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A SYSTEMATIC APPROACH FOR IMPLEMENTATION OF PROCESS SAFETY IN CHEMICAL INDUSTRY

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ABSTRACT:

In the chemical business, process safety is essential for guaranteeing safe operations and averting mishaps like harmful leaks and explosions. Eliminating and preventing process-related accidents are the primary goals. A methodical framework for implementing Process Safety Management (PSM) that may be tailored to companies in various phases of growth is proposed in this study. Four essential elements are involved in the implementation: introducing PSM, allocating PSM responsibilities, providing training, and carrying out audits. Risk assessments and process hazard analysis are important training components. Along with the significance of routine evaluations of the hazard assessment systems, the study also describes 14 components and techniques for preserving safety information, reacting to hazards, handling changes, looking into events, and educating staff in emergency responses.

KEYWORDS: Process Safety Management (PSM), Process Hazard Analysis (PHA), Risk Assessment, Accident Prevention, Safety Audits, Emergency Response Training.

INTRODUCTION

For many years, reports of unexpected discharges of toxic, reactive, or flammable liquids and gasses in operations using extremely hazardous chemicals have been made in a variety of businesses that use substances with these characteristics. Anytime these extremely dangerous compounds are not adequately regulated, there is a chance of an unintentional leak that could result in catastrophe, regardless of the industry that utilizes them. OSHA released the Process

Safety Management of Highly Hazardous Chemicals standard, which outlines rules for the management of hazards associated with processes involving highly hazardous chemicals, in an effort to promote safe and healthy workplaces. Particular requirements for the general and construction sectors address process safety management (PSM). In addition to establishing a thorough management program that incorporates technology, procedures, and management practices, OSHA's standard places a strong emphasis on the management of hazards related to highly hazardous compounds.

Table No: 1 Major Process Safety Incidents.

Incident	Effects
Bhopal, India, 1984 Union Carbide Methyl Isocyanate Release	>3800 fatalities, >100 000 Injuries $470 M compensation
Chernobyl, USSR, 1986 Nuclear Reactor Meltdown	30 acute fatalities, >130 000 Injuries
Gulf Oil Spill. USA, 2010 British Petroleum Deep water Horizon Oil Platform Explosion and Spill	11 fatalities from the explosion Extensive environmental damage, extensive damage to regional fishing and tourism industry, >$4.5 B USD in fines, >$42 B in civil settlements
Challenger Disaster, USA, 1986 NASA Explosion	Loss of crew (7 fatalities), loss of space shuttle (>$8 B USD), recovery of debris

LITERATURE REVIEW

Process Safety Management (PSM) is a systematic approach designed to prevent catastrophic incidents such as fires, explosions, and toxic releases in industries handling hazardous chemicals. According to Occupational Safety and Health Administration et al. (1992), effective PSM implementation requires identifying, evaluating, and controlling process-related hazards through structured safety procedures and operational controls. The regulatory framework established under OSHA's Process Safety Management standard has become a foundational guideline for industries worldwide.

Risk-based safety management has further evolved through the work of Center for Chemical Process Safety et al. (2007), who emphasized that organizational commitment, hazard identification, risk assessment, and continuous improvement are essential elements of process safety. Their guidelines highlight the integration of engineering controls, management systems, and workforce participation to reduce industrial risks.

In the Indian context, Oil Industry Safety Directorate et al. (2018) developed a Process Safety Management Framework specifically for petroleum and chemical industries. The framework focuses on leadership commitment, hazard analysis, mechanical integrity, work permit systems, and emergency preparedness to improve operational safety. Similarly, Petroleum and Explosives Safety Organization et al. (2016) established regulations for the safe handling and storage of pressure vessels and hazardous materials, contributing significantly to industrial accident prevention.

The legal foundation for occupational and industrial safety in India is supported by Government of India et al. (1948/1987) through the Factories Act, which mandates health, safety, and welfare measures for workers in industrial establishments. The Act emphasizes hazard control, employee training, and emergency preparedness to ensure safe working environments.

Hazard identification and evaluation methods are also critical components of PSM. Center for Chemical Process Safety et al. (2008) discussed systematic hazard evaluation procedures such as HAZOP, What-If Analysis, and Failure Mode and Effects Analysis (FMEA), which assist organizations in identifying potential operational failures and minimizing risks.

Further support for chemical safety practices is provided by National Fire Protection Association et al. (2019), who introduced standards for hazardous material classification, storage, and emergency response through NFPA 400. Likewise, National Safety Council et al. (2021) emphasized the importance of safety culture, employee competency, incident investigation, and continuous monitoring in strengthening process safety performance.

Recent standards developed by Oil Industry Safety Directorate et al. (2023a) highlighted the importance of work permit systems in controlling hazardous maintenance and operational activities, while Oil Industry Safety Directorate et al. (2023b) focused on safe handling procedures for hazardous chemicals to reduce occupational and environmental risks. Together, these studies and standards demonstrate that effective PSM implementation depends on regulatory compliance, hazard assessment, workforce training, and continuous safety improvement.

METHODOLOGY

Employee Participants:

For the PSM program to be successful, active employee involvement and participation must be a component. Employee participation is intended to use their knowledge, experience and unique perspectives when evaluating process safety matters. This element identifies the

various mechanisms available for employees to participate in the PSM program and defines the minimum requirements relating to employee engagement.

The employee participation has four parts:

A. Employee Awareness

B. Employee Involvement

C. Employee Access to Information

D. Appreciation

A. Employee Awareness -Employee awareness programs should provide information regarding the storage and handling of hazardous chemicals along with the related safety and health risks. Employees must also be informed about organizational safe work practices, general safety rules, and emergency response procedures. Awareness activities can be conducted through safety signboards, television displays, desktop notifications, posters, and quarterly safety newsletters or magazines.

B. Employee Involvement -Active participation of employees during the planning and execution of safety programs helps in identifying workplace hazards effectively and improves understanding of the safety management system. Regular training initiatives such as classroom sessions, on-site practical training, toolbox talks, and safety workshops should be arranged periodically to strengthen employee knowledge and participation in process safety activities.

C. Employee Access to Information

Workers should be provided easy access to important safety-related documents such as Material Safety Data Sheets (MSDS), Health, Safety and Environment (HSE) study reports, training materials, and Management of Change (MOC) forms in accordance with company procedures. Printed copies of MSDS, Standard Operating Procedures (SOPs), emergency response plans, and other relevant safety documents should be readily available in the plant supervisor's or department in-charge office.

Appreciation -Recognizing employees for their contribution to safety helps improve communication and cooperation between management and workers. Organizations can conduct activities and competitions such as identifying unsafe acts and conditions, selecting the best PSM champion, evaluating departmental work permit performance, monitoring plant safety achievements, and rewarding prompt emergency response actions. Appreciation may

be provided by the site head, factory manager, or safety manager in the form of certificates, awards, or mementos.

Process Hazard Analysis:

The process hazard analysis is a thorough, orderly, systematic approach for identifying, evaluating, and controlling the hazards of processes involving highly hazardous chemicals. The employer must perform an initial process hazard analysis (hazard evaluation) on all processes covered by this standard. The process hazard analysis methodology selected must be appropriate to the complexity of the process and must identify, evaluate, and control the hazards involved in the process.

For conducting PHA, employer shall determine and set the priority order for conducting processed hazard analysis based on extent of the process hazards, the number of potentially affected employees, the age of the process, and the operating history of the process.

At least every three years after the completion of the initial process hazard analysis, the process hazard analysis shall be updated and revalidated by a team meeting the standard's requirements to ensure that the hazard analysis is consistent with the current process. PSM

Department shall keep file of PHA and shall be available.

- ✓ Process hazard analyses shall be carried out for each process carried out at Site.
- ✓ Regular updates or revalidation for each process shall be carried out.
- ✓ Recommendations shall be properly implemented after each PHA
- ✓ Proper tracking system for closing of recommendations shall be made.

Table No: 2 Process Hazard Methodology.

TECHNIQUE	COMMENT
Hazard identification (HAZID)	Identification of significant hazards to ensure that there are appropriate measures in place to eliminate or reduce the risks to tolerable/ ALARP levels. Can be carried out once the basic process engineering design of a project or modification is known.
Hazard and operability study (HAZOP)	A rigorous line-by-line review, this requires the piping and instrumentation diagrams (P&ID) to be finalized with a good understanding of the safety barriers that need to be adopted as part of the project, or those already installed when restudying an existing plant. If done too early in the development of the P&ID, the HAZOP can quickly degenerate into a design review.
Process hazard review (PHR)	A rigorous system-by-system review designed to operate at a higher level than a HAZOP, applying learning gained during site operation to previous versions of the PHA or HAZOP.
Safety integrity	An assurance assessment that safety instrumented functions (SIF)

level (SIL) analysis	provide the required safety performance and integrity. Typically carried out in parallel with a HAZOP or PHR
Layer of protection analysis (LOPA)	A semi-quantitative tool for analysing and assessing risk. The timing would be similar to that for a HAZOP. Like HAZAN, it is a tool also often used for SIL analysis.
Failure mode and effect analysis (FMEA)	A systematic, typically qualitative, and methodical tabular technique for evaluating and documenting the causes and effects of known types of component failures.
"What if"	A simple-yet-structured brainstorming technique for determining likely hazards and judging the likelihood and consequences of those hazards occurring.

Operating Procedure:

A standard operating procedure (SOP) provides clear-cut directions and instructions as to the steps necessary to complete a specific task or process. SOPs are used to ensure that tasks are completed consistently and efficiently, and to reduce the risk of errors or omissions. Sops provide an "on-the-ground" explanation of what needs to happen to ensure a given process or task is completed as planned. Standard operating procedures are important because it allows organizations to systematize their internal processes, keep all team members and other stakeholders on the same page at all times, and move forward in a singular, cohesive manner. Perhaps the best way to illustrate the importance of developing standard operating procedures is to consider the negative impact of not doing so. Basically, it leaves too much up to chance: There's no guarantee that best practices will be followed at all times, that all team members will remain in alignment, or that the organization will continue to operate in a positive and effective manner. Operating procedures provide specific instructions or details on what steps are to be taken or followed in carrying out the stated procedures. The specific instructions should include the applicable safety precautions and appropriate information on safety implications. For example, the operating procedures addressing operating parameters will contain operating instructions about sequence of valve opening, pressure limits, temperature ranges, flow rates, what to do when an upset condition occurs.

Contractor Safety Management:

It is systematic approach to the Management of Contractors so that the risks to health and safety of contractors and subcontractors are minimized. Establishing good contractor safety management practices helps maintaining the safety of contractors and also supporting our EHSS goals.

General Safety Requirement for Contractors.

✓ The contractor Supervisors (or person in charge of the work) should ensure that:

✓ Permit to work shall be followed at site.

✓ They have received training in the Safety work permit system as applied in that location

✓ The people working for them have received adequate instruction in the system

✓ They discuss the job fully with the person issuing the permit

✓ The workmen are briefed on the details of the permit including any potential hazards, and on all the precautions taken or to be taken.

✓ The precautions are maintained throughout the work activity.

✓ The worker understands that if circumstances change work must be stopped and inform the supervisor.

✓ The work group stays within the limitations set on the permit (physical boundaries, type of work and validity time)

✓ On completion or suspension of the work the site is left in a safe condition and the permit issuer is informed & permit has been returned for closing.

✓ Individuals working within the Safety work permit system should ensure that, they have received instruction and have a good understanding of the safety work permit system at the installation where they work.

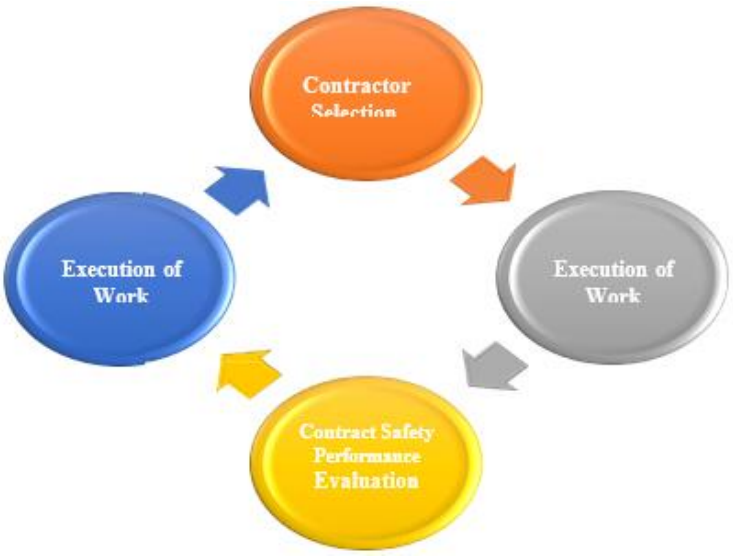

Figure No: 5 Contractor Safety Management

Mechanical Integrity:

Mechanical Integrity (MI) bound the activities necessary to ensure that equipment/assets are designed, fabricated, installed, operated and maintained in such a way that they provide the

desired performance in a safe, environmentally protected and reliable fashion. In short, it is the Life Cycle Asset Management (LCAM) process, including the above plus procurement, testing, commissioning and disposal of the assets. MI is a sub-set of an effective reliability program and overall asset management, specific to equipment types, and more tactical in nature including the evaluation of condition requirements through regular monitoring and inspection of the condition of these assets.

It relates effective Asset Management system that addresses not only safety requirements, but also provides effective asset policy, strategy, objectives and plans to ensure best-in-class management of assets that mitigates risk over the entire life cycle of the assets.

Implementing a phase-wise Mechanical Integrity (MI) system at site is a structured approach to ensuring that equipment is designed, installed, operated, and maintained to perform safely and reliably. It's typically part of a Process Safety Management (PSM) system, especially under OSHA's 29 CFR 1910.119 in the U.S., but it can be adapted globally.

Requirements of Mechanical Integrity		
Task-1 • Management Responsibility. • Facilitate Leadership Roles & Responsibilities • Organization Roles & Responsibilities • Reporting • Auditing	**Task-2** • Equipment Validation & Tasks Planning • Size & Design Validation • IQ, OQ & PQ Validation • Required Tasks Planning	**Task-3** • Inspection, Testing& Calibration and Preventive Maintenance • Task Selection & Scheduling • Task Execution & Monitoring • Asset Breakdown
Personnel Qualification; • Skills / Knowledge Assessment • Training Required • Training Verification & Documentation • Certification Requirements • Refresher Training • Contractor Training Requirement		

PROBLEM IDENTIFICATION AND OBJECTIVES

Problem Identification:

Unexpected thing never alarmed us. Many cases of unexpected releases of flammable liquids and gases, reactive materials, and toxic in processes that involve highly hazardous chemicals that killed workers and cause injuries have been reported for many years. Regardless of the industry that uses these highly hazardous chemicals, there is a possibility for an accidental release at any time if they are not properly managed and controlled. In return, it creates the possibility of disaster. Before it brings in the unwanted tragedy, prevention is better than

cure.

PSM 29 CFR 1910.119 has been introduced in the process industries to ensure the process facilities that have hazardous chemicals on site are operated safely. However, a major challenge is unavailability of easy technique for industries to implement PSM and comply with the requirements. PSM standard was not properly understand and followed by employer. In addition, the identified hazards information was not accessible by effected personnel. Thus, the implemented safety program.

Analysis the extant research was predominantly focused in PSM elements, particularly the Process Hazard Analysis (PHA) / Risk Management Program, Mechanical Integrity (MI), Process Safety Information (PSI), Incident Investigation, and Training, Emergency Response, Contractor Management, Compliance Audit, Employee Participation, and Management of Change. The extant literature though offers specific scientific methods/ solutions for risk assessment and improving mechanical integrity, and highlights the importance of PSM, there are no scientifically published research studies on factors causing the incidents in chemical and process industries. But the literature has indicated that non-coordination with other required elements may lead to disasters. No coordination between the process safety elements, therefore becomes inevitable to keep the process safe whenever any change takes place in management, chemical process, critical process equipment and technology during routine process operation and non-routine activities. This will ensure the process safety with necessary CAPA in the respective element so that whole PSM functions as intended. There are no studies which have focused on the coordination of PSM elements and failure of PSM system.

Objective:

This dissertation is significant to assist the process industries in order to have a better implementation technique of PSM in preventing the catastrophic accidents that lead to loss of life, significant property loss, as well as damage to the environment. The introduced well-structured technique hopefully can benefit the end user's priority to the safety at the workplace.

- To analyze the requirements for Mechanical Integration (MI) 29 CFR 1910.119(j)
- To establish framework of MI
- To develop prototype tool for easy explanation and implementation based on the framework and model.
- To conduct case studies for concept validation.

This project is a comprehensive research study about the development and statable approach of Process Safety Management System (PSM) for implementation in process industries focusing on the 14 elements of PSM and coordination. Analyze on the 14 elements of PSM has been done through the study of the requirements and identifying a necessary documentation. This is followed by development of framework and model for the focused element.

RESULT AND DISCUSSION

Sr. No	PSM Element	Focus	Practical insight from the research
1	Process Hazard Analysis	Various risk assessment & risk control methodology, facility sitting, Standards &Procedures.	1. Fuzzy risk assessment and risk aversion by computing the limits of rare events will help in boosting the PSM performance. 2. Accident Hazard Index is a multi-attribute method for process industry hazard rating. 3. Chain of events analysis, its control systems & the errors and calculation of fire & explosion index for loss control are used to assess process hazards. 4. Six step basic risk assessment, computer aided evaluation and fire and explosion index to improve plant safety & reliability. 5. Quantitative risk assessment, mechanism analysis, Hazard, and operability studies (HAZOP), quick risk assessment, dynamic safety analysis using boe-tie mapping and layer of protection analysis (LOPA) are applied in chemical process and oil& gas industries. 6. Chemical hazard recognition with a pre assessment about hazardous chemicals, identifying its reactivity hazards and taking adequate control measures will reduce the risks in process industries.
2	Process Safety Information	Process Risk Assessment	1. PSI assessment plays a vital role in preventing process related incidents which can be seen in process safety progress since last two centuries. 2. PSI deficiencies are to be encountered with clear hazard communication system as same as that of global harmonised system implemented for clear communication of hazardous chemicals.
3	Employee Participants	Safety culture and performance	1. Safety culture needs to be improved at workplace to reduce work related incidents.

			2. Positive safety culture can be achieved only by employee participation, management commitment, visible leadership, clear demonstration with clear attitudinal approach to prevent incidents in process plants
4	Management of Change	Management of Change Practice	1. Non-compliance to MOC and non-coordination with other required elements leads to disasters and the same can be achieved by bench marking MOC practices in process plants. 2. MOC should be exercised whenever a small change is taking place in the process, equipment, and technology
5	Mechanical Integrity	Equipment failure, Engineering. Techniques for failure education, Inherent safer design.	1. Inherent safer design, technical integrity, risk-based inspection and maintenance, engineering risk control techniques applied are major contributors for preventing equipment failure in process industry incidents. 2. Criticality assessment and analysis of process equipment with adequate inspection intervals will improve the mechanical integrity of process equipment. 3. Inherent safer equipment and process design along with suitable facility sitting for storage and handling of hazardous chemicals will effectively reduce the risk and ensures safer plant.
6	Incident Investigation	Root cause analysis, Earlier Incidents and Lessons learnt, facility sitting, anatomy of domino accidents.	1. Process incidents are investigated using root-cause analysis, failure modelling and the same shall be applied for investigating process incidents to prevent recurrence of similar incidents. 2. Near miss Incident management in the chemical process industry plays a vital role, if identified, reported, analysed, and controlled 3. Compliance to recent development in fire & explosion index and clear post incident review will further reduce process related incidents
7	Training	Operation knowledge Management, Safety training, Chemical Engineering Practices, Shutdown operation.	1. Process plant incidents can also be prevented with perfect knowledge management, safety training, blended training & practices during routine and non-routine activities including start-up & shutdown operations.

			2. Training to contract workmen is very important specially the orientation training to get familiarised with worksite. 3. Accident minimisation at large industries is possible with good training strategies by pooling knowledge and improving safety for contracted works
8	Emergency Control & Response planning	Protection of workplace during emergencies, Disaster risk management	1. Emergency planning and response plays a key role in disaster management during emergencies related to process nature, hazardous materials used to include shelter in place. 2. Disaster management in chemical industries plays vital role in minimizing the damage to industry and environment.
9	Contractor Management	Contractors dealing with multi-cultural workforce	1. Effective contractor management dealing with multicultural workforce in process plants handling hazardous chemicals becomes very important to prevent/minimize industrial incidents.
10	Permit to Work System	Effective permit to work system	1. Routine and non-routine operations pose enormous risk in process plants leading to major disasters. 2. Disasters can be prevented with more effective safe system of work (SSOW) for routine operations and Permit to work system (PTW) for non-routine operations.
11	Compliance Audit	Role of regulators & Audit review	1. Process safety management goal can be achieved only when a correct compliance audit is in place. 2. Comply with legal requirements, codes, set standards, procedures, and review of the same post safety audit for implementation of corrective actions and preventive actions (CAPA)
12	PSSR	Pre start up safety review	Review of equipment suitability before commissioning.
13	Operating Procedure	SOP	Importance of standards and need for procedures
14	Trade Secret	Trade Secrete	Confidential the documents and control of data. Access grant as per limitation of rights.

CONCLUSION

Process Safety Management (PSM) is essential in the chemical industry for preventing catastrophic incidents through a comprehensive systematic approach. Key conclusions highlight the necessity of PSM, which addresses inherent hazards in chemical processes through hazard identification, risk assessment, and control strategies. A holistic management

system is crucial, as the fourteen interconnected PSM elements require coordination across organizational functions. Leadership commitment and a strong safety culture are vital for the effectiveness of PSM, necessitating engagement from all employees. Continuous improvement is emphasized; ongoing maintenance and adaptation through regular audits and lessons learned are critical for sustained effectiveness. Additionally, personnel competency is fundamental, supported by comprehensive training and assessments. The report concludes that successful PSM implementation involves systematic approaches, strong leadership, adequate resources, and long-term commitment, ultimately providing a roadmap for effective PSM in process industries.

Future Directions:

- As new technologies emerge in the chemical sector, process safety management (PSM) must change.
- Important areas of attention consist of: Advanced process digitalization and automation. The application of AI and machine learning to risk assessment and hazard prediction. The application of Industry 4.0 technologies, such as predictive maintenance and real-time monitoring.
- The creation of process designs that are intrinsically safer. Cybersecurity is integrated with process safety. A greater focus on human-system interfaces and human considerations.
- Comprehensive PSM programs can result in operational excellence, protecting the environment, communities, and employees.

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