Functional FMEA analyze a system as a whole and improves the reliability by identifying the failures and enhances the safety of the system under study. Functional FMEA is used in this study and the system is the plants at the industry.

Occurrence (O)

Occurrence ratings for FMEA are based upon the likelihood that a cause may occur based upon past failures and the probability of frequency the failure occurs.

SCORE	LIKELIHOOD OF OCCURRENCE (O)	
9,10	Very frequently	Can happen more than two times in an year.
7,8	Frequently	Likely to happen once in 2 years
5,6	Occasional	Likely to occur in 3 years.
3,4	Rarely	Incident has occurred in similar facility and may occur here within 5 years
1,2	Unlikely	Given current practices and procedures, not likely to occur in the facility.

Table 1: Occurrence Rating

The occurrence is determined by analyzing the past failures, the frequency of failures and discussing with the safety experts. Table 1 gives the scoring criteria as per the industry ranges from 1-10.The occurrence is determined by studying and analyzing in the plant for three months and discussing with safety department.

Severity (S)

The end consequence or effect of a particular failure. It usually varies and it is ranked from 1-10. The severity of any failure varies from minor injuries to fatalities and property damages. The identified failures effects are given scores based on its effect. For example chlorine leakage can be fatal in the industry.

SCORE	SEVERITY OF RISK (S)	
9,10	Fatal	Results in major destruction to factory
7,8	Permanent disabling injury/can create acute health problems	Major destruction to process area.
5,6	One or more serious injury	Result in major destruction to equipment
3,4	Single injury , not severe, down time	Minor problem for equipment.
1,2	Minor or no injury; no lost time	No problem to equipment.

Table 2: Severity Rating

Detection (D)

Detection is an assessment of the probability that the existing controls will detect the cause of a particular failure and prevent it from happening.

SCORE	DETECTION (D)
10	Almost impossible
9	Very remote
8	Remote
7	Very low
6	low
5	moderate
4	Moderately high
3	High
2	Very High
1	Almost certain

Table 3: Detection Ranking

Detection is the ability of the existing devices to predict a potential failure and it can prevent a major hazard from happening.

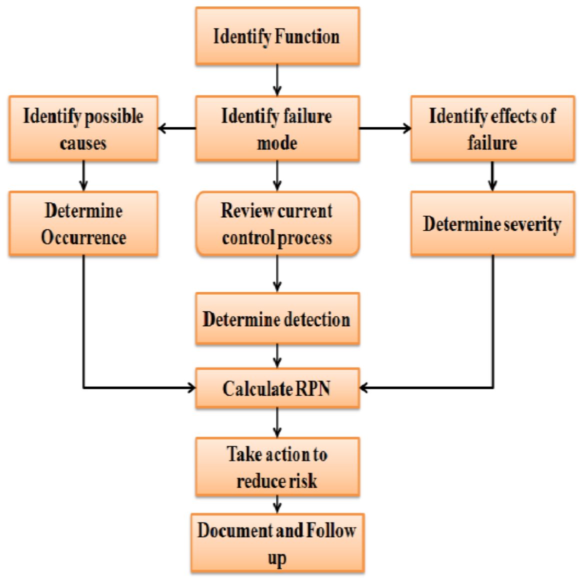

Fig. 1: FMEA Process

Risk Priority Number (RPN)

This is one of the method to prioritize the risks using FMEA . The higher the RPN number the risk will be on the unacceptable side.

Risk priority number (RPN) strategy is utilized to evaluate risk for which the accompanying components must be taken into account. RPN. It gives an idea on which risk has to be looked into more seriously and helps.

To rate the seriousness for every impact of failure.

To rate the probability of the event for each cause of a failure.

To rate the probability of detection for every failure or it is the probability of determining the failure before it damages the equipment.

RPN=SEVERITY×OCCURRENCE×DETECTION

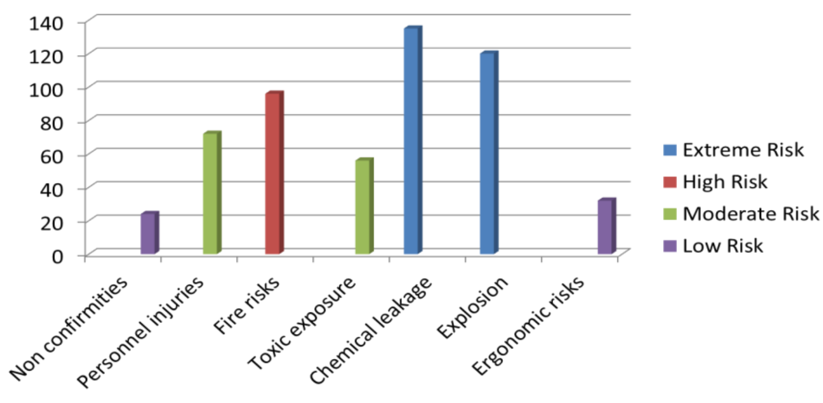

Fig. 2: RPN Chart

From the table using FMEA the risks are prioritized based on the ranking and leakage of chemicals and risk of explosion have the highest RPN and both have values above 100 and according to the companies safety criteria these risks are unacceptable and needs additional protective barriers thus reccomendations are given along with existing safe guards to improve the detectability and reduce the severity and occurrence of top 5 risks or failure modes .Fig 1 shows the FMEA process and Fig 2 shows the risks in terms of RPN value.

Table 4: FMEA Table

RISK	CAUSES	EFFECTS	S	O	D	RPN	RANK
Product non-conformities	Adding wrong chemicals to certain batches. Improper cleaning of pipes and tanks	Dissatisfaction of customers Loss of reputation Time and money waste.	4	2	3	24	7
Injuries to personnel	Employees not following safety procedures. Lack of awareness and supervision.	Loss of man hours Compensaations Medical costs	4	6	3	72	4
Fire risks	Visitors/workers using cigarettes in production area. Electrical and electrostatic spark.	Fire. Explosion. Severe personal injuries and property damage.	8	4	3	96	3
Toxic material exposure	Dealing with acids like HCl, sulphuric acids and other reactive chemicals. Workers not wearing proper safety equipments.	Operators get infected. Compensation and medical costs	7	4	2	56	5
Leakage of chemicals	Improper functioning of the valves. Deteriorated tanks used for filling and storing chlorine gas. When filter or pipeline gets clogged. Leakage when transferring chlorine from one cylinder to another.	Inhaling chlorine gas can be fatal. Loss of money due to spill. Chances of explosion when leaked gas react with air. Chronic respiratory disorders if the concentration exceeds limit.	9	3	5	135	1
Risk of explosion	flammable materials stored outside. Condenser and boiler explosion during chemical process.	Severe injuries to workers. Equipment damage. Financial loss. Environmental damage in worst scenario.	10	3	4	120	2
Ergonomic risks	Improper working postures like extreme bending and lifting. Poor ventilation systems.	Decreased productivity. Health issues	4	4	2	32	6

V. RESULTS

Table 5: Results and Recommendation Table

RISK/FAILURE	RANK	EXISTING CONTROL MEASURES	RECOMMENDATIONS	S	O	D	RPN
Leakage of chemicals		Manual Alarm signals PPE'S like SCBA, escape respirators	Automatic alarm systems Detector tubes will give chlorine concentration readings. Installation of sensors in pump that help to stop in case of high/low pressure. Ventilation fans should be provided with suction near floor level. Emergency kit at the site.	9	3	3	81
Risk of explosion		Periodic inspection by safety supervisor and safety audit by experts.	Provide automatic shut off valves at the pipings carrying chemicals. Carry out explosion risk assessments by specialists	10	2	3	60
Fire risks		Fire fighting equipments.	Installation of fire fighting alarms and systems. Training session to visitors and contract workers.	8	3	3	72
Injuries to personnel		Training and awareness. Safety signs and posters.	Install cameras to monitor unsafe acts. Penalties who doesn't follow safe procedures and incentives to workers who follow them.	4	4	3	48
Toxic material exposure		PPE like gloves ,clothing, boots etc..	Adjusted work schedules. Training workers/contract workers on importance of PPE.	6	3	2	36

The table4 shows the analysis and table 5 shows the results the recommendation and if this is implemented the RPN values of the unacceptable risks will come down under 100, which can be accepted.

VI. CONCLUSIONS

Using FMEA analysis the risks in the main plant including chlorine filling station has been identified and prioritized. Leakage of chemicals and risk of explosion have been found above acceptance level and protection barriers have been recommended. The additional control measures to minimize the risks has also been suggested. Risk Priority Graph has been plotted showing various risks with RPN. Although all the elements of loss management cannot be implemented the risk assessment is completed in the main plant in the industry where there are risks to workers and it is analysed in this project.

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