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ORIGINAL ARTICLE

Modeling the Chlorine Gas Dispersion in the Water Treatment Plant

Hadi Shamizadeh*[1], Ramin Alinejad Shahabi[1], Mehdi Arjmand[2]

[1] *Department of Chemical Engineering, Islamic Azad University Ahar Branch, Ahar, Iran*

[2] *Department of Chemical engineering, Islamic Azad University south Tehran Branch, Tehran Iran*

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KEYWORDS

Modeling;
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ABSTRACT: An issue rose for industrial safety and successful address of crisis involves quick and pragmatic decision that would reduce losses and accidents. This will become practical when in addition to studying of past accidents the industrial executives create the necessary readiness to face risks through precise estimation of the consequences of eventual accidents. The present research concerns modeling the consequences of chlorine gas dispersion in the wastewater installations. The transfer of knowledge and information in this study were gained from modeling the dispersion of chlorine in the water treatment plants, useful for managers and executives. Detection and specifying the risks of chlorine for the public and especially the staff and those residing near the water treatment plant, would result in the appropriate action against this lethal substance, which is the subject of this study. Identification of risks related to foreign agents and their negative impacts on water treatment plants containing chlorine tanks is among the objectives of this study. The modeling and accurate specification of the scope and level of danger created following the dispersion of chlorine was done using the PHAST software, which allowed a clear identification of danger zones created by the dispersion of Chlorine. This text reports the radius of areas affected by chlorine dispersion as well as the results of different conditions after running the model for variable physical and process conditions, and given their availability, these results can be compared with each other.

INTRODUCTION

Chlorine was discovered in 1744 in a Swedish Lab recognized as a new element in the year 1810. The name chlorine is taken from the Greek word of *Khloros* meaning, "light green"[1].

Chlorine gas is considered as a strategic chemical in the world as it has a broad application ranging from water treatment to industrial production. In addition to these benefits, chlorine is dangerous for human health so it is used in terrorist attacks. The unwanted dispersion of chlorine following an accident has resulted in fatalities [2].

Given the longstanding application of chlorine for disinfection of water and wastewater, the expressions chlorination has become synonymous with disinfection. Despite being considered as a disinfectant, chlorine still has its own specific risks, which require appropriate technical and management decisions to ensure immunity. This will

*Corresponding author: h-shamizadeh@iau-ahar.ac.ir (H. Shamizadeh)

only be realized when we are able to predict chlorine behavior after its emission from source.

To study the chlorine dispersion pattern after its emission from the source, the modeling should be based on predominant conditions. A model is in fact the simplified visualization of a reality, which lack all the parameters of the real world, but has enough to solve scientific and or management problems. Modeling is applied to predict or solve problems and in most cases, it is used to find the best solution [3].

Modeling the consequences of chlorine gas dispersion in the Ahar Water Treatment Plant, will help the management of this industrial unit to take the appropriate decision in their planning of critical conditions and the compilation of emergency action plans.

Study of the impacts of eventual accidents on the staff and people living near the considered treatment plant; determining the areas impacted by the spread of chlorine gas in the environment, providing assistance in crisis planning, preparing the Emergency Action Plan and estimating the impacts of risks caused by chlorine in the Ahar Water Treatment Plant were the objectives of this research.

MATERIALS AND METHODS

Modeling the dispersion of chemicals in the environment

The dispersion of gases in the environment depends on various parameters that affect the concentration of the said gases. The Most important parameters in modeling the dispersion of chemicals are the height of source of emission, the kinetic energy of the fluid, fluid density, ground level and weather conditions [4]. Each of these parameters affects in some way the dispersion of gases on the ground level. In this research, their impacts are studied using the PHAST software.

A number of criteria of toxicity are briefly presented in this section [5].

ERPG (Emergency Response Planning Guideline)

This is one of the most conventional criteria proposed by the AIHA (American Industrial Hygiene Association) to estimate the level of chemicals' toxicity. This criterion has three levels with different consequences. Table 1 shows the chlorine's ERPG in three levels.

TLV (Threshold Limit Value)

This criterion was established by ACGIH (American Conference of Governmental Industrial Hygienists) and consists of the average concentration of chemical in the air, in such a way that it would leave no negative impact on human health for eight hours in a day for 5 consecutive days in a week.

Table 1. Different ERPG values for chlorine

Chemical	ERPG (1ppm)	ERPG (2ppm)	ERPG (3ppm)
Chlorine	0.05	0.5	10

IDLH (Immediately Dangerous to Life and Health)

This criterion was established by NIOSH (National Institute of Occupational Safety and Health) and refers to the highest concentration of chemical in the air, to which individuals can be exposed for half an hour without a risk to their lives.

STEL (Short Time Exposure Limit)

This criterion was established by ACGIH (American Conference of Governmental Industrial Hygienists) and consists of the maximum concentration of a chemical, to which individuals can be exposed constantly for a period of 15 min without experiencing symptoms such as tear or damages to respiratory cells.

Analysis of the conditions

The parameters affecting the dispersion of toxic materials as well as the prevailing conditions was selected; and to ensure the overlap of studies, a combination of different meteorological conditions, vary according to the time of the day and seasons of the year, was considered. Besides, all parameters affecting the spread of chlorine were evaluated, while the existing conditions were identified and the correct data of the area were used. The most important parameter is the weather conditions. To incorporate the meteorological conditions in the scenario, the most stable conditions are considered conservatively, as they greatly reduce the time and volume of computations. Moreover, there are no worse situations during crises. The study area was the Ahar Water Treatment Plant. It was taken as a case study for modeling the consequences of accidents resulting from the dispersion of chlorine gas. The Ahar Water Treatment Plant was designed and constructed to supply a large portion of the water for the county of Ahar. This plant is located to the northwest of the city of Ahar, at an altitude of 1370 m above the sea on the Caleibar Road and behind the Ahar Power Plant. It has a nominal capacity of 0.445 m^3/s and currently operated at a capacity of about 0.17 m^3/s. The deeds to the plant's property, which covers an area of 53,400 square meters, belong to "East Azerbaijan Regional Water Company". The plant is accessible from the Caleibar Road to the northeast of Ahar and from behind the Ahar Power Plant. To treat water and to achieve the standards for drinking, the water in the plant undergoes two stages of chlorination (primary chlorination and final chlorination). As shown on the map, this treatment plant is close to a high-traffic road and is surrounded by agricultural lands. Furthermore, according to Figure 1, the expansion of residential areas towards the plant is quite obvious.

Figure 1.A view of the Ahar Water Treatment Plant

One-ton tanks are used in the Ahar water and wastewater treatment plants to store chlorine. The tanks' specifications are as follows (Table 2).

Table 2. Chlorine tanks' specifications

Shape of chlorine storage tanks	**Cylindrical**
Tank dimensions	Length 203 cm, diameter 80 cm
Weight of empty tanks	550 kg
Wall thickness	1 cm
Temperature of stored chlorine	Ambient temperature
State of stored chlorine	Liquid and gas
Level of liquid in the tank	90%
Pressure of each tank	9 bars

Table 2. Continued.

The height of pipe connected to the tank	One meter from the bottom of the tank
Diameter of pipe connected to the tank	1 inch

The climatic data required for modeling the different months of the year in Ahar were collected from the latest data available on the meteorological department's site, and the average maximum temperature and minimum humidity were selected as representatives of the six-month warm periods of the year (spring and summer), while the average minimum temperature and maximum humidity were considered as representatives of the cold seasons of the year (autumn and winter). Moreover, for each climatic condition, two cases of strong wind and breeze were considered and presented in the following tables (Table 3).

Table 3. The climatic condition [6]

	First	**Second**	**Third**	**Fourth**
Temperature	22 °C	22 °C	-12 °C	-12 °C
Wind velocity	9 m/s	1 m/s	8 m/s	1 m/s
Humidity	30%	30%	50%	50%
Weather stability	Fair	Completely stable	Fair	Completely stable

Note: (First) warm season with strong wind; (Second) warm season with breeze; (Third) winter season with strong wind; (Fourth) winter season with breeze.

The selection of weather stability category is among important issues in modeling the spread of chemicals, presented separately in the relevant tables for each climate condition.

Application of PHAST (Process Hazard Analysis Software Tool) software for modeling

This is the best software application for modeling the dispersion of chemicals in the environment. It is capable of modeling a broad spectrum of pure substances as well as compounds lighter or heavier than the air, and includes sudden and permanent releases as well as evaporation from the surface of ponds. The model also considers the height of release and the average topography, and has a higher accuracy compared with other similar models. Furthermore, in comparison with other software applications, PHAST functions more accurately. To understand better the results obtained from this software, we can superimpose the results of modeling on GIS and Google Earth maps [11].

Modeling the dispersion of chlorine in water treatment plant

After the necessary reviews during the evaluation of chlorine tanks' consequences, two scenarios of instantaneous release (Table 4) were selected as the worst conditions imaginable. Then these two scenarios were simulated in the four different weather conditions and the results were presented as top view at two different levels (ground level and 10 m above the ground) and side view. The corresponding criteria of damages were used to determine the studied concentrations, i.e. three levels of respiratory problems, death after half an hour and instant death were considered as the damage level and then the concentration corresponding to these damages (Table 5) were selected to report in the charts.

Table 4. The scenarios selected to evaluate the consequences of chlorine tank

1st scenario	Instantaneous release from 1-ton chlorine tank
2nd scenario	Instantaneous release from 3 chlorine tanks in a simultaneous manner

Table 5. Chlorine concentrations corresponding to the 3 levels of damages

Level of damage	Chlorine gas concentration (ppm)
Respiratory problems	30
Death after half an hour	60
Instant death	1000

RESULTS AND DISCUSSION

In the modeling of chlorine dispersion in Ahar Water Treatment Plant, the data from tables presented previously were used as the input for the advanced PHAST software.
In the presentation of forms obtained from the software, have been considered that chlorine concentration varies at different seasons, therefore the results of the selected concentrations are shown and wind direction changes throughout the day, therefore the results in top view of the effect zones are represented as circles, while the directions of dominant wind are shown as elliptical lines.

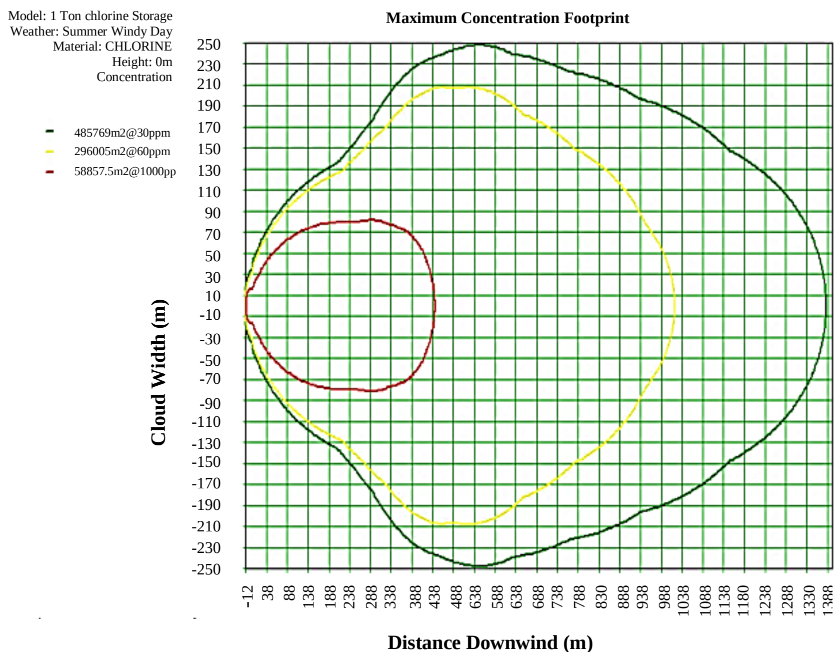

Figure 2. Concentration levels from top view at ground level1st scenario – 1st climatic conditions –concentration levels from top view and ground level

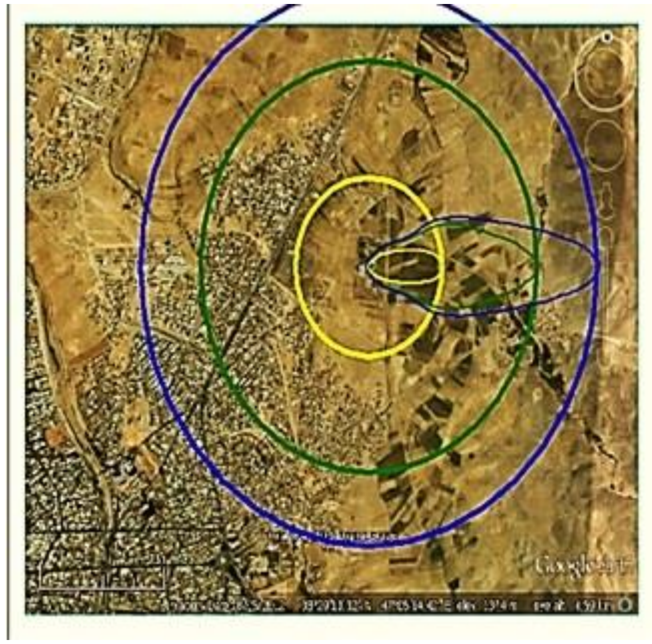

Figure 3. Concentration levels from top view at ground level on the map of studied area.

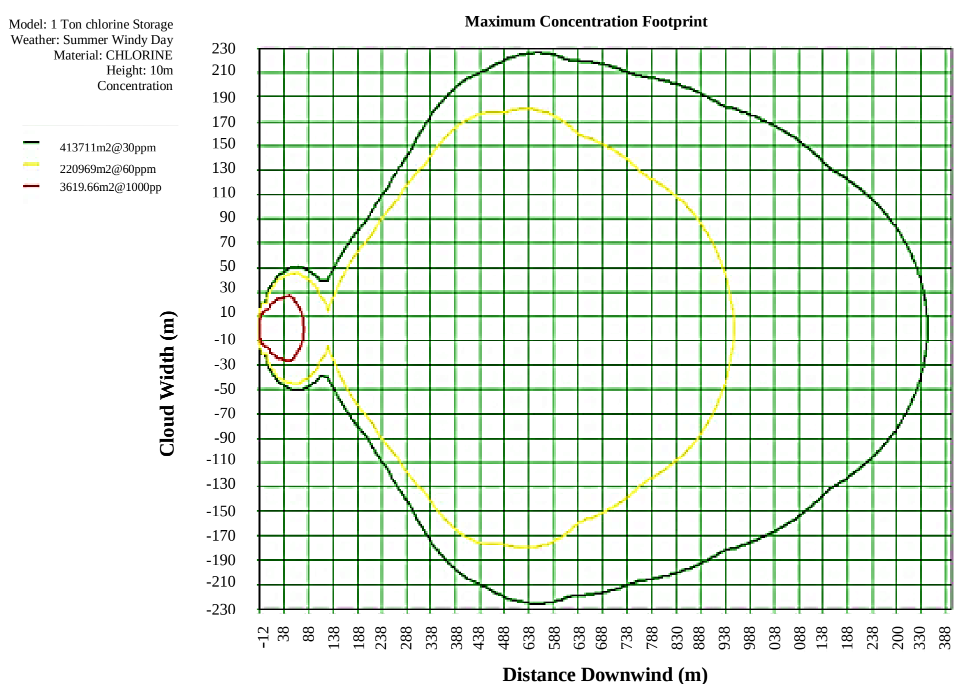

Figure 4. Concentration levels from top view at 10 m above the ground.
1st scenario – 1st climatic conditions –concentration levels from top view and at 10m above the ground

Figure 5. Concentration levels from top view at 10 m above the ground on the map of studied area.

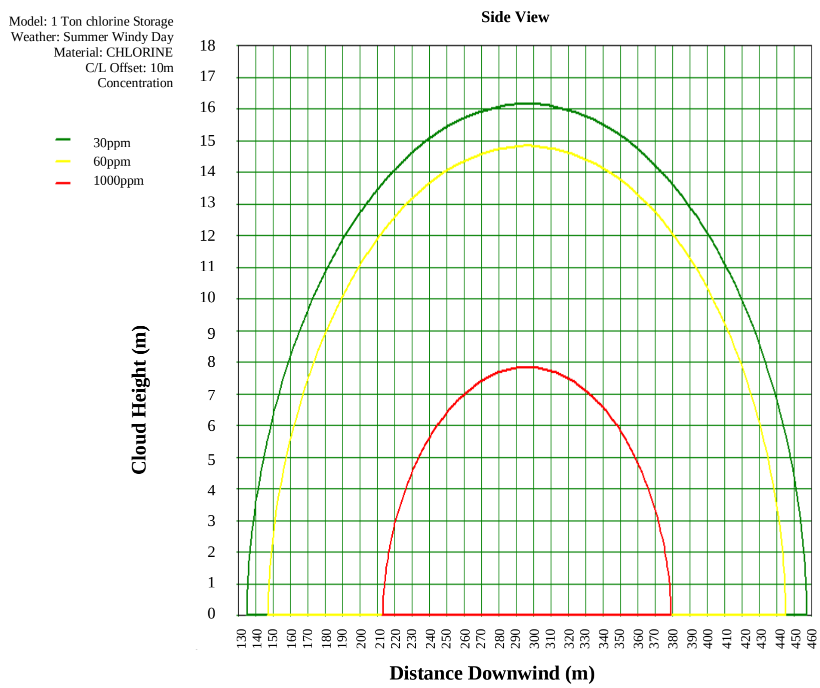

Figure 6. Concentration levels from side view.
1st scenario – 1st climatic conditions –concentration levels from side view

The results of the studies are presented in Tables 6 and 7.

Table 6. Review of the first scenario during the climatic condition.

Climatic condition	α	β	γ	δ	ε	Concentration level
	16	413,711	1,340	485,769	1,388	30
First	15	220,969	950	296,005	1,020	60
	8	3,619.66	86	58,857.5	440	1,000
	3.2	---	---	920,699	850	30
Second	2,9	---	---	636,528	720	60
	1.5	---	---	136,973	300	1000
	10.5	461,823	1,700	591,137	1,800	30
Third	9.8	194,871	1,070	327,466	1,200	60
	5	---	---	39,020.6	300	1,000
	2.4	---	---	888,583	1,60	30
Fourth	2.2	---	---	486,089	590	60
	1.2	---	---	111,080	250	1,000

Notes: (α) Maximum height of the concentration profile**, (β)** Maximum effect area on ground level in the direction of the wind, (**γ**) Maximum progress of concentration profiles at the height of 10 m above the ground, (**δ**) Maximum surface effect area in the direction of the wind at ground level, (**ε**) Maximum progress of concentration profiles in the direction of the wind at ground level**.**

Table 7. Review of the second scenario during the climatic condition.

Climatic condition	α	β	γ	δ	ε	Concentration level
First	21	973,179	1,983	1,074,260	2,000	30
	19	545,984	1,400	646,136	1,420	60
	10	11,652	140	127,132	630	1,000
Second	5	681,130	970	1,612,190	1,225	30
	4.6	81,558.7	880	1,184,560	1,050	60
	1/2	---	---	304,366	530	1,000
Third	15	839,076	1,957	965,878	1,963	30
	13.8	430,817	1,336	565,121	1,365	60
	7.7	1,172	48	101,249	495	1,000
Fourth	3.7	---	---	2,003,390	1,457	30
	3.4	---	---	1,173,770	913	60
	1.64	---	---	296,592	396	1,000

Notes: (α) Maximum height of the concentration profile**, (β)** Maximum effect area on ground level in the direction of the wind, (**γ**) Maximum progress of concentration profiles at the height of 10 m above the ground, (**δ**) Maximum surface effect area in the direction of the wind at ground level (**ε**) Maximum progress of concentration profiles in the direction of the wind at ground level**.**

The leakage risk of the chlorine gas, as a widely used chemical in industry is unavoidable. In the past and as the result of unwanted accidents and negligence in efficient control of the equipment, chlorine has caused death and has led to various fatalities and financial losses. Had such accidents been foreseen, there proper countermeasures would have been taken and the needed equipment would have been available and thus, the capacity to act during and after the crisis would have been enhanced and many financial losses would have been prevented and lives saved.

CONCLUSIONS

Here the results of modeling are explained for one scenario, but using the relevant data, the conclusions can be generalized for other results as well. The first scenario at the first climate conditions as shown in Table 9, the effect area of 30 ppm concentration in the direction of the wind is equal to 413,711 square meters, while the effect areas of 60 ppm and 1000 ppm chlorine gas concentrations would respectively be equal to 220,969 square meters and 3,619.66 square meters in the wind direction. Therefore and according to the results of this scenario, the Caleibar road and its surrounding residential zones, including the Ahar Power Plant zone and the village close to the Ahar Water Treatment Plant would be among the high risk zones affected by the occurrence of the first scenario at the first climatic conditions. In this scenario, the dispersion height of chlorine gas at concentrations of 30, 60 and 1,000 ppm would be in order 8, 15 and 16 meters. The interpretation of the first scenario at the first climatic condition was presented for illustration, and for review of other scenarios, the relevant charts and tables should be referred to. In most scenarios the residential areas of the power plant zone, the Caleibar road and the villages near Ahar Water Treatment Plant are included in the danger zone, if they are located in the direction of the wind, and chlorine can affect and destroy these regions as well as the residents and the agricultural products. According to the reviews and since the direction of the dominant wind is 270o, the selection of the site for operation of chlorine is relatively good, because the wind blows to the opposite direction of the densely populated areas, including the Ahar Power Plant region and this will reduce the extend of the accident.

However, since in this project due to the proximity of the residential areas to the Ahar Treatment Plant and the unpredictability of events such as earthquake and military attacks, the main risk radius is related to the occurrence of the considered scenarios. Therefore, one may ignore the repeatability parameter and focus only on evaluation of the consequences of the scenarios.

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The authors declare that there is no conflict of interest.

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