

# Risk Assessment of Chemical ( $H_3PO_3$ ) Plant and Storage Tank Hazards

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**Abstract-** Consequence analysis is a critical technique used to systematically evaluate the potential outcomes of hazardous events in industrial settings, such as chemical plants and storage tanks. This method involves predicting the magnitude and scope of consequences resulting from hazardous events, as well as estimating the likelihood or frequency of such occurrences. By grouping similar hazardous events, analysts can assess representative or bounding scenarios, providing a more comprehensive understanding of potential risks. Consequence analysis is typically carried out using specialized third-party software for consequence modeling and frequency assessment, although spreadsheets are often employed for certain calculations. This approach plays a pivotal role in ensuring safety, optimizing risk management strategies, and enhancing decision-making processes in industries dealing with hazardous materials.

**Keywords-** Phosphorous acid, RISK ASSESSMENT, hazardous materials, Frequency Analysis

## I. INTRODUCTION

In the increasingly complex and hazardous world of chemical processing, understanding and mitigating the risks associated with chemical substances is pivotal for ensuring safety and regulatory compliance. Phosphorous acid ( $H_3PO_3$ ), a compound with significant industrial applications, presents numerous challenges due to its reactive and corrosive nature. This paper delves into the myriad aspects of managing phosphorous acid in industrial settings, emphasizing the chemical properties, the routes of exposure and toxicity, storage concerns, protective equipment, and safety measures necessary for handling this hazardous material. Through an examination of these factors, the paper seeks to provide a detailed understanding of the potential hazards associated with phosphorous acid and the necessary precautions required to mitigate these risks.

Initially, the paper explores the intrinsic chemical properties and reactivity of phosphorous acid, focusing on its potential interactions with other substances. This analysis is crucial as phosphorous

acid's incompatibility with strong bases and certain metals poses significant risks, particularly within industrial environments that utilize metal equipment. By addressing the chemical's propensity to generate flammable and explosive hydrogen gas upon reacting with powdered metals or with specific bases like sodium hydroxide and potassium hydroxide, the paper underscores the need for stringent safety measures and proper storage protocols. These insights emphasize the critical importance of understanding chemical compatibility to prevent hazardous incidents.

Furthermore, the paper delves into the potential routes of exposure and toxicity associated with phosphorous acid. Its corrosive properties not only threaten safety at a chemical site but also compromise the integrity of material infrastructure surrounding containment systems. Through an examination of compatibility issues and storage tank design, the discussion illustrates the necessity of utilizing compatible materials that resist corrosive degradation. The focus extends to procedural and material precautions to manage the

risk of secondary reactions, such as the decomposition of phosphorous acid into phosphoric acid (Fig.1), further underscoring the multifaceted nature of chemical safety management in preventing unintended hazardous outcomes.

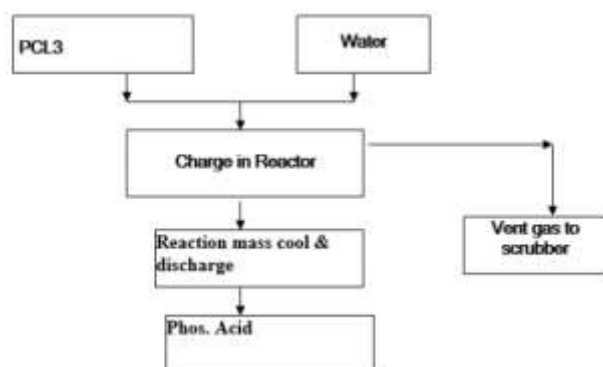


Figure 1: Process flow for phosphoric acid

In addressing these areas of concern, effective risk assessment methodologies, including both qualitative and quantitative analyses, are integrated into the safety protocols to evaluate and prioritize potential hazards. The methodology section emphasizes the importance of adopting multiple layers of safeguards and continuous process safety management systems. By weaving in historical incident analyses, this paper not only highlights strategies for enhancing operational safety but also brings attention to regulatory compliance and organizational practices imperative for fostering a proactive safety culture. Through this comprehensive approach, the paper equips chemical facilities with the foundational knowledge and strategic framework necessary for the safe management and handling of phosphorous acid.

## II. CHEMICAL HAZARDS AND RISKS

The chemical properties and reactivity of phosphorous acid ( $\text{H}_3\text{PO}_3$ ) present significant concerns due to its corrosive nature and potential for hazardous interactions. Phosphorous acid is an extremely reactive substance, particularly when its incompatibility with strong bases and certain metals comes into play. It is crucial to understand that when phosphorous acid comes into contact with finely powdered metals, it can "react... to form flammable and explosive hydrogen gas"[1]. This

presents a significant hazard, especially in industrial settings where metal equipment is prevalent. Furthermore, substances like sodium hydroxide and potassium hydroxide represent strong bases that should not be mixed with phosphorous acid due to this incompatibility[2]. These reactive characteristics underscore the necessity for stringent safety measures and storage protocols to mitigate risks associated with handling phosphorous acid.

Moreover, the corrosive nature of phosphorous acid is an essential factor to consider in its manipulation and storage. A chemical as corrosive if it causes visible destruction or irreversible alteration in living tissue at the contact site[4]. This attribute becomes particularly concerning when phosphorous acid contacts materials such as copper and stainless steel, as it is "extremely corrosive in presence of copper, of stainless steel(304), of stainless steel(316). Highly corrosive in presence of aluminium"[5]. The resultant materials degradation can lead to structural failures, chemical leakage, and significant safety hazards, reinforcing the need for compatible materials in construction and storage facilities. The corrosive properties thus necessitate a profound understanding and respect for the chemical's potential hazards, urging the implementation of appropriate safety measures.

In addition to its corrosivity and reactivity with metals, phosphorous acid's decomposition into phosphoric acid highlights further risks. The transformation of phosphorous acid under specific conditions, particularly when exposed to air, can lead to the formation of phosphoric acid, which carries its own set of risks[3]. This potential for decomposition requires that phosphorous acid is stored in "tightly closed containers in a cool, well-ventilated area" to minimize exposure to environmental elements that could trigger this reaction. The careful handling and storage protocols address these multifaceted hazards, ensuring that the chemical does not transform or react in ways that could jeopardize safety. These precautions and comprehensive understanding of phosphorous acid's properties are pivotal in preventing hazardous incidents and guaranteeing safe usage in various environments.

The chemical properties and reactions of phosphorous acid ( $\text{H}_3\text{PO}_3$ ) highlight significant risks, particularly when considering its incompatibility with various substances. Phosphorous acid, characterized by its corrosive and reactive nature, poses substantial threats when mishandled, especially in environments containing strong bases and finely powdered metals. The incompatibility with substances such as sodium hydroxide and potassium hydroxide, as well as certain metals, demands strict adherence to handling and storage protocols, as emphasized in guidance that stresses proper training prior to working with phosphorous acid [3]. This is vital to prevent reactions that could lead to potentially explosive outcomes, further illustrating the unpredictable nature of this chemical when not appropriately managed.

Furthermore, the corrosive properties of phosphorous acid present an additional layer of hazard, affecting both safety and infrastructure integrity. This underscores the imperative for using compatible materials in environments where phosphorous acid is present to avoid material degradation and eventual structural failures. Corrosivity in chemicals is defined as causing "visible destruction of or irreversible alteration in, living tissue by chemical action at the site of contact" [4]. Such definitions accentuate the significance of strict material compatibility and storage conditions to prevent the damaging effects of phosphorous acid on containers and protective equipment.

Additionally, under certain conditions, phosphorous acid can decompose into phosphoric acid, leading to further risks. This decomposition process, highlighted by the potential for external environmental factors to affect the stability of phosphorous acid, necessitates its storage in "tightly closed containers in a cool, well-ventilated area away from air" [3]. Such measures are essential to prevent inadvertent reactions and ensure the chemical remains stable over time. Moreover, the formation of phosphoric acid is not merely a transformation concern; it too can react with finely powdered metals to produce hydrogen gas, a

volatile and hazardous outcome [3]. Comprehensive understanding and implementation of these safety protocols and precautions are critical for preventing hazardous situations and safeguarding both personnel and facilities from the extensive dangers associated with phosphorous acid.

### **III. PHYSICAL HAZARDS IN CHEMICAL STORAGE**

In the design and construction of storage tanks for phosphorous acid, the critical factor is the material compatibility to prevent corrosion and potential leaks. Phosphorous acid exhibits "extreme corrosivity in the presence of copper, stainless steel (304 and 316), and high corrosivity in the presence of aluminum" [5]. Such corrosive interactions underscore the necessity for selecting materials that can withstand the reactive nature of phosphorous acid. Materials like special alloys or non-metallic components may offer better resistance, ensuring the structural integrity of the storage tanks. The attention to compatible materials is vital to prevent not only leaks but also structural failures, which could lead to hazardous chemical exposures and environmental contamination.

Furthermore, the implementation of secondary containment systems plays a pivotal role in mitigating risks associated with phosphorous acid storage. The incorporation of such measures ensures a layered approach to safety, effectively managing potential leaks and spills. Facilities often "utilize as many layers as necessary to adequately control their process hazards, with preference given to more reliable safeguards" [8]. This systematic approach may include containment dikes, double-walled tanks, or other barriers that contain any accidental releases. Minimizing the stored quantity is another critical strategy, as storing only the essential amount required for operations reduces the magnitude of potential hazards. Consequently, these design principles and safety features enhance the overall safety profile of facilities handling phosphorous acid.

By adhering to these guidelines, facilities can proficiently manage the risks associated with

phosphorous acid storage. The overall goal is to ensure the tank system's reliability and safety, fulfilling regulatory requirements while safeguarding employees and the environment. This methodological framework supports that "the facility can confidently manage the risks associated with the storage tank" [8]. Comprehensive risk management strategies, including proper training and adherence to safety protocols, solidify the facility's commitment to minimizing hazards. In tandem with regular maintenance and inspections, these efforts culminate in a robust safety structure that mitigates the inherent risks associated with storing such a hazardous chemical.

In analyzing the complexities involved in the storage of phosphorous acid, it is imperative to recognize the chemical's reactive nature, which poses significant challenges. Phosphorous acid exhibits incompatibility with various substances and is notably reactive with oxidizing agents, combustible materials, metals, and alkalis. Its extreme corrosivity in the presence of metals such as copper, stainless steel (types 304 and 316), and aluminum underscores the critical importance of using materials that can resist such corrosive interactions [5]. The utilization of specialized materials, such as certain alloys or non-metallic substances, becomes crucial in maintaining the structural integrity of storage tanks and mitigating the risks of leaks and failures. Therefore, selecting the right materials is foundational in reducing the likelihood of chemical exposure and environmental contamination.

Moreover, the implementation of appropriate safety measures within the storage infrastructure cannot be overstated. Facilities typically utilize as many layers as necessary to adequately control their process hazards. The preference for reliable safeguards is evident in the strategic design of storage systems, which prioritize safety and risk minimization [8]. For example, secondary containment systems, such as double-lined tanks and containment dikes, are integral to preventing accidental releases. Furthermore, minimizing the stored quantity of phosphorous acid within the tanks inherently reduces the potential hazard, as

less material equates to a lower risk in case of an incident. Such rigorous adherence to containment protocols bolsters the facility's capacity to control chemical hazards effectively.

Additionally, a holistic approach to managing the risks associated with phosphorous acid storage involves robust methodologies that encompass both preventive and corrective measures. By ensuring a facility can confidently manage the risks associated with the storage tank, the safety infrastructure is not only compliant but also proactive [8]. Comprehensive risk assessments, ongoing training, and strict safety protocols are vital in preparing for and mitigating potential chemical hazards. These actions are complemented by regular maintenance and inspections that verify the efficacy of existing safety measures and facilitate the early detection of any vulnerabilities. Collectively, these efforts forge a resilient safety framework that anticipates and addresses the inherent dangers of storing phosphorous acid, thereby safeguarding personnel, assets, and the environment.

In discussing the recommended protective equipment for handling phosphorous acid, several materials are advised for ensuring safety while minimizing exposure risks. Safety equipment manufacturers recommend Natural Rubber, Nitrile Rubber, Polyvinyl Chloride, Viton, or Neoprene as protective materials, noting their effective resistance to the corrosive properties of phosphorous acid [1]. The selection of these materials is vital for personal protective equipment (PPE), such as gloves, to prevent dermal absorption and subsequent irritation or burn injuries. The deployment of these materials enhances protective barriers, crucial in operations that involve the manipulation of hazardous chemicals. Additionally, the appropriate use of these materials reflects an understanding of chemical compatibility, reinforcing the importance of occupational safety in chemical handling environments.

Respiratory protection also forms a critical component of the safety measures required in environments with potential phosphorous acid

exposure, particularly through inhalation. In scenarios where exposure levels exceed  $1 \text{ mg/m}^3$ , using a NIOSH-approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode is essential to safeguard respiratory health [1]. However, improper use of respirators is dangerous, and such equipment should only be used if the employer has a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in OSHA 1910.134 [3]. Comprehensive training programs and safety protocols are necessary to ensure that protective equipment is correctly utilized, thereby averting potential health risks associated with inhalation of toxic fumes.

Moreover, the appropriate use of protective equipment is essential when managing the byproducts of phosphorous acid combustion, which may include phosphine, oxides of phosphorus, and hydrogen gas. These byproducts necessitate additional precautions, such as wearing protective equipment and using respiratory protective devices against the effects of fumes, dust, aerosols, or vapor, as outlined by Global Safety Management[6]. The complexity of chemical handling in settings with combustion risk underscores the necessity for rigorous safety protocols and equipment usage. This comprehensive approach not only mitigates the immediate dangers posed by phosphorous acid and its byproducts but also contributes to a proactive safety culture that prioritizes the health and safety of personnel, thereby ensuring a secure working environment.

#### IV. PROCEDURAL HAZARDS AND REGULATORY COMPLIANCE

Effective training programs for handling phosphorous acid are critical in preventing accidents and ensuring safety in chemical facilities. Employees must be equipped with the knowledge and skills necessary to handle such hazardous substances safely. Comprehensive training programs are not merely about imparting information; they involve a thorough understanding

of the chemical's properties, potential risks, and the procedures for safe handling. A key aspect of these training programs involves site-specific training, which tailors the information to the specific conditions and equipment used at a particular location. It is imperative that, as stipulated, Supplemental site-specific training, shall be given by the Principal Investigator or Responsible Supervisor for all employees and work-study's who work with hazardous chemicals. Documentation shall be maintained for 5 years[4]. This ensures that all personnel are aware of and understand how to safely manage phosphorous acid in their unique work environments (Table 1).

Table 1: Assumptions and their purpose

Description	Assumption Purpose
Scope of Work	Defining Boundary
Meteorological Data	Defining parameters for consequence modelling and risk estimation
Release Direction / release height	Consequence Analysis
Representative Hole Sizes	Consequence Analysis/Frequency Analysis
Release Frequencies	Base release frequencies for flanges, valves, pipe work, instrument connection and vessels
Isolatable section and Inventories	Criteria of defining isolatable sections
Hazard Scenarios	Release outcome & damage distances
Ignition Probabilities	Event Frequency Estimation
Representative Streams	Consequence Modelling
Isolation Time and Blow down	Inventory Analysis
Parts Count	Frequency Analysis
Impact Criteria	Impact Criteria are required in order to define the impact of defined physical effects on the receptors.
Consequence Modelling	Impacts the consequence results
List of Isolatable sections	Listing the scenarios for consequence modelling

In addition to tailored training programs, the role of administrative controls is fundamental in hazard prevention. These controls create a framework within which all safety procedures and protocols are executed. As noted, prevention remains paramount: Prevention is the most effective means of hazard control. Prepare your work area before beginning any work! Administrative controls: Ensure personnel are adequately trained on the chemicals and associated processes[7]. Administrative measures include establishing standard operating procedures, maintaining accurate records of training and incidents, and ensuring that all safety data sheets are accessible and understood. The coordination between administrative controls and training programs ensures that employees are not only informed but are also practicing safe chemical handling and hazard prevention measures consistently.

Furthermore, the integration of safety management practices is crucial in maintaining a safe working environment. Safety management involves continuous evaluation and improvement of safety protocols to adapt to new challenges and technological advancements. A robust safety management system encompasses risk assessments, regular safety audits, and feedback mechanisms that encourage reporting of unsafe conditions without fear of reprisal. By fostering a culture of safety where employees are empowered to take proactive measures, companies can significantly reduce the likelihood of accidents and ensure compliance with safety regulations. Comprehensive training and effective administrative controls form the backbone of such a safety culture, ensuring that all personnel are prepared to handle phosphorous acid safely and responsibly.

In addressing the safety protocols necessary for handling phosphorous acid, the foundation of any effective hazard prevention strategy lies in the institution of comprehensive training programs tailored to specific site conditions. Employees need to not only understand the inherent dangers associated with phosphorous acid but also how these manifest in their unique work environments.

This necessitates site-specific training regimes in which pertinent details, adapted to the physical and procedural nuances of the location, are conveyed. As outlined in the safety protocols, Supplemental site-specific training, shall be given by the Principal Investigator or Responsible Supervisor for all employees and work-study's who work with hazardous chemicals. Documentation shall be maintained for 5 years[4]. By adhering to these guidelines, organizations ensure that their personnel possess the competences required to manage phosphorous acid safely.

The implementation of robust administrative controls complements these training efforts by establishing a structured environment where safety is prioritized. It is crucial to prepare workspaces and operate within a clear framework that facilitates the execution of safety procedures impeccably. These controls encompass the formulation of standard operating procedures, the maintenance of comprehensive records of all training and incident reports, and the assurance that safety data sheets are both accessible and comprehended by all employees. Such measures enable a seamless integration of training and procedural compliance, fostering a resilient safety culture within the workplace[7].

Moreover, safety management practices play a pivotal role in the continuous improvement and adaptation of safety protocols necessary for phosphorous acid handling. By embedding risk assessments and conducting frequent safety audits, organizations can identify potential weaknesses in their existing systems and address them proactively. Creating an environment that encourages feedback and the reporting of unsafe conditions without repercussions further strengthens this safety framework. Consequently, fostering a workplace culture where employees are empowered to engage in proactive safety management not only reduces the likelihood of accidents but also ensures regulatory compliance. Through comprehensive training, diligent administrative controls, and dynamic safety management practices, organizations can establish a safe and responsible working environment.

## V. RISK ASSESSMENT METHODOLOGIES

Risk assessment in chemical plants is a multifaceted endeavor that encompasses both qualitative and quantitative methodologies. These methodologies serve as crucial tools in the identification and evaluation of potential hazards within the chemical industry. The qualitative approach often involves expert judgment and the use of checklists or hazard indices, which are essential in providing a broad overview of risk factors. Quantitative methods, on the other hand, delve deeper into numerical analysis and probabilistic modeling to assess the likelihood and impact of hazardous events. Both approaches are integral in prioritizing risks and formulating necessary mitigation strategies. The integration of both qualitative and quantitative data enhances the accuracy and reliability of risk assessments, making them indispensable tools for maintaining safety within chemical plants.

A significant component of risk assessment lies in historical incident analysis. By examining past events, chemical plants can identify patterns and prevent future occurrences. Best practices in safety management, such as process safety management (PSM) systems, are often rooted in the lessons learned from historical incidents. These practices are vital for facilitating a proactive rather than reactive approach to safety. The Environmental Protection Agency underscores the comprehensive integration of risk management strategies, highlighting that these strategies should encompass the entire lifecycle of chemical processes, "from initial process and facility design, through initial startup, to on-going operations"[8]. Such integration ensures that safety is a continuous consideration, adapting and enhancing strategies as the process and environmental conditions evolve.

Enhancing safety and operational efficiency also involves the implementation of multiple layers of safeguards. As highlighted, "facilities typically utilize as many layers as necessary to adequately control their process hazards, with preference given to more reliable safeguards" [8]. For instance, the design of atmospheric storage tanks involves

minimizing the amount of hazardous material stored and incorporating secondary containment provisions. This approach not only mitigates the risk of leaks and structural failures but also aligns with inherent safety principles. The continuous evolution of risk mitigation strategies, driven by technological advancements and regulatory requirements, underscores the importance of adaptability in chemical risk management. As such, ongoing improvements and the adoption of best practices are essential in enhancing the overall safety and efficiency of chemical plant operations.

In assessing risks in chemical plants, qualitative and quantitative methodologies serve as pivotal tools for understanding and addressing potential hazards. The qualitative approach often involves a systematic evaluation using expert judgments, checklists, and hazard indices to provide a comprehensive overview of potential risk factors. This broad assessment is essential for recognizing various types of hazards that may not be immediately apparent and setting the stage for more detailed analyses. Quantitative methods, in contrast, rely on numerical data and probabilistic modeling to examine the likelihood and severity of hazardous events. These methods are invaluable for identifying the probability of risk occurrence and understanding its potential impact. The combined use of both qualitative and quantitative approaches in risk assessment ensures a thorough evaluation, facilitating informed decision-making and prioritizing risks for effective mitigation strategies.

Enhancing risk assessment requires integrating historical incident analysis with best practices in safety management. Historical data provide crucial insights into recurring patterns, enabling the mitigation of potential dangers and the prevention of similar occurrences. The Environmental Protection Agency emphasizes the significance of adopting risk reduction strategies across the lifecycle of a chemical process, stating, "the integration of a variety of risk reduction or risk management strategies that work toward making a facility and its chemical processes as safe as possible. Usually, these strategies are applied to a chemical process throughout its life cycle: from

initial process and facility design, through initial startup, to on-going operations" [8]. This comprehensive perspective ensures that safety measures are not static but are continuously adapted as processes develop and conditions change. By implementing lessons learned from past events, chemical plants can foster a proactive safety culture that anticipates and mitigates potential risks before they occur.

Further complexity arises in managing process hazards through a layered approach to safeguards, as different risk controls are employed throughout a facility. For instance, the design and operation of storage tanks holding hazardous chemicals involve implementing numerous protective layers, as articulated, "Facilities typically utilize as many layers as necessary to adequately control their process hazards, with preference given to more reliable safeguards. Thus, an atmospheric storage tank containing a highly hazardous chemical might contain the minimum amount of material needed for the process to operate reliably (inherent - minimization), have secondary containment provisions"[8]. Such strategies not only conform to inherent safety principles by reducing the quantity of hazardous materials stored but also ensure that additional containment measures mitigate the risk of accidental releases. These multi-layered protective strategies, combined with ongoing safety improvements, reinforce the commitment to maintaining high safety standards and operational efficiency in chemical plants.

## VI. CONCLUSION

The concluding examination of phosphorous acid's properties and handling underscores the quintessential importance of safety protocols and risk assessment in chemical management. Phosphorous acid's reactivity, corrosivity, and decomposition potential present a complex web of hazards that necessitate a multi-faceted approach to prevention and control. The intrinsically dangerous interactions with strong bases and finely powdered metals, culminating in the formation of explosive hydrogen gas, demand rigorous training and adherence to strict safety measures within

industrial settings. Moreover, its corrosive impact on metal infrastructure and capacity to rapidly degrade materials like copper and stainless steel further emphasize the critical need for selecting compatible materials in storage and construction, to prevent chemical leaks and equipment failures.

The paper highlights the necessity for comprehensive understanding and stringent governance in the storage and handling of phosphorous acid. This involves utilizing advanced storage tank designs comprised of non-metallic materials or special alloys, alongside implementing secondary containment systems and reducing stored quantities. Together, these strategies form a robust framework that effectively contains and minimizes the physical hazards posed by phosphorous acid. The adherence to such sophisticated engineering controls not only safeguards facilities from potential exposure and contamination but also aligns with best practices of risk mitigation strategies, reinforcing safety throughout the chemical lifecycle from design to operation.

Additionally, the human element plays a pivotal role in managing the risks associated with phosphorous acid. Establishing comprehensive training programs tailored to site-specific conditions is indispensable. Such programs ensure that personnel are equipped with the necessary knowledge and skills to handle phosphorous acid safely, emphasizing preventative strategies to mitigate potential incidents.

The integration of administrative controls further supports a structured approach to safety, ensuring that procedures are consistently followed. This seamless coordination between training and procedural compliance forms the backbone of a resilient safety culture. Coupled with continuous evaluation and evolution of safety management practices, facilities can proficiently mitigate hazards and ensure compliance with regulatory requirements, thus exemplifying a proactive approach in maintaining occupational safety and environmental integrity.



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