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Safety Management System & Anhydrous Ammonia Safety

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Abstract
Safety Management Systems (SMS) are essential for preventing workplace accidents and ensuring the safe handling of hazardous substances in industrial environments. Anhydrous ammonia is one of these compounds that is frequently utilised in manufacturing processes, fertiliser manufacture, and refrigeration; nonetheless, its poisonous, corrosive, and potentially dangerous nature poses serious dangers to both human health and the environment. By measuring employees' awareness of safety procedures, identifying the main risks connected to handling ammonia, assessing the efficacy of current safety measures, and investigating methods for enhancing workplace safety, the current study investigates the role of Safety Management Systems in improving anhydrous ammonia safety. A structured questionnaire was used to gather data from 100 respondents using a descriptive study approach. The results show that the majority of workers are well-informed about safety management procedures and identify exposure to harmful gases as the main risk connected to anhydrous ammonia. The study also shows that while current safety precautions are generally effective, ongoing safety training, sophisticated leak detection systems, emergency response exercises, and better personal protective equipment are thought to be essential for improving safety performance. The study comes to the conclusion that minimising hazards and fostering a safe working environment in enterprises using anhydrous ammonia require a well-implemented Safety Management System that is backed by technology protections, employee knowledge, and regulatory compliance.

Keywords: Safety Management System, Anhydrous Ammonia, Industrial Safety, Hazard Management, Risk Assessment, Workplace Safety

INTRODUCTION

Safety management has become an essential component of modern industrial operations, particularly in industries that handle hazardous chemicals, toxic substances, and high-risk processes. Ensuring the safety of people, equipment, and the environment has become a crucial organisational responsibility as industrial operations continue to grow and technological breakthroughs introduce increasingly complex systems. The purpose of a Safety Management System (SMS) is to prevent accidents, injuries, property damage, and environmental contamination by identifying, evaluating, controlling, and continuously monitoring workplace dangers. Safety rules, risk assessment protocols, staff training initiatives, emergency preparedness plans, incident reporting systems, and regulatory compliance needs are all integrated into day-to-day operations via an efficient SMS. Safety management systems greatly enhance organisational

effectiveness, operational dependability, and sustainable industrial development by cultivating a proactive safety culture and encouraging continual improvement [1].

Anhydrous ammonia is one of the most commonly employed hazardous chemicals in industrial processes because of its economic significance and adaptability. It is widely used in refrigeration systems, food processing facilities, chemical production plants, pharmaceutical businesses, and new energy applications. It is also a crucial basic ingredient in the making of fertiliser [2]. Anhydrous ammonia poses significant health, safety, and environmental risks despite its industrial importance. It is a colourless gas that smells strongly and is poisonous, corrosive, and perhaps combustible. Inhalation, skin contact, or ocular contact can all result in ammonia exposure, which can have negative health effects ranging from minor irritation to serious respiratory distress, chemical burns, irreversible eye damage, and in severe cases, even death. In addition, unintentional ammonia leaks may result in dangers to neighbouring communities, operational difficulties, environmental damage, and financial losses [3].

The requirement for thorough safety management procedures has increased due to the growing reliance on anhydrous ammonia in industrial and energy-related applications. The potentially disastrous effects of insufficient safety controls have been shown by industrial mishaps involving ammonia leaks, storage tank failures, pipeline ruptures, equipment faults, and transportation disasters [4]. In order to detect hazards, evaluate risks, and put effective preventive measures in place, organisations must adopt strong risk management methods. Fundamental elements of ammonia safety management include appropriate handling and storage practices, frequent equipment inspections, sophisticated leak detection systems, personnel awareness and competency development programs, emergency response planning, and adherence to occupational safety legislation. The chance of accidents can be greatly decreased and overall workplace safety performance can be improved by including these measures into a thorough Safety Management System [5].

In sectors that handle anhydrous ammonia, risk assessment and hazard identification are very crucial. Organisations can identify possible sources of risk, assess the likelihood and seriousness of unfavourable events, and implement suitable control measures thanks to these procedures. Ammonia-related risks are frequently assessed using a variety of risk assessment methods, including as Hazard Identification (HAZID), Hazard and Operability Studies (HAZOP), Failure Mode and Effects Analysis (FMEA), and Quantitative Risk Assessment (QRA). By putting these approaches into practice, organisations can increase risk management decision-making processes, enhance emergency readiness, and create proactive safety measures [6].

Employee involvement is essential to preserving ammonia safety in addition to technological and operational safeguards [7]. Employees that are well-versed in safety procedures, emergency protocols, and danger identification are better able to avoid mishaps and react to emergencies. Regular emergency drills, safety awareness campaigns, and ongoing training programs all help to build a strong safety culture and motivate staff members to take an active role in workplace safety

initiatives [8]. These initiatives enhance organisational resilience and regulatory compliance in addition to lowering occupational risks.

In light of this, the current study investigates the role that safety management systems have in controlling the dangers related to anhydrous ammonia. Employee awareness of safety management procedures, perceived risks associated with ammonia exposure, the efficacy of current safety precautions, and methods for enhancing workplace safety are the main topics of the study. In order to facilitate the safe handling, storage, transportation, and use of anhydrous ammonia, it also examines risk assessment methods, preventive measures, emergency response plans, and legal requirements. The study intends to improve knowledge of ammonia safety management through this analysis and offer suggestions for enhancing safety procedures in industrial settings.

1.1. Objectives of the Study

1. To examine the concept and importance of Safety Management Systems (SMS) in industrial workplaces.
2. To identify the hazards and risks associated with the storage, handling, and transportation of anhydrous ammonia.
3. To evaluate safety measures, risk control practices, and emergency response procedures for preventing ammonia-related incidents.
4. To suggest effective strategies for improving anhydrous ammonia safety through the implementation of a comprehensive Safety Management System.

1.2. Hazard Identification and Risk Assessment of Anhydrous Ammonia

Anhydrous ammonia (NH_3) is a colorless gas characterized by a sharp and pungent odor and is one of the most widely utilized industrial chemicals worldwide. Fertiliser production, refrigeration systems, food processing businesses, chemical manufacturing facilities, pharmaceutical companies, and new hydrogen energy uses all depend on it. Ammonia is generated, stored, transported, and handled in huge quantities every day due to its widespread industrial use and economic significance. Because of its poisonous, corrosive, and sometimes combustible qualities, anhydrous ammonia is categorised as a hazardous chemical despite its many industrial advantages [9]. As a result, ammonia-using enterprises need to have thorough safety protocols to safeguard employees, machinery, the environment, and nearby communities.

Anhydrous ammonia is dangerous due in large part to its physical and chemical properties. Ammonia is a gas in normal air circumstances, but it can be kept as a liquid under moderate pressure. Liquid ammonia quickly expands and vaporises when released from pressurised systems, creating a dense cloud of deadly vapour. Workers and surrounding residents may be exposed to hazardous concentrations of this vapour as it spreads swiftly. Ammonium hydroxide, a corrosive substance that can result in severe chemical burns, is created when ammonia, which is extremely soluble in water, combines with moisture found in human tissues. Ammonia can also react with specific materials and chemicals, raising additional safety issues in industrial processes. Ammonia can produce combustible mixtures in certain concentration ranges and climatic conditions,

increasing the risk of fire and explosion even though it is not very flammable under normal circumstances.

Anhydrous ammonia exposure poses major health risks as well as issues with workplace safety. The concentration of exposure, length of contact, and mode of exposure all affect how severe the health impacts are. Even at comparatively low doses, inhalation—the most common exposure route—can irritate the nose, throat, and respiratory system. Higher quantities can cause pulmonary oedema, severe coughing, breathing problems, chest pain, and long-term lung damage. Because liquid ammonia cools quickly during expansion, direct contact with it can result in frostbite injuries. Ammonia exposure can also result in corneal damage, severe skin burns, eye discomfort, and, in severe situations, lifelong blindness. If prompt medical assistance is not given, extremely high ammonia concentrations can be lethal. Therefore, ammonia-related occupational safety procedures must include employee knowledge, appropriate training, and the usage of personal protective equipment [10].

Numerous variables, such as equipment malfunction, pipeline rupture, valve failure, corrosion, poor maintenance, design flaws, operational errors, and transportation events, can result in industrial accidents involving anhydrous ammonia. One of the biggest causes of ammonia-related mishaps is still human error, especially when employees disregard safety regulations or regular operating procedures. Toxic gas exposure, environmental contamination, production interruptions, property damage, and financial losses are all possible outcomes of accidental releases. Large-scale ammonia leaks can affect nearby communities by poisoning water and air supplies and requiring emergency evacuation protocols. Even a relatively tiny ammonia leak might have serious repercussions if improperly regulated, as historical industrial events have shown. In order to react quickly to unintentional leaks, organisations must constantly monitor operational circumstances and create efficient emergency preparedness strategies.

Risk assessment and hazard identification are essential components of a successful safety management system. Identifying possible sources of risk related to ammonia handling, storage, transportation, and processing operations is known as hazard identification. Risk assessment methods are used to determine the likelihood of occurrence and the seriousness of any repercussions after risks have been identified. In industrial contexts, a number of well-established approaches are frequently employed. Hazard Identification (HAZID) assists in identifying potential risks at various phases of operation. Deviations from intended operating conditions and their possible effects are methodically examined by the Hazard and Operability Study (HAZOP). Equipment failures and their effects on system performance are assessed using Failure Mode and Effects Analysis (FMEA). Mathematical models are used in Quantitative Risk Assessment (QRA) to calculate the probability and consequences of accident scenarios. By using these strategies, organisations may efficiently allocate resources, prioritise risks, and put in place appropriate control mechanisms to reduce hazards [11].

Organisations must put in place thorough preventive and mitigation procedures to lessen the probability and effects of ammonia-related events. Proper facility design, routine equipment maintenance and inspection, installation of leak detection systems, automated shutdown mechanisms, pressure relief devices, and continuous monitoring technologies are examples of preventive measures. To make sure that employees are aware of ammonia hazards, emergency protocols, and safe handling techniques, frequent employee training sessions should be held. Minimising exposure hazards requires the use of personal protective equipment, such as respiratory protection, chemical-resistant clothes, goggles, gloves, and face shields. Furthermore, it is important to construct and regularly assess disaster preparedness measures, such as evacuation plans, emergency response teams, spill containment protocols, first-aid facilities, and frequent mock drills. The efficacy of safety management procedures is further reinforced by regulatory compliance, safety audits, and continuous improvement programs.

2. REVIEW OF LITERATURE

Maia et al. (2025) carried out a thorough analysis of ammonia handling safety procedures in industrial, energy, and propulsion applications. The study looked at the increasing use of ammonia as a fuel and energy carrier and emphasised the safety issues related to its manufacture, storage, use, and transportation. In order to highlight the significance of putting strong safety procedures and risk management frameworks in place, the authors examined a number of accident scenarios involving ammonia leakage, unintentional exposure, and operational failures. According to the review, engineering controls, continuous monitoring systems, emergency preparedness measures, and employee training programs are all necessary for efficient safety management. The authors also stressed that the creation of thorough safety regulations, regulatory compliance, and technological developments targeted at lowering operating risks are critical to the successful integration of ammonia into developing energy sectors. The study found that in order to reduce accidents and guarantee the safe use of ammonia in industrial and energy-related applications, proactive safety procedures and strategies for continuous improvement are crucial [12].

Khudhur et al. (2022) provided a thorough analysis of the risk assessment techniques and safety concerns related to industrial ammonia refrigeration systems. The study looked into the operational risks that are frequently seen in refrigeration plants, such as corrosion, equipment failure, pressure system failures, ammonia leaks, and human mistake. The authors examined how well different risk assessment techniques work in industrial environments and talked about how well they can detect and reduce possible risks. The results showed that because ammonia is poisonous and corrosive, ammonia refrigeration systems, despite their high efficiency, present serious dangers. In order to reduce workplace accidents, the evaluation emphasised the significance of emergency response planning, leak detection technology, preventive maintenance programs, and systematic hazard identification procedures. The study also highlighted how operational reliability and workplace safety are greatly enhanced by frequent personnel training and rigorous adherence to safety regulations. The authors came to the conclusion that industrial refrigeration facilities can

successfully lower operating risks and improve safety performance by including risk assessment procedures into a thorough Safety Management System [13].

Shikder et al. (2025) examined risk situations related to anhydrous ammonia transportation as a new source of clean energy. The study concentrated on identifying transportation-related risks and assessing their possible outcomes in light of the growing demand for ammonia as an alternative fuel and hydrogen carrier. The flow of ammonia via pipelines, railroads, road tankers, and marine transportation systems was examined by the authors in relation to historical event data, accident scenarios, transportation routes, and risk variables. The results showed that unintentional emissions during transportation could have detrimental effects on infrastructure, public safety, human health, and the environment. According to the report, human error, insufficient safety protocols, equipment failure, and transportation accidents are the main causes of transportation-related occurrences. In order to reduce transportation hazards, the authors also stressed the significance of putting in place cutting-edge monitoring technologies, real-time leak detection systems, strict regulatory frameworks, and well-developed emergency response plans. The study came to the conclusion that in order to guarantee the secure and sustainable transportation of anhydrous ammonia in future energy supply chains, a proactive risk management strategy is crucial [14].

Kocsis et al. (2015) carried out an industrial safety analysis of ammonia-related incidents, focusing on cold storage and refrigeration facilities. In order to determine the main causes and contributing elements of ammonia-related mishaps, the study looked at past accident records and incident reports. According to the investigation, the most common causes of ammonia escapes and industrial accidents were corrosion, poor maintenance procedures, equipment malfunction, operational flaws, and human error. The authors noted that regular inspections, timely maintenance, improved staff awareness, and appropriate safety management procedures could have avoided numerous accidents. The study also emphasised the detrimental effects of ammonia leaks on human health and the environment, such as respiratory ailments, hazardous exposure, property damage, and disruptions to operations. The authors suggested implementing thorough safety management plans, frequent safety audits, employee training programs, emergency preparedness measures, and ongoing monitoring systems in light of the findings. The study came to the conclusion that in order to minimise accidents and enhance overall industrial safety performance, organisations handling ammonia must implement a proactive safety culture and uphold rigorous adherence to safety standards [15].

3. RESEARCH METHODOLOGY

The methodical approach used to gather, analyse, and interpret data in order to accomplish the goals of a research study is referred to as research methodology. It offers a methodical framework that guarantees the correctness, validity, and dependability of the study results. The efficiency of Safety Management Systems (SMS) in controlling the risks related to anhydrous ammonia was investigated in the current study using a suitable methodology. Assessing employee awareness,

identifying significant risks, analysing current safety precautions, and investigating methods to improve workplace safety are the main objectives of the methodology. To get thorough understanding of anhydrous ammonia safety procedures in industrial settings, both primary and secondary data sources were used.

3.1.Research Design

The present study adopted a descriptive research design to examine the role of Safety Management Systems (SMS) in ensuring anhydrous ammonia safety in industrial environments. Because it makes it easier to gather, analyse, and interpret data on employees' understanding of safety procedures, perceived risks, the efficacy of current safety measures, and methods for enhancing ammonia safety, the descriptive approach was deemed suitable.

3.2.Population of the Study

The population of the study consisted of employees working in industries where anhydrous ammonia is utilized, including safety officers, plant operators, maintenance personnel, supervisors, and other workers involved in the handling, storage, and transportation of ammonia.

3.3.Sample Size

A sample of 100 respondents was selected for the study. The sample represented employees from different departments associated with safety management and ammonia handling operations.

3.4.Sampling Technique

Simple Random Sampling was employed to select respondents from the target population. This method reduced sampling bias and improved the dependability of the results by guaranteeing that every employee had an equal chance to participate in the study.

3.5.Sources of Data

Primary Data

Primary data were collected directly from respondents through a structured questionnaire designed to gather information regarding:

- Awareness of Safety Management Systems.
- Perceived hazards associated with anhydrous ammonia.
- Effectiveness of existing safety measures.
- Preferred strategies for improving workplace safety.

Secondary Data

Secondary data were collected from books, research articles, safety manuals, government regulations, industry reports, and published literature related to occupational safety, process safety management, and anhydrous ammonia handling practices.

3.6.Research Instrument

A structured questionnaire was used as the primary data collection instrument. Both closed-ended and multiple-choice questions covering different aspects of safety management and anhydrous ammonia safety were included in the questionnaire. The tool was created to guarantee answer simplicity, dependability, and clarity.

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3.7.Data Collection Procedure

Data were collected by distributing questionnaires to selected respondents. Participants were informed about the purpose of the study, and their responses were kept confidential. The completed questionnaires were collected, verified, and compiled for analysis.

3.8.Data Analysis Techniques

The collected data were analysed using simple statistical tools such as frequency distributions and percentage analysis. To make interpretation and comprehension easier, the results were displayed in tabular form. The investigation concentrated on determining awareness levels, significant safety risks, opinions about how well safety precautions work, and suggestions for enhancing anhydrous ammonia safety procedures.

4. RESULT AND DISCUSSION

The results and discussion section presents the findings obtained from the analysis of data collected from 100 respondents regarding Safety Management Systems (SMS) and Anhydrous Ammonia Safety. Employees' understanding of safety management procedures, their opinions of the risks connected to anhydrous ammonia, the efficacy of current safety precautions, and their preferred methods for enhancing workplace safety are the main topics of the investigation. The responses were interpreted using frequency and percentage analyses, which offered insightful information on the state of safety management in industries that use anhydrous ammonia. The results aid in comprehending staff readiness, risk perception, and safety priorities, which helps create safer management procedures.

Table 1: Awareness of Safety Management System (SMS)

Awareness Level	Frequency	Percentage (%)
Highly Aware	42	42.0
Aware	35	35.0
Moderately Aware	15	15.0
Slightly Aware	6	6.0
Not Aware	2	2.0
Total	**100**	**100.0**

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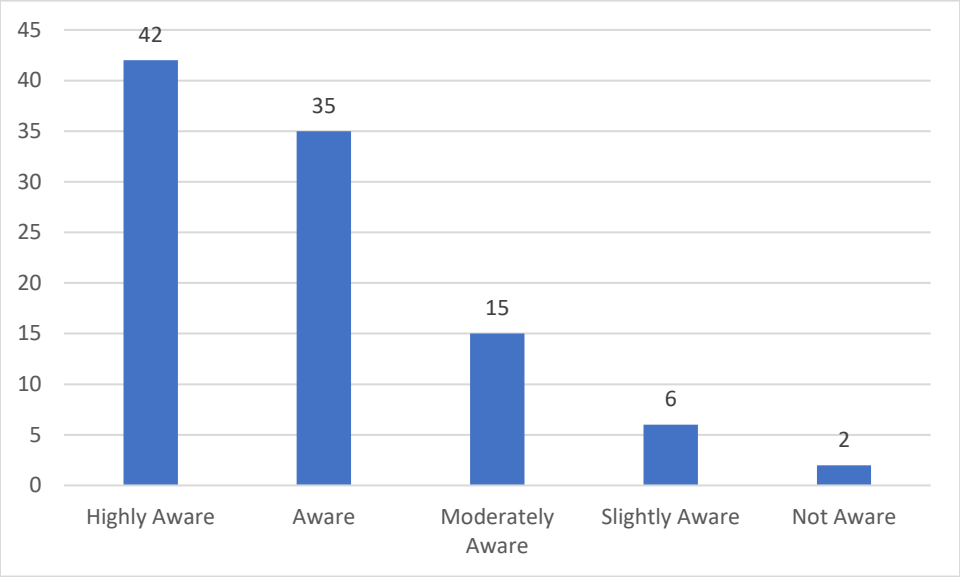

Figure 1: Graphical Presentation of Awareness of Safety Management System (SMS)

Table 1 reveal that a substantial majority of the respondents possess a good level of awareness regarding Safety Management Systems (SMS). Among the 100 respondents surveyed, 42% reported being highly aware of SMS practices, while 35% indicated that they were aware of the system and its operational procedures. Additionally, 15% of respondents were moderately aware, whereas only 6% were slightly aware and 2% were not aware at all. These findings suggest that safety management concepts are well recognized among employees working in environments where hazardous substances such as anhydrous ammonia are handled. The high level of awareness may be attributed to organizational safety training programs, workplace safety policies, and regulatory requirements.

Table 2: Perceived Hazards Associated with Anhydrous Ammonia

Hazard Type	Frequency	Percentage (%)
Toxic Gas Exposure	38	38.0
Respiratory Problems	27	27.0
Fire and Explosion Risk	18	18.0
Skin and Eye Burns	12	12.0
Environmental Pollution	5	5.0
Total	**100**	**100.0**

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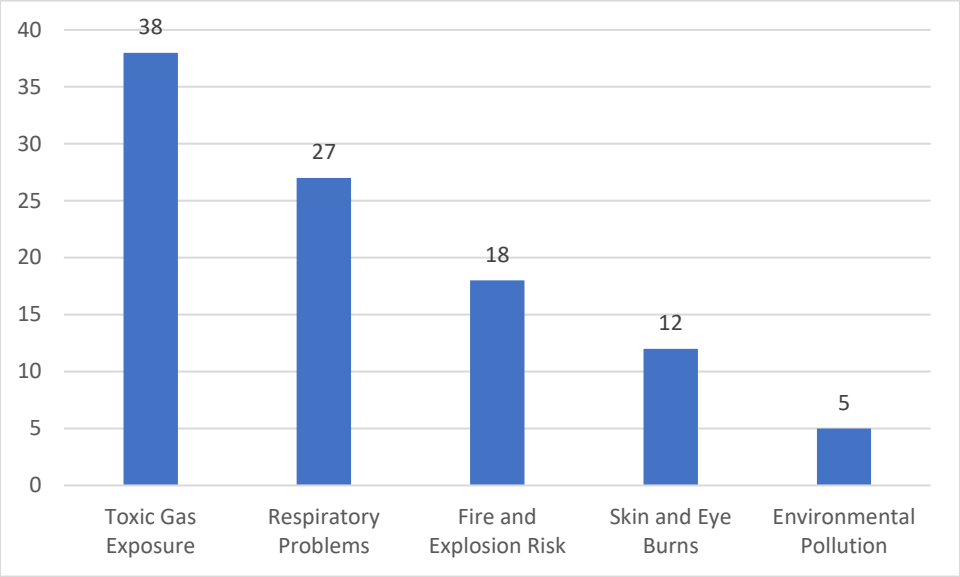

Figure 2: Graphical Presentation of Perceived Hazards Associated with Anhydrous Ammonia

Table 2 illustrates the respondents' perceptions of the major hazards associated with anhydrous ammonia. According to the results, 38% of respondents said that exposure to harmful gases is the biggest risk. Concerns about inhalation exposure and its negative health impacts were highlighted by the fact that 27% of respondents reported respiratory issues. 18% of respondents said there was a chance of fire and explosion, and 12% said burns to the skin and eyes were significant risks. Five percent of respondents said they were concerned about environmental contamination. The findings show that workers are especially conscious of the immediate health concerns associated with ammonia exposure. To reduce occupational and environmental risks, these findings highlight the significance of putting in place efficient hazard identification processes, leak detection systems, and emergency response mechanisms.

Table 3: Effectiveness of Existing Safety Measures

Response	**Frequency**	**Percentage (%)**
Highly Effective	31	31.0
Effective	40	40.0
Moderately Effective	18	18.0
Ineffective	8	8.0
Highly Ineffective	3	3.0
Total	**100**	**100.0**

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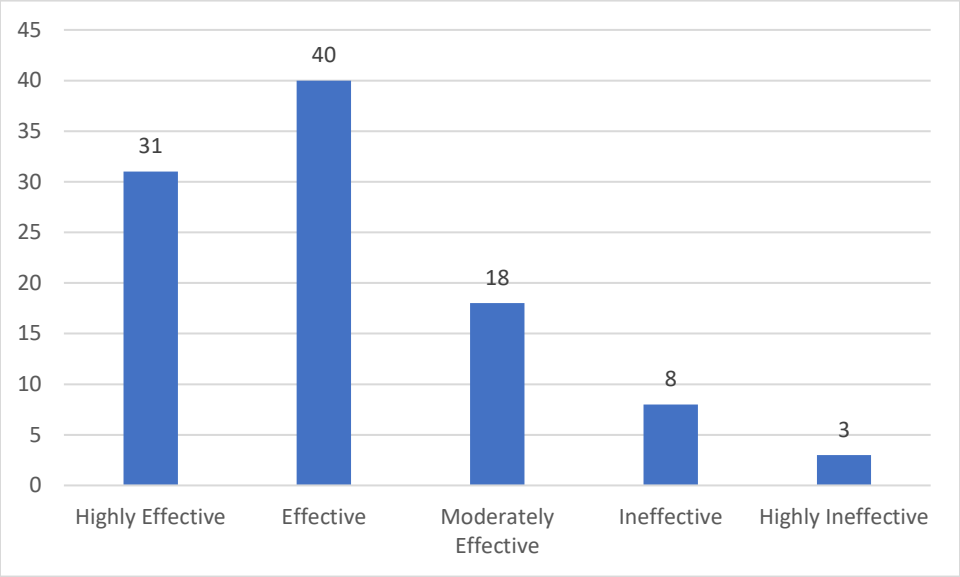

Figure 3: Graphical Presentation of Effectiveness of Existing Safety Measures

Table 3 indicate a generally positive perception of the effectiveness of existing safety measures for handling anhydrous ammonia. 40% of respondents thought the current safety measures were successful, while 31% thought they were very effective. Additionally, 18% of respondents thought the measures were somewhat successful. On the other hand, just 8% and 3% of respondents, respectively, said that the current policies were unsuccessful and extremely ineffective. The results imply that the majority of workers are confident in the safety protocols, tools, and management techniques used by their companies. To attain greater levels of workplace safety, however, it is still important to continuously enhance safety training, maintenance procedures, monitoring systems, and emergency readiness, as indicated by the number of respondents who voiced dissatisfaction with the current measures.

Table 4: Preferred Strategies for Improving Anhydrous Ammonia Safety

Safety Improvement Measure	**Frequency**	**Percentage (%)**
Regular Safety Training	34	34.0
Advanced Leak Detection Systems	28	28.0
Emergency Response Drills	20	20.0
Improved Personal Protective Equipment (PPE)	12	12.0
Strict Regulatory Compliance	6	6.0
Total	**100**	**100.0**

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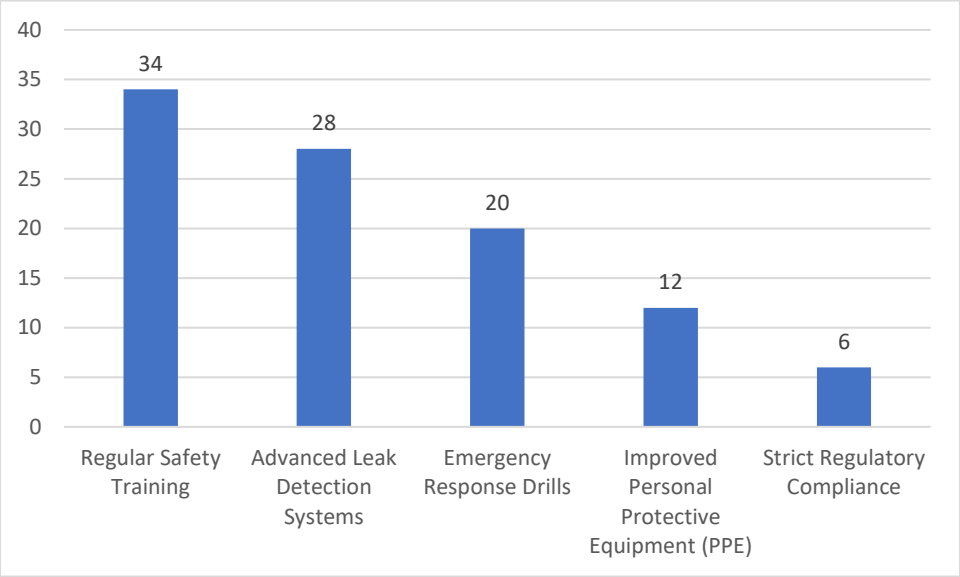

Figure 4: Graphical Presentation of Preferred Strategies for Improving Anhydrous Ammonia Safety

Table 4 identify the strategies most preferred by respondents for improving anhydrous ammonia safety. 34% of respondents chose regular safety training as their preferred course of action, demonstrating the perceived significance of employee competency and knowledge in averting accidents. 28% of respondents said they preferred advanced leak detection systems, highlighting the necessity of technology solutions to detect and control ammonia leaks early on. Twenty percent of respondents endorsed emergency response drills, indicating the significance of readiness in handling unintentional releases. Twelve percent of respondents selected better personal protective equipment (PPE), while six percent stressed more stringent regulatory compliance. These results show that workers value both preparedness-based and preventive methods to safety management, underscoring the necessity of an all-encompassing approach that incorporates technology, protective gear, training, and regulatory compliance.

5. CONCLUSION

The present study concludes that Safety Management Systems (SMS) play a crucial role in ensuring the safe handling, storage, transportation, and utilization of anhydrous ammonia in industrial environments. The findings indicate that the majority of employees possess a good level of awareness regarding safety management practices and recognize the significant hazards associated with anhydrous ammonia, particularly toxic gas exposure, respiratory problems, fire and explosion risks, and skin and eye injuries. The study further reveals that existing safety measures are generally perceived as effective in controlling workplace hazards and preventing accidents. However, the results also highlight the need for continuous improvement in safety management practices through regular safety training programs, advanced leak detection technologies, periodic emergency response drills, and the provision of appropriate personal

protective equipment. Effective hazard identification, risk assessment, preventive maintenance, and employee participation were found to be essential for reducing operational risks and enhancing workplace safety. Furthermore, strict compliance with safety regulations, continuous monitoring systems, and proactive risk management strategies are necessary to strengthen organizational safety performance and prevent ammonia-related incidents. Therefore, industries handling anhydrous ammonia should adopt an integrated approach that combines robust Safety Management Systems, technological safeguards, employee awareness, emergency preparedness, and regulatory compliance to create a safer, healthier, and more sustainable working environment while protecting workers, industrial assets, and the surrounding environment.

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