QUANTITATIVE RISK ASSESSMENT AND DISPERSION MODELLING USING ALOHA FOR CHLORINE GAS HANDLING FACILITY

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FACULTY OF ENGINEERING
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RESEARCH REPORT SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SAFETY, HEALTH AND ENVIRONMENT ENGINEERING

**FACULTY OF ENGINEERING
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QUANTITATIVE RISK ASSESSMENT AND DISPERSION MODELLING USING ALOHA FOR CHLORINE GAS HANDLING FACILITY

ABSTRACT

Malay-Sino Chemical Industries Sdn Bhd (Lahat) is a chlor-alkali industry consist of Emergency Chlorine Gas Handling Facility (ECGHF) which have the tendency to affect the plant workers and nearby residential area in the event of accidental chlorine gas release. HAZOP tool with risk assessment was used to identify the hazard and quantifying the hazards in order to prioritize the recommendations at the ECGHF. Possible incident scenario was selected from the HAZOP outcome which was the chlorine gas release from the stack due to scrubbing flow failure. The consequences of the released chlorine gas to the atmosphere was simulated by using ALOHA Vr 5.4.7 software where heavy gas dispersion model was selected which identifies the impacted area along with the concentration of the chlorine gas for TWO (2) wind direction (East and West) with other atmospheric conditions remain the same. The maximum emission rate was selected which is at 199kg/hr. Based on the findings from the modelling for both wind directions, the toxic threat zones and distances along with the concentration of chlorine plume remain same for both wind directions which is at 0.5ppm (1,100m), 2ppm (537m), and 20ppm (161m) and represented in Yellow, Orange, and Red lines and the threat zones are of 1,100m maximum radius. The probit analysis indicated there's no human fatality percentage predicted due to the chlorine gas exposure. The map from google satellite was used to identify the impacted residential areas in which the areas are Bukit Merah Village, Taman Menglembu Impiana Adril, and Taman Pasir Wang. Recommendations were proposed to eliminate the chlorine gas release from the ECGHF thus increasing the safety and reliability of operation.

Keywords: HAZOP with Risk Assessment, ALOHA Vr 5.4.7, Chlorine Gas, Dispersion Model, Dose- response model.

PENILAIAN RISIKO QUANTITIF DAN PENYEBARAN PEMODELAN MELALUI PENGGUNAAN ALOHA DI KEMUDAHAN YANG MENGENDALIKAN GAS KLORIN

ABSTRAK

Malay-sino Chemical Industries Sdn Bhd (Lahat) adalah sebuah industri chlor-alkali yang mempunyai Emergency Chlorine Gas Handling Facility (ECGHF) yang boleh mempengaruhi kesan terhadap pekerja di kilang dan kawasan perumahan yang terdekat jikalau terdapat pelepasan gas klorin secara tidak sengaja. Kemudahan HAZOP dengan penilaian risiko telah digunakan untuk megenalpasti dan mengquantifikasi ancaman untuk mengutamakan cadangan pengesyoran di ECGHF. Salah satu senario kemungkinan yang dipilih melalui hasil HAZOP iaitu penyebaran gas klorin daripada cerobong disebabkan kegagalan peredaran aliran. Akibat daripada pelepasan gas klorin yang disebarkan ke atmosfera telah dipamerkan melalui penggunaan perisian ALOHA versi 5.4.7 yang mana model serakan gas berat telah digunakan untuk menentukan kawasan yang terlibat dan kepekatan gas untuk DUA arah pengaliran udara (Timur dan Barat), dengan keadaan atmosfera yang lain-lain telah dimalarkan adalah sama. Kadar pemancaran telah ditetapkan di 199kg/jam. Berdasarkan keputusan yang diperolehi melalui pemodelan untuk kedua-dua arah angin, zon ancaman toxik, jarak dan kepekatan plum klorin kekal sama untuk kedua-dua arah angin iaitu pada 0.5ppm (1,100m), 2ppm (537m) dan 20ppm (161m) dan telah digambarkan melalui garisan Kuning, Oren dan Merah dan jarak masimum zon ancaman ialah 1,100m. Analisis probit meramalkan tiada peratusan kematian manusia akibat daripada dedahan gas klorin.

Peta dari satelit Google telah digunakan untuk mengenal pasti kawasan perumahan yang terlibat iaitu Kampung Bukit Merah, Taman Menglembu Impian Adril dan Taman Pasir Wang. Pengesyoran yang telah dicadangkan dapat membasmikan pelepasan gas klorin dari ECGHF dan juga meningkatkan keselamatan dan kebolehpercayaan operasi tersebut.

Keywords: HAZOP dengan penilaian risiko, ALOHA Vr 5.4.7, Gas Klorin, Penyebaran Pemodelan, Dos Tindak Balas Model.

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LIST OF SYMBOLS AND ABBREVIATIONS

AEGL	:	Acute Exposure Guideline Levels
ALOHA	:	Areal Location Of Hazardous Atmospheres
C	:	Concentration
Cl_2	:	Chlorine Gas
D	:	Tank
DI	:	Demineralized Water
DRMA	:	Decision Risk Matrix
E	:	Heat Exchanger
ECGHF	:	Emergency Chlorine Gas Handling Facility
ERPG	:	Emergency Response Planning Guidelines
FAHP	:	Fuzzy- Analytical Hierarchy – Process
FMEA	:	Failure Mode Effect Analysis
FRP	:	Fiber Reinforced Plastic
FT	:	Flow Transmitter
FTA	:	Fault Tree Analysis
H_2	:	Hydrogen Gas
H_2O	:	Water
HAZOP	:	Hazard And Operability Studies
IDLH	:	Immediate Danger To Life And Health
LOC	:	Toxic Level Of Chemicals
LOPA	:	Layer Of Protection Analysis
MHI	:	Major Hazard Installation
NaCl	:	Sodium Chloride
NaOCl	:	Sodium Hypochlorite

NaOH	:	Sodium Hydroxide
NOAA	:	National Oceanic And Atmospheric Administration
P	:	Pump
P&ID	:	Process And Instrumentation Diagram
PAC	:	Protective Action Criteria
PFD	:	Process Flow Diagram
PI	:	Pressure Indicator
ppm	:	Parts Per Million
Pr	:	Probit
PVC	:	Polyvinyl Chloride
t	:	Time
TI	:	Temperature Indicator
TNB	:	Tenaga Nasional Berhad
USEPA	:	United States Environmental Protection Agency
V	:	Valve

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background

Malay-Sino Chemical Industries Sdn Bhd (Lahat) which is situated in the Bukit Merah Industrial Park, as per Figure 1.1, is surrounded by few residential areas namely Taman Menglembu Impiana, Bukit Merah village, and Taman Pasir Wang. It manufactures Chlor-Alkali products by electrolysis process of Sodium Chloride (NaCl) and Demineralized water (DI) producing Sodium Hydroxide, Chorine gas, and Hydrogen gas. In the chemical terms, its explained as the disintegration of NaCl and water (H_2O) forming Sodium Hydroxide (NaOH), Chlorine (Cl_2) and Hydrogen (H_2). The chemical formula is represented as below (Jung, Postels, & Bardow, 2014)

$$2NaCl + 2H_2O \longrightarrow Cl_2 + 2NaOH + H_2$$

In general, the Hydrogen gas and the Chorine gas is channeled to the Hydrochloric Acid plant in which the Chlorine gas is combust with Hydrogen gas. In order for 100% combustion of chlorine gas in the burner, 90% of the chlorine gas is channeled to the burner with 100% Hydrogen gas. The balance 10% Chlorine gas is channeled to the Emergency Chlorine Gas Handling Facility (ECGHF) plant. ECGHF plant produces Sodium Hypochlorite product by scrubbing chlorine gas with 18% Sodium Hydroxide solution in an absorber tower.

ECGHF plant operates at the highest chlorine gas flow in the Malay-Sino Chemical Industries Sdn Bhd (Lahat). The chlorine gas is heavy green-yellow gas with a strong odor. It is said to be poisonous and the toxicity of the gas depends on the duration of exposure in which at a concentration of 1-3 ppm it leads to eye and oral membrane irritant, at a concentration of 15ppm it leads to pulmonary symptoms and it can be fatal at 430ppm within 30 minutes (Morim & Guldner, 2019).

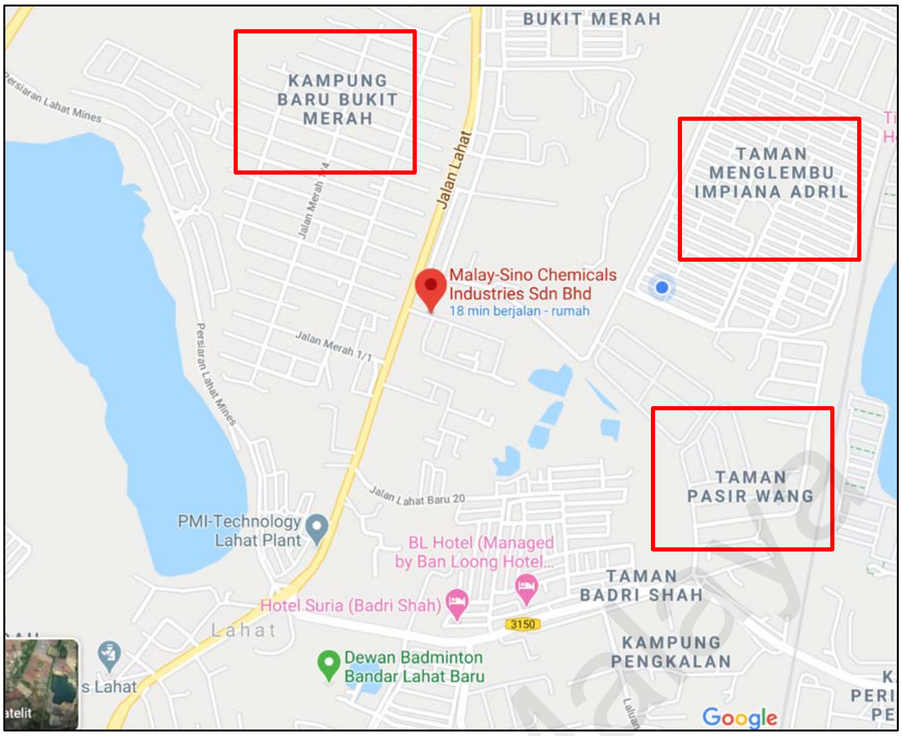

Figure 1.1: Location of Malay-Sino Chemical Industries Sdn Bhd (Lahat)

The chemical plant in this study is characterized as Major Hazard Installation (MHI) that deals with toxic gas which is Chlorine gas and MHI possess risk to the people whom are working and the neighborhood (Ramli, Ghani, Hamid, & Desa, 2018).

Safety analysis are conducted to ensure the inherent risks are small and within the acceptable risk zone or tolerable zone which focuses on the emission of chlorine gas from the ECGHF plant.

HAZOP studies, accident consequence models, and risk estimation models are commonly used to determine the best available options for improving the design of the existing system.

Literature review found there’s various techniques available for hazard identification and safety analysis for the chemical plants. Most widely used analysis method for identifying the hazards is the HAZOP in chemical processing plants (Bendib, Zennir, Mechhoud, & Bouziane, 2019).

HAZOP with risk assessment method was selected for the study. The purpose of considering the risk assessment methodology is to provide a systematic method to review the effect of failures on the overall system which include measuring and categorizing the risk to the severity, probability and the frequency to obtain the risk ranking in which this will be used for qualitative reasoning in order to prioritize the recommendations (Trammell & Davis, 2001).

Apart of identifying the systems risk, it's important to study the consequence of the risk in which, the impact of chlorine gas release from the plant. Referring to the accident involving Ferric Chloride and Sodium Hypochlorite mixture leading to chlorine gas emission on 17th September 2016 at the plant which affected 2 workers from the plant, 6 firemen's, and the area that was affected with the odour of chlorine gas was Bukit Merah village (thestar, 2016). It is understood that, there's no chlorine gas dispersion studies were carried out for the Bukit Merah Industrial Park.

Through literature review, ALOHA have been widely used to study and predict the chemical release in the past such as ammonia gas release from a storage tank (Anjana, Nair, Sajith, Amarnath, & Indu, 2018), acetylene release from the cylinder (Ilić-Komatina, Galjak, & Belošević, 2018), and chlorine gas dispersion model at Teluk Kalong, Kemaman (Law & Gimbun, 2020). The impact on human due to the chlorine gas exposure is further evaluated using probit analysis.

1.2 Scope of Study

The study is being carried out on ECGHF at Malay-Sino Chemical Industries Sdn Bhd (Lahat). It focusses on identifying the possible hazards in the facility which leads to chlorine gas emission from the stack, the chlorine gas release scenario is designed to evaluate the concentration and the distance of the chlorine gas dispersed along with the calculation estimating the human fatality percentage due to the chlorine gas exposure.

1.3 Process Description

The objective of setting up the Sodium Hypochlorite Plant is to convert the chlorine content in the waste air gas into Sodium Hypochlorite (NaOCl) solution by absorbing with Caustic Soda solution (Escudero-Oñate, 2014). The reaction taking place in the Absorption Tower is given as below:

$$Cl_2 + 2NaOH \longrightarrow NaOCl + NaCl + H_2O$$

Referring to the Figure 3.2, 18% NaOH (200-210gpl) will be taken in the Hypo Saturation pit (D810A&B) by opening the respective ON-OFF valves and circulation through the tower is established via respective Hypo Circulation pumps (P810A&B). Chlorine gas mixture from the plant is passed through the bottom of the absorption tower which is packed with PVC Raschig type packing. The chlorine gas passes upwards through the packing and meets the dilute caustic solution which dribbles downwards from the top of the tower. The chlorine gas gets absorbed in Caustic Soda solution and the net reaction produces Sodium Hypochlorite solution which flows by gravity from the tower bottom outlet to the saturation pit (D810 A&B).

The heat of reaction involved in the formation of hypochlorite (About 350kcal/kg of chlorine absorbed) is removed by the Hypo Heat Exchanger E 810 which is circulated with cooling water. The circulation of the Caustic-Hypo mixture through the tower is continued until all the Caustic is consumed up to an excess content of 20-25gpl. This excess is maintained for the stability of the hypochlorite solution.

After the conversion process of the caustic solution into the Hypochlorite solution in D810A in completed. D 810B is brought into operation. The contents of D810A are pumped by Hypo Transfer Pump P 802A&B to existing Hypo Storage Tank.

Meantime D 810B will be in service. When the Hypochlorite concentration in Tank D810B reaches the desired level, once again the process is switched over to tank D 810A.The end point of the absorption reaction can be checked by analyzing the sample for excess alkali with respect to available chlorine.

1.4 Problem Statement

Currently, there's chlorine gas release at the Sodium Hypochlorite plant which is recorded from the installed sensors in the plant (refer Appendix A). As we're aware, chlorine gas is toxic and its harmful to human health. Due to chlorine gas release (max 0.09ppm), evacuations have to be carried out to prevent any impacts to the working personnel's health. Even though no accidents affecting personnel's health is recorded due to very mild concentration, it is shall not be taken for granted hence lack of safety measures may even cause high concentration of chlorine gas emission in which this leads to harm the public health.

Its significant to investigate and identify the potential cause of the chlorine gas release from the plant. It is an important task for the management to ensure safe operation of the plant and to understand in case of the chlorine gas release at the maximum flow, which are the impacted area surrounding the plant. Study will be conducted to identify the potential causes, the impacted area due to the chlorine gas release, and propose recommendation to eliminate the chlorine gas release from the sodium hypochlorite plant

1.5 Objective of the Study

The specific aim of the study is to:

i. Identify the potential risk in the system that contribute to the chlorine gas emission from the stack.

ii. Provide recommendations to eliminate chlorine gas release at the ECGHF plant stack which in turn improves the plant operability and reliability

iii. To predict the distance of the chlorine gas dispersion along with the concentrations that impacts the surrounding residential area.

iv. To evaluate the probability of human fatality percentage due to the chlorine gas exposure.

The objective of this study is to determine the main cause or possible hazards in the process that could contribute to chlorine gas release from the stack by using HAZOP technique with risk assessment for the selected node from the Figure 3.2, propose related risk elimination measures, and to predict the distance travelled by the gas at different concentrations and the impacted area by utilizing **ALOHA** Vr 5.4.7 software. The impact of the chlorine gas exposure on people which focuses fatality percentage is calculated by using probit analysis.

1.6 Significant of the study

The results of the study are expected to table out the safety and operational setbacks using single absorption tower in plant designs. Apart of this, the results from the ALOHA studies can be used for future studies to develop an emergency response and evacuation route planning in case accidental chlorine gas release at the Bukit Merah Industrial Park, Lahat, Ipoh. It may assist operational personnel to understand more about the ECGHF setup which in turn increases the awareness and the critical level of the system.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to Chlor-Alkali Industry

Chlor-Alkali industry products are of chlorine and sodium hydroxide in which it is referred as the biggest electrochemical industry. It is said as electrochemical industry due to the process in which the sodium chloride is disintegrated by the application of electricity. The basic chemicals that is used for the day to day life which is ranked from zero to ten in the world is said to be chlorine and sodium hydroxide. The industry of detergent, Oleochemicals, pharmaceuticals, plastics, herbicides and pesticides mainly consume the sodium hydroxide and chlorine as their raw materials (O'Brien, Bommaraju, & Hine, 2007).

2.2 Chlor-Alkali Technologies

Up to the 20th century, the mercury cells technologies was used which was about 55% usage in the Europe, and the diaphragm cell usage was about 75% in the United States followed by the membrane cell which was about 90% in the Japan (Garcia-Herrero, Margallo, Onandía, Aldaco, & Irabien, 2017).

The mercury cells in which this technology produces sodium hydroxide at 50% concentration and this method was banned after identifying that mercury can impact human life and few have been reported due to poisonings in Niigata and Minamata in 1972, Japan started to convert into membrane technology (Lakshmanan & Murugesan, 2014). No new mercury plants were built since 1984 and the new plants erected in India and china were off the membrane technologies (Garcia-Herrero et al., 2017).

The sodium hydroxide concentration that is produced from the diaphragm cell which uses the chrysotile asbestos for the separation are only off 12%-15% concentration. Further concentrating to meet the industry grade which is 50%, it is channeled to a double effect or triple effect evaporators. The caustic grade from the diaphragm cell is said to be low due to its high content of sodium chlorate which is formed by side reaction due to the migration of catholyte medium to the anolyte medium compartment stated about 1.3% (Lakshmanan & Murugesan, 2014).

The technology that is widely used today in the chlor-alkali industry is the membrane technology in which its principle of working is by selective permeability which allows the selected ion to pass through. This membrane comprises of anodic and cathodic side in which the anodic is made up of the per flurosulfonic acid films and the cathodic is made up by per flurocarboxcylic acid film depending on the operation condition (Lakshmanan & Murugesan, 2014).

2.3 Chlorine Gas Generation

The chlorine gas is generated from the electrolyser. The electrolyser have TWO (2) compartment which is the anodic and cathodic compartment. The treated brine is channeled into the anodic compartment whereas the demineralized water is channeled into the cathodic compartment. The dis integration of the brine takes place by introducing potential energy which is the electricity which permeates the sodium ion to the cathodic compartment combining with the hydroxyl ion in the cathodic compartment.

Chlorine gas is generated in the anodic compartment when the brine breakdowns sodium ion and chlorine ion and hydrogen gas is generated in the cathodic compartment breaking down the water molecules into hydroxide and hydrogen ion. The depleted brine is sent for sodium chlorate decomposition unit by pH reduction and increasing the temperature 85 Degree C to 95 Degree C before its channel back into the saturator, refer Figure 2.1 below for process flow details (Bommaraju, Orosz, & Sokol, 2010)

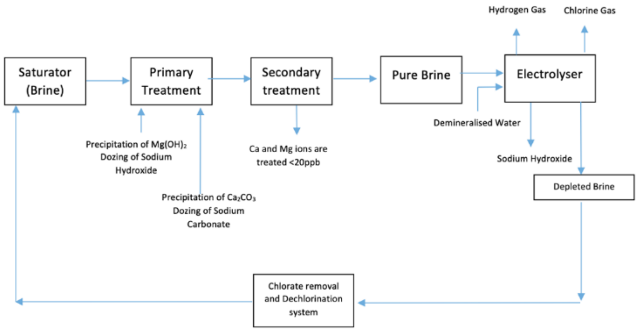

Figure 2.1: Brine Treatment for Electrolyser operation

2.4 Chlorine Gas Toxicity

Chlorine gas concentration from ranges 0.1ppm-0.3ppm can be detected by humans. At a concentration of 1ppm-3ppm of chlorine gas exposure, irritation occurs which can be tolerated about one hour. Beyond 30ppm, shortness of breath, cough and chest pain occurs. Chlorine gas concentration above 400ppm for 30 minutes is fatal and concentration above 1000ppm leads to fatal within few minutes (White & Martin, 2010).

2.5 Chlorine Gas Scrubbing at ECGHF

Chlorine gas with sodium hydroxide (NaOH) an alkaline water is channeled to a packed column. Typically, this produces sodium hypochlorite. The product consist of 5%-15% of available chlorine (w/w) in sodium hypochlorite with 0.25%-0.35% of free NaOH and 0.5% - 1.5% of NaCl (Escudero-Oñate, 2014).

The scrubbing liquid (sodium hydroxide) is channeled to the top of the column which flows downwards through the packings as the gas stream (chlorine gas) is channeled into the column from the bottom and flows upward the column through the support of the blower. This increase the absorption surface area for the liquid and gas mass transfer application. Common packed columns are known as the absorbers (Kankanamge, Matarage, & Perera, 2019).

2.6 Introduction to Risk Assessment

Risk assessment is known as studies that is used to identify, analyze, and quantify the risk for industrial plants to make calculated decision. Over the years, various techniques for hazard identification and safety analysis have been designed for chemical processing plants (Arena, Criscione, & Trapani, 2018).

Most industries commonly uses the technique such as process hazard checklist, hazard and operability studies (HAZOP), fault tree analysis (FTA), failure mode and effect analysis (FMEA), layer of protection analysis (LOPA), relative ranking analysis (hazard indices) and etc. Comparing of all of the methods, there's no single method that can analyze and support for all safety aspects. Chemical processing plants commonly uses HAZOP technique for the hazard identification (Bendib et al., 2019).

Decision making based on evaluated risk collects the data's on the possibility of one or more unwanted failures that can occur in a clearer direction and orderly in which facilitates the management to make appropriate decisions (Izvercian, Ivascu, Miclea, & Radu, 2012).

Risk assessment methods is crucial to sustain and continuously improve the plants safety and performance (Loganathan, Neog, & Rai, 2018).

2.7 Quantitative and Qualitative Risk Assessment

Risk assessment is used to support decision making in all systems starting from the conceptual design stage, operation and maintenance phases until the demolishing stage.

It comprises of TWO (2) types of risk analysis method:

I. Qualitative analysis
II. Quantitative analysis

Qualitative risk analysis is commonly performed on all risk and for all projects. It is also referred as management technique which examines the probability and the impact of the risk which uses descriptive scale for measurement of the occurrence.

Quantitative risk analysis is limited in which the use is depending on the type of the project, the project risk, and the available data for the analysis which it uses numerical scale (Tiusanen, 2017).

2.8 Introduction to Hazard and Operability Studies (HAZOP)

The HAZOP method is originated from the Division of Organic Chemistry heavy ICI, in which it's a British international chemical company in the year 1963 (Galante, Bordalo, & Nobrega, 2014).

This method is widely used in chemical plants to identify the hazards involve in handling the hazardous substances in which this method derives with propose measures which in turn minimize or eliminate the potential sources of risk (Ashish, Gerald, & Shanmuga Prakash, 2017).

The objective of conducting HAZOP studies is to eliminate or reduce the hazards by analyzing the deviations that is designed which in turn leads to safety, health and environmental issues (Lee, Shigrekar, & Borrelli, 2019).

As refereed from (Ashish et al., 2017), The advantages and disadvantages of the HAZOP studies as below:

The advantages of HAZOP:

I. Is a systematic and complete assessment of the setup/equipment with the aim to identify the dangerous occurrence/state
II. Able to identify and evaluate the possible consequences due to the failure

III. Finding the dangerous situation or condition it can be

IV. Increases the operational efficiency by identifying the possible breakdown occurrence that disturbs the operation.

V. The participants on the HAZOP have better understanding on the process in in which a new information regarding the equipment or the process may be acknowledged.

2.9 HAZOP Methodology

A team that comprises the technical experts from various departments such as process operators, instrument departments, design and mechanical department are formed to carry out the HAZOP studies. The project head/leader is normally nominated as the leader (Rossing, Lind, Jensen, & Jørgensen, 2010)

Steps of HAZOP

Pre-meeting → Meeting → Post-Meeting

<u>Pre-meeting</u>

The crucial responsibilities of the leader is before the pre-meeting is to collect the information related to the area of the study/or the plant in which to prepare the complete process flow diagram(PFD)/process and instrumentation diagram(P&ID) , the data sheet of the chemical in the process and the plant layout (Rossing et al., 2010).

The complete process parameters during normal and abnormal operations are identified prior the meeting. Moving forward, he than keeps the team updated on the meeting dates and makes sure the participants attend the meetings.

Meeting

At the start of the meeting, the leader explains the scope of the study and the technique on how to apply the HAZOP method. The complete process of the area that to be assessed is explained with the PFD/P&ID along with the functions and current challenges faced. The node is separated by the leader based on the systems. Brainstorming is carried out by the team evaluating each section in the node in which the identified process parameters and the deviations are included in a structured manner. The sequence in the HAZOP study starts with the deviation, possible causes, consequences and ends with the action required.

The deviation that require further consideration and actions are tabled out and recorded down in which the actions to be taken is assigned to a person in charge (PIC) to complete the task (Rossing et al., 2010).

Post-Meeting

The leader follows up with the assigned person for the task on the status of the implementations and if necessary, review meeting will be conducted to feedback on the pending actions and status.

Table 2.1: Traditional HAZOP Table

Guide Word	Deviation	Possible Causes	Consequences	Action Required
Flow	No flow			
	Less flow			
	Reverse flow			
	More flow			

Table was developed by (Crawley & Tyler, 2015)

2.10 HAZOP with Risk Assessment

Traditional HAZOP as refereed in the literature review, is used to identify the hazards in a process facility in which provided actions to minimize or eliminate the risk up to tolerable level. Its more efficient to include the risk assessment method in the HAZOP in which the target for the recommendations provided in the HAZOP study to review on the effect of failure and the systems can be provided systematically by using risk assessment method (Trammell & Davis, 2001).

To put the targets effectively on the action required, severity of the risk is determined in which apart of identifying the potential risk using HAZOP, it is also designed to quantify the risk. After analyzing the normal and abnormal operation parameter's, the guide words that to be used for the HAZOP studies are Pressure, Transferring, Flow, Level, Temperature, Time, Service Failure, Instrumentation, and Measure. This selection of the guide words is in line with (Kotek & Tabas, 2012) in which these words are derived with reference to the current operating parameters at the plant.

To prioritize the recommendations, it's important to ensure the frequency estimates, probability estimates, and the severity estimates are identified so that the risk ranking obtain is accurate which further used for the qualitative reasoning for the recommendations (Marhavilas, Filippidis, Koulinas, & Koulouriotis, 2019).

By utilizing the HAZOP with risk assessment method, its able to identify the potential risk, determining the severity of the risk, in which the risk reduction method could be put in place at the targets (Huang et al., 2018).

Through literature review, it was noticed that HAZOP are integrated with Decision Risk Matrix (DRMA) and the Fuzzy Analytical Hierarchy Process (FAHP) in which it is also mentioned that the hazards can be ranked accordingly and actions can be taken referring to the particular deviations (Marhavilas, Filippidis, Koulinas, & Koulouriotis, 2020).

In conjunction with the problem statement, a part of quantifying the Severity (S) and Likelihood (L) as a risk matrix applied by (Marhavilas et al., 2020), It's also important to identify and quantify the existing safety precautions that is in place that prevents the event from occurring.

As stated by (Huang et al., 2018), it is mentioned as Control Degree (U) which quantifies the current safety practice that prevents the occurrence of the events. With the rating 1-5, it is rated for each criterion. The outcome from the risk evaluation is determined by ($R^* = S \times L \times U$). Referring to (Huang et al., 2018), the high risk deviations can be identified for the Sodium Hypochlorite plant process.

2.10.1 Risk Rating Criteria's:

Table 2.2: Level determining criteria's

Level	Severity (S)	Control Degree (U)	Likelihood (L)
5	Affect the safety of system operation, resulting in the huge loss of life and property.	No instrumentation, control or protective measures	Happens at least once a year
4	System loses main function and works in a bad condition.	Only passive protection system	Happens once in each maintenance cycle
3	Property goes down, affect the use and operation of system	Have measuring instrument or emergency stop	Happens only once in history
2	A slight impact on system performance	Instrumentation with alarm or active protection system	It has happened in this industry.
1	The system will not have an impact	Automatic control and alarm instrumentation	Never happened

Table was developed by (Huang et al., 2018)

Table 2.3: Risk Level and Action Required

Risk Level	Score	Risk Rating	Action Required
I	1 - 24	D - LOW	No Action Required
II	25 - 49	C - MODERATE	Strengthen the maintenance and preventive measures
III	50 - 74	B - CRITICAL	Improve prevention and control measures
IV	75 - 125	A - SIGNIFICANT	Revisit the design, implement additional control measures

Table was developed by (Huang et al., 2018)

2.11 Consequence Model

Consequences models are also an important area in the Quantitative Risk Assessment (QRA) in which the consequences of the potential accident can be quantified and evaluated which is a necessary step for the risk management process (Sellami, Nait-Said, Chetehouna, de Izarra, & Zidani, 2018).

It is said that the major outcome from the chemical disasters are in the form of fire, explosion, and toxic release. Toxic release, explosions, and fire are the three common types of major accident that occurs in the process industry. When it is referred to toxic gas dispersion, these gasses are released from three types of sources to the atmosphere, dispersion of harmful chemicals through combustion product, toxic gas released form an explosion, and dispersion of a toxic gas (Lovreglio, Ronchi, Maragkos, Beji, & Merci, 2016). Such as the Bhopal gas tragedy (1982) in which the toxic chemical released became air borne have drawn more attention due to the potential of damaging larger area dispersing through the air (Anjana et al., 2018).

According to (Lovreglio et al., 2016), the study for the consequences of the toxic gas dispersion include three steps, the source estimation, modeling of the toxic gas, concentration estimation of the toxic gas, and the impact of the toxic gas on the people (Lovreglio et al., 2016).

The term dispersion is used to describe the diffusion of toxic or flammable gas or vapor in the atmosphere (Anjana et al., 2018)

2.12 Selection of Dispersion Model

Many dispersion models have been developed to predict the gas concentration and gas dispersion which are Gaussian models, Box models Lagrangian particle and puff model, and computational fluid dynamics model (Lovreglio et al., 2016).

The common dispersion models used in atmospheric dispersion modelling are the Gaussian type models. This model assumes the pollutant disperses according to normal statistical dispersion in which at the point of release the concentration is at maximum and decreases both in the vertical and lateral directions. The further the gas travels, the smaller the concentration until it is closer to zero. (Nikita, Santosa, Kasim, Prasetyo, & Ayash, 2020).

The modelling method software that supports Gaussian dispersion model and heavy gas dispersion model is ALOHA (Areal Location Of Hazardous Atmospheres) in which the software is developed by the National Oceanic and Atmospheric Administration (NOAA) in collaboration with USEPA (Environmental Protection Agency) (Nikita et al., 2020).

2.13 Information required for ALOHA

To model with ALOHA, it requires the information on the weather which comprises the wind speed and the direction, the humidity, stability class, and the air temperature. Moving forward, the chemical properties and the source strength are also to be known which is available in the ALOHA library and the sources information can identified through the HAZOP studies in this paper. Atmospheric data considered for the studies which was obtained for the state of Perak referring from (Shamsuddin et al., 2017).

2.14 ALOHA Vr 5.4.7 Methodology

The ALOHA Vr 5.4.7 software can be downloaded from the United States Environmental Protection Agency (USEPA) webpage for free. The sequence for the modelling using ALOHA Vr 5.4.7 is as per Figure 2.2.

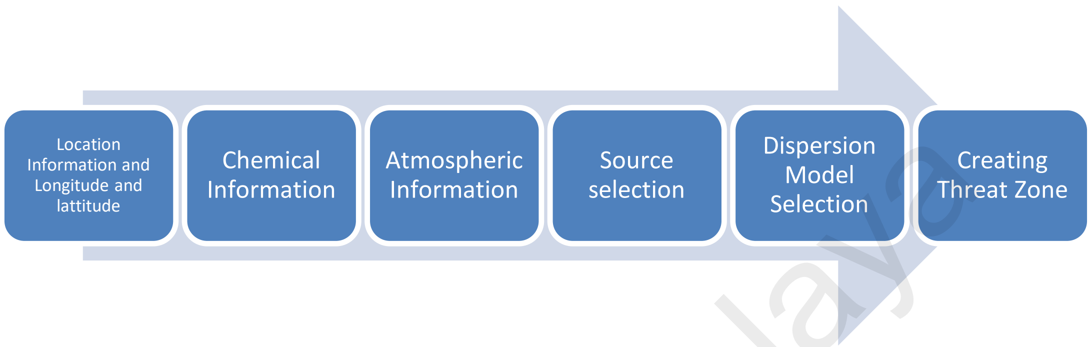

Figure 2.2: ALOHA Vr 5.4.7 Software flow diagram

The location information in which it comprises the elevation height of the city and the coordinates of the location is keyed in. The building parameters are selected such as sheltered or unsheltered single or double storied buildings.

The chemical is selected in the list in which as per our literature review, ALOHA library consist approximately 700 pure chemicals in the database (Law & Gimbun, 2020).

The atmospheric conditions are keyed in which the wind speed, the wind direction, ground condition, the cloud condition, air temperature, stability class, and the humidity is fed in the software. This data is commonly obtained from resources such as the countries meteorological webpages and in reference with other articles related to the location of the study.

The sources are selected in which this is typically from the scenario that is obtained from the hazard analysis which comprises the type of source, the amount, and the height at which it is released.

The calculation option in ALOHA consist of Gaussian and Heavy gas dispersion model in which this solely depends on the medium involved in the study. The toxic threat zone is displayed in which by selecting the AEGL.

The threat zone is further extracted in the form of KML format which is uploaded in the google earth to obtain the exact impacted area which includes the information on the threat zone and the concentrations of the gas.

2.15 Dose-Response Model

This model derives the relationship between the mortality rate (probability of death) and dose on people and environment (Soman, Sundararaj, & Devadasan, 2012). The model is expressed by the equation as below:

$$Pr = a + b \ \ln V$$

Pr - probit, is the measure of the percentage of a population which is subjected to the effects of the given intensity V which undergo certain damaging effect. The constant a and b are determined from the information's on accidents or sometimes from experiment's on animals (Hee et al., 2004). Hence, the percentage of the human fatality due to the chlorine gas exposure can be predicted by using the above relationship. The probit to the percentage conversion table is refereed from (Hee et al., 2004).

CHAPTER 3: METHODOLOGY

The methodology adopted is conducted in a series of steps which is explained in the Figure 3.1 in which the required information is collected, HAZOP studies is conducted, the scenario that leads to chlorine gas release is selected and dispersion modelling is carried out.

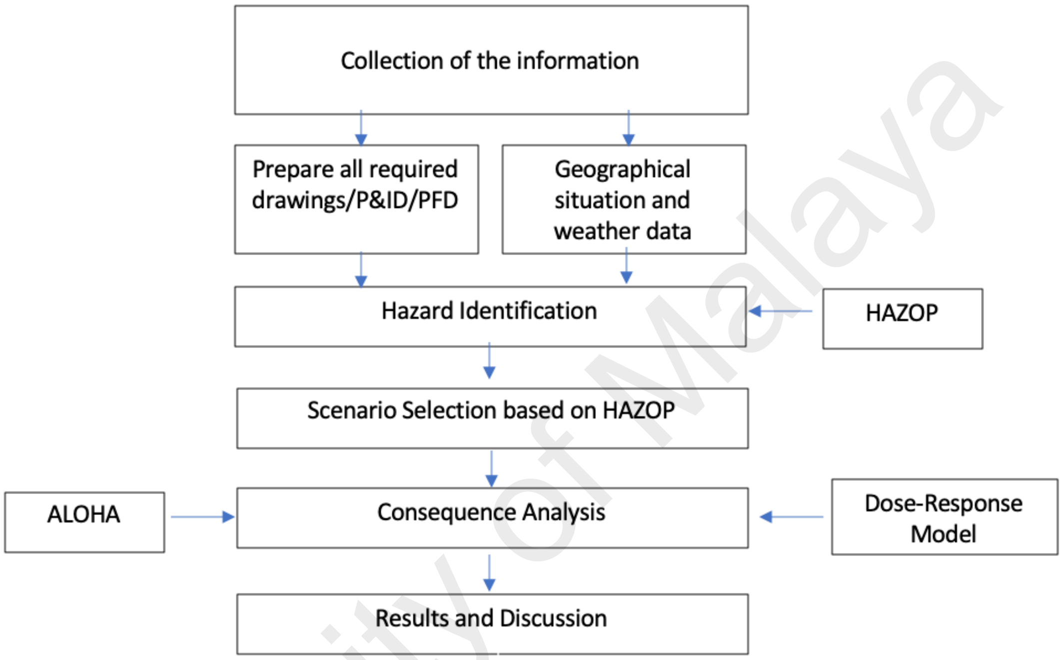

Figure 3.1: Methodology of Quantitative Consequence Analysis

3.1 Collection of Information

The Process Flow Diagram (PFD) of the Sodium Hypochlorite plant is collected in which the valves, pumps, heat exchangers and the local gauges are labelled.

The literature review indicated that to simulate the dispersion modelling using ALOHA requires the substance involved, geographical data’s longitude & latitude of the plant location, relative humidity, wind direction, ambient temperature, and atmosphere stability. These data are obtained from references in the literature review.

3.2 Hazard Identification

A team was formed which comprises from the process departments which include the operators, instrumentation departments, and the mechanical department. A leader is nominated from the process team who's familiar with the Sodium Hypochlorite plant operations. The flow process of the HAZOP is shown in the Figure 3.2.

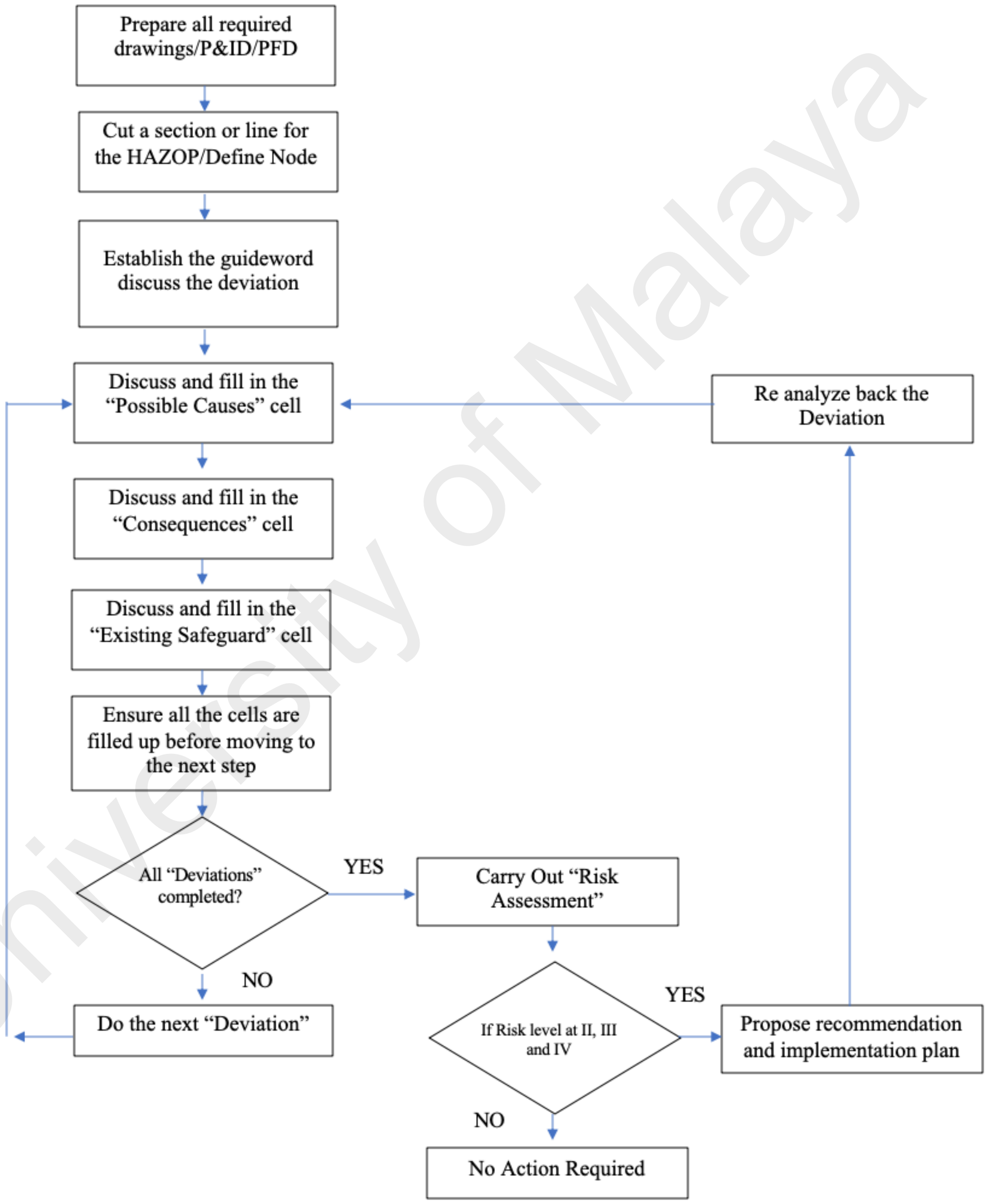

Figure 3.2: HAZOP Flow Chart

3.2.1 Node Separation, Guide word and Deviation Settlement

The node separation for the HAZOP is typically carried out referring to the process in which it can comprise more the one device in a single node. The whole process is divided into FOUR (4) nodes which are the scrubbing liquid circulation system, absorption column and receiving system, waste gas blower system, and the transfer system. This separation was done based on the systems. The meaning of each node is given in Table 3.1.

Node 1, Node 2, and Node 4 is selected for the HAZOP studies which comprises the Scrubbing Liquid Circulation Flow System, Absorption Column and Receiving System, and the Transfer system. Waste gas blower system ensures the chlorine gas moves upward the column increasing the surface area thought the packing. This system was omitted because in case of failure, it's an advantage which prevents the chlorine emitting from the stack.

Deviations are selected from key operating process parameters that ensures the operations is in the good condition. The guide words and the deviations that are established for the studies is listed in the Table 3.2. Meaningless deviations such as the maintenance error was eliminated in which it increased the efficiency and accuracy of the studies.

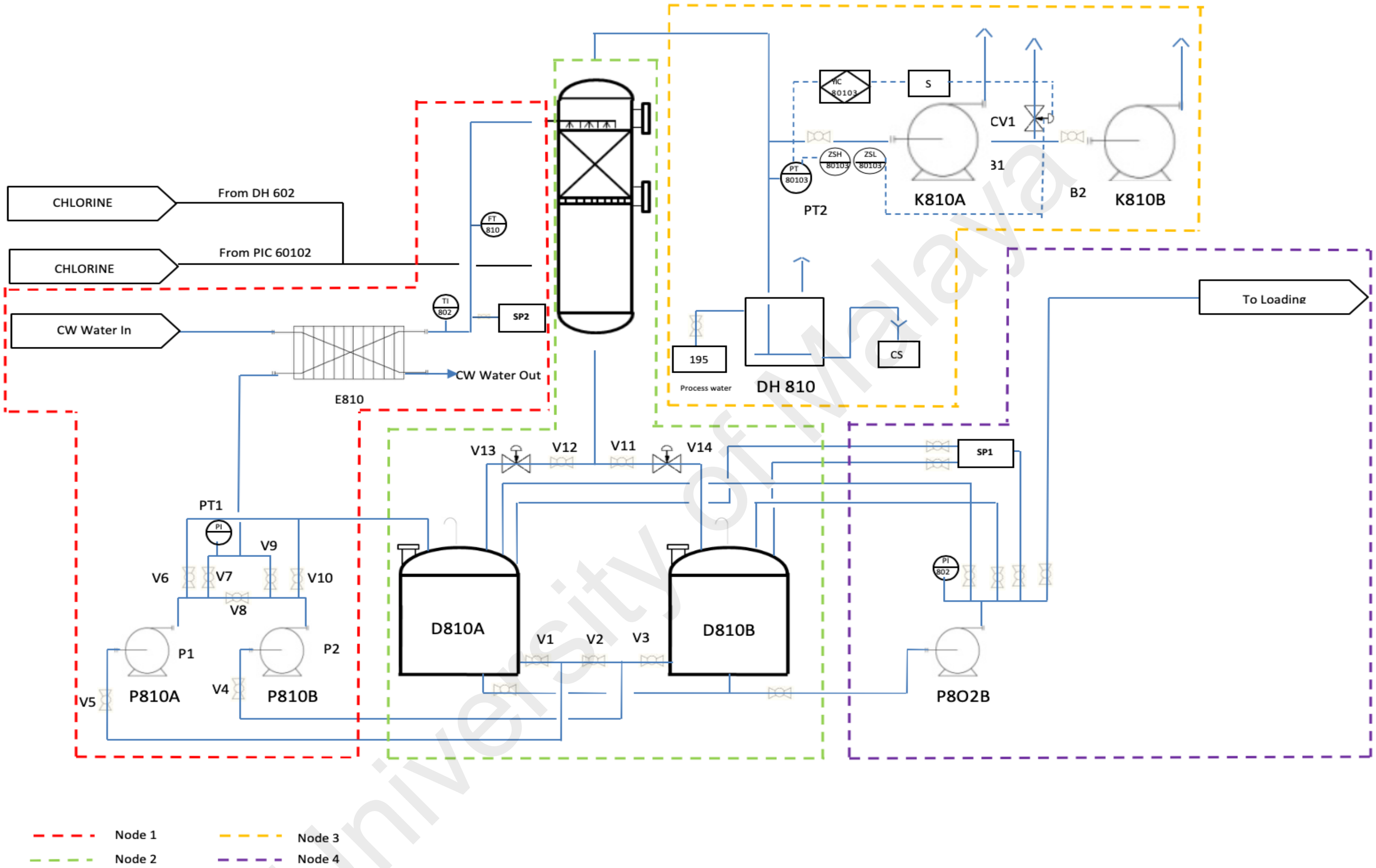

Figure 3.3: Simplified PFD of Sodium Hypochlorite plant

Table 3.1: Node Division for the Sodium Hypochlorite plant

Node	Keywords	Explanation
1	Scrubbing Liquid Circulation System	18% NaOH is circulated by pumps to the tower
2	Absorption Column and Receiving System	The chlorine gas is absorbed in the column with the scrubbing liquid which is collected in the tanks below
3	Waste Gas Blower System	The column is maintained in the suction pressure to ensure the chlorine gas move upward in the column through the packing's
4	Transfer System	Saturated product is transferred to the storage tank

Table 3.2: Guide word and Deviations (Excerpt)

Guide Words	Deviation
Flow	No Flow
	Less Flow
Level	More Level
Temperature	High Temperature
Pressure	High Pressure At discharge
	Low Pressure At discharge
Service Failure	Air failure
	Power failure
	Generator failure
Instrumentation	Calibration
Measure	Saturation Point/Reaction Abnormality
Transferring	18% NaOH transfer to D810A or D810B
	Saturated batch transfer to storage tank

3.2.2 Deviation, Possible Cause, Consequences, and Existing Safeguard

The process of the HAZOP is sequenced from the Deviation, to the possible cause which is basically gives an input what can cause the deviation to occur, than consequences which gives an input on the results if the deviation to takes place, and lastly on the existing safe guard that is currently in practice that prevents/controls/mitigate the occurrence of the deviation.

Each of the deviation, the possible cause, consequences, existing safeguard are studied looking into mainly on the process flow, operational safety and the existing safety protection in place.

3.2.3 Risk Rating and Recommendation for HAZOP

The risk assessment is carried out in which the risk ratings for the Severity, Control Degree and the Likelihood is obtained from Table 2.2. The score is obtained by multiplying the Severity, Control Degree and the Likelihood to determine the risk level which is given in the Table 2.3. The rating for the consequences for each deviation is evaluated in which the outcome for the risk level II, III, and IV, recommendations are provided.

The typical deviations along with the highest risk rating from the analysis result is given in the Table 3.3.

3.3 Scenario Selection

The deviation with the highest risk rating from the HAZOP studies was selected in which an incident description is tabled out for the consequence analysis. This scenario is used to model the heavy gas dispersion to identify the impacted area and the concentration of the gas.

Table 3.3: Analysis Table of HAZOP (Excerpt)

Guide Word	Deviation	Possible Cause	Consequences	Existing Safe Guard	Risk Rating (1 to 5)					Recommendation
					S	L	U	*	R	
Flow	No Flow	P810A or P801B trip/didn't operate V1 or V3 not open V7 or V9 is not open E 810 chocked	No scrubbing liquid flow to the tower leading to chlorine gas release	PI 801A to indicate pressure and alarm at the site FT 810 to monitor scrubbing flow	5	4	4	80	IV	To install 2nd scrubbing tower as back up to contain chlorine breakthrough from 1st tower
	Less Flow	P810A or P801B poor efficiency V1 or V3 not fully open V7 or V9 is not fully open E810 partially chocked	Less circulation flow to the saturation tank and chlorine gas might release	PI 801A to indicate pressure and alarm at the site FT 810 to monitor scrubbing flow	5	4	4	80	IV	To install 2nd scrubbing tower as back up to contain chlorine breakthrough from 1st tower

Guide Word	Deviation	Possible Cause	Consequences	Existing Safe Guard	Risk Rating (1 to 5)					Recommendation
					S	L	U	*	R	
Level	More Level	D810A and D810B mal-operation	Sodium Hypochlorite overflow from the tank	Bund wall to collect the spill	3	1	4	12	I	-
Temperature	More Temperature	E810 cooling water side chocked	PVC FRP pipes deform leading to rupture	TI 802 to monitor scrubbing flow temperature	3	1	4	12	I	-
Pressure	More Pressure at discharge	Valve V7 or V9 not fully open	No scrubbing liquid flow to the tower leading to chlorine gas release	PI 801A to indicate pressure and alarm at the site FT 810 to monitor scrubbing flow	5	4	4	80	IV	To install 2nd scrubbing tower as back up to contain chlorine breakthrough from 1st tower
		E810 chocked								

Guide Word	Deviation	Possible Cause	Consequences	Existing Safe Guard	Risk Rating (1 to 5)					Recommendation
					S	L	U	*	R	
Pressure	Less Pressure	P810A or P810B cavitation	Inconsistent circulation flow to the saturation tank and chlorine gas might release	PI 801A to indicate pressure and alarm at the site FT 810 to monitor scrubbing flow	5	4	4	80	IV	To install 2nd scrubbing tower as back up to contain chlorine breakthrough from 1st tower
Service Failure	Air failure	ON/Off valve (V13 and V14) fail open	Saturation Batch mix over with fresh batch 18% Sodium Hydroxide	To operate isolation valve V12 and V11 accordingly	3	1	5	15	I	-
	Power failure	TNB Power fail	P810 A or P810 B fail to operate	Generator to supply power as back up	5	4	5	100	IV	To install deluge tank to the 2nd tower which scrubs the remnant chlorine gas through gravitational flow
	Generator failure	Generator couldn't start on time due to mechanical problem	No power to operate the circulation pumps leading to chlorine gas emission	To check the generator condition/test run every Monday	4	4	5	80	IV	

Guide Word	Deviation	Possible Cause	Consequences	Existing Safe Guard	Risk Rating (1 to 5)					Recommendation
					S	L	U	*	R	
Instrumentation	Calibration	PI 801A and FT 810 wrong indication/faulty reading	In case of emergency, fail to operate leading to chlorine gas emission	Calibration every 6 months once	4	4	4	64	III	To install interlock which triggers to trip the membrane plant in case failure in circulation flow
Human Factor	Saturation Point	Operator did not monitor hourly reading/falsifying the reading	The batch over saturated leading to chlorine gas emission	N/A	4	4	4	64	III	To install Oxidation Redox potential meter to monitor online
Transferring	18% NaOH Transfer to D810A or D810B	Operator did not prepare fresh batch	No circulation flow due to no fresh batch leading to chlorine gas emission	Plant superintendent to verify each batch saturated and preparation is being done	4	4	4	64	III	To install standby pump
		Transfer pump fail								
	Saturated batch transfer to storage tank	Transfer pump fail	No circulation flow due to no fresh batch leading to chlorine gas emission	Plant superintendent to verify each batch saturated and preparation is being done	4	4	4	64	III	To install standby pump

3.4 Consequence Analysis

Referring to the literature review, to modelling is conducted by using ALOHA Vr 5.4.7 which consists of heavy gas dispersion modelling. To model the dispersion, it requires information on the geographical location, the chemical information, atmospheric information, sources type, and the modelling method to be used.

The data's that was used for the simulation was obtained from (Shamsuddin et al., 2017) and This data is evident in which during the accident involving Ferric Chloride and Sodium Hypochlorite mixture leading to chlorine gas emission on 17th September 2016 at the plant, the area that was affected with the odour of chlorine gas was Bukit Merah village which about 500m East from the plant (thestar, 2016).

Table 3.4: Sources Data and Strength

Name of Chemical	Chlorine Gas
Molecular Weight	70.91g/mol
Ambient Boiling Temperature	-34.04 ^{o}C
Fugitive release from stack during scrubbing flow failure	199kg/hr
Sources release height (Stack Height)	7m

Table 3.5: Atmospheric Data

Meteorological conditions	Low Sun and cloudy – Malaysia's average meteorological condition – Stability Class B
Temperature	33^{o}C
Humidity	82.3%
Average Wind Speed	3m/s – 7.2m/s
Most frequent wind direction	East and West

Table 3.6: Study Area information

Coordinates	4.32m 53s° N, 101.02m41s° E
Temperature	33^{o}C
Site Elevation	22m above sea level

The ALOHA’s chemical library consists of toxic level of chemicals (LOC) such as AEGLs (Acute Exposure Guideline Levels), ERPGs (Emergency Response Planning Guidelines), IDLH (immediate Danger to Life and Health), and PACs (Protective Action Criteria) and they’re linked with the nature of the chemical during simulation.

This study takes into account on the AEGLs in which it estimates the concentration at which people will begin to experience health effects if they’re exposed to the airborne chemical for a specific length of time. It consists of THREE (3) tiers in which AEGL-3 indicates the airborne concentration which leads to life threatening effects or death, AEGL-2 indicates the airborne concentration which leads to long lasting adverse health effects or an impaired ability which is irreversible, and the AEGL-1 indicates the airborne concentration that leads to experiencing notable discomfort such as irritation or certain non-sensory effects which is reversible. The AEGLs was developed by the AEGLs National Advisory Committee which is further reviewed and published by the National Research council of the National Academy of Sciences (NOAA, 2019).

As per the Table 3.4 for the sources strength data and strength, the chlorine gas is emitted at continuous rate in which the plant operates max of 199kg/hr of chlorine gas flow. The stack is at 7m height from the ground which is considered as the emitting source height.

The estimation function of wind velocity and solar radiation is known as stability. It consists of classes from A until F indicating extremely unstable atmospheric condition till moderately stable condition. Comparing the stability classes, it is said that the more stable the atmosphere, the higher or dangerous the concentrations are (Al-Sarawi, 2017).

In this study, heavy gas dispersion model is chosen for downwind dispersion because the chlorine gas is denser than the air (Dash, Pradhan, & Singh, 2018). The atmospheric data's considered is as per Table 3.5. The wind speed that is simulated is 3m/s in which as per studies by (Paul, Mondal, & Choudhury, 2014) shows that chlorine gas dispersion is faster and dispersed in a larger area at higher wind speed in which reduces the area of higher concentration in a short span. Hence, to study for higher risk for the chlorine gas dispersion area and concentration, lower wind speed is considered which is 3m/s is selected.

The simulation was carried out for TWO (2) wind direction using the same stability class B (Malaysia's Average Meteorological Condition) taking into consideration on the information from (James Diebel, 2016) where the wind direction is mostly from East (4.2 months) and West direction (5.4 months) throughout the year for the city of Ipoh.

3.5 Dose-Response Model

To estimate the impact on people and environment from the exposure of the chlorine gas which is at the maximum area 1,100m as per the ALOHA studies, it can be done by calculation using probit analysis (Na, Jeon, & Lee, 2018). This analysis provides probability of human death by using the probit function.

The equation for the chlorine death is given as below:

$$Pr = k1 + k2 \ \ln C^{2.0}\, t$$

where *Pr* is the probit, C is the concentration in ppm, t is the duration of exposure in minutes, k1 and k2 are the constants given as -8.29 and 0.92 (Louvar). The probit *Pr* is further converted into percentages by the use of the probit and percentage table (Louvar).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results of the HAZOP

By analyzing the HAZOP study referring to the Table 3.3, which was conducted on the Sodium Hypochlorite process plant, the potential risk of the system was identified. The HAZOP studies was conducted for the Node 1, Node 2, and Node 4. The guide word Flow, Pressure, and Service Failure for the Node 1 indicated the most critical system in the plant with the highest risk rating.

The second highest risk rating was for the guide word instrumentation, human factor, and transferring. The existing installed systems are only of passive protection system which is able to trigger the failure.

This Node's outcome causes the release of chlorine gas to the atmosphere from the stack. To mitigate the identified risk, recommendation have been proposed in which this ensures to increase the operational safety and the reliability of the plant

4.2 Selected Scenario for ALOHA Modelling

The significant scenario out of many hazards with the highest risk that was identified through the HAZOP study is as below:

Table 4.1: Scenario Selection

Identified Hazard	Incident Description	Duration
Chlorine gas release to atmosphere	Accidental Chlorine gas release from the stack due to scrubbing flow failure.	45 minutes (Time required to rectify the scrubbing flow and trip the upstream plant inclusive with scrubbing remnant chlorine gas in the pipeline)

4.3 Results from ALOHA

Simulation 1 (Wind Direction to - East)

The first simulation was carried out based on the atmospheric data obtained from (Shamsuddin et al., 2017). The location of the plant is located at Bukit Merah Industrial Estate, Lahat, Ipoh, Perak as per in the Figure 1.1. ALOHA simulation indicates the toxic threat zones and distances along with the concentration of chlorine plume at 0.5ppm (1.1km), 2ppm (537m), and 20ppm (161m) which is represented in Yellow, Orange, and Red lines as per the Figure 4.1. The radius of the wind direction confidence lines is at 1.1km. It is clear that the concentration of the chlorine gas decreases with the distance from the emission source. Figure 4.2 shows the maximum impacted area obtained from ALOHA which is overlaid on the Google Earth.

It is clear that the threat zone is in densely populated area which is the Bukit Merah Village. Figure 4.3 indicates the ALOHA threat point that was created at the interested point within the residential area to study the severity of the exposure. Examining the exposure severity at the point, the outdoor concentration reaches at 1.2ppm within 5 minutes from the release time and maintains throughout 60 minutes duration. The maximum indoor concentration at the point is 0.573ppm which is very close to the AEGL-1 value for chlorine at (0.5ppm).

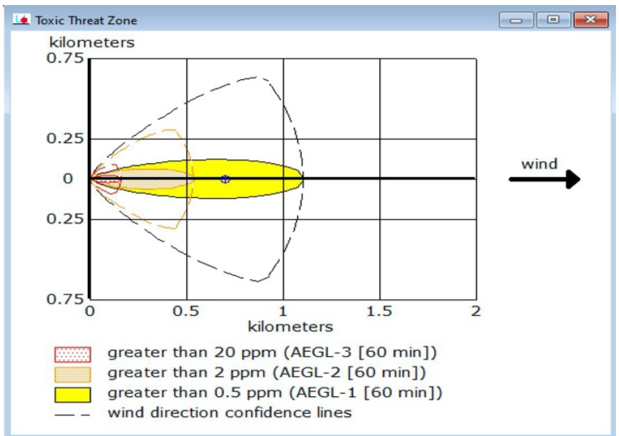

Figure 4.1: Toxic Threat Zone *(Wind Direction - East)*

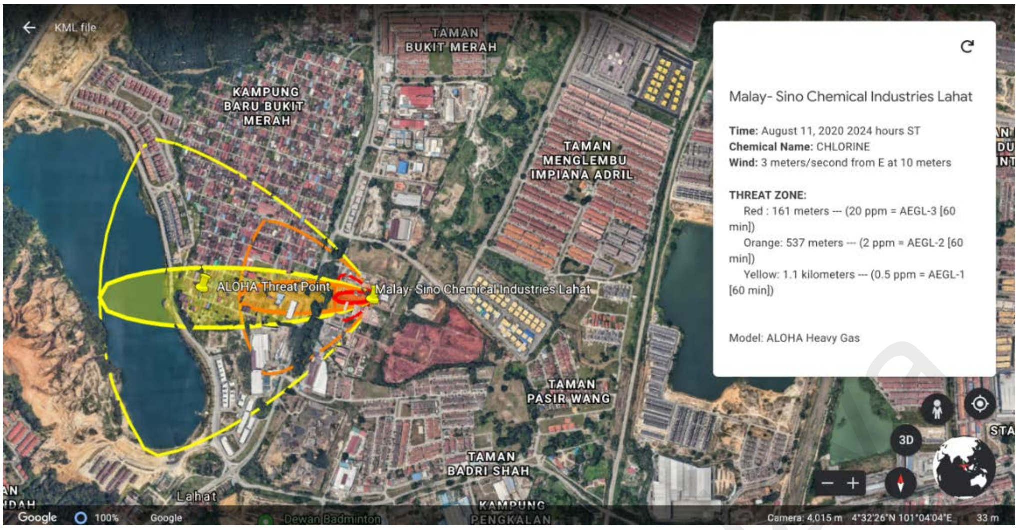

Figure 4.2: Chlorine Toxicity Impacted area *(Wind Direction - East)*

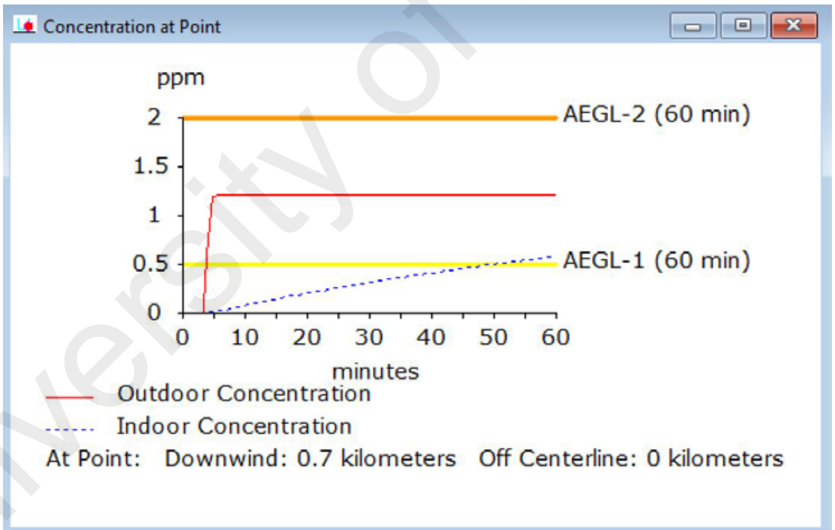

Figure 4.3: Concentration at the Point of interest *(Wind Direction - East)*

Simulation 2 (Wind Direction to - West)

As for the second simulation, the same atmospheric conditions are used changing on the wind direction from East to West. The Toxic threat zones and distances along with the concentration of chlorine plume is at 0.5ppm (1.1km), 2ppm (537m), and 20ppm (161m) which is as per Figure 4.4. As seen on the Figure 4.5, the impacted area is clearly on Taman Menglembu Impian and Taman Pasir Wang in which the concentration recorded at the point of threat is at 0.0985ppm in less than 5 minutes for outdoor and the indoor the maximum recorded at 0.0469ppm as per the Figure 4.6.

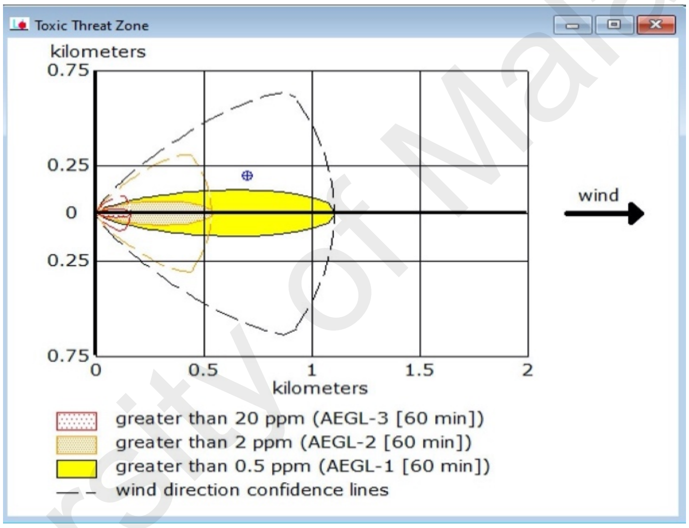

Figure 4.4: Toxic Threat Zone *(Wind Direction - West)*

Figure 4.5: Chlorine Toxicity Impacted area *(Wind Direction - West)*

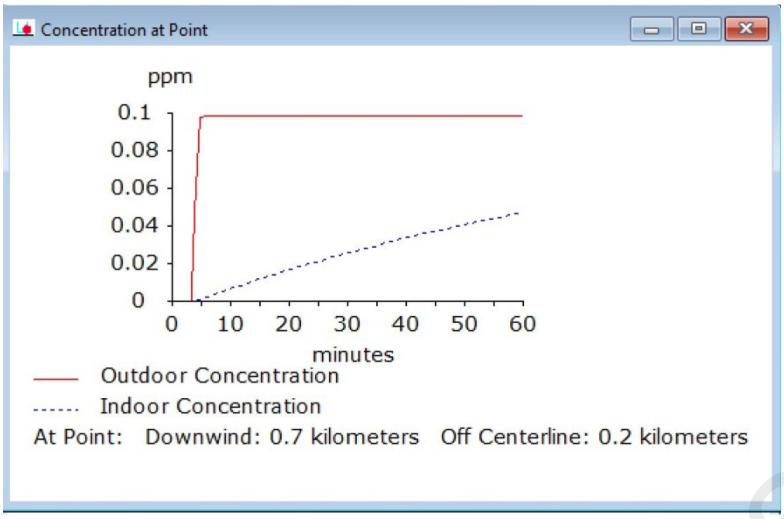

Figure 4.6: Concentration at the Point of interest *(Wind Direction - West)*

4.4 Results from Dose-Response Evaluation

Data's from the ALOHA which are the concentration at different distance and the duration of exposure is used for the probit calculation. Table 11 represents the data's from ALOHA studies used for the probit calculation.

Table 2: Concentration and Duration values of exposure

Threat Zone	Time – t (minutes)	Concentration - C (ppm)	$C^{2.0}$	$C^{2.0}$ t
RED (161m)	60	20	400	24,000
ORANGE (537m)	60	2	4	240
YELLOW (1,100m)	60	0.5	0.25	15

By substituting the above calculated values to the equation, the table below indicates the fatalities at different level of chlorine concentrations. The fatalities percentage at different distance is calculated and tabulated in the Table 12.

Table 3: Probit value by Threat Zones

Threat Zone	Probit Value	Possibility of Death
RED (161m)	0.35	None
ORANGE (537m)	-3.25	None
YELLOW (1,100m)	-5.80	None

Referring to the Table 12, the probit value which is further converted into the percentage of possible human fatality indicated negative in which there's no human fatalities predicted from the exposure of chlorine concentration at the threat zones.

4.5 Discussions

The HAZOP studies with risk assessment were carried out for the important nodes and it was found that the scrubbing liquid circulation system (Node 1) was the main risk in the system where the deviation for Flow, Pressure, and Service failure indicated risk level of Significant (IV) in which it leads to release of chlorine gas to the atmosphere.

Based on the ALOHA studies results, it indicated that the residential area for the different wind directions effects the neighboring residential area which is the Bukit Merah Village, Taman Menglembu Impiana Adril, and Taman Pasir Wang. The red zone that is indicated in the Figure 4.2 and Figure 4.5 is in the plant premise at 161m radius in which there's no human fatality is predicted from the probit analysis for the red zone, orange zone, and yellow zone.

People whom are at the residential area which is at the Yellow Zone (AEGL-1) and Orange Zone (AEGL-2) which means they're exposed up to 2ppm concentration could result to discomfort such as eye irritation and long-lasting adverse health effects or an impaired ability if the exposure is at 2ppm concentration up to 60 minutes continuous.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

By this work, analyzing the sodium hypochlorite plant process using the HAZOP method with risk assessment have indicated the potential risk that can lead to chlorine gas emission which was identified that the Node 1 is the most critical system which leads to the chlorine gas release to the environment.

The choice of applying the HAZOP with risk assessment to the referred plant was highly advantages because of the numerous hazards involved in the process. Apart of this, the highest continuous chlorine gas flow channeled among the plants in Malay-Sino Chemical Industries (Lahat) is the sodium hypochlorite plant.

Risk prioritizing have indicated and helped the HAZOP team to achieve the most significant risk factors and also protecting the safety of the workers health by implementing the most important safety measures as stated by (Koulinas, Demesouka, Marhavilas, Vavatsikos, & Koulouriotis, 2019).

Moving forward due to this release of chlorine gas to the environment, the impacted zone that the chlorine gas dispersed along with the concentration of the gas which is largely depending on the atmospheric conditions was evaluated with the use of ALOHA software.

It indicated that the residential area which are Bukit Merah Village, Taman Menglembu Impiana Adril, and Taman Pasir Wang are the affected areas.

There’s no human fatality percentage predicted from the studies for the chlorine gas exposure at the threat zones of concentrations 20ppm, 2ppm, and 0.5ppm at the radius from 161m to 1,100m.

5.2 Recommendations for Improvements

Hence, recommendation was provided to install a 2nd scrubbing tower with a deluge tank (emergency head tank) which eliminates the emission of the chlorine gas from the stack incase power failure and scrubbing flow failure.

This recommendation is in line with (Kundu, 2010) in which the design of the waste air de chlorination unit consist of TWO(2) towers in series connection.

This improvement ensures to eliminate the chlorine gas emission from the stack at any operational condition.

The estimated cost for the facility upgrading as per the recommendation is estimated to be RM 800,000.

5.3 Recommendations for future Studies

For future studies, this data on the chlorine gas release from the Bukit Merah Industrial Park can be used to develop safe evacuation pathways for the impacted residential areas.

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