Introduction

Phosphoric acid, or orthophosphoric acid, is an acidic oxide containing phosphorus, with the chemical formula H_3PO_4. It is considered a triprotic acid. This chemical compound ranks second globally in production, after sulfuric acid. It plays a crucial industrial role, mainly used in fertilizer production (accounting for about 85%), metal surface treatment, pharmaceutical industries, fermentation processes, wastewater treatment, cleaning products, heat-resistant adhesives, as well as in mineral chemistry and food industries.

2. Properties of Phosphoric Acid

- Phosphoric acid is a triprotic acid that can donate three protons (H^+) to form salts such as dihydrogen phosphate, hydrogen phosphate, and phosphate.
- At room temperature, pure anhydrous phosphoric acid is a white solid with a density of 1.83. It melts at 42.4°C, turning into a viscous, colorless liquid. It is highly soluble in water.
- Phosphoric acid is non-flammable and non-explosive. However, when it reacts with metals, hydrogen is released, which is highly flammable, and forms an explosive mixture with oxygen in the air in concentrations ranging from 4% to 75%. It can also form flammable or explosive mixtures with nitrates, chlorides, and calcium carbide.
- Phosphoric acid causes corrosion of ferrous metals, zinc, and aluminum. Stainless steel, copper, bronze, and brass resist pure acid well, but they are affected by industrial or technical acids. Only lead, carbon, graphite, and some rubber materials resist it well (at temperatures between 100°C and 110°C).

3. Uses of Phosphoric Acid

Phosphoric acid, with the molecular formula P_2O_5, is a key material in the chemical industry, often ranking second in usage after sulfuric acid (H_2SO_4). Its annual production reaches about 65 million tons, compared to 40 million tons in the late 1970s. It is used in aqueous solutions in many essential applications, including :

- Production of superphosphate fertilizers.
- Manufacturing of detergents and various types of phosphates.
- Rust removal and metal surface treatment.
- Cleaning of metal and other solid surfaces such as tiles and ceramics.
- Cleaning production equipment in food industries.
- Used as an adhesive for heat-resistant materials and ceramics.
- In the food industry as an acidulant, especially in cola beverages.
- Wastewater treatment.
- Reacting with latex rubber.
- Catalyzing acid processes in petrochemical industries.
- Pharmaceutical manufacturing.
- Used as a pH regulator and antioxidant.
- Textile dyeing.
- Fertilizer production.

4. Phosphoric Acid Production Processes

Phosphoric acid is produced using two different methods with varying raw materials :

4.1. Thermal Process

Phosphorus in phosphate rock is sublimed by heating at high temperatures with carbon in the form of coke.

This conversion occurs in an electric furnace heated to 1500°C.

Phosphorus is then separated at 45°C in a scrubbed column.

The liquid phosphorus undergoes oxidation in a combustion furnace, converting to P_2O_5, which is then hydrated to produce phosphoric acid. This method produces high-purity phosphoric acid but consumes a large amount of energy, making the product expensive.

4.2. Wet Process

This method involves reacting phosphate rock with sulfuric acid under specific temperature conditions according to the following reaction : Phosphate + Sulfuric Acid + Water → Phosphoric Acid + Gypsum. The wet process is divided into four main stages :

1. Raw material preparation, either dry phosphate rock or phosphate slurry.
2. Attacking the raw material with a strong acid (typically sulfuric acid, though nitrogen or hydrochloric acids may also be used).
3. Filtration to extract phosphoric acid.
4. Neutralization, forming the final product and secondary by-products.

Note : Neutralization is a chemical process aimed at adjusting or neutralizing the acidity or alkalinity of a substance by adding another material with opposing properties. In phosphoric acid manufacturing, neutralization involves adding an alkaline substance (such as sodium hydroxide or lime) to neutralize the acidity of the produced acid. Wet processes are widely used in the global industry because they produce phosphoric acid at a low cost.

This process uses pure fluorapatite to represent phosphate rock. The crystallized nature of gypsum varies with the "n" value :

- n = 0 → $CaSO_4$: Anhydrous method → Reaction temperature > 105°C, P_2O_5 concentration between 50% and 55%.
- n = 1/2 → $CaSO_4 \cdot 1/2\ H_2O$: Semi-hydrous method → 30°C < T < 100°C, P_2O_5 concentration between 40% and 50%.
- n = 2 → $CaSO_4 \cdot 2H_2O$: Fully hydrous method → 70°C < T < 80°C, P_2O_5 concentration between 28% and 32%.

5. Concentration

Phosphoric acid concentration is often expressed in terms of P_2O_5. The conversion equation is as follows:

$$[H_3PO_4] = [P_2O_5] \times 196 / 142$$

For example, if an acid contains 54% P_2O_5, its concentration would be 74.5% phosphoric acid.

6. Raw Materials

Wet industrial processes rely on attacking naturally occurring phosphorus-containing minerals using concentrated sulfuric acid (75-98%). The primary minerals are calcium phosphate types :

- $Ca_{10}(PO_4)_6F_2$ (Fluorapatite)
- $Ca_3(PO_4)_2 \cdot CaCl_2$ (Chlorapatite)
- $Ca_3(PO_4)_2 \cdot Ca(OH)_2$ (Hydroxyapatite)

7. Sulfuric Acid Consumption

The reaction rate or specific consumption of sulfuric acid is the ratio between the amount of sulfuric acid used and the amount of phosphate processed in the phosphoric acid production process. This is commonly expressed as T = "H_2SO_4" / "Phosphate".

$$T = \frac{Acide\ sulfurique\ consommé}{\text{Phosphate introduit}}$$

8. Phosphates

Phosphate is a chemical compound derived from phosphoric acid (H_3PO_4) by losing or replacing one or more hydrogen atoms in its molecular structure with other atoms or functional groups (such as mineral or organic groups). Examples of phosphates include :

- Dihydrogen phosphate ion ($H_2PO_4^-$) : formed after losing one hydrogen atom.
- Hydrogen phosphate ion (HPO_4^{2-}) : formed after losing two hydrogen atoms.
- Phosphate ion (PO_4^{3-}) : formed after losing three hydrogen atoms. Examples of phosphates :
- Calcium phosphate ($Ca_3(PO_4)_2$) : Mainly used in fertilizer production.
- Ammonium phosphate ($(NH_4)_2HPO_4$) : Used in some chemical fertilizers.
- Sodium phosphate (Na_3PO_4) : Used as a cleaning agent or in chemical industry.

In mineral chemistry, these ions are used in some fertilizers, detergents, as corrosion inhibitors, or food additives (E338 to E343 for orthophosphates, E450 to E455 for polyphosphates). When present in high concentrations in water, they are a source of eutrophication (sometimes turning water unsuitable).

In organic chemistry, phosphate refers to organic phosphorus compounds, where the substituted groups are carbon chains, often called organic phosphates.

9. Applications of Phosphates

- **Fertilizers** : Phosphate is widely used in fertilizers due to its phosphorus content, which is essential for plant growth.
- **Food industry** : Some phosphates are used as food additives to improve texture, preserve products, or regulate acidity.
- **Water treatment** : Phosphates are also used in water treatment to prevent scaling in equipment.

10. Phosphate Fertilizers

Phosphate fertilizers are those containing phosphorus, an essential nutrient for plants. Phosphorus plays a vital role in various biological processes in plants, including photosynthesis, respiration, root formation, flowering, and fruiting. Phosphate fertilizers are primarily manufactured from phosphate rock, which contains phosphorus in the form of calcium phosphate. This is processed to produce soluble forms that plants can absorb easily. Examples of Phosphate Fertilizers are :

1. **Single Superphosphate (SSP)** : Manufactured by reacting phosphate rock with sulfuric acid, producing single calcium phosphate ($Ca(H_2PO_4)_2$) and gypsum ($CaSO_4$). It contains around 16-20% phosphorus (P_2O_5).
2. **Double Superphosphate (DSP)** : Made using a larger amount of sulfuric acid than SSP, producing double calcium phosphate ($CaHPO_4$). It contains around 40% phosphorus (P_2O_5) and is more concentrated than SSP.
3. **Ammonium Phosphate** : Produced by reacting ammonia with phosphoric acid, resulting in mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP). These fertilizers are widely used in areas needing both nitrogen and phosphorus.
    - **MAP** : Contains about 11-12% nitrogen (N) and 48-50% phosphorus (P_2O_5).
    - **DAP** : Contains about 18% nitrogen (N) and 46% phosphorus (P_2O_5).
4. **Calcium Phosphate** : A natural form of phosphorus used directly as fertilizer in certain cases. It is less soluble than other phosphate forms, so it is available to plants more slowly.
5. **Organic Phosphate-based Fertilizers** : Manufactured from natural sources such as animal or plant waste, usually containing organic phosphorus, which must be converted to a mineral form before plants can absorb it.

11. Advantages of Phosphate Fertilizers

1. **Promote plant growth** : Phosphorus is crucial for root development, flowering, and fruiting. Providing adequate phosphorus enhances crop yield.
2. **Enhance photosynthesis** : Phosphorus plays a role in the formation of ATP (adenosine triphosphate), essential for photosynthesis and energy production in plant cells.

3. **Increase resistance to diseases** : Adequate phosphorus helps plants resist diseases and cope with harsh climatic conditions.
4. **Long-term effect** : Some phosphate fertilizers, like rock phosphate, have a long-lasting effect on soil as phosphorus is released slowly.

12. Environmental Effects of Phosphate Fertilizers

1. **Water pollution risks** : Excess phosphorus, especially when dissolved in water, can cause environmental issues. It promotes algal blooms in rivers and lakes, leading to eutrophication, which negatively affects water quality and aquatic biodiversity.
2. **Resource depletion** : Phosphate rock reserves are limited, and increased reliance on phosphate fertilizers may lead to future shortages.