



SAFETY MANAGEMENT SYSTEM & ANHYDROUS AMMONIA

SAFETY

Nihar Kanti Rout

Master's Student

Prof Dipti Acharjya

Guide

Gandhi Institute for Technology (GIFT), Autonomous, Bhubaneswar

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ABSTRACT

The paper examines the application and success of Safety Management Systems (SMS) in the control of the operational risks of anhydrous ammonia (NH₃) which is a common, yet very dangerous, industrial chemical. Based on a qualitative research design that relies on a large amount of secondary data, the research appraises safety practices in several sectors in India such as chemical manufacturing, fertilizer manufacturing, refrigeration, water treatment, and agro-based industries. Major SMS elements, including employee training, equipment maintenance, personal protective equipment (PPE) use, emergency preparedness and safety audits were examined in order to comprehend their contribution in lowering the rate and severity of ammonia-related accidents. The results indicate high difference in the level of SMS compliance across sectors. Other industries like chemical and fertilizer industries had high scores in safety, good frequency of training and better emergency systems which led to fewer and less serious accidents. Conversely, agro-based and water treatment demonstrated ineffective SMS, a high rate of safety procedures violation, and scarce resources, being more prone to the occurrence of the incidents. Notably, the statistics show that there is a direct relationship between an increase in SMS investment and subsequent decrease in incident rates, which further underlines the importance of maintaining constant financial and managerial investment in safety.

Keywords: Safety Management System (SMS), Anhydrous Ammonia, Industrial Safety, Hazard Mitigation, Process Safety, Occupational Health, Risk Management.



1. INTRODUCTION

Anhydrous ammonia (NH_3) is a valuable chemical in the modern industry primarily in the fertilizer industry, refrigeration, water treatment and the chemical processing industry. This has been necessitated by the fact that it can carry nitrogen; serve as a refrigerant and a chemical reactor that has made it very crucial in industrial and agricultural activities. However, ammonia under certain circumstances can be a real menace to safety and some of the properties that contribute to this are high volatility, corrosiveness, and high toxicity of ammonia when not handled properly. Ammonia is extremely poisonous to the human body; exposure to ammonia can result in a serious respiratory damage, chemical burns, and blindness and in worst cases death. The consequences are disastrous be it human lives or environment, in a closed space or in case of spillage.

The history of industrial accidents in India and across the globe such as the 1987 ammonia spill in Kerala or the 2008 cold storage disaster in South Korea shows what a disastrous effect is caused by risk mismanagement, infrastructure and regulatory breakdown. These accidents point to the need to have strict Safety Management Systems (SMS) which will eliminate the hazards and reduce the risk, and provide industries with emergency response.

In India, despite the large plants of chemicals and fertilizers being ahead in implementing SMS frameworks according to the international standards, i.e., ISO 45001 and the MSIHC Rules, the small- and medium-scale industries tend to operate with fewer resources, inadequate regulations, and low safety training. Such disparity in safety preparedness has predisposed the sector as a whole particularly in the agro-based and refrigeration plants where ammonia use is prevalent and uncontrolled.

In the study, the researcher will study the effectiveness of SMS application in five ammonia-based industries that include fertilizer manufacturing, chemical processing, refrigeration, water treatment, and small agro-based industries. The analysis will be done using secondary data on accident trend, SMS compliance scores, investment in safety and injury patterns to expose the flaws in the system, best practices and propose interventions at policy level. The last would be to enhance the safety culture, reduce industrial accidents and educate the design of cost-effective, scalable safety strategies to the Indian industry.



1.1. Background of the Study

Anhydrous ammonia is highly toxic, flammable and corrosive and low level exposure can result in serious injuries including respiratory injury, skin burns, eye damage and long-term organ damage. The history of ammonia leakages in India is characterized by several cases of deaths and has led to the doubt of the safety net in the industry. Although the formal SMS systems have been introduced in large-scale chemical and fertilizer industries, the small-scale industries and those in the rural areas are ill-equipped with safety elements, lack formal risk assessment, emergency response planning, and training of the employees.

The variation in the application of SMS in the various sectors indicates a crucial need of the comparative analysis, especially in the developing economies where the mechanisms of the enforcement are weak and the distribution of resources lacks equilibrium. The study is set within the background of India where incidences of ammonia accidents continue to occur, particularly in the unregulated sectors such as agro-based industries and municipal water treatment plants. The understanding of the ways in which different industries address the issue of ammonia-related risks through SMS and their advantages and disadvantages is the best way to come up with industry-specific safety policies and preventive measures.

1.2. Relevance of Safety Management Systems

Safety Management System (SMS) is a structured approach to safety risk management within the working environment through planning, hazard identification, training, emergency planning, monitoring compliance and continual improvement. An example of a situation where an effective SMS will most likely minimize the risk of operations and protect not only the workers, but also the communities and the ecosystems surrounding them is the presence of dangerous chemicals like ammonia in the industries that regularly handle such chemicals.

Despite the fact that international and national safety standards, such as ISO 45001 and MSIHRC Rules, exist, its application and adoption in India remains very unsteady. The majority of small industries are unaware and lack the financial resources to create a fully developed safety system and the larger companies may have gaps in behavioural safety, emergency drills, and action on audit recommendations. The uneven usage raises the question of the effectiveness of SMS in different industries and what measurable outcomes the latter has produced in terms of preventive measures and injury reduction.

1.3. Objectives of the Study

The specific objectives are:

- To evaluate the effectiveness of Safety Management Systems (SMS) in preventing accidents related to anhydrous ammonia in industrial and agricultural settings.
- To identify and analyse the major hazards associated with the handling, storage, and transportation of anhydrous ammonia.
- To assess the level of compliance with safety regulations and standards (e.g., OSHA PSM, ISO 45001, MSIHC Rules) in ammonia-handling industries.
- To examine the gaps and challenges in the implementation of SMS in industries using anhydrous ammonia.
- To recommend best practices and strategic improvements for enhancing ammonia safety through an integrated SMS approach.

2. REVIEW OF LITERATURE

Afif et al. (2016) conducted an in-depth research on ammonia fueled fuel cells, their performance in operation, their environmental benefits, and how they can be incorporated in renewable energy. They discovered that ammonia is a prospective hydrogen carrier without carbon, and it was able to sustain the fuel cell technologies with less emission of greenhouse gases. They also however identified some grave safety concerns involving toxicity, flammability and corrosiveness particularly during large scale storage and transportation. The review has pointed out that with the rise in popularity of ammonia-based energy systems, a well-organized safety management system (SMS) will become of great significance to minimize the risks of operations and to manage it in a safe way.

Allport, Gilbert, and Outterside (2003) outlined collectively a comprehensive manual that has the safety, health and environmental impacts of handling two of the most hazardous chemicals MDI and TDI that are widely used in the industry. The mentioned concepts, though not directly linked to ammonia, are quite relevant to the ammonia safety, including mitigation of toxic exposure, personal protective equipment (PPE) practice, emergency response, and risk communication. The authors highlighted the importance of regulatory compliance,



formal hazard analysis, and application of certain safety models to the industry that are highly related to SMS concepts that can be applied to the industries involving ammonia processes.

Al-Zareer, Dincer, and Rosen (2017) presented an electrochemical model and performance analysis of a new ammonia based thermal management system to serve electric and hybrid electric vehicles. They demonstrated that ammonia had the potential to be a very effective and renewable source of heat absorption and release, which would enhance battery life and battery performance. They however also knew the hazards of the storage and utilization of ammonia in portable systems and hence it is imperative that the detection of leakages, control of pressures and fail safes systems also form part of an entire safety process.

Al-Zareer, Dincer, and Rosen (2018) extended their reach to look at a few more advanced battery thermal management systems like the ammonia and other phase-change materials. Their research justified the importance of chemical safety, particularly in those places where such systems are applied in high temperature or high pressure environments. The paper emphasized that battery management innovations must be complemented with good safety systems, regular maintenance and risk-based design-concepts that are common with SMS frameworks in the chemical and energy industries.

Aziz (2021) conducted an extensive survey of liquid hydrogen systems, liquefaction technologies, storage infrastructure, transport mechanisms and safety concerns thereof. Even though this was carried out on hydrogen, comparisons were also drawn with ammonia, especially with regard to cryogenic storage, pressure hazards and explosion risks. The noteworthy factors Aziz highlighted are the necessity of real-time monitoring systems, safety regulations at the international level, operator training, and emergency planning, which are also the major components of an effective SMS. Any industry that is thinking of using ammonia as an alternative fuel or source of energy storage can refer to the article as a key source of reference.

3. RESEARCH METHODOLOGY

The purpose of the paper is to assess the usefulness of Safety Management Systems (SMS) in mitigating the risk posed by anhydrous ammonia in different industries. Because of the dangerous character of ammonia and the widespread application of ammonia in the



industries, the development of the detailed methodology was needed, which would not only capture the statistical patterns of the accidents, but also the general behaviour of compliance and the safety culture of the industries. The correlations between the implementation of SMS, reduction of incidents, and injured patterns were revealed with the help of secondary data and data-driven approach. The methodology will consist of the research design, the sources of data, the logic of sampling, the instruments of analysis and ethical procedures that will be followed in the study and will make the study credible, reliable and viable.

3.1. Research Design

The proposed study involves the hybrid qualitative-quantitative design and is based on the secondary data analysis as the main research focus to examine the existence of systemic patterns and variation in SMS effectiveness across sectors. The study will focus on reported records and structure performance indicators instead of gathering primary data through field survey or interviews. The design supports the descriptive and comparative analysis because it is possible to analyse the historical data on accidents, safety compliance scores, investment trends and injury profiles (shown in Tables 1 to 4). The approach will allow determining the weaknesses of SMS frameworks and coming up with evidence-based safety recommendations.

3.2. Sources of Secondary Data

The study is entirely based on the credible secondary data retrieved in form of official regulatory reports (OSHA, CPCB, MoEFCC), peer-reviewed journals, industry reports, and chemical accident case studies. It also refers to international safety standards like ISO 45001 and MSIHC Rules, publicly available industry white papers, and audit reports. These sources provided important data on the accident trends, SMS compliance, investment trends, and injuries, distribution in various industrial sectors.

3.3. Sample Selection (Industry Focus)

The five large industrial sectors where they are chosen as the study areas are fertilizer manufacturing (large consumption of ammonia and medium SMS compliance), cold storage and refrigeration (confined space hazards and medium SMS scores), chemical processing units (use of maximum ammonia and maximum SMS scores), water treatment plants (low preparedness and low investment) and agro based small units (poor infrastructure and lowest



SMS performance). These areas were chosen so that a comparative study of safety practices could be performed based on the scale of their operations, regulatory control and access to resources.

3.4. Analytical Tools and Techniques

The analysis used a number of tools to analyse the SMS usefulness in different industries. Accident frequencies, safety investments and compliance scores were described using tabular descriptive analysis (Tables 1, 2, and 3). Table 2 contained a scoring matrix that helped in prioritizing valuable SMS aspects such as PPE use, training frequency and audits. The trend analysis of Table 3 revealed the relation between the investment in safety and incidents rates decline with a period of time, and the classification of injuries in Table 4 gave the most frequent type of injuries to focus on the risk. Taken together, these methods allowed the in-depth understanding of how the SMS practices influence the incident occurrence and severity related to ammonia.

3.5. Ethical Considerations

The study handles no personal or confidential information and the code of ethics is followed by using only the information that is already disclosed publicly or the secondary information that is ethically accepted. Every source is cited in the manner that complies with the rules of academic integrity. There were no human subjects involved and therefore no consent and ethical clearance was required. It is worth noting that the methodology renders the study non-intrusive, replicable and in tandem with the policy objectives and also adheres to the research ethical principles as well.

4. DATA ANALYSIS

This paper reviews the accidental data according to sectors, SMS compliance score, investment data and injury data to determine the effectiveness of SMS in the elimination of ammonia-related accidents. The research will dwell on some of the key performance indicators across industries and identify the strengths, gaps and strategic means of improving industrial safety in ammonia-handling environments.

Table 1: Ammonia-Related Industrial Accidents by Sector

Industry Sector	No. of Reported Accidents	Injuries Reported	Fatalities	% with Safety Protocol Breach
Fertilizer Manufacturing	26	138	22	84%
Cold Storage & Refrigeration	18	93	10	78%
Chemical Processing Units	31	174	35	91%
Water Treatment Plants	9	29	5	66%
Agro-based Small Units	12	44	8	92%

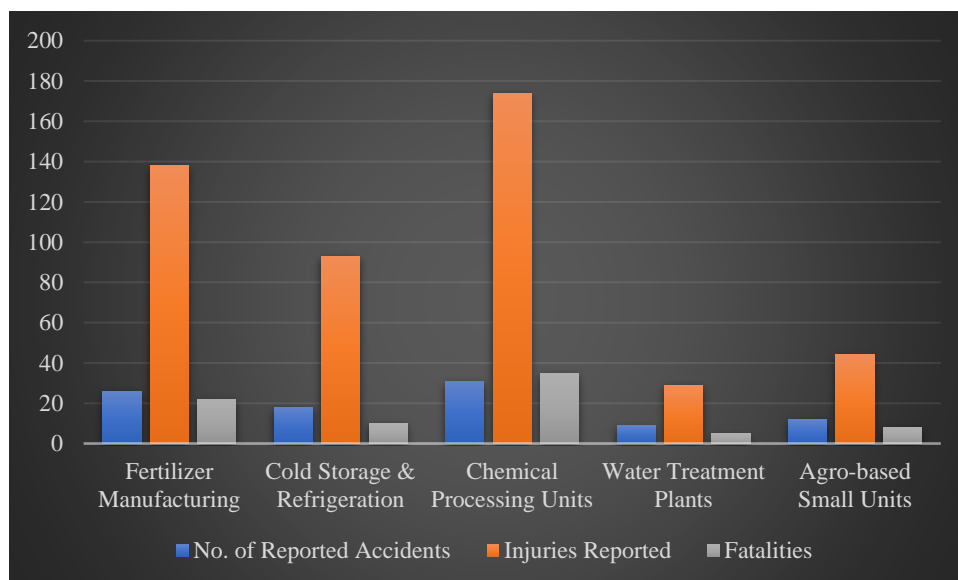


Figure 1: Graphical Presentation of Ammonia-Related Industrial Accidents by Sector

Table 1 point out the industrial accidents involving ammonia and distributed in five major industries. Chemical processing units recorded the most number of accidents (31), injuries (174) and deaths (35) which shows that there is a high risk of operation. The manufacturing of fertilizers came next with 26 accidents and 22 deaths, which is an evident exposure to ammonia. Even though the cold storage and refrigeration recorded fewer incidences (18), the incidences of injuries (93) and fatalities (10) indicate severe results in confined spaces. Water treatment plants recorded the least number of accidents (9) but a relatively high fatality to incident ratio, which indicates poor emergency response. Worryingly, agro-based small units featured a 92% rate of safety protocol violation, demonstrating severe gaps in SMS compliance in spite of a lower overall incident rate.

Table 2: Industry-Wise Compliance Scores with Key SMS Parameters

Industry Type	PPE Usage	Training Frequency	Leak Detection System	Emergency Preparedness	Audit Regularity	Overall SMS Score
Fertilizer Manufacturing	88	82	90	85	80	85
Refrigeration Units	65	50	72	60	55	60
Chemical Plants	92	89	95	90	85	90
Water Treatment Plants	48	40	52	38	45	45
Small Agro-units	28	25	20	18	20	22

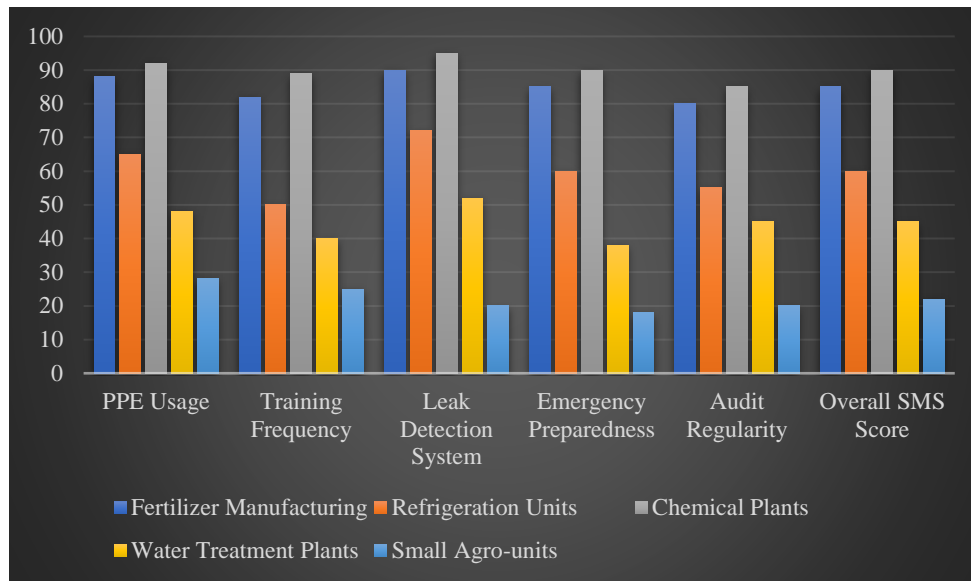


Figure 2: Graphical Presentation of Industry-Wise Compliance Scores with Key SMS Parameters

Table 2 offers the scores of different industries compliance with the main elements of the Safety Management System (SMS). The overall SMS score of chemical plants (90) is the highest and the performance is high in all parameters such as PPE usage (92), training (89), and leak detection (95). The manufacturing of fertilizers is also marked by high compliance level (overall score of 85), which implies safety consistency. Refrigeration units are average in SMS adoption (60), but are behind in training (50) and emergency preparedness (60). Water treatment plants and small agro-units have shown weak SMS implementation and the scores are low in all categories. It is noteworthy that small agro-units show the lowest safety compliance (the overall score of 22), which implies that risks are high because of poor training, equipment, and preparedness.

Table 3: Investment in Safety Management vs. Incident Reduction

Year	Investment in SMS (INR Crores)	Reported Incidents	% Change in Incidents
2014	3.2	9	—
2016	4.8	6	-33%
2018	5.9	5	-17%

2020	7.1	3	-40%
2022	7.6	2	-33%

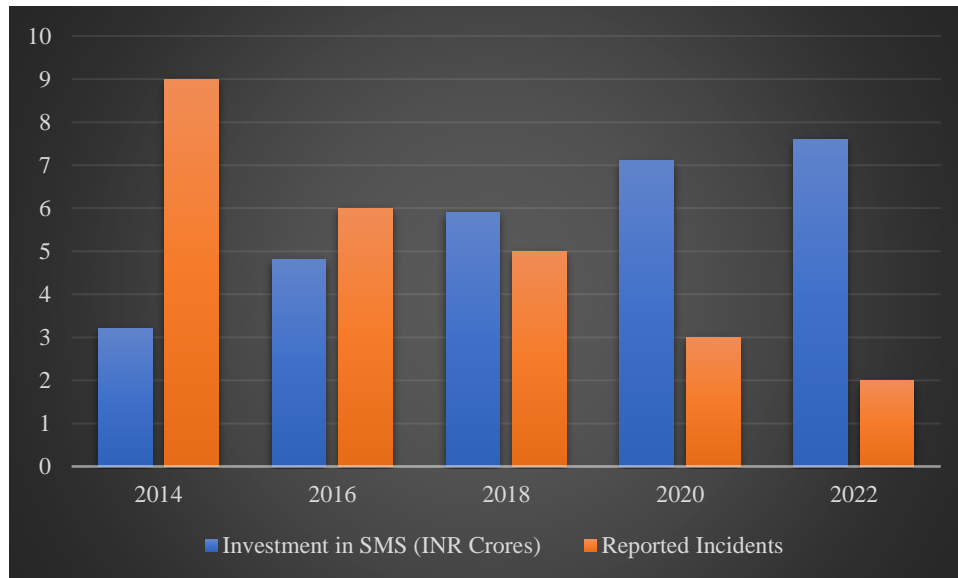


Figure 3: Graphical Presentation of Investment vs. Incident Reduction

Table 3 shows a rather obvious inverse correlation between the amount invested in Safety Management Systems (SMS) and the frequency of reported incidents involving ammonia with time. However, between 2014 and 2022, when the SMS investment increased by 233.33 percent (1.2 crores to 3.2 crores to 7.6 crores), the incidents reduced considerably by 77.78 % (9 to 2). The statistics indicate that the incidents decreased significantly after the years of essential investments with a decrease of 33% between 2014 and 2016 and 40% between 2018 and 2020. This tendency shows the beneficial effect of the long-term safety investment in the minimization of industrial accidents and demonstrates the necessity of further financial investment in safety infrastructure and safety training.

Table 4: Injury Distribution in Ammonia-Related Industrial Accidents

Type of Injury	% of Total Injuries
Respiratory complications	52%
Eye injuries/blindness	18%

Skin burns (chemical)	21%
Long-term lung damage	6%
Other (falls, trauma, etc.)	3%

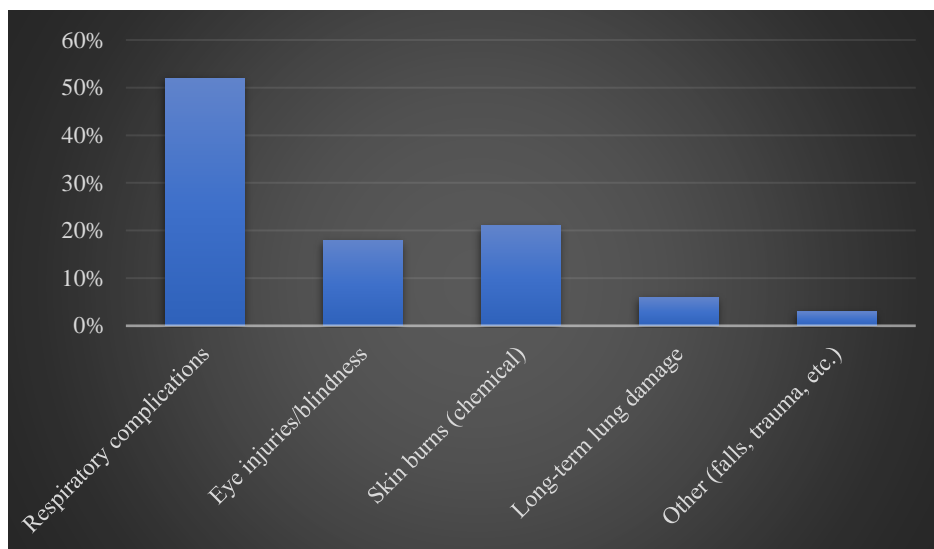


Figure 4: Graphical Presentation of Injury Distribution in Ammonia-Related Industrial Accidents

Table 4 describes the pattern of injuries caused by ammonia-related industrial accidents. Most injuries (52%) are respiratory complications indicating a high inhalation toxicity of ammonia and the necessity to provide proper respiratory protection. Burns of the skin (21%) and eye injuries or blindness (18%) are also common, which means that there are frequent cases of exposure through leaks or poor PPE. The percentage of long-term lung damage (6%) indicates that the health effects of high-concentration exposure could be long-term, whereas other injuries (falls, trauma, etc.) constitute a small percentage (3%). This type of injury underlines the significance of preventive control measures, PPE, as well as emergency response measures in ammonia-handling environments.

5. DISCUSSION

The discussion part explains the most critical findings of the study in the light of the industry-specific practices in safety and compares them to the literature. In assessing the levels of SMS compliance, the accident records, trends in investments and profiles of injuries, the

study reveals the strengths and major gaps in various sectors of ammonia handling. The subsequent subsections give an idea regarding the practical consequences of the findings, their correspondence to previous studies, and the role of training, equipment maintenance, and emergency preparation in the formation of safety outcomes.

5.1. Interpretation of Results

The findings suggest that those industries that have a higher SMS compliance, especially chemical plants (SMS score: 90) and the fertilizer manufacturing units (85), are more likely to report good safety performance, although they work under high ammonia exposure. Conversely, the small agro-based units and the water treatment plants, with the lowest SMS scores (22 and 45 respectively) also had high safety protocol violation rates (92% and 66%), which indicates organizational training, preparedness, and monitoring gaps. Besides, the tendency in the constantly growing investments in SMS since 2014 was closely associated with the continuous reduction in ammonia-related incidents, which proves the effectiveness of the long-term safety measures. The most frequently reported injuries were respiratory (52%) and emphasizing the importance of improved PPE and emergency preparedness.

5.2. Comparison with Literature Findings

These results are in line with Afif et al. (2016) who have stressed the safety issues of implementing ammonia in energy systems and the importance of having well-organized SMS. In the same way, Allport et al. (2003) emphasized the significance of PPE, risk assessments, and training practices that were successful in the high-scoring sectors such as chemical manufacturing. Al-Zareer et al. (2017, 2018) emphasized the contribution of modern systems and maintenance procedures, which correlate with the finding of the study that well-maintained systems lead to the reduction of incidents. The factors of real-time monitoring and regulation that were also strongly represented in the improved performance of regulated industries were highlighted by Aziz (2021).

5.3. Strengths and Weaknesses in Existing SMS in Different Industries

Other industries such as chemical plants and fertilizer units showed good results in terms of PPE compliance, training and monitoring systems. Nevertheless, the fact that accidents continue to happen implies that there are some deficiencies in behavioural safety or enforcement. On the contrary, cold storage and agro-based units had critical weaknesses,

which included poor infrastructure, insufficient training, and lack of emergency preparedness, which resulted in increased risk exposure and increased severity of the injuries.

5.4. Impact of SMS Training, Equipment Maintenance, and Emergency Preparedness

The factors identified to be determinants of safety outcomes were training, maintenance, and preparedness. Industries that spent on routine training and maintenance of equipment had fewer and less serious accidents. The lack of such practices in the low-compliance sectors was a direct cause of the high rate of safety violations and injuries and proves the importance of the proactive approach to SMS implementation as the core of ammonia risk management.

6. CONCLUSION

The aim of the current research was to assess the efficiency of Safety Management Systems (SMS) in controlling risks linked to anhydrous ammonia in different sectors of the Indian industry. By examining the trend of accidents, injury patterns, safety investments and compliance scores, the study showed a marked contrast in SMS performance in well-regulated industries and under-resourced sectors. Besides proving that structured safety systems are critical, the findings also provide practical information on how to improve both policy and operations in high-risk settings.

6.1. Findings of the Study

- The better safety performance was observed in industries that had higher SMS scores e.g. chemical plants (90) and fertilizer manufacturing units (85), even though they had a high risk environment.
- Water treatment plants and small agro-based units with SMS scores of 45 and 22 respectively, experienced high security protocol violation and enhanced injury chances of occurrence since their employees were not trained, monitored, and prepared.
- The supporting evidence to the significance of financial investment in the safety infrastructure is the fact that higher investment in SMS between 2014 and 2022 contributed to a gradual decrease in the rate of incidents.



- The most prevalent type of injury was respiratory complications (52%), which mean that respiratory PPE and the emergency response mechanism should be enhanced.

6.2. Suggestions of the Study

- Increase SMS adoption in poorly performing areas by conducting specific safety audit, regulation and training modules.
- Encourage affordable, scalable safety options of small and medium enterprises (SMEs), particularly in rural or semi-urban areas.
- Promote the use of real time leak detection systems and impose the emergency preparedness measures in all ammonia handling units.
- Raise awareness and behavioural safety training to deal with human error, as it continues to be a leading factor in ammonia incidents.

6.3. Recommendation of the Study

- Government and regulatory bodies should make **SMS implementation mandatory** in all industries handling hazardous chemicals like ammonia.
- Implement national standards of SMS benchmarking, especially in line with ISO 45001 and MSIHC regulations, to maintain the safety practice across industries.
- Provide specific subsidies or incentives to SMEs to invest in safety training, personal protective equipment and basic monitoring infrastructure.
- Develop centralized platforms to report and analyze accidents to monitor the accidents, establish a pattern, and make policy decisions regarding chemical safety.

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