Malaysian Journal of Chemical Engineering & Technology 4 (1) (2021) 58–66

Malaysian Journal of Chemical Engineering & Technology

Journal Homepage: http://myjms.mohe.gov.my/index.php/mjcet

Consequence assessment using threat zone analysis on sulphuric acid production plant

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Abstract

The consequence assessment is one of the crucial methods in the process safety engineering fields to determine and quantify the threat zone derived on the respective chemical plant and this method will guide the designer regarding the most suitable preventive measure to avoid the disaster of a chemical plant. This work highlights the consequence assessment on sulphuric acid production plant using threat zone analysis, one of the steps in Quantitative Risk Assessment. The plant has decided to produce 80,000 MT per year of sulphuric acid in Malaysia with the selected site location of Kerteh, Terengganu. The process layout and location of the equipment installed for the processing steps of sulphuric acid production have been simulated by the Aspen HYSYS simulation software. All possible hazardous chemical for every equipment has been identified and the consequence assessment method focusing on threat zone distance was developed through the six steps of methodology to estimate the worst-case scenario. Distance of threat zone was simulated using ALOHA, MARPLOT and Google Earth software. Results show that the absorber tower produces the worst-case scenario among all equipment in the plant, which red threat zone of toxicity reaches more than 10 km to the surrounding area.

Article Info

https://doi.org/10.24191/mjcet.v4i1.12971

Article history:

Received date: 28 March 2021
Accepted date: 23 April 2021
Published date: 30 April 2021

Keywords:

Consequence assessment
Distance
Modelling simulation
Sulphuric acid
Threat zone

1.0 Introduction

Sulphuric acid is an inorganic compound that is highly destructive and a vigorous mineral acid. It has a stingy smell and dulls to yellow viscous in the colour that is water-soluble at all accumulation. Typically, the acid has been marketed as a dark brown fluid to warn buyers of the dangers of treating this acid. The fluid became dark brown due to the addition of dye during the production process (Speight, 2016). Sulphuric acid production plant may consist of variable possible chemical from raw materials, intermediate, product and by-product.

The main raw material for the sulphuric acid production plant is sulphur, which is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200) (Sulphur Safety Data Sheet, 2012). All chemicals related to the production of sulphuric acid may be considered hazardous and dangerous to the people surrounding. Concentrated sulphuric acid is highly corrosive and can cause severe burns if not properly treated. In certain cases, these harmful chemicals will corrode skin, paper, metals and even rocks. If sulphuric acid contacts the eyes directly, this may cause permanent blindness. This chemical can cause internal burns, permanent organ damage and likely death if swallowed (Sulphuric Acid MSDS Information, 2014). Sulphuric acid is a chemical that is harmful and would give serious damage. The stimulation may arise from digestion, excretion as well as skin contact. Consumption of sulphuric acid may affect the inflammation and soreness also incinerate suffer to the gasping section, smelling organ and esophagus. Constant digestion of sulphuric acid would severely cause kidney problem and lung illness (Cheremisinoff & Rosenfeld, 2009).

Sulphuric acid has various uses and performs a significant role in almost all industrial products. Sulphuric acid is majorly used in the production of phosphate fertilizers besides its usage as an explosive material, petroleum products, detergent, and many other materials. Sulphuric acid is crucial and significant in the processing of fertilizers such as ammonium sulphate and superphosphate. These fertilizers are produced by the addition of sulphuric acid to the rock phosphate (Cheremisinoff, 2010). Besides, sulphuric acids are generally adopted in the production of chemicals included in the processing of hydrochloric acid, dyes and pigments, sulphate salts, explosives, synthetic detergents, and drugs. Sulphuric acid also can be treated to wipe off the contaminant from gasoline and other oil materials in petroleum refining. Furthermore, the uses of sulphuric acid are valuable in metal processing such as scrubbing the iron and steel before polish with tin or zinc (Cheremisinoff, 2010).

The sulphuric acid plant may face an accidental problem if the plant management did not take seriously the risk assessment and the safety aspects of the plant and the workers. Regardless of how well a plant is planned and run, there is the opportunity for incidents to occur. Incidents might be as mild as slight leakage or overflow to a serious disaster like a chemical explosion that enables an immediate emergency response for the whole plant. An emergency plan must be prepared for any scenario that is feasible to happen and the authorized person should be educated so they can develop themselves to respond and to mitigate the effects of an incident (Sulphuric Acid Plant Safety - Accidents, 2020).

Back in the year 2018 on 25th September, where a person was killed in an explosion at a chemical plant in Arab, Alabama. The explosion happens due to the tank which previously held sulphuric acid where several people were working on that 7,000-gallon tank. This is an example of an accident in the sulphuric acid plant (Sulphuric Acid Plant Safety - Accidents, 2020). Major disasters in history imply that the management system failures during design, operation and maintenance lead significantly to the occurrence of accidents (Papazoglou et al., 2003; Piccinini & Demichela, 2008; Tixier et al., 2002). The distribution of incident situations to nonprimary accident equipment triggered a large number of significant unexpected accidents or domino effects in chemical and process plants (Cozzani et al., 2005). The majority of the accidents that occurred are induced by management procedures failures (Jenssen, 1993; Klinke & Renn, 2002; Wang, 2017).

To quantify and analyses the consequence assessment associated with the production plant of sulphuric acid, the Hazard Identification, must be done first. (Crawley & Tyler, 2015; Dunjó et al., 2010; Khan & Abbasi, 1998; Suhardi, Estianto, & Laksono, 2016; Wells, 1997). Objectives of this research are to identify the potential hazard that will arise from every processing chemical install in each piece of equipment of sulphuric acid production plant and to assess and quantify the consequence derives from the sulphuric acid production plant using threat zone analysis that involves the evaluation of the distance in the red zone of the area affected (Apostolakis, 2004; Fang & Duan, 2014; Khan et al., 2009). These analyses supported with chemical inventory estimation and plant piping flow, which assessments and choices are based on a suitable and practical design backed by HYSYS simulation software.

2.0 Methodology

2.1 Steps of risk assessment

Fig. 1 shows the step of risk assessment consists of collecting data, hazard identification, list of scenarios, simulation using ALOHA, MARPLOT and Google Earth, selection of dispersion model, result and consequence effect.

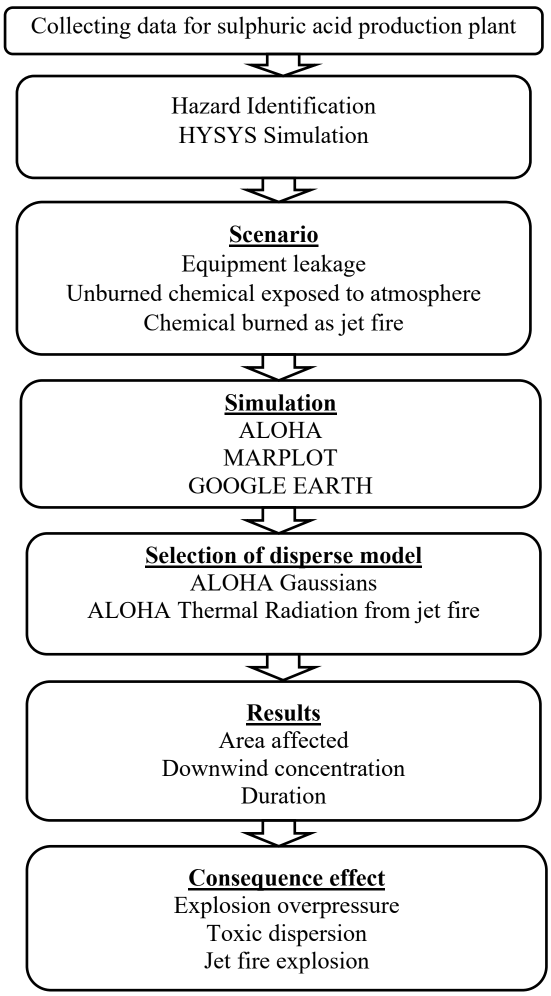

Fig. 1: Steps of risk assessment.

2.2 Data collection

The investigation is done under the site condition of the production sulphuric acid plant. The site location of the sulphuric acid plant is located in Kerteh, Terengganu. The plant location is surrounded by an industrial plant. The collected data referring to the site condition of sulphuric acids production plant such as surrounding area humidity and topography, sulphuric acid production plant layout, locations of all the equipment involved for the sulphuric acid production, processing conditions and parameters, all the chemicals used in the sulphuric acid processing, and consequences modelling, resulting to fire, explosion overpressure and toxic exposures.

2.3 Modelling and simulation

The study is conducted using the Aspen HYSYS, ALOHA, MARPLOT and Google Earth simulation software. The fluid package that been used in the HYSYS simulation to produce 80,000 metric tons per year of sulphuric acid is Peng-Robinson. This is due to the suitability of this fluid package with the chemical composition of sulphuric acid production (Stryjek & Vera, 1986). Fig. 2 shows a process flow diagram (PFD) for sulphuric acid production. The ALOHA is simulated to determine the distance, radius, area affected and downwind concentration of the chosen location, which is located at Kerteh, Terengganu.

The simulation was conducted with various diameter leakage of the equipment and four different wind direction. The severity effect from the area affected threat zone can be depicted through the simulation from the MARPLOT and Google Earth software. The coordinate location is Latitude 4°31’25.0” N Longitude 103°25’28.0” E and has an elevation of about 3 meters. The parameter of the location has a wind speed of 6 miles/hour, air temperature of 28 °C, urban or forest roughness, stability class C, no inversion height and has a relative humidity of 83%.

2.4 Process condition

By referring to the process layout of the sulphuric acid production, the process flow diagram that been simulate from the HYSYS software simulation shows every processing flow of equipment and also the processing stream starting from the feed of raw material up until the production stream of sulphuric acid as well as the recycle stream. The PFD of sulphuric acid production is based on the design proposed by Ashar & Golwalkar (2013). Based on the PFD and the material stream table as well as the composition stream table, major chemical installed in each major equipment that may be considered hazardous can be identified. Table 1 lists major chemicals that are installed and process conditions for every major equipment involved in the production of sulphuric acid.

Table 1: Chemical installed and process condition for each major equipment

Major Equipment	Major Chemical	Process Condition			
		Pressure (kPa)	**Temp. (°C)**	**Mass (kg)**	**Vol. (m^3)**
Drying Tower	H_2SO_4	140	37	1,378,670	450
Sulphur Burner	S	230	137	93,461	300
Multibed Reactor	SO_3	114	422	106	67
Absorber Tower	H_2SO_4	140	207	995,800	450
Electro-static Precipitator	H_2S	210	420	82.9	67

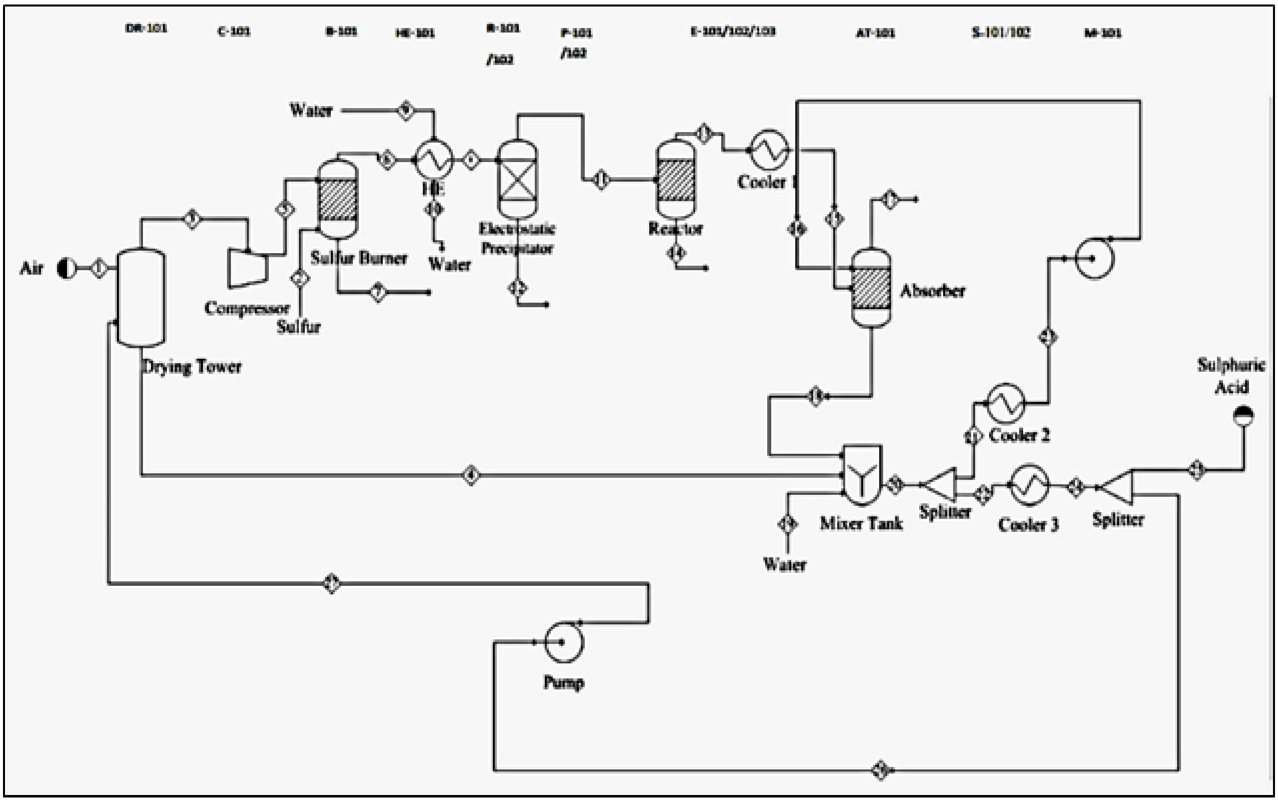

Fig. 2: Process flow diagram of the production of 80,000 metric tons per year (Ashar & Golwalkar, 2013).

3.0 Results and discussion

3.1 Drying Tower

Fig. 3–5 show the area affected by sulphuric acid installed in the drying tower equipment at 10, 25, and 150 mm diameter leakage simulated at four wind direction which is SSE, NNE, ESE, and N, respectively. The operating pressure of this drying tower equipment is 140,000 Pa and the temperature within the equipment is 37 °C.

From Fig. 3, the smallest diameter leakage, which is 10 mm has the lowest distance of area affected which the distance affected of the red zone and orange zone area only 13 meters respectively while the distance affected of the yellow zone area is162 meters. Threat zone of red and orange zone was not drawn because the effects of near-field patchiness make dispersion predictions less reliable for short distances.

From Fig. 5, the biggest diameter leakage which is 150 mm has the highest distance of area affected which the distance affected of the red zone and orange zone area is 100 meters, respectively, while the distance affected of the yellow zone area is 1,300 meters. Threat zone of red and orange zone was not drawn because dispersion predictions are unreliable for lengths less than the maximum diameter of the puddle which is 200 meters. The distance of the area affected observed is increasing from 10 mm diameter leakage until 150 mm diameter leakage. The bigger the diameter leakage of the equipment, the higher the distance of area affected by the simulation. The maximum severity of the area affected is achieved when the diameter leakage reaches 150 mm while the minimum severity of the area affected is achieved when the diameter leakage reaches 10 mm.

3.2 Sulphur Burner

The major chemical installed in the sulphur burner equipment is sulphur. The operating pressure of this sulphur burner equipment is 230,000 Pa and the temperature within the sulphur burner equipment is 137 °C. Based on the ALOHA simulation, this chemical sulphur installed in the sulphur burner equipment shows no result of threat zone thus no threat zone was plotted on the Google Earth map to determine the severity of the area affected.

3.3 Multibed Reactor

Fig. 6–8 show the area affected by sulphur trioxide installed in the multi-bed reactor equipment at 10, 25, and 150 mm diameter leakage simulated at four wind direction which is SSE, NNE, ESE, and N, respectively. The operating pressure of this multi-bed reactor equipment is 114,000 Pa and the temperature within the multi-bed reactor equipment is 422 °C.

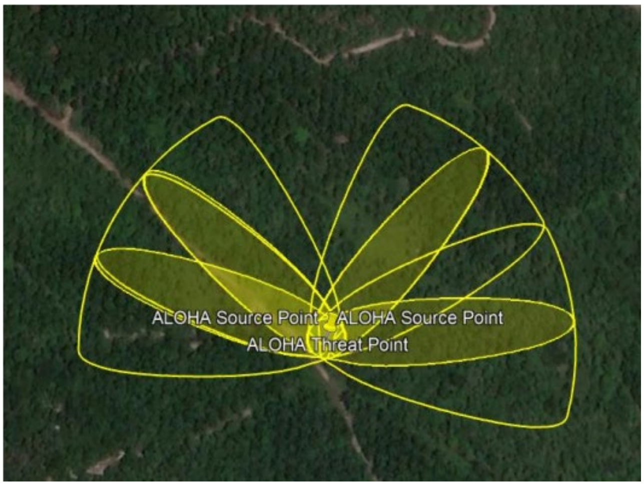

Fig. 3: Area affected from 10 mm diameter leakage (drying tower)

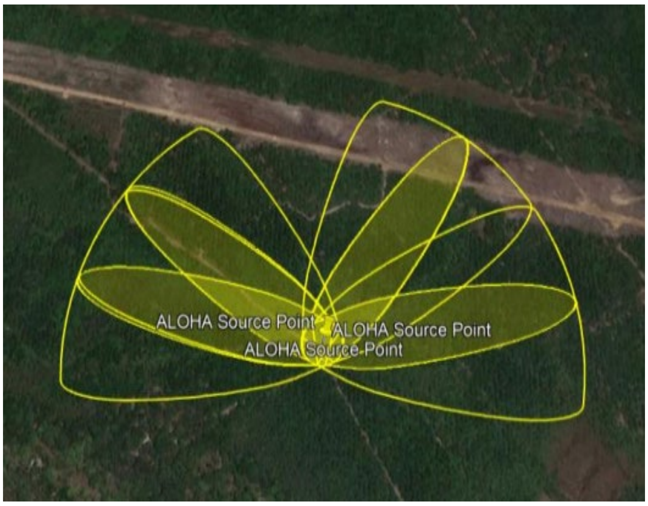

Fig. 4: Area affected from 25 mm diameter leakage (drying tower)

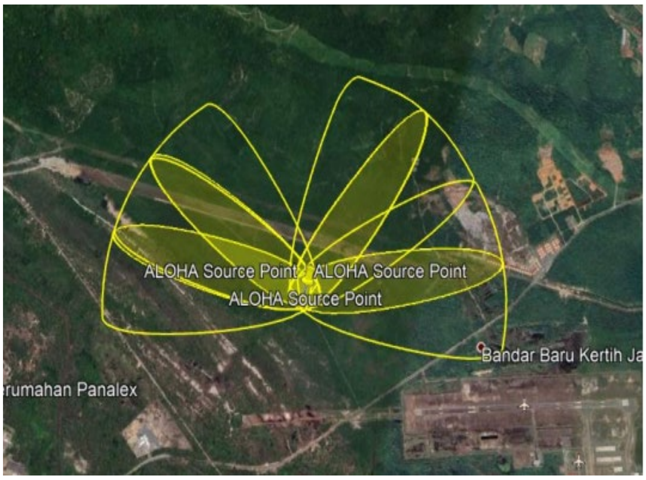

Fig. 5: Area affected from 150 mm diameter leakage (drying tower)

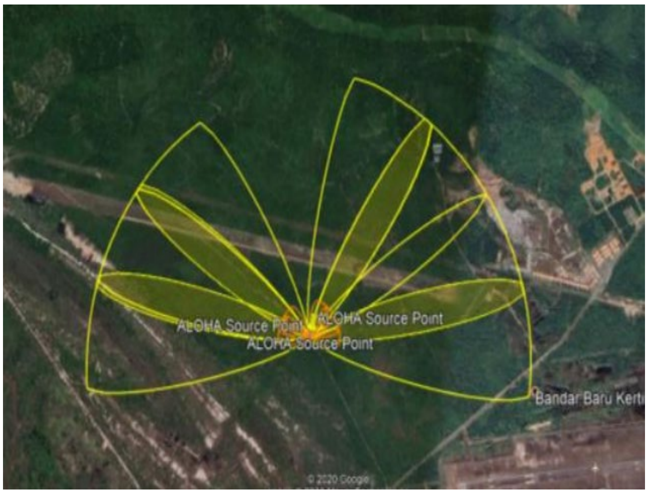

Fig. 6: Area affected from 10 mm diameter leakage (multibed reactor)

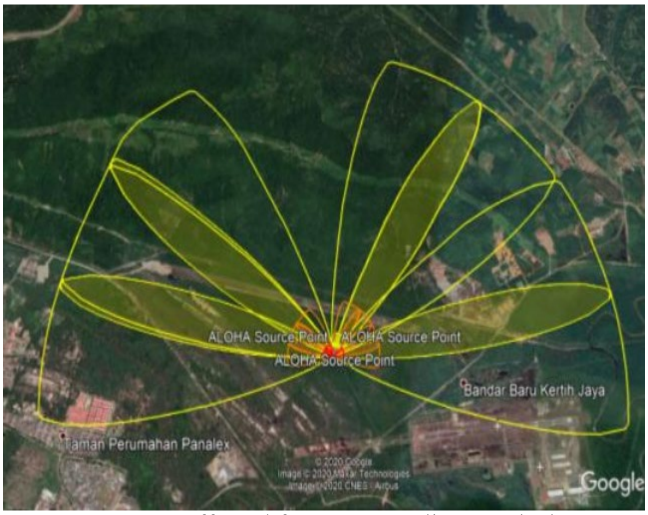

Fig. 7: Area affected from 25 mm diameter leakage (multibed reactor)

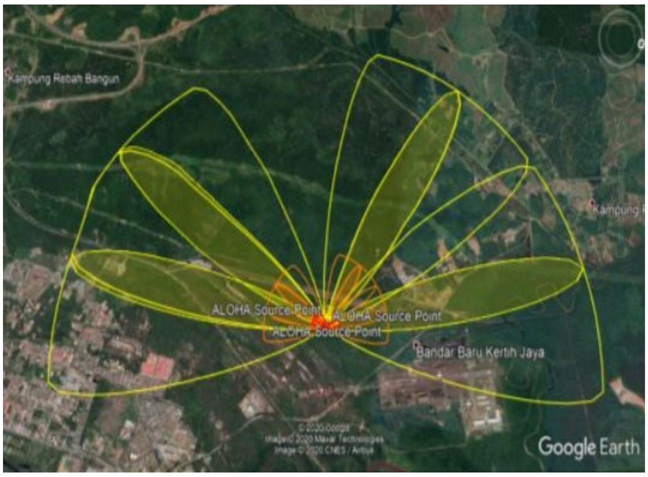

Fig. 8: Area affected from 150 mm diameter leakage (multibed reactor)

Based on Fig. 6, the smallest diameter leakage which is 10 mm has the lowest distance of area affected which the distance affected of the red zone area is 36 meters, orange zone area is 161 meters while yellow zone area is 1,200 meters. Red threat zone was not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances

From Fig. 8, the biggest diameter leakage which is 150 mm has the highest distance of area affected which the distance affected of the red zone area is 185 meters, orange zone area is 820 meters while yellow zone area is 3,600 meters.

The distance of the area affected observed is increasing from 10 mm diameter leakage until 150 mm diameter leakage. The bigger the diameter leakage of the equipment, the higher the distance of area affected by the simulation. The maximum severity of the area affected is achieved when the diameter leakage reaches 150 mm while the minimum severity of the area affected is achieved when the diameter leakage reaches 10 mm.

3.4 Absorber Tower

Fig. 9 until Fig. 11 show the area affected by sulphuric acid installed in the absorber tower equipment. Fig.s 9, 10, and 11 display the affected area of sulphuric acid at 10, 25 and 150-mm diameter leakage simulated at four wind direction which is SSE, NNE, ESE, and N, respectively. The operating pressure of this absorber tower equipment is 140,000 Pa and the temperature within the absorber tower equipment is 207 °C.

Based on Fig. 9, the smallest diameter leakage which is 10 mm has the lowest distance of area affected which the distance affected of the red zone area is 947 meters, the orange zone area is 4,400 meters while the yellow zone area is greater than 10,000 meters.

From Fig. 11, the biggest diameter leakage which is 150 mm has the highest distance of area affected which the distance affected of red zone area is greater than 10,000 meters with 130 mg/m^3, orange zone area is greater than 10,000 meters with 7.3 mg/m^3 while yellow zone area is greater than 10,000 meters with 0.17 mg/m^3.

The distance of the observed area affected is increasing from 10 mm diameter leakage until 150 mm diameter leakage. The bigger the diameter leakage of the equipment, the higher the distance of area affected by the simulation. The maximum severity of the area affected is achieved when the diameter leakage reaches 150 mm while the minimum severity of the area affected is achieved when the diameter leakage reaches 10 mm.

3.5 Electrostatic Precipitator

Fig. 12–14 show the toxic area affected by the leaking hydrogen sulphide installed in the electrostatic precipitator equipment that is not burned and escape to the atmosphere at 10, 25, and 150-mm diameter leakage simulated at four wind direction which is SSE, NNE, ESE, and N, respectively. The operating pressure is 210,000 Pa and the temperature within the electrostatic precipitator equipment is 420 °C.

Fig. 9: Area affected from 10 mm diameter leakage

Fig. 10: Area affected from 25 mm diameter leakage

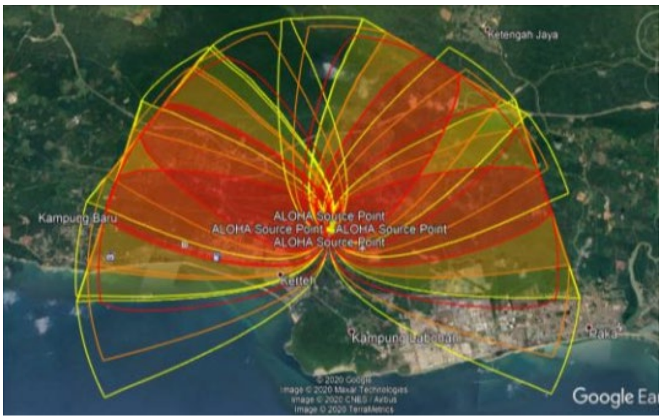

Fig. 11: Area affected from 150 mm diameter leakage

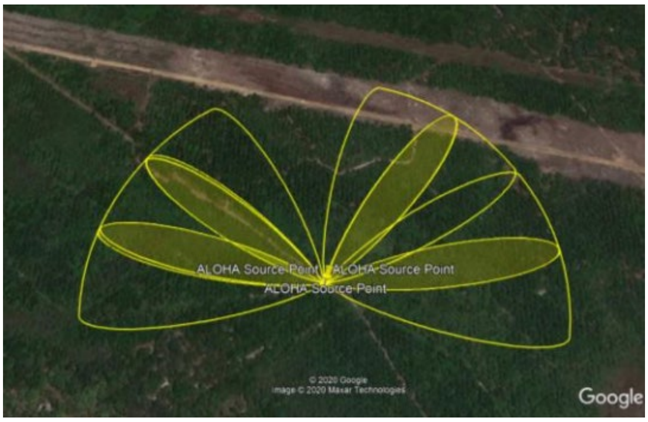

Fig. 12: Toxic area affected from 10 mm diameter leakage

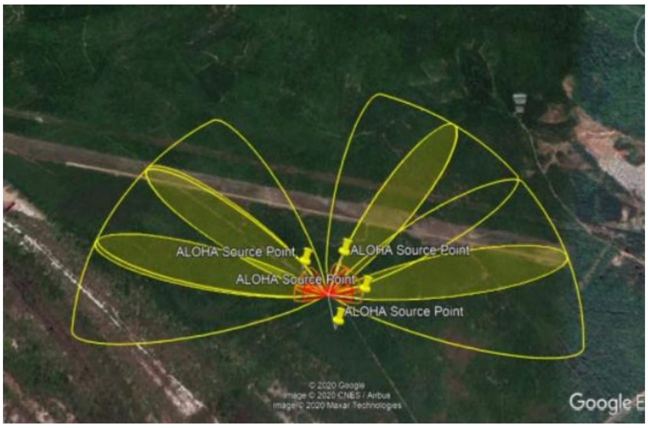

Fig. 13: Toxic area affected from 25 mm diameter leakage

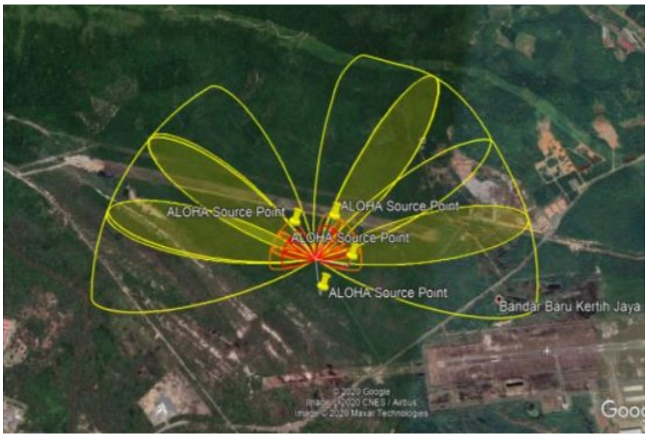

Fig. 14: Toxic area affected from 150 mm diameter

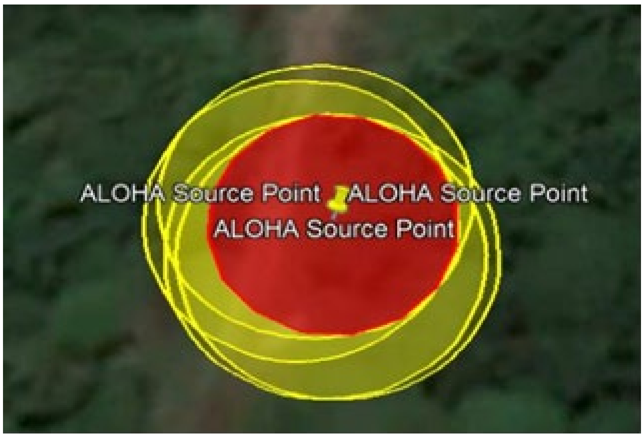

Fig. 15: Jet fire area affected from 150 mm diameter

The smallest diameter leakage (10 mm) has the lowest distance of toxic area affected which the distance affected of red zone area is 34 meters with 50 parts per million, orange zone area is 47 meters with 27 parts per million while yellow zone area is 342 meters with 0.51 parts per million. Red and orange threat zone were not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances. Meanwhile, the biggest diameter leakage (150 mm) has the highest distance of toxic area affected which the distance affected of red zone area is 224 meters with 50 parts per million, orange zone area is 305 meters with 27 parts per million while yellow zone area is 1,500 meters with 0.51 parts per million. The distance of the toxic area affected observed is increasing from 10 mm diameter leakage until 150 mm diameter leakage. The bigger the diameter leakage of the equipment, the higher the distance of the toxic area affected by the simulation. The maximum severity of the toxic area affected is achieved when the leaking hydrogen sulphide reaches 150 mm diameter leakage.

Fig. 15 shows the jet fire area affected by the leaking and burning hydrogen sulphide installed in the electrostatic precipitator equipment at 150 mm diameter leakage simulated at four wind direction which is SSE, NNE, ESE, and N. The duration simulated is at maximum duration which is 60 seconds. The distance of jet fire-affected of red zone area is 10 meters equal to 10.0 kW/m^2 impact, orange zone area is 10 meters equal to 5.0 kW/m^2 impact while yellow zone area is 15 meters equal to 2.0 kW/m^2 impact. The maximum severity of the jet fire area affected achieve for the red zone area where the severity is potentially lethal within 60 seconds while the minimum severity of the jet fire area affected achieve for the yellow zone area where the severity is only pain within 60 seconds. The medium severity comes for the orange zone area where the severity is second-degree burns within 60 seconds.

3.6 Comparison of worst-case scenarios

Based on the comparison of the worst-case scenario of each piece of equipment as stated in Table 2, it can be concluded that the equipment of absorber tower with the major chemical installed of sulphuric acid (H_2SO_4) would produce the most severe scenario at 150 mm diameter leakage. This is because this

Table 2: Comparison distance of area affected of the worst case scenario for each equipment

Equipment	Chemical	Diameter Leakage (mm)	Distance of Area Affected - Red Threat Zone
Drying Tower (Toxic dispersion)	Sulphuric Acid, H_2SO_4	150	100 meters --- (130 mg/(m^3) = PAC-3)
Sulphur Burner	Sulphur, S	150	No threat zone
Multibed Reactor (Toxic dispersion)	Sulphur Trioxide, SO_3	150	185 meters --- (160 mg/(m^3) = AEGL-3 [60 min])
Absorber Tower (Toxic dispersion)	Sulphuric Acid, H_2SO_4	150	greater than 10 kilometers --- (130 mg/(m^3) = PAC-3)
Electrostatic Precipitator (Jet fire explosion)	Hydrogen Sulphide, H_2S	150	10 meters --- (10 kW/(m^2) = potentially lethal within 60 sec)

toxic scenario produces the longest distance of the red zone for the area affected which is greater than 10 km. The severity of the toxicity scenario may lead to fatality and injury to the workers and people nearby. The multi-bed reactor, which contains sulphur trioxide produce the second-worst case as the distance of the red threat zone reach 185 metres, followed by a drying tower (100 metres), electrostatic precipitator (10 metres) while no threat zone produces for the sulphur burner.

4.0 Conclusions

This study analyses the consequences of every major chemical installed, namely sulphuric acid, sulphur, sulphur trioxide and hydrogen sulphide in each of the major equipment including the drying tower, sulphur burner, multi-bed reactor, absorber tower and electrostatic precipitator in the production of the sulphuric acid plant.

From the findings, the toxic release of sulphuric acid from the absorber tower is considered as the most severe as it has the longest red threat zone towards the surrounding whereas another major equipment only causing the red threat zone limited within 185 meters. However, this study not highlight frequencies per year of the scenario for fire, explosion overpressure and toxic. Therefore, future works will focus on the determination of frequencies, which will contribute to the quantification of risk in term of individual risk criteria.

Acknowledgement

The authors would like to acknowledge School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM) and the Ministry of Education (MOE) for the 600-RMI/FRGS/5/3 (0094/2016) grant, for all the funding and support given in establishing this project.

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