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Integrated PSM Framework for Hazard Identification, Risk Assessment and Consequence Analysis of Chlorine Handling Operations in Chemical Process Industries

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Abstract: *Chlorine is one of the most extensively used hazardous chemicals in the chemical process industry due to its vital role in the production of bleaching agents, disinfectants, plastics, synthetic rubber, pharmaceuticals, agrochemicals, water treatment chemicals, and numerous industrial intermediates. Despite its widespread industrial applications, chlorine is highly toxic, corrosive, and reactive, making its storage, transportation, and handling a significant process safety challenge. Even a minor accidental release can result in severe consequences, including toxic exposure, environmental contamination, equipment damage, and potential fatalities. Therefore, systematic hazard identification, quantitative risk assessment, consequence analysis, and effective mitigation strategies are essential to ensure safe chlorine handling operations.*

The present study focuses on the assessment of process safety risks associated with chlorine handling in a chemical process industry using an integrated Process Safety Management (PSM) approach. The research involves the identification of potential hazards throughout the chlorine handling system, including storage cylinders, pipelines, valves, vaporizers, and transfer operations. Hazard identification techniques such as structured checklists, workplace observations, document review, and questionnaire-based surveys were employed to identify unsafe acts, unsafe conditions, equipment failures, and human error that may lead to accidental chlorine releases. The identified hazards were further analyzed using qualitative and quantitative risk assessment techniques to evaluate the probability of occurrence and the severity of their consequences.

Consequence analysis was carried out using ALOHA (Areal Locations of Hazardous Atmospheres) software to simulate different accidental chlorine release scenarios under varying meteorological conditions. Worst-case and alternative release scenarios were analyzed to estimate toxic dispersion distances, threat zones, exposure levels, and potential impacts on workers, nearby communities, and the surrounding environment. The effectiveness of various passive and active mitigation measures, including scrubber systems, water spray curtains, ventilation, emergency shutdown systems, confined storage arrangements, and leak detection systems, was evaluated to reduce the consequences of accidental chlorine releases.

The study also examines the effectiveness of emergency preparedness and response planning by incorporating atmospheric dispersion modelling, exposure assessment, building air infiltration considerations, and emergency response strategies such as shelter-in-place, controlled evacuation, emergency communication, and incident command procedures. The influence of environmental parameters such as wind speed, atmospheric stability, release quantity, and release duration on toxic cloud dispersion was also investigated to understand their impact on emergency response planning and risk reduction.

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Based on the findings of the risk assessment and consequence analysis, appropriate engineering controls, administrative controls, operational procedures, inspection and maintenance practices, employee competency development, and emergency preparedness measures have been recommended to strengthen the Process Safety Management system. The proposed mitigation strategies are intended to minimize the probability of chlorine release incidents, reduce occupational health and environmental risks, improve regulatory compliance, and enhance overall industrial safety performance.

The outcomes of this research provide a practical framework for risk identification, consequence assessment, and mitigation planning for chlorine handling operations in chemical process industries. The study demonstrates that integrating Process Safety Management principles with hazard identification techniques and ALOHA-based consequence modelling significantly improves decision-making for accident prevention, emergency planning, and sustainable industrial safety management. The proposed methodology can also be adapted for the risk assessment of other hazardous chemicals handled in process industries.

Keywords: Chlorine Handling, Process Safety Management (PSM), Hazard Identification, Risk Assessment, Consequence Analysis, ALOHA Simulation, Toxic Gas Dispersion, Chemical Process Industry, Mitigation Strategies, Emergency Response Planning, Industrial Safety Engineering, Occupational Health and Safety.

I. INTRODUCTION

Chlorine is one of the most widely used toxic gases worldwide. The acute hazards of chlorine have long been recognized and the means of safely handling chlorine have been detailed by numerous industry groups and associations. Efforts to reduce the risk of toxic gas releases have been redoubled in recent years as awareness has increased and risk management legislation and regulations have been enacted requiring all facilities using such materials to evaluate and reduce these risks. State programs, such as New Jersey's Toxic Catastrophe Prevention Act (TCPA) of 1986 [1], will soon be followed by a nationwide program driven by OSHA requirements and the Clean Air Act reauthorization

A. Chlorine:

The element chlorine (CL) is one of the 92 natural elements found on our planet [2]. The diatomic molecule Cl_2 is formed when two chlorine atoms combine chemically at room temperature (standard temperature and pressure). Chlorine gas consists of Cl_2 molecules. The bonding between the two chlorine atoms in the Cl_2 molecule is relatively weak which makes the molecule highly reactive

Fig. 1: green-yellow colour of chlorine gas

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S. No	Property	Notations/Quantity
1.	Atomic weight	35.5
2.	Molecular weight	70.905
3.	Boiling point (at1atm)	−34.6°C
4.	Melting point	−100.98°C
5.	Viscosity (20°C)	0.346mPas
6.	Color	Yellow-green
7.	Critical temperature	144°C
8.	Critical pressure	76.1atm
9.	Degree of dissolve of water	0.7g/100g H_2O(20 °C)
10.	Specific gravity	2.5

Table 1 Properties of Chlorine

B. ALOHA

ALOHA was developed by the United States Environmental Protection Agency and the National Oceanic and Atmospheric Administration to assist chemical emergency planners and responders. It can simulate the dispersion for over 900 chemicals and is primarily used in the simulation of accidental release of hazardous substances and the dispersion of chemical vapour [5]. ALOHA allows for the source to be defined in one of four ways (direct source, puddle source, tank source, or pipe source) in order to model various accident scenarios. ALOHA deals specifically with human health hazards associated with inhalation of toxic chemical vapours, thermal radiation from chemical fires, and the effects of the pressure wave from vapour-cloud explosions.

II. LITERATURE REVIEW

Dennis C. Henderson Rohm et.al [7] Process hazard analysis and quantitative risk assessment provide valuable input both for the initial design and for the continuing operation of chemical processing facilities.

Rajesh Paul et.al [8] this study investigates the impact of accidental release of Chlorine gas in surrounding areas. The impact is studied using standard dispersion modeling techniques considering various locations with different surface conditions (urban or rural) in different seasons and meteorological conditions.

Dandrieux - Bony. A et.al [9] Accidental dangerous releases either toxic or flammable can occur during process, storage or transportation. Though the dispersion and modeling of large releases of dangerous products have already been studied, small releases (small plumes dispersion) are seldom concerned even if they are more likely to occur.

Noura Mohammad Al-Sarawi et.al [10] The purpose of this paper is to evaluate the extend of the threat zone of two mobile accidental atmospheric releases of chlorine and butane on the I-95 Highway by estimating the downwind dispersion of the chemical plumes using the numerical model ALOHA (Area Locations of Hazardous Atmospheres) and by graphing the boundaries of the threat zone using MARPLOT (Mapping Application for Response, Planning, and Local Operational Tasks).

Predrag Ilic et.al [11] this paper investigates the impact of accidental release of chlorine gas in surrounding areas consequences of chlorine gas leak studying the negative effects on both the environment and individuals. Chlorine and its consequences have a far more reaching effect in society that one may have imagined.

Sirma Stenzel et.al [12] several air dispersion models are available for the prediction and simulation of hazard areas associated with accidental releases of toxic gases. The model packages (commercial or free of charge) include a chemical database, an intuitive graphical user interface (GUI) and automated graphical output. They are easy to use and can operate fast and effectively during stress situations.

Dev D. Jani et.al [13] Plume dispersion modeling systems are often used in assessing human exposures to chemical hazards for epidemiologic study. We modeled the 2005 Graniteville, South Carolina, 54,915 kg railcar chlorine release

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using both the Area Locations of Hazardous Atmospheres (ALOHA) and Hazard Prediction and Assessment Capability (HPAC) plume modeling systems. We estimated the release rate by an engineering analysis combining semi-quantitative observations and fundamental physical principles.

Ambalathumpara Raman Soman et.al [14] in the current industrial scenario there is a serious need for formulating strategies to handle hazardous substances in the safest way. Manufacture, storage, and use of hazardous substances pose a serious risk to industry, people, and the environment. Accidental release of toxic chemicals can lead to emergencies.

Javad Salehi Artimani et.al [15] the necessity of confronting current incidents of the world has intensified the issue of safety observation and preparedness in critical conditions for societies. These incidents, which have been mostly related to industrial incidents, have been accompanied by serious environmental damages and many financial and life losses. Risk assessment includes management system to observe necessary requirements in order to reduce irreversible hazards.

Fajrul Falakh et.al [16] Water Treatment Plant (WTP) is an important infrastructure to ensure human health and the environment. In its development, aspects of environmental safety and health are of concern. This paper case study was conducted at the Water Treatment Plant Company in Semarang, Central Java, Indonesia. Hazard identification and risk assessment is one part of the occupational safety and health program at the risk management stage.

Naimeh Setareshenas et.al [17] in the recent years, world has seen a wide range of major accidents with a number of fatalities, economic losses, and damage to the environment. These accidents can lead to serious danger to human health and the environment which can be occurred inside or outside the establishment. Consequence assessment is very important to predict and prevent deleterious effects of these events. Chlorine is a toxic material that is used in Water Treatment Plants as disinfectants. The aim of this study is to determine and identify the locations with high risk near the water treatment plant of Rasht, in the north of Iran.

Ali M Abdullah et.al [18] Chlorination is used in the worldwide to produce drinking water in the most developing world. Frequently lack of proper sanitation and pollution control increases the organic content in water sources thereby increasing the potential of trihalo methane (THMs) formation. This paper evaluated the lifetime cancer risk and the hazard index caused by THMs contained in drinking water from four areas of Alexandria Governorate, northern of Egypt. Oral exposure and the health risk were estimated using a probabilistic approach.

Literature Gap

Despite the significant research available on chlorine release modelling and consequence analysis, several important gaps still exist. Most previous studies have primarily focused on atmospheric dispersion modelling and the estimation of toxic threat zones under different meteorological conditions using software such as ALOHA, PHAST and HPAC. Limited attention has been given to the integration of Hazard Identification, Risk Assessment, Process Safety Management (PSM), questionnaire-based safety assessment, and practical mitigation strategies within a single comprehensive framework.

Furthermore, many studies concentrate on predicting accident consequences after a chlorine release rather than identifying the root causes, unsafe acts, unsafe conditions, equipment failures and operational deficiencies that lead to such incidents. There is also insufficient emphasis on field-based hazard identification using structured checklists and employee questionnaires, which are essential for understanding real industrial safety practices. Additionally, previous research provides limited guidance on integrating engineering controls, administrative controls, emergency preparedness, and risk mitigation measures into an effective decision-making framework for chlorine handling operations.

Therefore, the present study aims to bridge these gaps by developing an integrated approach that combines Hazard Identification, Risk Assessment, ALOHA-based Consequence Analysis, questionnaire and checklist methodologies, and Process Safety Management principles to identify hazards, evaluate risks, and recommend practical mitigation strategies for safer chlorine handling in the chemical process industry. This integrated methodology is expected to

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improve accident prevention, emergency preparedness, occupational safety, and overall process safety performance in chemical industries

III. AREA OF STUDY

The present study focuses on the assessment and evaluation of hazardous chemical handling practices, emergency preparedness, and consequence analysis in a chemical manufacturing industry. Chemical process industries involve complex operations, high-temperature and high-pressure systems, storage and handling of hazardous chemicals, and continuous processing activities, which create significant risks to workers, surrounding communities, and the environment. Despite continuous improvements in process safety management, industrial accidents due to equipment failure, human errors, operational deviations, and external events continue to occur in chemical industries.

The selected study area is a chemical manufacturing organization engaged in the production of agrochemicals, specialty chemicals, intermediates, polymers, pigments, and other advanced chemical products. The organization has established modern manufacturing facilities supported by advanced process technologies, quality management systems, environmental protection measures, and occupational health and safety practices. The company has achieved significant recognition in the chemical sector through technological innovation, research and development activities, export performance, and implementation of international management system standards such as ISO 9001, ISO 14001, and OHSAS 18001.

The study organization manufactures various chemical products including insecticides, herbicides, fungicides, public health chemicals, veterinary products, chemical intermediates, and high-performance polymers. Due to the involvement of hazardous chemicals during production, storage, transportation, and processing activities, the facility requires systematic hazard identification, risk assessment, and emergency management planning to minimize the possibility and consequences of major industrial accidents.

Among various hazardous chemicals handled in the plant, Chlorine has been selected as the primary hazardous component for the present investigation. Chlorine is widely used in chemical industries and possesses highly toxic, corrosive, and reactive characteristics. Accidental release of chlorine due to leakage from cylinders, pipeline failure, valve malfunction, improper storage, or handling errors may result in toxic gas dispersion, affecting workers, nearby populations, and the environment. Therefore, proper storage, handling, transportation, monitoring, and emergency response measures are essential for ensuring safe chlorine management.

Figure 2 Improper way of handling Chlorine Cylinder

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Figure 3 Proper way of handling Chlorine cylinder

The present study includes the evaluation of chlorine handling systems, identification of potential failure scenarios, analysis of previous incidents, assessment of hazard zones, and review of existing preventive and emergency control measures adopted in the organization. The study emphasizes the importance of consequence analysis and Emergency Response Planning (ERP) for reducing the impact of chemical accidents. Worst-case accident scenarios are considered to evaluate the possible consequences of hazardous chemical release and to improve preparedness for emergency situations.

The overall objective of this research work is to analyze the existing safety practices associated with chlorine handling in a chemical manufacturing industry and to develop recommendations for improving process safety, emergency preparedness, and risk mitigation strategies. The outcomes of this study can contribute towards safer chemical handling practices and provide a systematic approach for controlling major accident hazards in chemical process industries.

IV. PROBLEM FORMULATION

This study is a part of a research program which problematic was the security of small storage sheds of chlorine and their protection with water sprays. It aims at controlling the consequences of chlorine dispersion in public swimming pools where bottles of liquefied chorine are stored in these small storage sheds.

The study was led as follows. In a first time, chlorine dispersion experiments have been carried out, both in open field conditions (without water curtain) and with specific configurations of water sprays to study mitigation of toxic clouds by forced dispersion. The experiments aimed at reproducing an accident on small chlorine storage shed. Open field dispersion concentrations have been compared to the simulations on several models (two heavy gas dispersion models and a Gaussian model). These results enhanced that models are not always efficient to predict concentrations in particular conditions such as small releases of product (chlorine in that case) and short distances to the source (dozens of meters – near field of the release). Indeed, dispersion models are mostly validated on the basis of past dispersion experiments which implied large quantities of hazardous products and great distances from the source.

A. Problem due to Chlorine Handling:

Discovered in 1774 by Carl Wilhelm Scheele, who mistakenly thought it contained oxygen. Chlorine was given its name in 1810 by Humphry Davy, who insisted that it was in fact an element [19]. The pure chemical element has the physical form of a diatomic green gas. The name chlorine is derived from chorus, meaning green, referring to the colour of the gas. Chlorine gas is two and one half times as heavy as air, has an intensely disagreeable suffocating odour, and is exceedingly poisonous. In its liquid and solid form it is a powerful oxidizing, bleaching, and disinfecting agent.

- **Problem 1:** What are the useful effects of Chlorine?
- **Problem 2:** How can people be exposed to Chlorine?
- **Problem 3:** What are the harmful effects of Chlorine?

- **Problem 4:** What happens to Chlorine in the body?
- **Problem 5:** What are the immediate health effects of Chlorine exposure?
- **Problem 6:** What can you do if you think you may have been exposed to a release of chlorine?
- **Problem 7:** How is chlorine exposure treated?

B. Environmental effect of Chlorine:

Chlorine dissolves when mixed with water. It can also escape from water and enter air under certain conditions. Most direct releases of chlorine to the environment are to air and to surface water. Once in air or in water, chlorine reacts with other chemicals. It combines with inorganic material in water to form chloride salts, and with organic material in water to form chlorinated organic chemicals.

V. METHODOLOGY ADOPTED

The type and design of this research based on time research is cross sectional because the process of collecting data and observation of the variables done at once or at one particular time. While in terms of place, this research includes field research, because the research conducted and the way researchers in getting the data is directly plunged into the field by conducting interviews and observation When viewed from the way of data collection, this study is observational because researchers obtain data through observations and interviews to workers and related parties in the company.

In addition to the labeling requirements, GHS requires a standard format for Safety Data Sheets (SDS) that accompanies hazardous chemicals. Note the change in terminology from MSDS. SDSs must contain a minimum of 16 elements [20].

1) Identification,
2) Hazard(s) identification,
3) Composition/information on ingredients,
4) First-aid measures,
5) Firefighting measures,
6) Accidental release measures,
7) Handling and storage,
8) Exposure controls/personal protection,
9) Physical and chemical properties,
10) Stability and reactivity,
11) Toxicological information,
12) Ecological information,
13) Disposal considerations,
14) Transport information,
15) Regulatory information, and
16) Other information.

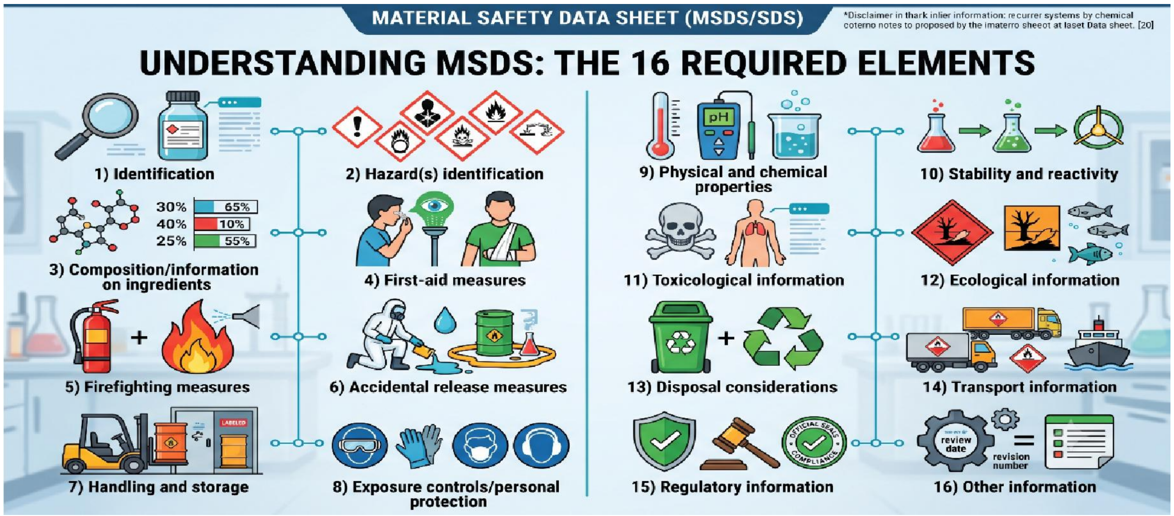

Figure 4 Material safety data Sheet

A. Types of methods adopted mainly: -

1) Measurement and calculation on the basis of Physical and Chemical Characteristics.
2) Measurement and Calculation on the basis of Software.

ALOHA allows the user a choice of several accident scenarios, then uses an appropriate source algorithm to inject material into the air over a limited time. The source emission time may vary between limits of one minute to one hour. A flat, homogeneous earth is assumed. For purposes of solar radiation and day/ night decisions, time is fixed at the moment the leak begins.

ALOHA is the hazard modeling program for the CAMEO software suite, which is used widely to plan for and respond to chemical emergencies. ALOHA allows to enter details about a real or potential chemical release, and then it will generate threat zone estimates for various types of hazards. ALOHA can model toxic gas clouds, flammable gas clouds, BLEVEs (Boiling Liquid Expanding Vapor Explosions), jet fi res, pool fires, and vapor cloud explosions. The threat zone estimates are shown on a grid in ALOHA and they can also be plotted on maps in MARPLOT, Eris's Arc Map, Google Earth, and Google Maps.

B. Modes for Study:-

As from company points we discuss many of the safety checklist above for calculation of various hazards their types and prevention. Bus as we know we focused in chlorine and its hazards for our study in this work. We also mentioned in various previous sections that chlorine will harm a person in many ways but the main can done by water and wind. So here we now presenting the main modes for our study i.e. the methodologies adopted by us on the basis of chlorine in water and air.

Drinking untreated water is not recommended. Microorganisms like coli, cryptosporidium and giardia lamblia can be present due to contamination by human sewage and animal wastes, and can cause diarrhea, vomiting and cramps. Ground water is sometimes less prone to these micro-organism as the soil above acts as a filter, but they can still be present. Chlorination, along with other treatment steps, is commonly used to disinfect drinking water because it kills a wide variety of micro-organisms. Chlorine has been used since the early 1900's and is responsible for the virtual Elimination of typhoid fever.

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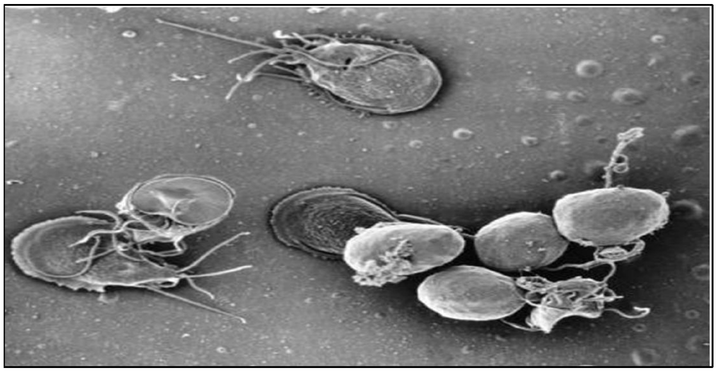

Fig. 5: Giardia Lamblia [21]

Wind Chlorine Measures Emission of pollutant is a function of atmospheric stability and conditions in addition to the dependence on wind speed and direction. The available information should be analyzed and the information relating to stable conditions should be selected for investigating and assessing the maximum risk.

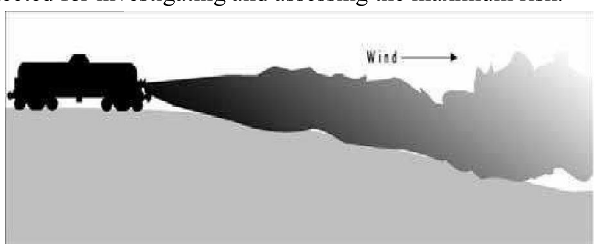

Fig. 6: Cloud spread as a result of gravity [22]

S.N	Notation	Description
1.	Wind	1 m/s
2.	Stability level	E
3.	Air temperature	15^0 C
4.	Relative humidity	40%
5.	Roughness level	urban zone

Table 2: Meteorological Information

S.N	Notation	Description
1.	Model of chlorine storage tanks	cylindrical
2.	Dimensions of tanks	203 cm, width(diameter): 80cm, radius: 40 cm
3.	Mass of empty tanks	550 kg
4.	Thickness of wall	1cm
5.	Stored chlorine temperature	below -8^0 C
6.	Situation of the stored chlorine	liquid and gas
7.	Liquid level available in tank	90%
8.	Pressure of each tank	7 bar
9.	Height of pipe to tank joining place	1 m below the tank
10.	Diameter of the pipe connected to tank	1 inch

Table 3: Information of Chlorine Gas Storage Tanks

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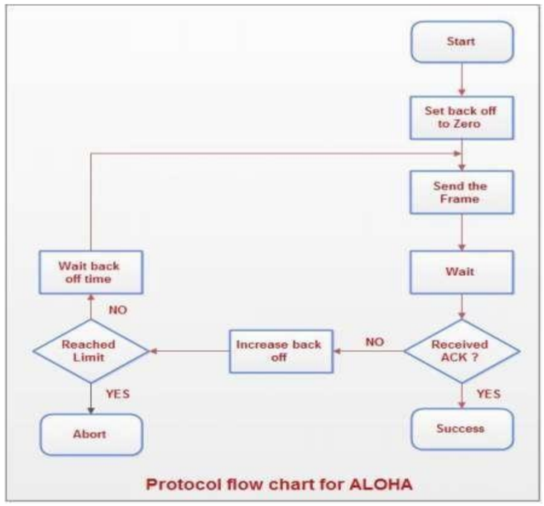

Fig. 7: ALOHA Flow Chart

VI. DATA INTERPRETATION AND RESULTS

Hygine Result:-

Chlorine has been used for disinfection of drinking-water in this plant. Because chlorine is a toxic material so its dispersion is very dangerous for human health. Quantitative risk assessment is also useful in the ongoing management of risk in a hazardous facility. The results and conclusions of a risk analysis are only valid if the actual operation of the facility is consistent with the assumptions of the analysis.

Thus a risk analysis is not a onetime review which can be filed away and forgotten once the final report is written and the recommendations implemented. To obtain the full benefits of the analysis, it must serve as a reference document for continuing plant operations.

In particular, it is necessary to continually review operations for consistency with the assumptions of the analysis, to ensure that the results of the analysis represent actual operation as closely as possible.

S.N	Profile	2024	2025	2026
1	Obesity	4	6	5
2	Vision Profile (Abnormal - Glasses)	1	12	23
3	Hypertension Profile (High BP)	10	36	39
4	Overweight	9	22	27
5	Diabetes Profile	4	1	1
6	Low Hemoglobin (No of persons)	17	18	24
7	Audiometric	0	0	0
8	Underweight	0	1	3

Table 4: Medical check trend from 2024 to 2026

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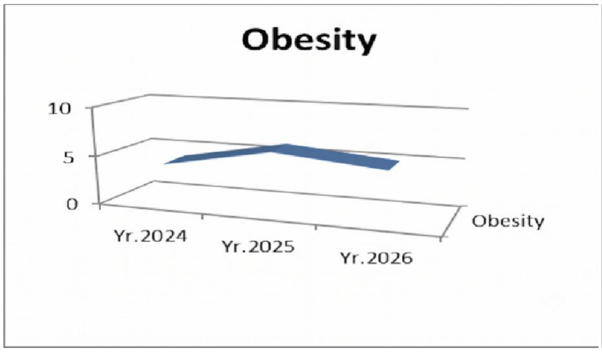

Figure 8 Obesity (2024-2026)

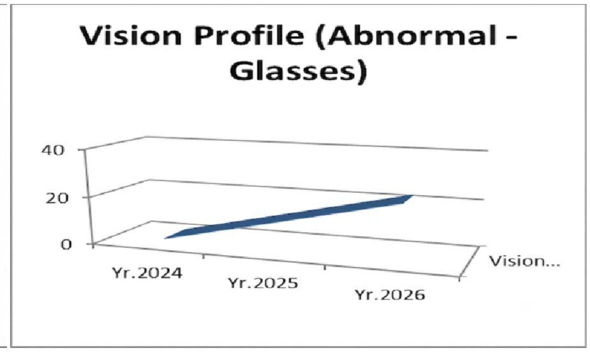

Figure 9 Vision Profile (Abnormal Glasses) (2024-2026)

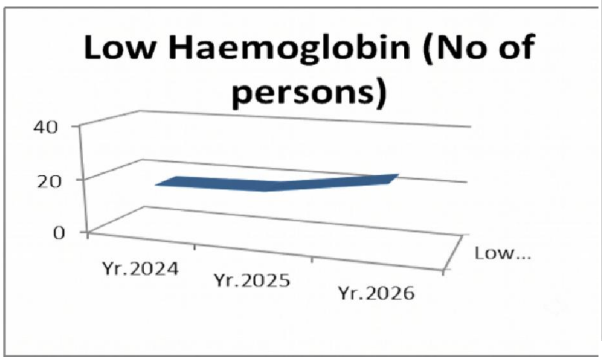

Figure 10 Low Hemoglobin (No. of persons) (2024-26)

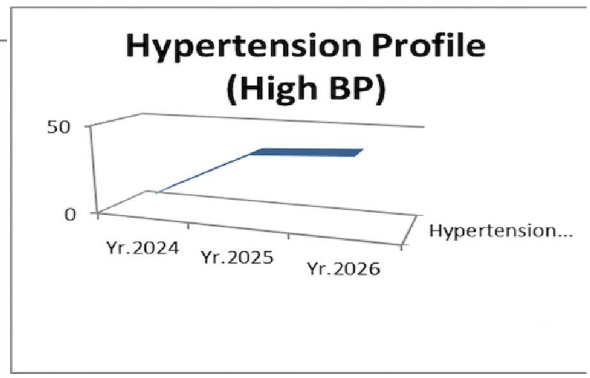

Figure 11 Hypertension Profile (High BP) (2024-2026)

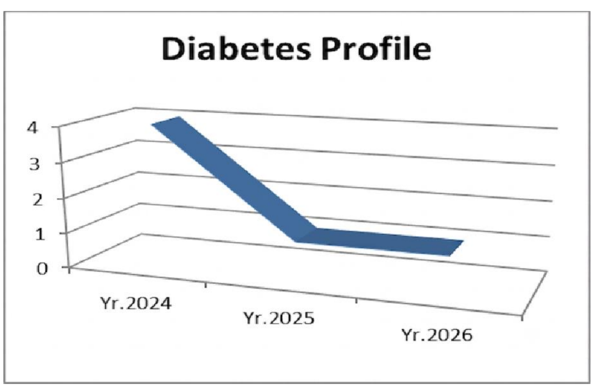

Figure 12 Diabetes Profile (2024-2026)

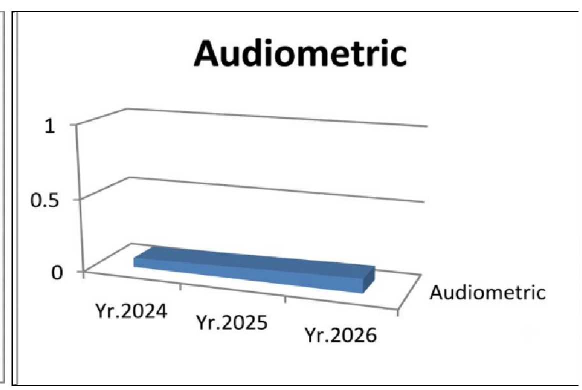

Figure 13 Audiometric (2024-2026)

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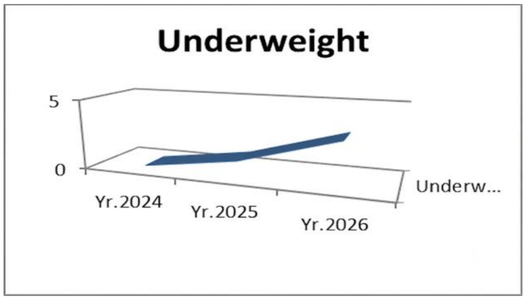

Figure 14 Underweight (2024-2026)

Compression of Medical results after modification for recent years The risk assessment updates evaluated societal risk using the F-N curve, and also estimated individual risk in the area in and around the plant. The individual risk estimates were presented in the form of risk contours connecting points of equal individual risk on a local map.

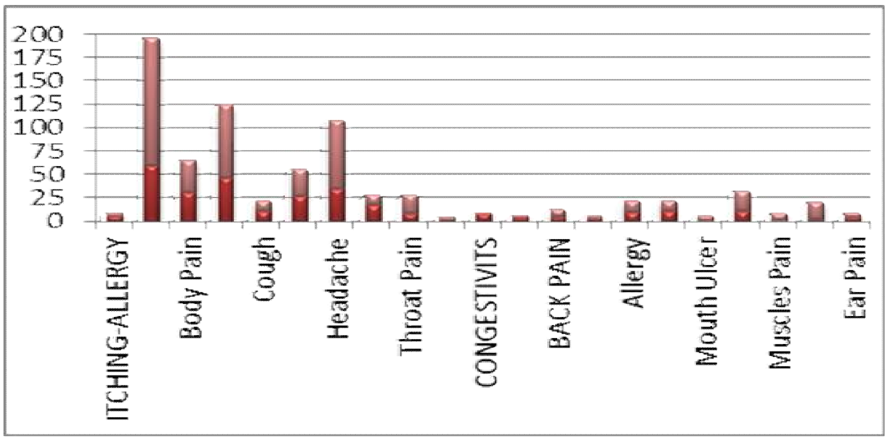

Fig. 15: Graphical Representation Medical Trends 2024-2025

This risk presentation format conveys information about the geographic distribution of risk in the vicinity of the plant. It also allows the contribution of various potential sources individual risk at particular locations (for example, at the control room) to be evaluated. After performing and evaluation the task using betterment we will again conclude our results for recent years. After modification and works on basic previous hazards we will again conclude the results as shown below:

S.N	OPD	2024	2025
1.	Itching-allergy	6	3
2.	Acidity	59	137
3.	Body Pain	31	34
4.	Cold	46	78
5.	Cough	11	11
6.	Fever	27	28
7.	Headache	34	74
8.	loose motion	17	11
9.	Throat Pain	8	20

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10.	Vomiting	2	3
11.	CONGESTIVITS	8	0
12.	EAR PAIN	4	2
13.	BACK PAIN	4	8
14.	Toothache	3	3
15.	Allergy	10	12
16.	Dressing	11	11
17.	Mouth Ulcer	1	5
18.	Old wound / Other	11	21
19.	Muscles Pain	1	7
20.	Eye Infection	2	18
21.	Ear Pain	4	4

Table 5 Medical Check Trends 2024-2025

Results on software basis:-

Water treatment process in of physical, chemical and microbial type. Thus, chlorine had a main role in water treatment according to traditional methods. Chlorination process was performed in two initial and final stages in order to remove and destroy undesirable and pathogenic organisms, relatively modify color, odor and flavor and do sterilization

S.N	Notation	Description
1.	Used model	Heavy gas
2.	The LOC specified by the user	IDIH=10 PPM
3.	Emission duration	10 min
4.	Maximum mean rate of substance emission	150.14 min/kg
5.	Total emitted substance	kg

Table 6 the following information was obtained by stimulation

S.N	Notation	Description
1.	Red lines	2.1 miles (2 PPM=AEGL-3(60 min))
2.	Orange lines	1393 yard (20 PPM=AEGL-2(60 min))
3.	Yellow lines	3.9 miles (0.5 PPM=AEGL-1(60 min))

Table 7 Acute Exposure Guideline Levels (AEGL)

This model presents concentration limit for critical concentration rate or level of concern (specified by the user as LOC concentration by being applied to the software (its rate for chorine was IDHL-10ppm using the handbook)), maximum rate of outdoor concentration which was 1050000 PPM from the emission point and maximum rate of indoor concentration which was 4990 PPM.

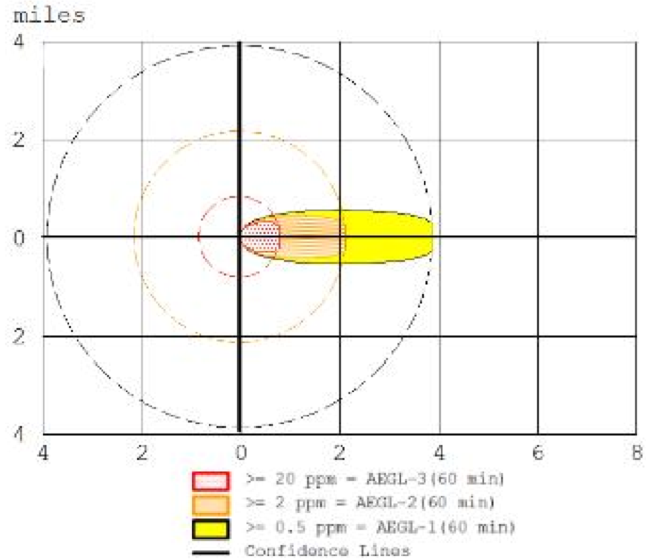

Figure 16 Threatened zones in terms of distance

Outdoor and indoor concentration rates of chlorine cloud are demonstrated in terms of time in different distances from the point of emission e.g. shown in Figure 16 above and maximum rate of concentration is given in terms of time from the range of threatened zones during the emission of chlorine gas and also outdoor and indoor concentration rates of pollutant are shown in terms of different distances from the pollutant's emission

Overall finding

1. 21 accidents occurred from to unsafe act, 4 from unsafe condition and 1 from other causes. Unsafe act, unsafe condition and other causes contribute 80.769%, 15.384% and 3.846% respectively.
2. Highest number of accident occurred is due to fall from height (6 accident) hence it is measure problem at workplace after that burn and slip/trip/fall are one of the measure problems (5 accident each) and the lowest number of accident occurred is due to accident by transportation (1 accident) .
3. Out of total majority of accident cases belongs to age group of (18-25) because of their lack of experience and unsafe action in doing the mechanical work makes themselves highly vulnerable to accidents.
4. Incident and frequency rate is highest in the year 2024-25. Incident rate in the year 2024-25 is 4.184 and frequency rate in the same year is 1.766.
5. Depending on incident rate and frequency rate at overall basis the trend of the accident/incident is going in downward direction.
6. Majority of worker who involved in accident because they are less experienced, less educated, newly employed, don't know safe working process properly and not having specific knowledge on does and don'ts possessed.
7. Worker do not want to follow or adhere with safety rules and SOP, they work on their own will.
8. It is found that tools, material, equipment's are left on surfaces after work has been done i.e. poor housekeeping.
9. 75-100% workers know unsafe acts are dangerous but they follow shortcuts instead of following safe work procedure

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VII. CONCLUSION

In order to prevent accidents a basic knowledge on unsafe Acts and unsafe condition by workers of the factory is a must. Universally appreciated safety theory says that an accident is the consequence of an unsafe act or unsafe condition. This statistical data shows that, the maximum percentage of accidents is associated with human error or unsafe act (near about 80%). The analysis also shows that according to category of accident the majority of accident is occurred due to fall from height hence working at height is a risky job and according to age group of worker 18-25 years age group have higher percentage of accident than other age group is due to lack of experience and training.

It is essential to enforce the worker to do their job with safety and appraisal should be give to the worker who did their job with safety or who following safety rules and regulations. It is suggested that proper training is required to the worker in order to make consciousness about safety and for reducing risk, hazard, unsafe condition, unsafe act and subsequently rate of accident. Reviewing previous accident/incident, following the rule and regulation (HSE), implementation, development in design, engineering control will always reduce the graph of accident and management or safety organization should follows this concept

VIII. FUTURE SCOPE

Other factors apart from unsafe act or unsafe condition like literacy rate (education level)/ratio of supervision to workers/time of accidents/ medical condition of workers should be consider for designing or developing the solution of present circumstances and for future too.

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