Emergency Response Planning for Urea Manufacturing Industries by Predicting Atmospheric Dispersion of Ammonia

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Abstract— **Population growth is one of the major constraintsfor the economic growth of India. Increase in food demand due to population growth burdens the current food supply. To meet the food demand and supply, soil productivity is enhanced by using fertilizers. Currently, these fertilizers play a vital role in Indian agricultural sector. High nitrogen content and high solubility in water makes urea a convenient source of nitrogen. Therefore, it is widely used as a nitrogenous fertilizer. Urea is manufactured by ammonia and carbon dioxide. The high demand and supply of urea requires huge quantity of ammonia. As, ammonia has adverse effect on human health, its accidental release risks the nearby surroundings. Hence, prediction of ammonia gas dispersion in the surrounding atmosphere will aid in identification of possible affected area with prediction of extent of consequences on human beings and environment. In the present work, open source software, Areal Locations of Hazardous Atmospheres (ALOHA), is used for risk assessment of sudden release of stored ammonia gas in urea manufacturing plant. ALOHA identifies toxic threat zones at particular location depending upon the storage and meteorological conditions. Identification of affected zone as well as gas concentration at specific location will support in emergency response planning. Identification of the most probable affected zone will help in devising prompt warning system for person to evacuate, shelter and/or lockdown. Further implementation of water scrubbers or curtains or sprayers with quick responding communication system and medical facilities with antidotes will reduce the number of affected persons and severity of the incident.**

Keywords— **Emergency Response Plan, Toxic Gas Release, Ammonia, ALOHA, Air Dispersion, Risk Assessment**

I. Introduction

India is a developing country and is currently having population of about 1.2521 billion. It is ranked second in terms of population after china [1]. Providing food and shelter to these gigantic population is a real challenge. Available agricultural land is covered by human to satisfy their basic need. As a developing nation, India is also performing excellently in industrial sector which causes further reduction in available land for agricultural purpose. Therefore there is strong need to increase production capacity of land exponentially, which can only achieved by fertilizers. Urea is one of the most commonly used to enhance fertility of soil. It is a source of nitrogen for plants and is manufactured from ammonia and carbon dioxide. To manufacture one mole of urea stochiometrically two moles of ammonia is required. In India forecast for the production urea is 32029000 tonns for the year 2014-15 [2], so this is going to lead towards larger production rate of ammonia.

Ammonia is having great industrial importance. It is used majorly in the fertilizer industries. It is also used as a cooling medium in chemical industries due to thermodynamic its properties and as a basic product for the industrial synthesis of various products [3], [4]. Ammonia is colourless substance and having very pungent and irritating odour [5].

Ammonia is considered as one of the classical example irritant. For ammonia, OSHA PEL is 50 ppm, whereas as per ACGIH, TLV-TWA and TLV-STEL are 25 ppm and 35 ppm respectively. NIOSH has also furnished an IDLH concentration of 300 ppm. It can severely affect upper part of respiratory system and can cause immediate death at higher concentrations [6].

In the present work, attempts have been made to identify the potential threat zones created by release of ammonia by open source software, ALOHA, at arbitrary location near Ahmedabad. With the help of potential threat zones, an Emergency Response Plan (ERP) has been proposed.

II. Methodology

For estimation of toxic threat zones ALOHA-DEGADIS (Dense Gas Dispersion) model is used by ALOHA as ammonia behaves like dense gas cloud. ALOHA is open source program developed jointly by the National Oceanic and Atmospheric Administration (NOAA), United States, and the United States Environmental Protection Agency (EPA) as a part of CAMEO (Computer Aided Management of Emergency Operations) software suite. ALOHA uses ambient air pressure as independent of position and time. ALOHA also assumes that pollutant and air will behave as non-interacting ideal gases. Therefore, ALOHA is designed to model time dependent release [7].

Ammonia is having lower molecular weight and density at atmospheric conditions than air but it forms dense mixture due to subsequent evaporative cooling effect of droplet of material produced by the mechanism release [6].

III. RESULTS AND DISCUSSION

Ammonia leakage from the damaged storage tank of capacity of about 1500 MT in arbitrary urea manufacturing plant near Ahmedabad, Gujarat is considered for ALOHA modelling. Latitude and longitude of selected site was collected by Google Earth. Meteorological data is collated from AWS Data, Indian Meteorological Department Weather Panel [8]. Data considered for modelling of accidental release of ammonia are discussed in following subsections.

A. Site Data

Geographic location of the accidental ammonia release is 23º 4.00N, 71º 31.4E. Date and time of the release is 28th July 2014 at 1:00 Hours. Considered type of buildings in the area downwind of the release are sheltered double storied building i.e. building air exchanges per hour of 0.25.

B. Chemical Data

Molecular weight, ambient boiling point, vapor pressure at ambient temperature, and ambient saturation concentration of ammonia from ALOHA library are considered. The considered level of concern for modeling of liquefied ammonia gas release is 60-min ERPGs (Emergency Response Planning Guides) value of ammonia having ERPG-1, ERPG-2, & ERPG-3 values 25 ppm, 150 ppm, & 750 ppm, respectively.

C. Meteorological Data

Wind speed of 3 knots from WNW at 3 meters is considered for the dispersion modeling. Urban or forest ground roughness for dispersion of gas is considered with relative humidity of about 99%, full cloud cover having air temperature of about 26.6 °C. Hence, Pasquill stability class D i.e. neutral atmospheric turbulence is considered for the accidental release [9].

D. Release Data

Accidental leak from hole of about 1 inch diameter at 0.4 meter above the vertical cylindrical tank of 18 meter tank diameter and 8 meter tank height is considered. Hence, ammonia storage tank volume is about 2,000 KL having about 1,500 MT of liquid ammonia. No burning of ammonia is considered for the accidental release.

Considering all the above mentioned parameters, ammonia escaped as a mixture of gas and aerosol i.e. two phase flow. Hence, ammonia behaves like heavy gas.

Ammonia toxic threat zone is an area where a toxicity of ammonia has exceeded our Level of Concern (LOC) [7]. Toxic treat zone results of the ALOHA modeling is presented in the form of contour plots on Google Earth Images with scale.

It can be seen, in Fig. 1, after an hour of release, ammonia cloud can spread out to cover about 4 km downwind area. Hence, release of ammonia will affect maximum number of personnel and environment within the range of 4 km. Industry should follow very strict rules and regulations for health and safety. Also, considering this study, industry should have to incorporate better preventive measures for the non-occurrence of the accidental release as well as absorbing media showers or safety hoods, for reduction in the release concentration.

Fig. 1 Toxic threat zone contour plots showing different ERPGs concentration.

For the study, four locations were selected, where the inside and outside airborne concentration of the ammonia were predicted by ALOHA. Fig. 2 shows the first selected location within the plant. This location comes under red toxic threat contour having airborne ammonia concentration greater than ERPG-3 i.e. 750 ppm.

Fig. 2 First selected location for the indoor and outdoor airborne ammonia concentration.

For effective planning of ERP, ALOHA also shows point location concentration. In Fig. 3, it can be seen that, ammonia cloud having airborne concentration more than 2,000 ppm will take nearly five minutes to reach the plant. Hence, all the employees working in the night shift should be alerted about the emergency. The wind socks should be easy visible from every location of the plant so that personnel can run secures their self by evacuating in cross wind direction. Considering very less response time, industry should provide personnel protective equipments with training to reduce the damage.

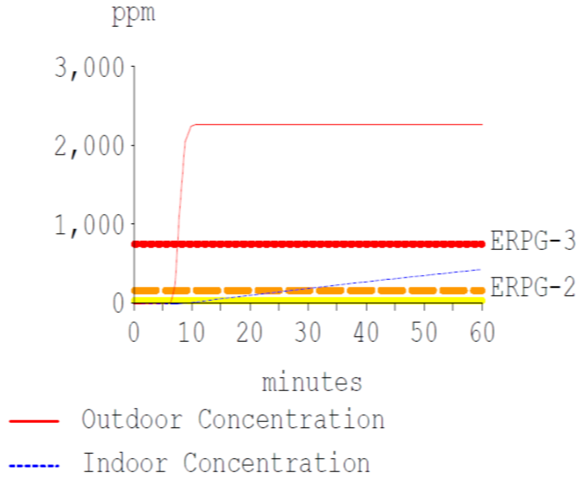

Fig. 3 Indoor and outdoor airborne concentration of ammonia within the plant.

Fig. 4 shows second selected location i.e. administrative building of the plant. This location comes under orange toxic threat contour having airborne ammonia concentration greater than ERPG-2 i.e. 150 ppm.

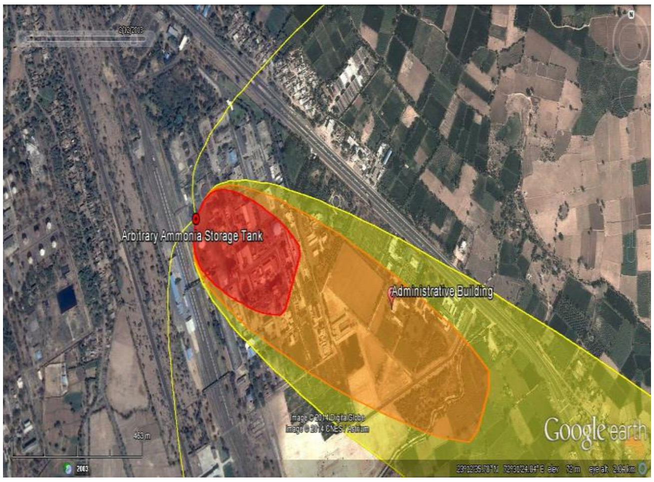

Fig. 4 Second selected location for the indoor and outdoor airborne ammonia concentration.

In Fig. 5, it can be seen that, ammonia cloud having airborne concentration more than 250 ppm will take nearly 25 minutes to reach the administrative building of the plant. Hence, all the employees working in administrative building will surely have more time compared to personnel working in the plant. Utilizing this extra time, administrative department shall do communication with ambulance, fire brigade, traffic police, municipal corporation, affecting neighbourhood, plant authorities, etc., and also arrange transportation for the workers and others personnel present in the plant. They should be trained for these type of emergencies and know whom to contact for better response. The wind socks should be easy visible from every location of the plant so that personnel can run secures their self by going in cross wind direction. Considering very less response time, industry should provide personnel protective equipments with training to reduce the damage.

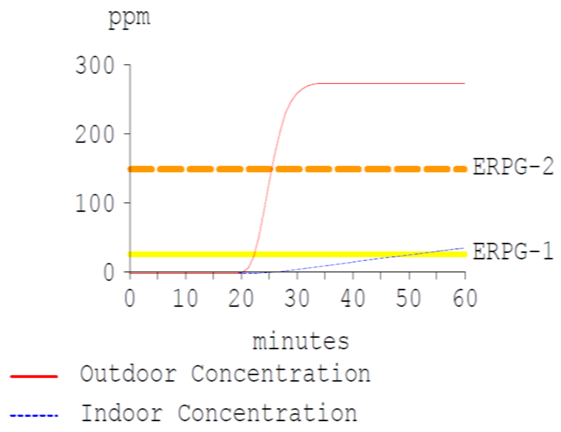

Fig. 5 Indoor and outdoor airborne concentration of ammonia in administrative building of the plant.

Figure 6 shows third selected location i.e. restaurants and road in downwind direction. This location comes under yellow toxic threat contour having airborne ammonia concentration greater than ERPG-1 i.e. 25 ppm.

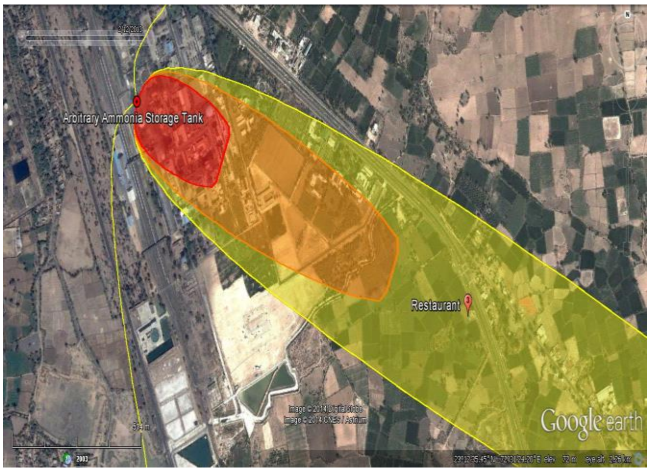

Fig. 6 Third selected location for the indoor and outdoor airborne ammonia concentration.

In Figure 6, it can be seen that, ammonia cloud having airborne concentration more than 100 ppm will take nearly 35 minutes to reach restaurants and road. Hence, the restaurant should be informed about the accident and to take preventive measures like closing it and evacuating in crosswind direction. Wind direction along with safe region should be informed by informing authority. Traffic police should also be informed about the same, so that they can manage the traffic in the affecting region. Antidotes should be provided to this region with the help of nearby private and government hospitals. All the ambulance will be well informed about the scenario and will be trained for the remedial actions.

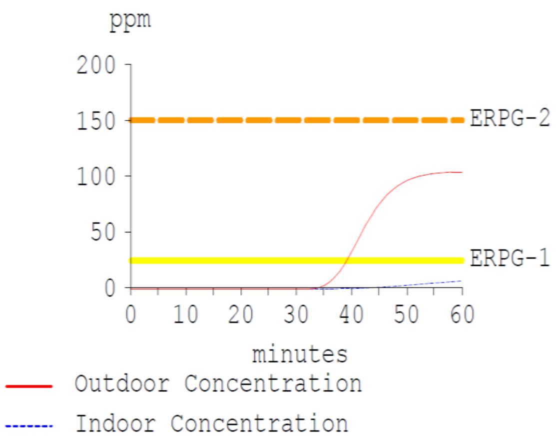

Fig. 7 Indoor and outdoor airborne concentration of ammonia in administrative building of the plant.

Fig. 8 shows fourth selected location i.e. residential area in downwind direction. This location also comes under yellow toxic threat contour having airborne ammonia concentration greater than ERPG-1 i.e. 25 ppm.

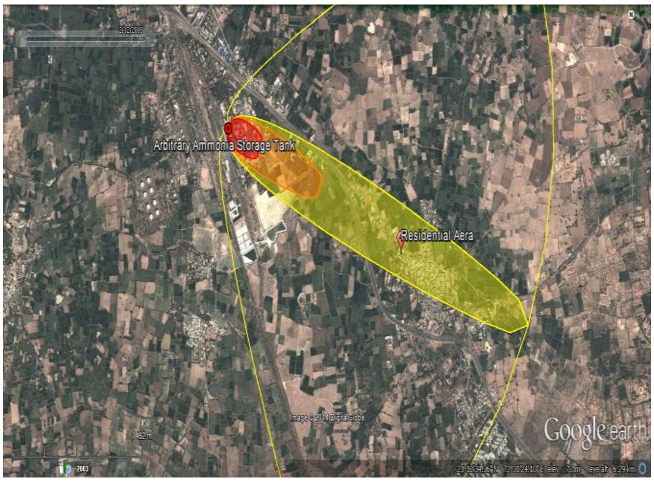

Fig. 8 Fourth selected location for the indoor and outdoor airborne ammonia concentration.

In Fig. 9, it can be seen that, ammonia cloud having airborne concentration more than 35 ppm will take nearly 45 minutes to reach residential area. Hence, all the residential area should be informed about the accident via telephones. The industry should have contact numbers of authorities of the societies or security in-charge of the same. The residential should be informed to close all the windows and doors to reduce diffusion of the indoor airborne concentration of the ammonia. Industry should also inform the residential area about the chemicals they handle and their effects with antidotes. So that, they can include the antidotes in their respective first aid kits.

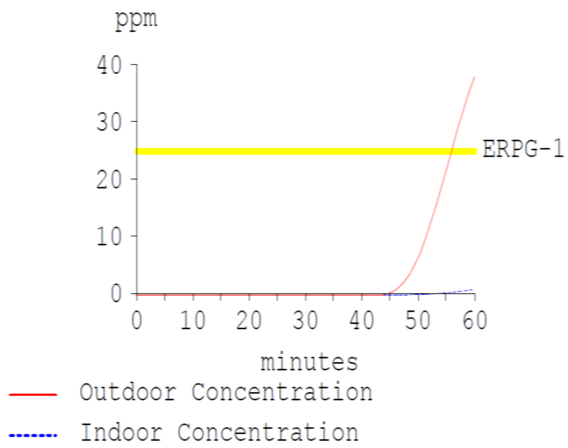

Fig. 9 Indoor and outdoor airborne concentration of ammonia in residential area in downwind direction.

Fig. 10 shows all the selected locations from bird eye view, from the arbitrary ammonia storage tank, with toxic threat contour. The severity of the accidental scenario can be seen very clearly in this figure.

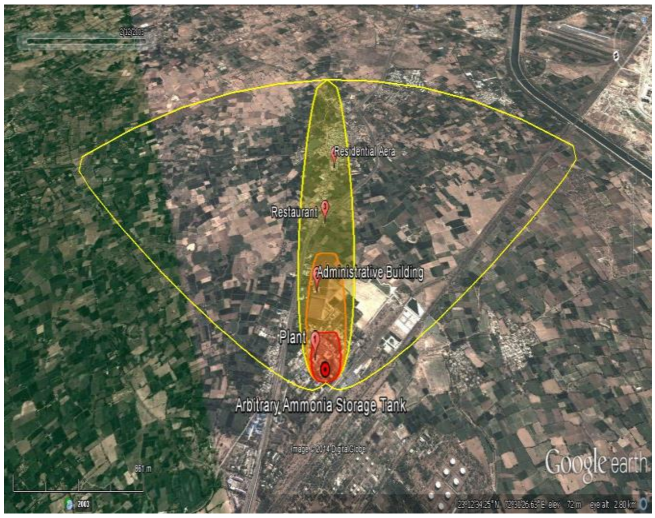

Fig. 10 All selected locations from bird eye.

The results of ALOHA dispersion modeling is summarized in the shown below table.

TABLE I
ALOHA RESULTS OF DISPERSION MODELLING

Location	**Distance from Source, meter**		**Max Concentration (in the first hour), ppm**	
	Down-wind	**Off center-Line**	**Outdoor**	**Indoor**
Plant	158	83	2,280	439
Administrative Building	710	80	273	36.2
Restaurants	1407	15	104	7.18
Residential Buildings	2100	80	37.8	0.938

IV. CONCLUSIONS

Study shows ALOHA helps in predicting toxic threat area by considering metrological as well as storage data. This open source software has considerable potential for better planning of the ERP. Ammonia's pungency is however a significant advantage as it can be detected by smell at concentrations of 5ppm upwards and therefore warns personnel against remaining in a harmful concentration. Short term exposure to concentrations of about 200 ppm will cause irritation and discomfort to the mucous membrane and the eyes but with no lasting consequences. Exposure to concentrations above 1500 ppm will damage or destroy body tissue whilst exposure to 2500 ppm and above increases the risk of fatality. ALOHA also enables to identify the point indoor and outdoor airborne concentration of the ammonia, which is very beneficial for the response planning by considering severity and time.

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