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Influence of monsoon seasons on accidental chlorine leak and dispersion around Gebeng industrial area

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Abstract. This paper presents the prediction of hypothetical chlorine leak dispersion around Gebeng industrial area using Areal Location of Hazardous Atmosphere (ALOHA) software. The effect of the different wind speed and direction to chlorine dispersion in the meteorological microscale area was investigated. The wind speed ranging from 1.32 to 10.7 m/s obtained from a local weather station was considered. Heavy gas dispersion model was used to determine the concentration of chlorine plume within the area of concern. The leakage rate was set to correspond to a leakage from the chlorine tank at 792 kg/h. The result showed that the residential areas R1 and R2 are affected by the plume dispersed by southwest and northern winds, respectively. A greater hazard area was found when the wind speed is below 2.3 m/s. Meanwhile, the hazard zone reduced to nearly half when the wind speed is above 5.4 m/s. The appropriate evacuation routes were developed to reduce risk of exposure to toxic gas. Finding from this work is useful to understand the risk of noxious gas dispersion around Gebeng industrial area.

1. Introduction

Gebeng in Pahang is one of the leading industrial areas in Malaysia which supply petrochemical products such as polymers. Chlorine is commonly used in the polymer and petrochemical plants, e.g., Polyplastics Asia Pacific and Petronas-MTBE. Exposure to chlorine can cause acute or chronic effects depending on its concentration. For instance, tickling of the nose and throat can occur at a level of 0.014 ppm [1]. Above 1 ppm, chlorine can cause a mild irritation of eyes, respiratory system, and headache. Higher level at 30 ppm resulted to chest pain, nausea, dyspnea, and cough [2]. A chlorine leak incident can be dangerous when it occurs nearby the residential area. Furthermore, the wind speed and wind direction affect the dispersion of chlorine gas [3]. Therefore, it is important to evaluate the risk of chlorine leaks from industrial plant to the residential area which include the identification of a safety evacuation route.

The gas dispersion model such as Areal Location of Hazardous Atmosphere (ALOHA) has been widely employed for the risk assessment of accidental release of hazardous gases. For instance,

Gharabagh et al. [4] employed a heavy gas dispersion model for the assessment of chlorine pipeline failure. Derudi et al. [5] focused on the liquefied natural gas releases from a regasification plant. ALOHA is easy to use and requires relatively low computational demand. Unlike the computational fluid dynamics (CFD) simulation, ALOHA can provide the prediction within minutes. Whereas a result of a CFD simulation may take at least a few days to obtain, and even longer duration is needed if the simulation involves larger computational area or grid density. Therefore, ALOHA is suitable for a fast risk evaluation of chlorine gas dispersion. Hence, the current study aims to predict the effect of wind direction and wind speed on the chlorine leaks dispersion around Gebeng industrial area using ALOHA. In addition, a safe evacuation route for Gebeng industrial area in the event accidental leakage of chlorine is proposed based on the simulation result.

2. Method

ALOHA 5.4.7 was developed by the National Oceanic and Atmospheric Administration's (NOAA) and U.S. Environmental Protection Agency (EPA) [6]. It is often used to study the gas dispersion of noxious chemical in the event of an accidental release using either the Gaussian or Heavy gas dispersion models. In the present work, the heavy gas dispersion model was used instead of the Gaussian model since the chlorine is denser than air. ALOHA accounts for the gravitational forces in which the dispersion of heavy gas is affected by the wind and atmospheric turbulence. Approximately 700 pure chemicals are included in the chemical database of ALOHA [7-8]. All chemicals are treated as non-reactive chemicals.

In the present work, the incident scene is the pipeline leaks connected to a 1000 L horizontal cylindrical tank which is often used commercially. The liquefied chlorine (1.30 T) is stored at ambient temperature. The maximum chlorine leakage rate of 792 kg/h was calculated by equation (1) [9]:

$$Q_T(t) = \frac{A_h L_c}{v_g - v_l} \sqrt{\frac{1}{N_F T_t c_{pl}}} \qquad (1)$$

where $Q_T(t)$ is the mass flowrate, A_h is the area of leak source, L_c is the heat of vaporization, v_g and v_l are the specific volume of gas and liquid phases, respectively, T_t is the temperature of the fluid, c_{pl} is the heat capacity of fluid, and N_F is given as:

$$N_F = \frac{v_l L_c^2}{2(P_{eff} - P_a) C_{dis}^2 (v_g - v_l)^2 T_t c_{pl}} + \frac{l_p}{l_c} \qquad (2)$$

where P_{eff} is the effective pressure, P_a is ambient pressure, C_{dis} is the discharge coefficient at 0.61, l_p is the length of pipe, and l_c is 0.1 m. The concentration of chlorine plume is calculated using the heavy gas dispersion model which is almost similar to Colenbrander's model [10]:

$$C(x, y, z) = C_c(x) e^{\left[-\left(\frac{|y| - b(x)}{S_y(x)} \right)^2 - \left(\frac{z}{S_z} \right)^{1+n} \right]} |y| > b(x) \qquad (3)$$

$$C(x, y, z) = C_c(x) e^{\left[-\left(\frac{z}{S_z} \right)^{1+n} \right]} |y| \le b(x) \qquad (4)$$

where $C(x,y,z)$ is the concentration of the plume, $C_c(x)$ is the centerline ground-level concentration, $S_y(x)$ is the horizontal dispersion coefficient, $S_z(x)$ is a vertical dispersion coefficient, and $b(x)$ is the half-width of homogeneous core section. $S_y(x)$ and $S_z(x)$ were obtained from the algebraic expressions for a specific atmospheric stability class, which is developed by Briggs [11]. The concentration of chlorine in the threat zone analysis was set at 0.014 ppm (tickling effect), 1 ppm (mild irritation), and 30 ppm (life-threatening effect). The dispersion of chlorine plume was set at a meteorological

microscale, which is about 10 km. ALOHA is deemed valid for use in this work because Gebeng industrial area has a mainly flat terrain with 8 to 10 m elevation from sea level.

The wind direction in Gebeng industrial area is affected by the southwest monsoon usually occurs during the dry season (June to September) and the northeast monsoon occurs during the wet season (November to April). Northern wind dominates the wet season, whereas the dry season is dominated by the southwest wind [12]. The two inter-monsoon seasons are during May and October, respectively (see figure 1). A partly cloudy model was chosen in the ALOHA setup since Kuantan has over 55% cloudy days annually. The humidity was set at 80% and air temperature was set at 26.9 °C, respectively. Hourly meteorological data were obtained from Kuantan Meteorological Department [13]. Simulation was performed for the mean and maximum wind speed.
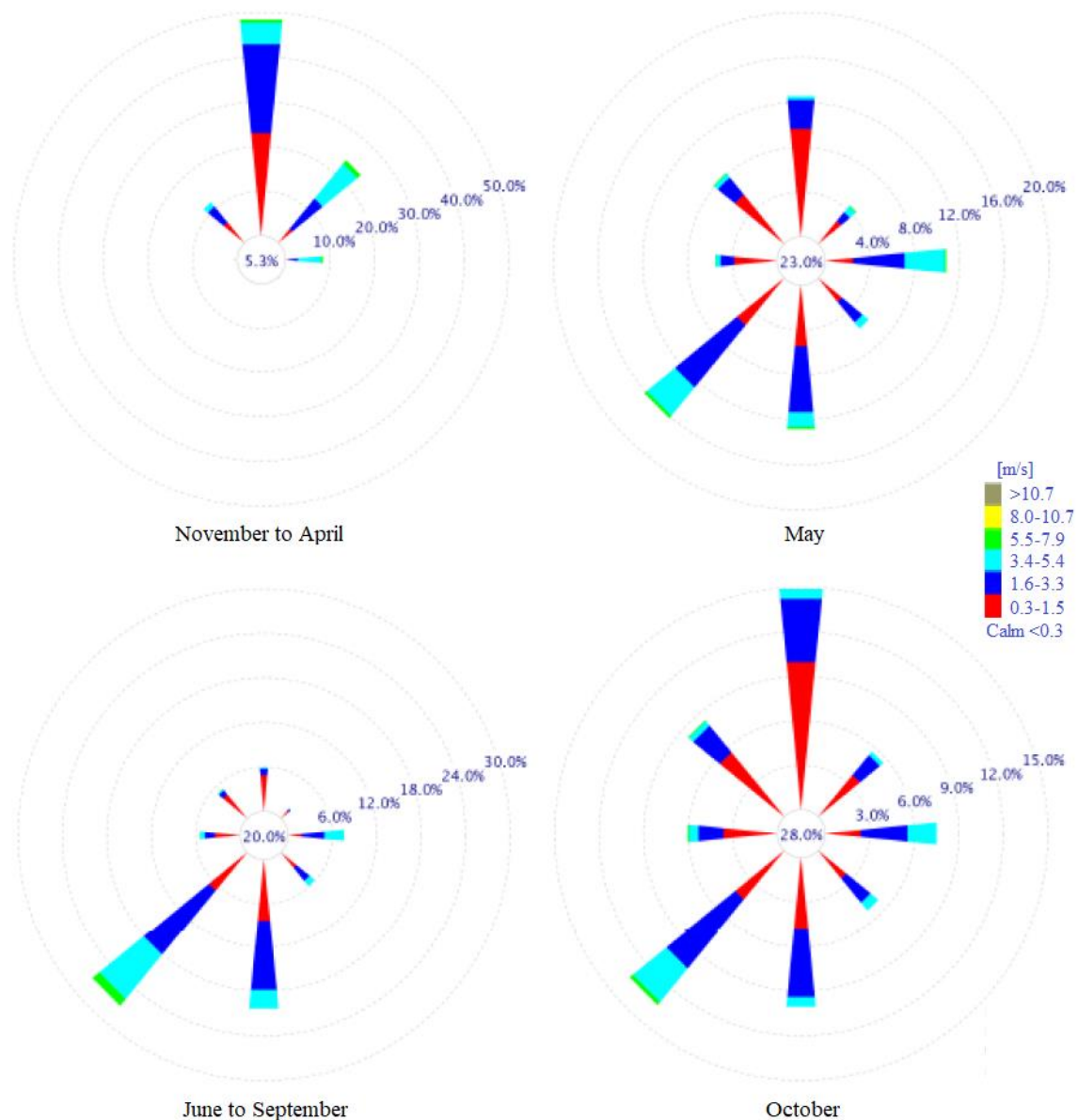

Figure 1. Windrose for Gebeng industrial area. Data averaged from 1998 to 2007 [13]

3. Results and discussion

Figure 2 shows the Gebeng industrial area which measures about 15 km (west-east) × 14 km (north-south). The potential chlorine leak is marked where the chemical plants that utilize chlorine are situated. The two residential areas marked as R1 and R2 are located in the north and south of the industrial area, respectively. Residential area R1 covering Kampung Baging, Sanctuary Resort, Kampung Darat Sungai Ular, Kampung Sungai Ular, mosques, resorts, homestays, and Kampung Gebeng. Whereas, R2 includes mosques, Kampung Berahi, Balok Perdana, Kampung Seberang Balok, Kampung Balok, Kampung Balok Baru, Nelayan Balok market, homestays, and schools.

A hypothetical chlorine leakage that occurred in a chemical plant at Gebeng industrial area was predicted for the case of two monsoon winds with varying windspeed. The mean wind speed is between 1.32 to 2.3 m/s and the maximum wind speed is in the range of 5.4 to 10.7 m/s. Figures 2(a) and (b) show the chlorine plume dispersed by the northern wind at mean and maximum wind speed, respectively from November to April. Whereas, figures 2(c) and (d) show the chlorine plume for the cases of southwest wind (June to September) with the mean and maximum wind speed, respectively. The result shows that the plume dispersed by a lower wind speed formed a wider and larger hazard zone. A lower wind speed is not strong enough to push the dense chlorine plume and hence causing the plume to accumulate closer to the leak source. Therefore, the nearby residential area is exposed to a higher hazard risk.

At approximately 0.55 km from the leak source, the concentration exceeds 30 ppm for all wind speeds below 2.3 m/s. RP Chemicals (M) Sdn Bhd and the area along Jalan Gebeng 1/10 are affected by the plume dispersed by southwest and northern winds, respectively. In contrast, the plume at a level of 30 ppm only dispersed up to the distance of 0.395 km with the higher wind speed (>5.4 m/s) and there is no residential area affected. During the month of November to April with the lower wind speed (see figure 2(a)), the area from south of the Balok Makmur mosque until the kindergarten Tadika Seri Zamrud are exposed to the plume at a mild concentration of 1 ppm. Meanwhile, the area from the Seri Makmur petrol station to Villaku Residence is affected by the plume at a concentration of 0.014 ppm. During June to September (see figure 2(c)), the area within 5 km distance from Eastman Chemical (M) Sdn Bhd to Tenshin Ore Trading Sdn Bhd are affected by the concentration of 1 ppm, while the area from Grandee Biotechnologies Sdn Bhd to Kemaman Seaview Hotel are affected by the level of 0.014 ppm. With the higher wind speed, the residential areas R1 (from Grandee Biotechnologies Sdn Bhd northeastern towards Kemaman Seaview Hotel) and R2 (from Bernas ECMS warehouse southern towards Tanahair Ventures Sdn Bhd) are mostly affected by the plume at the level of 0.014 ppm, as shown in figures 2(b) and (d). During the inter-monsoon month in May and October every year, wind mainly comes from the North and Southwest direction. Therefore, both residential areas of R1 and R2 are affected should the accident occur during the inter-monsoon season in a manner to that of combined the effect of both the north and southwest wind.

The result shows that an accidental chlorine leak from Gebeng industrial area is not causing a life-threatening chlorine concentration in the nearby residential area of all cases evaluated, i.e., high and low wind speed at two different monsoon seasons. However, even at a lower concentration of 0.014 ppm, a safety evacuation is necessary in the event of an accidental chlorine release. A proper emergency preplanning is necessary in the event of accidental chlorine leaks from the chemical plant. School and public hall are often used as an assembly evacuation point in the event of an accident. The proposed assembly evacuation point is towards north or west of the residential area R2 during November to April, as shown in figures 2(a) and (b). The suitable evacuation locations such as schools, i.e., Sekolah Kebangsaan Cherating and Sekolah Menengah Kebangsaan Sungai Baging, which are located at north of residential area R2 are in 19 to 24 km and 16 to 21 km, respectively, from the affected area. While, the school, Sekolah Kebangsaan Lembah Jabor at the west of residential area R2 is within 12 to 16 km from the affected area.
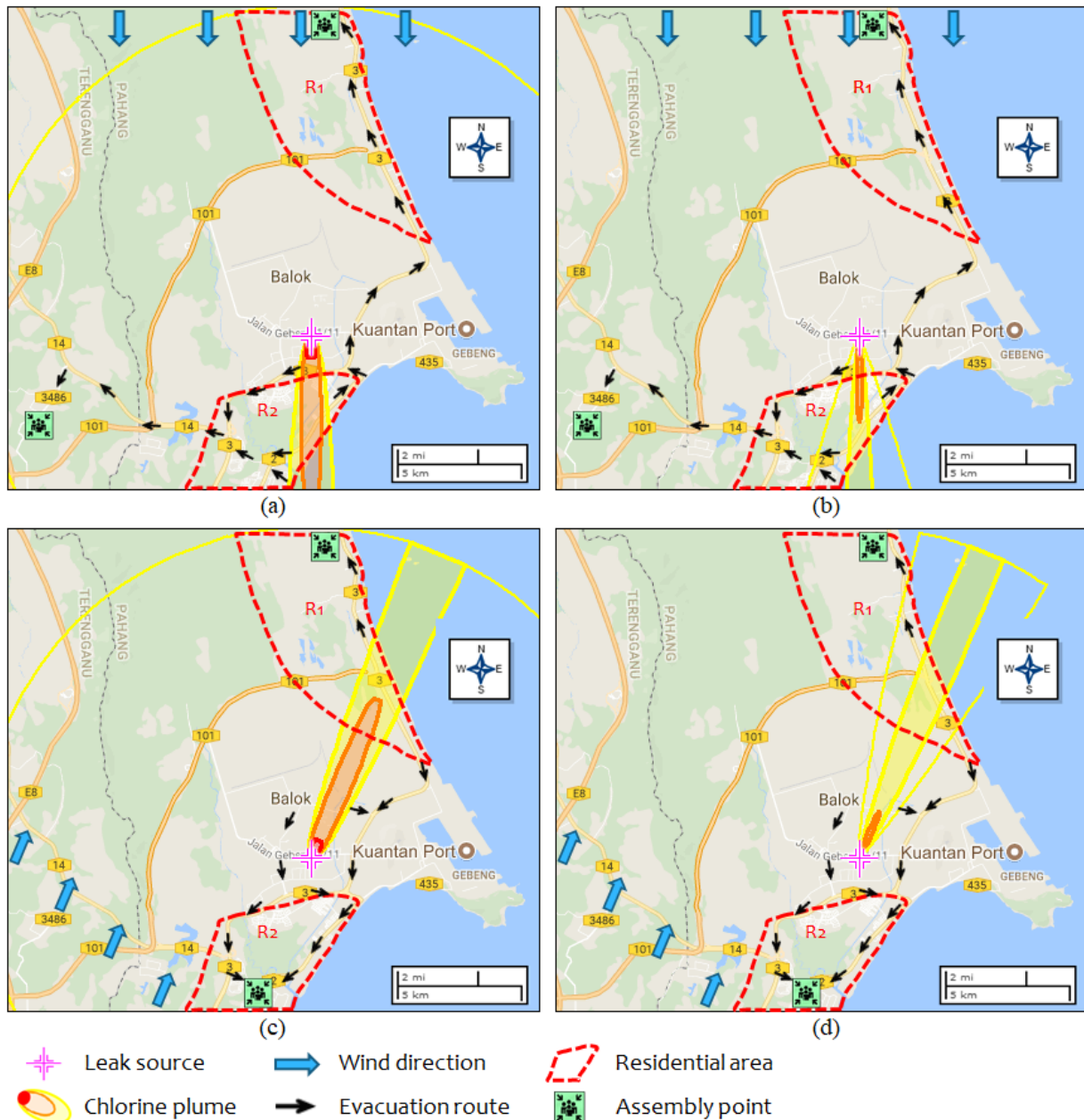
Figure 2. Prediction of chlorine plume dispersion and evacuation route around the Gebeng industrial area for the northern wind (November to April) at (a) mean wind speed, (b) maximum wind speed, and southwest wind (June to September) at (c) mean wind speed, (d) maximum wind speed

The evacuation route for the accidental leaks of chlorine during June to September is shown in figures 2(c) and (d), whereby the residents should move towards the north or southwest of the residential area R1 for safety purpose. The residents nearby the Kemaman Seaview Hotel should move north towards the schools, i.e., Sekolah Kebangsaan Cherating and Sekolah Menengah Kebangsaan Sungai Baging, which are about 9 to 11 km and approximately 8 km, respectively from the affected area. While, the residents staying around the leak source should move southwest towards the safer locations such as the school Sekolah Kebangsaan Balok and the public hall Dewan Orang Ramai Balok, which are located around 9 and 14 km, respectively from the affected area.

In the event of an accident during the inter-monsoon month in May and October, a combined risk of both the north and southwest wind should be considered due to higher frequency of wind from both directions during this period. Utilization of the school Sekolah Kebangsaan Lembah Jabor at the west of residential area R2 is the best option during the inter-monsoon season.

4. Conclusion

A risk assessment of chlorine leak dispersion around Gebeng industrial area has been successfully performed using ALOHA heavy gas dispersion model. It was found that the dispersion of chlorine plume is significantly affected by the wind condition. The plume released during June to September affecting the residential area R1. While the residential area R2 is affected by the plume released during November to April. A lower wind speed produced a wider plume and affects a larger area of the residential area in comparison to the higher wind speed. It can be concluded that the risk of exposure to hazardous chlorine concentration is two-fold higher at a wind speed below 2.3 m/s compared the one above 5.4 m/s. The result shows that an accidental chlorine leak from Gebeng industrial area is not causing a life-threatening chlorine concentration in the nearby residential area of all cases evaluated. The result obtained from this work is useful to predict the hazardous zones and potential impact area due to accidental chlorine leakage. The results also provide a guidance to determine a safe emergency evacuation route in the event of accidental chlorine leaks.

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