Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/01/jls.htm
2015 Vol.5 (S1), pp. 3370-3378/Babaei et al.

Research Article

MODELING CONSEQUENCE OF DISPERSION OF CHLORINE GAS IN TREATMENT PLANT INSTALLATIONS

Farzam Babaei[1], Mehdi Ardjmand[2], Javad Salehi Artimani[3*]

[1]*Department of Environment and Energy, Science and Research Branch,Islamic Azad University, Tehran, Iran*

[2]*Islamic Azad University, South Tehran Branch, Graduate Center, Tehran, Iran*

[3]*Young Researchers and Elite Club South Tehran Branch, Islamic Azad University,Tehran,Iran*

[*]*Author for Correspondence*

ABSTRACT

Risk assessment is a common method for managing effective safety tools in order to decrease the risk resulted from different incidents; however, since the probability of some incidents is never eliminated, this method introduces an algorithm to quantitatively evaluate the risk and reduce the risk resulted from different incidents to a cost-effective level; also, each economic analysis requires the optimization of financial resources. The objective of this study was to model the consequence of dispersion of chlorine gas in treatment plant installations in order to protect population and the environment from the storage of this toxic substance. To model this process, Jalalieh Water Treatment Plant located between Fatemi square and Fatemi crossroads, which is one of the high-density areas in city of Tehran, was investigated.

Keywords: *Risk Assessment, Safety, Water Treatment Plants, Chlorine, Crisis Preparation*

INTRODUCTION

In many cases, the occurrence of incidents is not perceptible, predictable, and avoidable. The necessary preparation for responding to these crises at the time and location of occurrence requires the identification and assessment of risky locations. The occurrence of incidents in high-density spots entails an extensive range of destructive effects in the society. The level of damage caused by these incidents depends on the extension level of the first reaction to the incident at the occurrence site and its surrounding areas.

An appropriate response to these circumstances requires suitable coordination between regional institutions and people, which can be achieved by increasing awareness level of the society in terms of risk probability and need for mutual preparation to cope with it.

Objectives

- Investigating and analyzing the results of individual risk analysis
- Investigating and analyzing the results of social risk analysis
- Investigating and analyzing the results of mortality probability
- Investigating and analyzing the results of maximum possible concentration
- Investigating and analyzing the results of the side view of chlorine gas dispersion

MATERIALS AND METHODS

Data and Information

- ***Meteorological Data***

Emission of pollutants not only depends on the wind speed and direction, but also is a function of atmospheric stability rate and atmospheric conditions. The available information need to be analyzed and the information related to stability conditions must be selected to investigate and evaluate maximum risk. In this study, meteorological information related to city of Tehran was collected from Mehrabad Meteorological Station and was analyzed at different times of the year. Then, the atmospheric conditions related to high stability were considered (TPAPM, 2010).

- ***Population***

To calculate the level of social risks resulted from the emission of pollutants, population density and distribution of the studied risk area should be investigated. Population distribution is a function of both time and location factors and varies during day or night and in public locations and buildings. Furthermore, in risk assessment, it is necessary to consider the population groups which are exposed to different levels of risk (inside and outside the site) (USCHI, 2002).

- ***Local Information***
  - Location: Tehran, Jalalieh Water Treatment Plant, Dr. Fatemi Street
  - Altitude from sea level: 1245-1260 m
  - Time: March 2012(NMO, 2012).
- ***Chemical Information***
  - Chemical name: Chlorine
  - Molecular weight: 70.91 kg-mol/ kg
  - Threshold limit value - time weighted average: 0.5 ppm (parts per million; concentration unit, equivalent to mg/m^3)
  - Immediately dangerous for life and health: 10 ppm
  - Footprint level of concern (as a concentration of the pollutant, at which dangerous and harmful effect is revealed) : 10 ppm
  - Boiling temperature: -34.03°C
  - Vapor pressure at ambient temperature: more than 1 atm (pressure unit) (Verschueren, 1983).
- ***Meteorological Information***
  - Wind speed and stability level: Considering the table of Pasquillstability classes and wind speed, F-2, D-5, and B-1 stability conditions can be used for the worst conditions.
  - Air temperature: 20°C
  - Relative humidity: 40%
  - Roughness surface: Urban region (TPAPM, 2010).
- ***Calculating Frequency of Occurrence***

In this section, the occurrence probability of chlorine gas is calculated. For accurate calculation of the occurrence probability, P&ID document is needed to count the numbers of valves, flanges, equipment, etc. and to calculate the occurrence probability using computational Excel prepared according to information of DNV accredited company.

- ***Scenario***
  - Scenario type: Leak
  - Leakage type (inside or outside the building): inside the building
  - Leakage diameter: 1"
- ***Information Relating to Chlorine Gas Storage Tanks***
  - Shape of chlorine gas storage tanks: Cylindrical
  - Dimensions of tanks: Length: 203 cm, width (diameter): 80 cm, radius: 40 cm
  - Mass of empty tank: 550kg
  - Thickness of wall: 1 cm
  - Temperature of the stored chlorine: Less than -8°C
  - State of the stored chlorine: Liquid and gas
  - Level of liquid inside the tank: 90%
  - Pressure of each tank: 7 bar
  - Height: 4 m (height of the building's vent is considered.)
  - Diameters of the tube connected to the tank: 1" (TWSC, 2011).
- ***Information of the Building and its Air Conditioning***
  - Type of air conditioning system: Obligatory
  - Location of the vent: On the wall
  - Diameter of the vent: This value is used for the calculation of the speed of exhaust gas and has a slight effect on the results of modeling.
  - Flow rate of the vent: This value has a major effect on results.

This value is between one and four times of complete discharge of indoor air per minute; in the present project, considering the dimensions of the building, flow rate of the all fans was obtained between 22000 and 88000 m^3/h.

- Dimensions of the building: 23*4*4 m^2

- ***Simulation***

In this paper, PHAST Risk model was used for the risk assessment.

PHAST is the air dispersion model for evaluating emission of pollutants and predicting the rate of dispersion. PHAST Risk model can be used to study risk assessment. PHAST is one of the most powerful and well-known software which has been proposed for modeling incidents resulted from the release of toxic and explosive substances or their subsequent fire or explosion. PHAST software is among the various products which have been developed by DNV Software Company, one of the pioneers in evaluating risks and industrial accidents. This software has been considered as one of the decision-making tools for companies and governments in terms of industrial hazards and general safety. Results from different studies on (UDM) Unified Dispersion model (the model used in the software), which was presented by DNV, indicate that this model is very efficient both theoretically and practically in predicting accidents. What follows are among the capabilities of this software:

- Determining the emission distance of chemical substance using physical properties and toxicity rate of the substance
- Capability of performing computations at determined time
- Drawing the affected areas in terms of concentration of chemical substance
- Capability of predicting the concentration of chemical substance in closed and open spaces during emission of the pollutants
- Drawing the concentration of chlorine gas at specific points after 1 h emission of pollutants in terms of concentrations in open space, at ground level, and inside buildings
- Individual and collective risk analyses

Water treatment process in Jalalie Water Treatment Plant was of physical, chemical, and microbial type. Therefore, according to traditional methods, chlorine had a major role in water treatment. Chlorination process is done in two primary and final stages to eliminate unfavorable and pathogenic organisms, to relatively modify color, taste, and smell, and to disinfect the water. The chlorine used in this treatment plant was stored in 3 tanks: (JTPB, 2008).

1. ERPG (Emergency Response Planning Guidelines) Criterion

This criterion has been established by AIHA (American Industrial Health Association) and is composed of three levels:

- ERPG-1: is the maximum concentration of chemical substance in the air, to which all people can be exposed for 1h without any trouble or sensing any undesirable smell.
- ERPG-2: is the maximum concentration of chemical substance in the air, to which all people can be exposed for 1 h without suffering any serious or irreparable damage or inability to take safety measures.
- ERPG-3: is the maximum concentration of chemical substance in the air, to which all people can be exposed for 1 h without any life threat (Artimani, 2012).

2. Investigating Emission Range of Chlorine Gas

Emission of chlorine gas is a direct function of wind direction (Hannal and Change, 2008; USCHI, 2002). To investigate the emission manner of chlorine gas (Map 1), the location of Jalalie Water Treatment Plant, in which chlorine is stored for being consumed for water treatment, is shown in orange color. Also, important and strategic uses are specified in the map legend. In Diagram 1, the threatened areas are determined in terms of distance.

Research Article

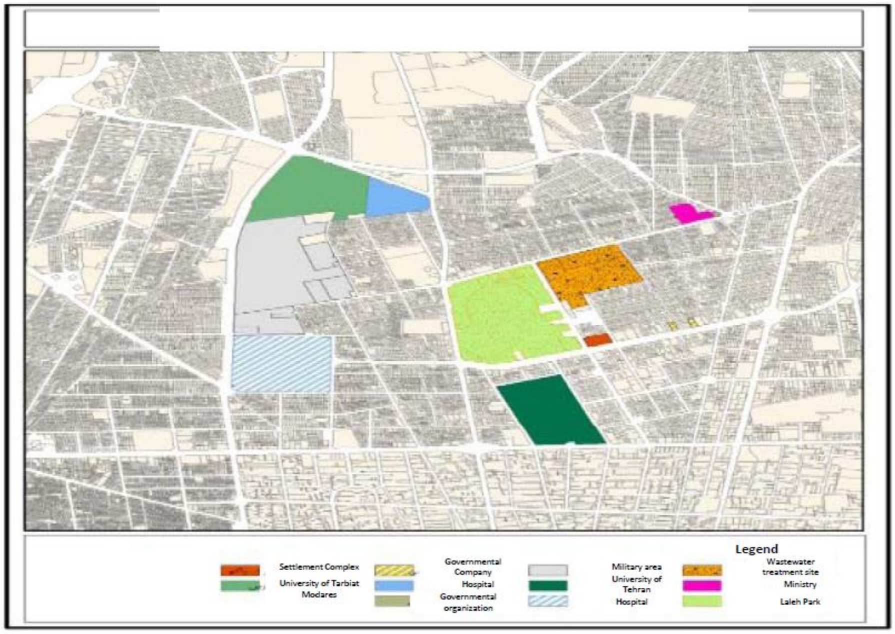

Figure 1: Map of general view of strategic and high-density uses surrounding JalalieWater Treatment Plant (Artimani, 2012)

RESULTS AND DISCUSSION

Results of Individual Risk Analysis for Different Weather Conditions

Individual risk diagram indicates various risk levels which are applied to a person. Results of risk analysis for all three weather conditions and the combination of the three weather conditions are shown in Figure 1. The area within the levels of 10^{-6} and $10^{4}$was called ALARP and the areas outside 10^{-6} level were acceptable in terms of risk. The activity inside the area with the risk level of $10^{4}$was considered risky. The area between the levels of 10^{-6} and 10^{-4}did not has acceptable risk and the measures required for risk reduction in this area must be quickly taken. As shown in Figure 2, the entire treatment plant was located in the area with high risk which was considered risky. Moreover, many surrounding areas of the treatment plant up to the building of Civil Servants Pension Fund were located in ALARP zone, for which the necessary risk reduction measures had to be quickly taken. As was expected, the western part of the treatment plant was exposed to higher risk in F-3 and D-5 weather conditions, in which wind was dominantly from the west, compared to the B-1 weather conditions.

Figure 2: Results of individual risk for three types of weather conditions

Figure 3: Results of individual risk for F-2 weather condition

Figure 4: Results of individual risk for D-5 weather condition

Figure 5: Results of individual risk for B-1 weather condition

Results of Social Risk Analysis

According to the risk criterion mentioned in Figure 2, collective risk was not accepted at all and the line related to collective risk (blue line) was at two ALARP and high-risk areas. With technology development and increased safety in urbanization industry, such risk level is not acceptable in any country around the world and is treated as an uninhabitable and risky area. Thus, it is recommended to take all the necessary measures for the reduction of the risk caused by the chlorine gas dispersion in the considered treatment plant. Measures such as using substances with the lower level of risk, instead of chlorine gas, using a better air conditioning system (locating the vent exhaust at a higher point than the current level (4 m) or using a more number ofvents with higher discharge flow rates), preparing a reaction plan for emergency conditions, using chlorine gas neutralization system, and developing guidelines for conducting studies on the risk management of treatment plants before their construction can decrease the related risk.

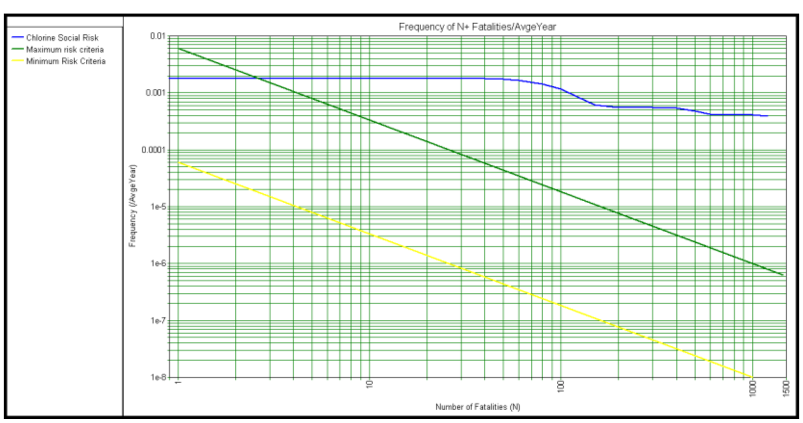

Figure 6: Results of the social risk of chlorine gasdispersion as F-N diagram for all three weather conditions

Results of Mortality Probability in Different Weather Conditions

Results of the mortality probability at three 0.1, 0.01, and 0.001 levels for each of the weather conditions are presented in Figures 7, 8, and 9, respectively.

These results were presented under the assumption of west prevailing wind and during the year, all directions can be definitely exposed to this level of mortality. As was shown, in F-2 weather conditions, more distant areas were affected and, in B-1 weather conditions, the areas with more surfaces were influenced. The weather conditions with minimum risk we related to D-5 area due to higher wind speed and, consequently, quicker mixture of air with chlorine gas.

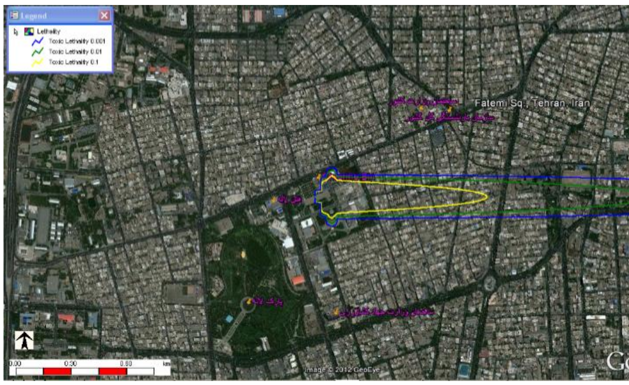

Figure 7: Mortality probability of people in F-2 weather conditions and west wind

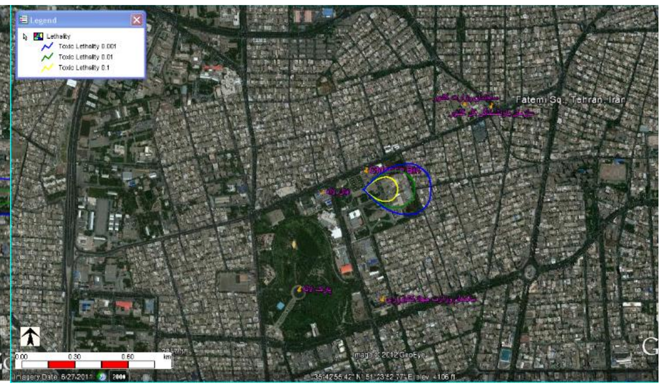

Figure 8: Mortality probability of people in D-2 weather conditions and west wind

Figure 9: Mortality probability of people in B-2 weather conditions and west wind

Maximum Concentration of Chlorine Gas from Top View in Different Weather Conditions

Considering the variations in the concentration of chlorine gas over time at each point, the results related to the maximum concentration of chlorine gas for three concentrations of 1, 3, and 20 ppm are shown from the top view in Figures 3, 4 and 5, respectively.

These concentrations were corresponding to ERPG-1, ERPG-2, and ERPG-3, respectively. As can be observed, in F-2 weather conditions, more distant areas were affected and, in B-1 weather conditions, the areas with more surfaces were affected.

The weather condition with minimum risk was D-5, due to higher wind speed and, consequently, quicker mixture of air with chlorine gas.

Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/01/jls.htm
2015 Vol.5 (S1), pp. 3370-3378/Babaei et al.
Research Article

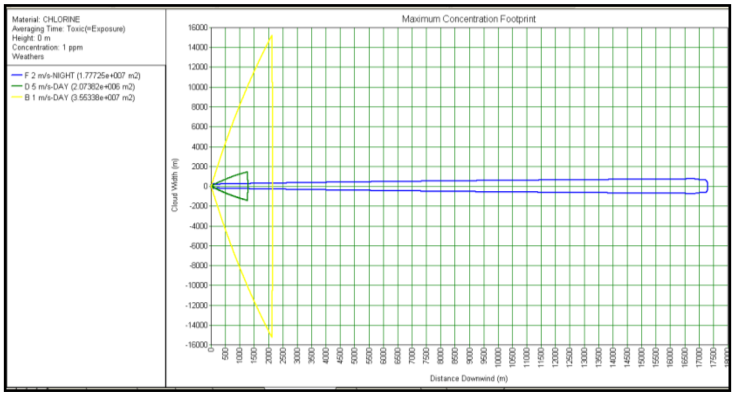

Figure 10: Maximum concentration of chlorine gas from top view for 1 ppm (ERPG 1) and different weather conditions

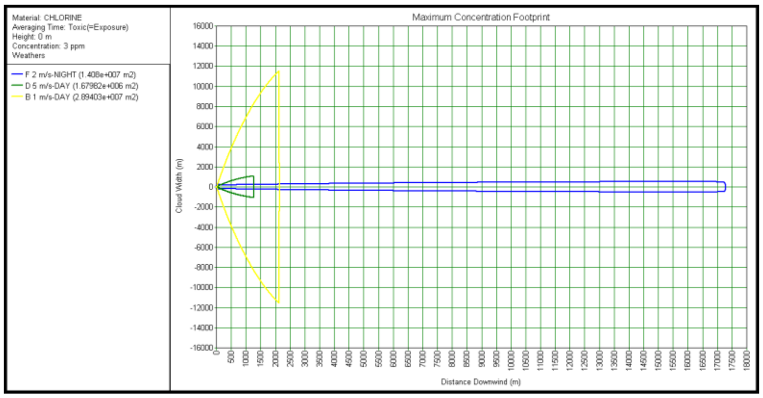

Figure 11: Maximum concentration of chlorine gas from top view for 3 ppm (ERPG 2) and different weather conditions

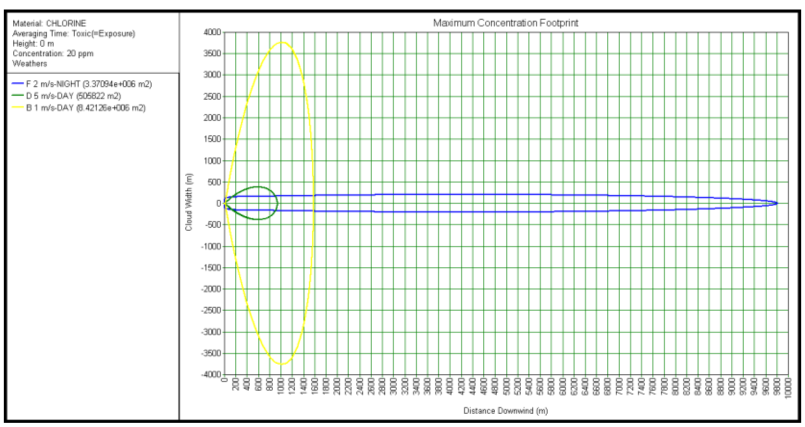

Figure 12: Maximum concentration of chlorine gas from top view for 30 ppm (ERPG 3) and different weather conditions

Side View of Chlorine Gas Dispersion for Different Weather Conditions

The side view results related to chlorine gas dispersion are presented in Figures 7, 8, and 9for all the three weather conditions and concentrations of 1, 3, 10, and 20 ppm. The concentration of 10 ppm was corresponded to IDLH. As was expected, the less the air stability, the more the chlorine gas dispersion in the vertical direction to the ground level. In other words, in B-1 weather conditions (unstable atmospheric conditions), gas was mostly dispersed in the vertical directionand, in F-2 weather conditions, and it was mostly in the horizontal direction.

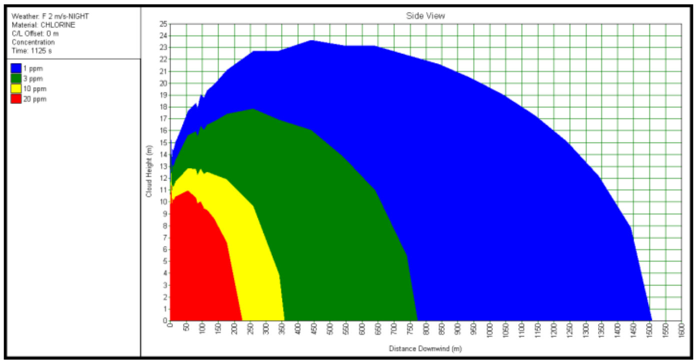

Figure 13: A view of chlorine gas dispersion in F-2 weather conditions

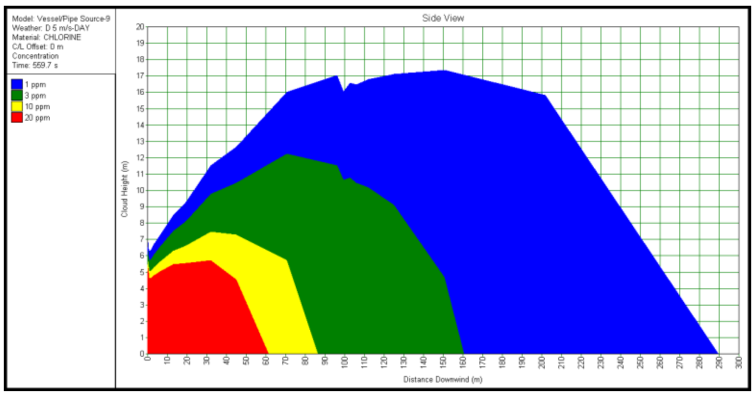

Figure 14: A view of chlorine gas dispersion in D-5 weather conditions

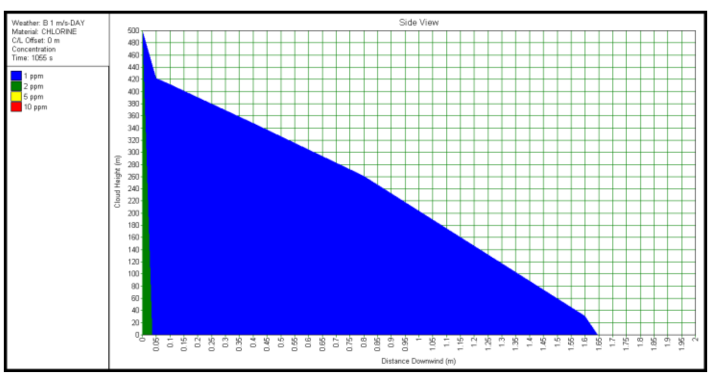

Figure 15: A view of chlorine gas dispersion in B-1 weather conditions

Conclusion

Risk of chlorine gas leakage, as a common substance in water and sewage treatment plants, is inevitable. Based on the current capacities, Jalalieh treatment plant should consider some solutions for replacing novel treatment methods such as using nano-sciences, using ozone instead of chlorine, or transferring the treatment plant to a less populated area in future. Furthermore, Chlorine Leakage Office and Tehran Water and Sewage Company are recommended to use an alarm or any other suitable methods for informing to notify all the areas exposed of chlorine dispersion at the time of leakage. Among the high-density areas which must be notified at the time of chlorine leakage are buildings of Ministry of Interior, Ministry of Jihad-e Agriculture, Tehran Water and Sewage Company, Civil Servants Pension Fund, residential buildings surrounding the plant, Sasan and Pars private hospitals, clinical buildings and banks located in Keshavarz boulevard, between Valiasr square and the end of this boulevard, LalehPark, University of Tehran, TarbiatModares University, Imam Khomeini Hospital Complex, Tehran Heart Center, University of Medical Sciences (affiliated to the army of Islamic Republic of Iran) located on Chamran Highway, near Tow hid square, and Saman Residential Complex located at the crossroads of Keshavarz boulevard and Hijab street. Furthermore, according to the prevailing wind direction, buildings of Ministry of Interior and Civil Servants Pension Fund are among the areas which will be exposed to the chlorine concentration of 20 to 1050000 ppm at the time of chlorine leakage (either intentionally or unintentionally) in Jalalieh Treatment Plant; this amount of chlorine concentration is very dangerous and lethal. To get prepared for coping with the risks of chlorine leakage in Jalalie Treatment Plant, organizations, institutions, and residential buildings which are exposed to the risk of chlorine leakage must activate their passive defense and also train their employees and residents about the risk of chlorine gas and its coping methods by publishing brochures or holding some maneuvers.

REFERENCES

Artimani Salehi J (2012). Modeling and Assessing Risk analysis of Chlorine Gas in Water Treatmen Plants. *European Journal of Experimental Biology* **2**(6) 2151-2157.

Hanna1 S and Chang J (2008). Gaps In Toxic Industrial Chemical (Tic) Model *Systems*. Available: Harmo.Org/Conferences/Proceedings/_Cavtat/.../O_S1-01.Pdf.

JTPB (2008). *Jalalie Treatment Plant Brochure*, 1st edition, Deputy of Operation, Management, Maintenance and Operation of Treatment Plants, Jalalie Treatment Plant Affairs. Available: www.tpww.co.ir.

NMO (2012). National Meteorological Organization, Documents obtained from the database CD, Office of Database, Quality Control, and Information Management. Available: www.weatsher.ir/Farsi and www.irimet.net/irimo/publications/metrayaneh.pdf.

TPAPM (2010). Mehrabad Station, Tehran Province Air Pollution Monitoring Center, Tehran Head Office of Environmental Protection.

TWSC (2011). Information obtained from documents of Chlorine Leakage Office, Tehran Water and Sewage Company.

U.S. Chemical Safety and Hazard Investigation Board (2007). DPC Enterprises Chlorine Release, Investigation Digest, Festus, Missouri August 14, 2002, CSB Headquarters: 2175 K Street NW, Suite 400, Washington D.C.

U.S. Chemical Safety and Hazard Investigation Board (2007). Safety Bulletin, Emergency Shutdown Systems For Chlorine Transfer, No. 2005-06-I-LA. Available: Www.Cal-Osha.Com/Download.Aspx?Id=80162&Langtype=1033.

Verschueren K (1983). *Handbook of Enviornmental Data of Organic Chemicals,* 2nd edition (NY:Van Nostrand Reinhold Co.) New York.