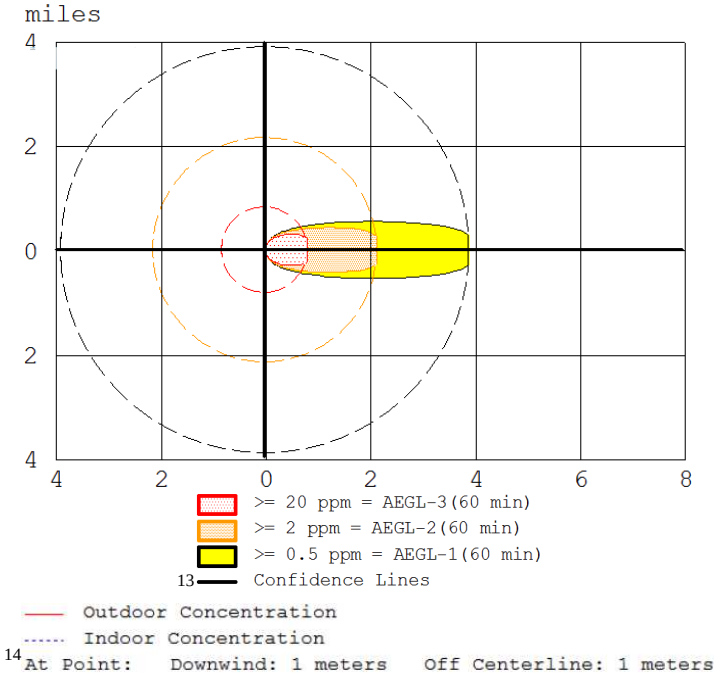


Figure 1: Threatened zones in terms of distance

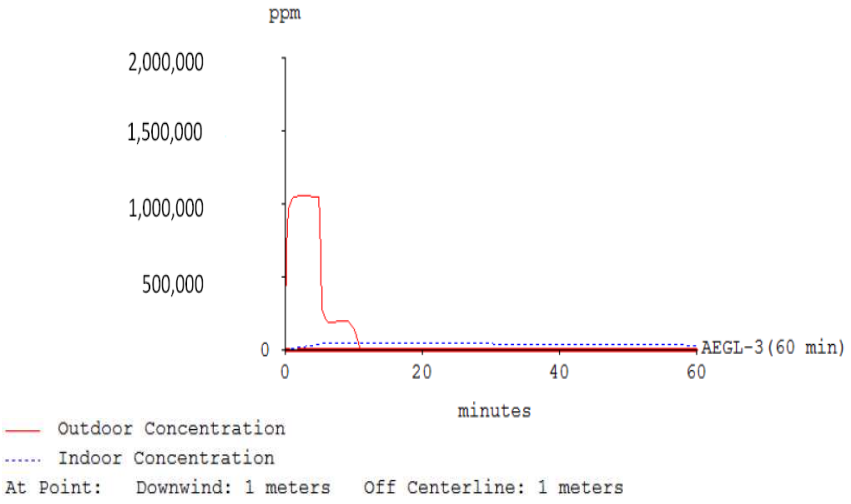


Figure 2: Concentration rate of chlorine gas over time in 1 m downstream, 1 m out of the centerline

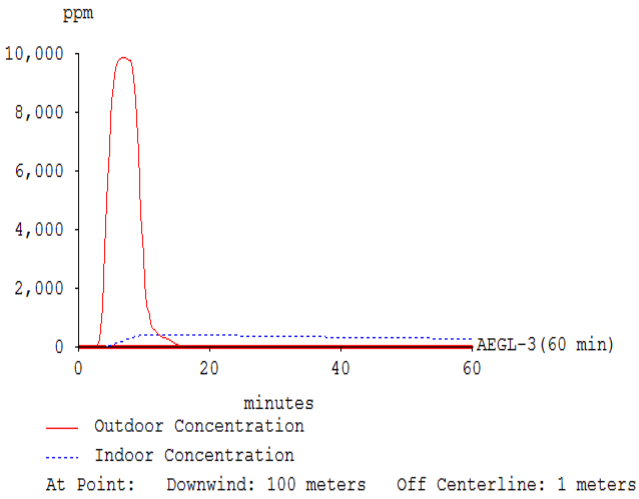


Figure 3: Concentration rate in terms of time from the threatened zones in 100 m downstream, 1 m out of the centerline
Figure 4: Concentration rate in terms of time from the threatened zones in 100 m downstream, 100 m out of the centerline

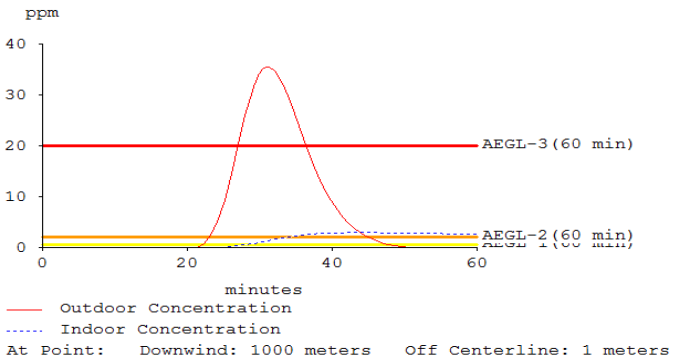


Figure 5: Concentration rate in terms of time from the threatened zones and the comparison between hazardous positions leveling in 1000 m downstream, 1 m out of the centerline

Mean of Pollutant Emission

Figure 6 shows mean rate of pollutant emission over time of emission since chlorine gas is released from the pressure tank. At the beginning of this process, the released rate of pollutant was high and fell over time. The maximum rate of pollutant emission equalled 331 *pounds/minute*.

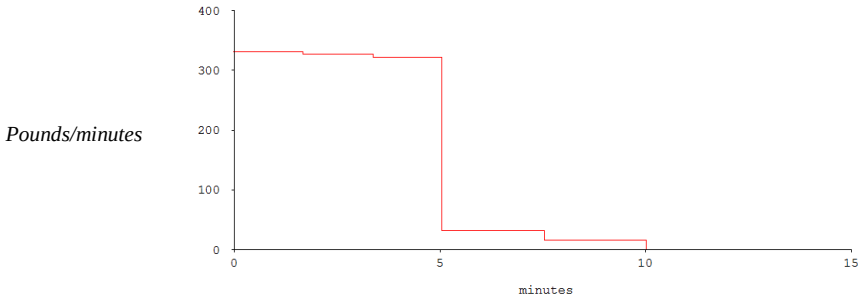
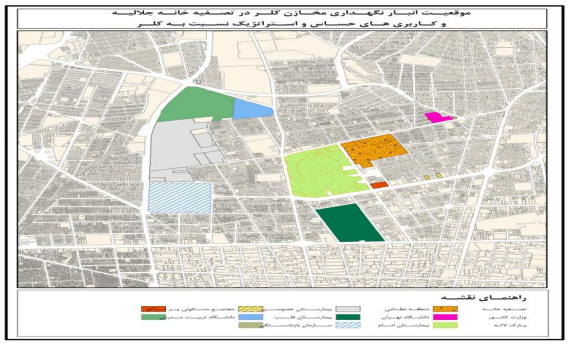


Figure 6: Mean rate of pollutant emission over time of emission

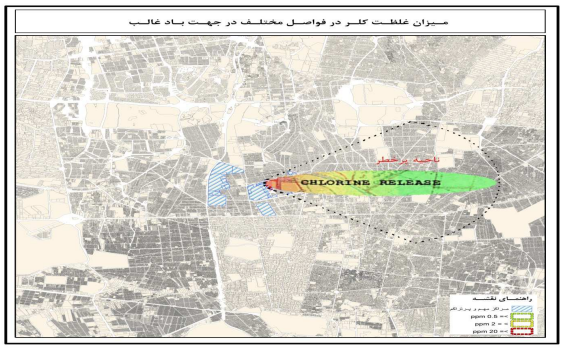
Studying Emission Range of Chlorine Gas

Emission manner of chlorine gas is a direct function of wind direction [9], [7]. In order to study emission manner of chlorine gas (Map 1), location of Jalalieh Water Treatment Plant, in which chlorine was stored for water treatment, is marked with orange color and also important and sensitive uses are specified considering the map guide. Using

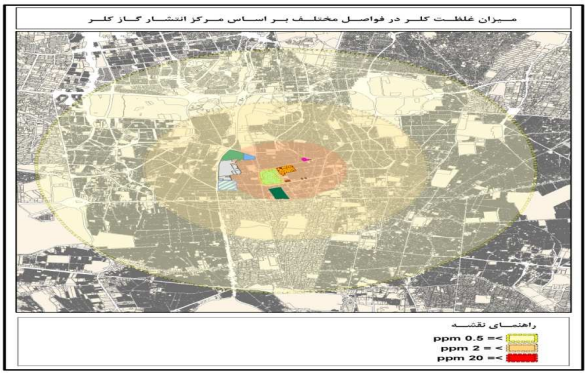
the figure of the threatened zones in terms of distance (Figure 1), chlorine concentration rate is shown in different distances in the direction of prevailing wind in Map 2. However, Map 3 demonstrates concentration (*ppm* or mg/m^3) relative to the distance from the leakage point in all directions. Thus, Map 2 is drawn considering the prevailing wind of Tehran (the western wind) and shows emission manner of chorine gas and concebtration rate of chlorine in terms of distance from emission center in wind direction. These zones are the most hazardous zones at the time of chlorine emission and vulnerable zones are also specified in this map.



Map 1: General view of sensitive and high density uses around Jalalieh Water Treatment Plant [5]



Map 2: Chlorine concentration rate in different distances in direction of prevailing wind [5]



Map 3 shows concentration (mg/m^3 or ppm) relative to distance from the leakage point in all directions (considering the map guide) [5].

CONCLUSION

Emission risk of chlorine gas is inevitable as a highly applied substance in water and sewage treatment plants. If the threatened zones by the chlorine emission in Jalalieh Water Treatment Plant can be generally classified, the following can be given: concentration rates of chlorine cloud of above 20 ppm, 2 ppm and 0.5 ppm are toxic with radius of 1 km, 3.5 km and 4.5 km from chorine emission center, respectively. It is suggested for Jalalieh Water Treatment Plant to have some solutions on its agenda for replacing modern treatment methods through using nano sciences, using ozone instead of chorine or transferring the water treatment plant to a sparsely populated zone in future. Also, Chlorine Leakage Department and Tehran Water and Wastewater Company are recommended to inform all the risk-exposed zones of chlorine emission at the emission time by alarms or any other suitable information methods. The densely populated centers, which should be informed at the time of chlorine emission,

include buildings of Ministry of the Interior, Ministry of Agricultural Jihad-e-Agriculture, Water and Wastewater Company of Tehran Province, Civil Service Pension Fund, residential buildings around the treatment plant, private Sasan and Pars Hospitals, physicians' buildings and banks located at Keshavarz Boulevard, from Valiasr Square to the end of Keshavarz Boulevard, Laleh Park, University of Tehran, Trabiat Modares University, Imam Khomeini Hospital, Cardiac Hospital, Faculty of Medical Sciences (Iran's Army), located at Chamran Highway, near Tohid Square and Saman Residential Complex, located at the juncture of Keshavarz Boulevard and Hejab Street. In addition, considering the direction of prevailing wind, buildings of Ministry of the Interior and Civil Service Pension Fund are the zones which are exposed to chlorine concentration from 20 ppm to 1050000 ppm at the time of chlorine emission (intentionally or unintentionally) in Jalalieh Water Treatment Plant, which is very hazardous and virulent. In order to get prepared for confronting hazards resulting from leakage of chlorine in Jalalieh Water Treatment Plant, organizations, agencies, institutions and residential buildings which are at the risk of chlorine leakage should activate their passive defense. Also, the personnel and inhabitants of the buildings should get familiar with the risk of chlorine gas by means of brochures or holding maneuvers to train them how to confront chlorine emission. Tehran Water and Wastewater Company can have a predetermined plan in cooperation with Firefighting Organization to protect the personnel of Jalalieh Water Treatment Plant as well as the public who are exposed to chlorine gas at the time of chlorine leakage either as pedestrians or inhabitants of the high risk zone (the threatened zones specified in this paper). In order to have a proper reaction while confronting these incidents, trained forces and suitable equipment are required.

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