CL304 - Chemical Process Technology

Phosphoric Acid and Its Derivatives

Group No. - 1

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Introduction-

- ***Definition and Chemical Structure:*** Phosphoric acid is a mineral acid with the chemical formula H_3PO_4. It is a weak acid obtained from phosphate rock through various production methods.
- ***Sources and Production Methods:*** Phosphoric acid can be produced by treating calcined bone with sulfuric acid, filtering off the phosphoric acid, and evaporating it. It can also be manufactured on a large scale using the electric furnace method.
- ***Industrial Importance and Applications:*** Phosphoric acid has extensive industrial applications, such as making processed cheese, conditioning oil-well-drilling mud, and preparing enamels and glazes for pottery. It is a crucial component in various industries due to its versatile uses.

Physical and Chemical Properties-

Physical Properties of Phosphoric Acid:

- ***Appearance:*** Phosphoric acid is a colorless, odorless liquid.
- ***Density:*** It has a density of approximately 1.88 g/cm^3.
- ***Solubility:*** Phosphoric acid is highly soluble in water.
- ***Acidity:*** It is a strong acid with a pH of around 2.8 in its concentrated form.
- ***Boiling Point:*** The boiling point of phosphoric acid is about 158°C.
- ***Corrosiveness:*** It is corrosive to metals and tissues due to its acidic nature.

Chemical Properties of Phosphoric Acid

- ***Formation of Phosphorus Pentoxide (P_2O_5):*** Phosphoric acid reacts with oxygen to form phosphorus pentoxide (P_2O_5).
- ***Formation of Metaphosphoric Acid:*** Phosphorus pentoxide reacts with water to form metaphosphoric acid.
- ***Formation of Pyrophosphoric Acid:*** Phosphorus pentoxide reacts with water to form pyrophosphoric acid.

- ***Formation of Orthophosphoric Acid:*** Phosphorus pentoxide reacts with water to form orthophosphoric acid.

Phosphorus pentoxide: $4P + 5O_2 \rightarrow 2P_2O_5$

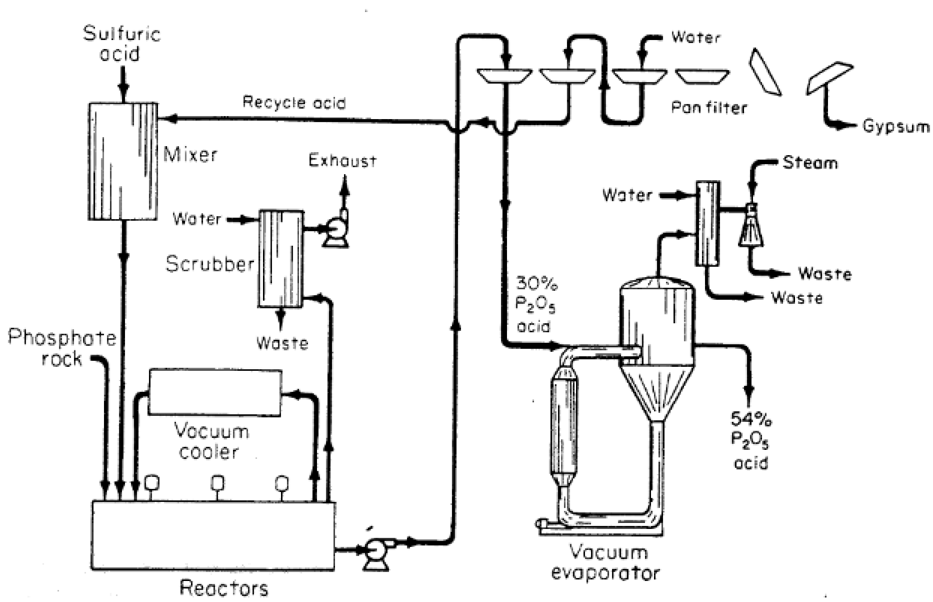
Metaphosphoric acid: $P_2O_5 + H_2O \rightarrow 2HPO_3$

Pyrophosphoric acid: $P_2O_5 + 2H_2O \rightarrow H_4P_2O_7$

Orthophosphoric acid: $P_2O_5 + 3H_2O \rightarrow 2H_3PO_4$

Production of Phosphoric Acid-

1. **Wet Method of Production-** The wet method of producing phosphoric acid, also known as the dihydrate process, is one of the most common methods used industrially to manufacture phosphoric acid. This process involves the reaction of phosphate rock with sulfuric acid to produce phosphoric acid and several byproducts.

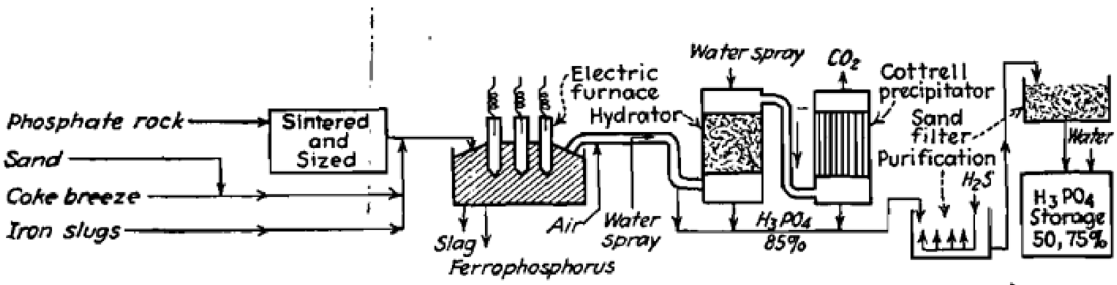


Here is a detailed explanation of the wet method of producing phosphoric acid:

- ***Phosphate Rock Preparation:*** Mined phosphate rock is crushed into a fine powder to increase surface area.
- ***Digestion Process:*** Crushed phosphate rock is mixed with sulfuric acid in a reactor to initiate digestion.

- ***Chemical reaction:*** Phosphate rock + sulfuric acid → phosphoric acid + gypsum + hydrofluoric acid.
- ***Filtration Step:*** The reaction mixture is filtered to separate solid gypsum from the liquid containing phosphoric acid.
- ***Concentration:*** The filtered phosphoric acid solution undergoes concentration to increase its phosphorus pentoxide (P2O5) equivalent concentration.
- ***Purification:*** Additional purification steps like solvent extraction or crystallization may be used to remove impurities and improve phosphoric acid quality.
- ***Final Product:*** High-purity phosphoric acid, typically with a concentration of 50% to 54% P2O5, is obtained and ready for use in various industries.
- ***Byproducts Management:*** Gypsum can be recovered and utilized in industries such as construction. Hydrofluoric acid and other hazardous compounds require proper handling and treatment.

2. Electric Furnace Method- The electric furnace method, also known as the thermal process, is an alternative approach to producing phosphoric acid that utilizes high-temperature reactions instead of traditional wet chemical reactions. This method is beneficial for converting low-grade phosphate ores into phosphoric acid.



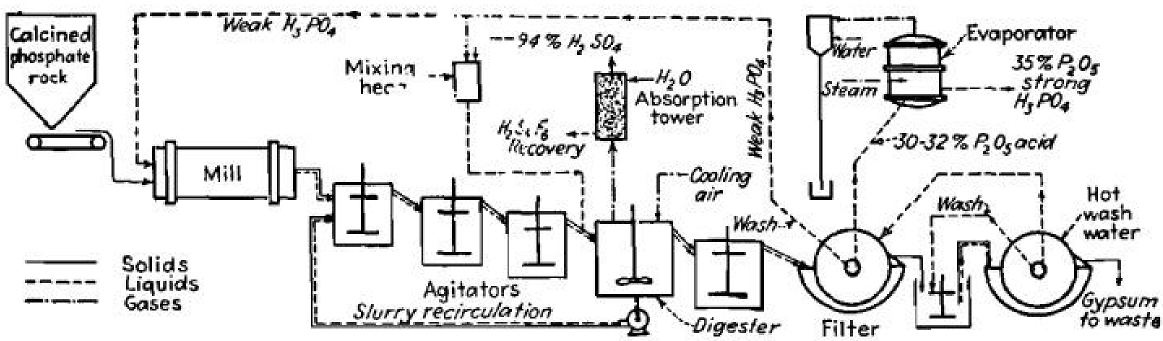
Phosphate rock (69.8 B.P.L.)	3,970 lb	Iron	depends on ferrophosphorus requirements	Per ton 85% H_3PO_4
Silica rock	1,270 lb	Electricity	3,460 kw-hr.	
Coke breeze	748 lb	Direct labor	(est.) 0.5–1 man-hr.	

Below are the key steps and details of the electric furnace method:

- ***Raw Material Preparation:*** Crush and grind phosphate rock for increased reactivity.
- ***Roasting:*** Heat rock in an electric furnace (800-1200°C) to convert it to reactive form (Ca(PO3)2).
- ***Leaching:*** Use sulfuric acid to dissolve reactive phosphates, forming a phosphoric acid solution.
- ***Separation and Purification:*** Employ filtration, solvent extraction, and precipitation techniques.
- ***Concentration:*** Concentrate phosphoric acid solution to increase P2O5 content.
- ***Final Product:*** Obtain high-purity phosphoric acid (50-54% P2O5) suitable for various applications.

The significant advantages of this process include the ability to process low-grade ores, potential energy efficiency, and utilization of different phosphate rock types. The considerable challenges include high energy consumption due to high furnace temperatures and costly equipment.

3. **<u>Dorr Strong Acid Process -</u>** By neutralizing phosphoric acid or a combination of phosphoric and sulfuric acid with ammonia, the Dorr Strong Acid Process produces monoammonium or diammonium phosphate.



The steps in the process are as follows:

- Ammonia and phosphoric acid, or a combination, reacted to produce monoammonium or diammonium phosphate.

- The product was combined with granules that had already been made and dried.
- Two-stage purified diammonium phosphate that has been stripped of contaminants such as Fe, Al, F, Ca, and Mg.
- Filter evaporated, ammonia-saturated, and crystallized to be sold.
- ***Continuous Process:*** T.V.A. created a pilot-plant-scale continuous process for producing crystalline diammonium phosphate by passing pure 75–85% H_3PO_4 and anhydrous ammonia gas into a saturated mother liquor.
- ***Final Product**:* To produce pure diammonium phosphate for sale, the product is dried, centrifuged, and crystallized.

4. **Blast Furnace Method -** The blast furnace method for making phosphorus involves using a blast furnace similar to those in the steel industry. The process was first patented in France in 1867 but became commercially successful in 1929. The blast furnace used is approximately 95 ft. high and has a maximum capacity of 250,000 lb. P_2O_5 per day.

Derivatives of Phosphoric Acid-

Phosphoric acid, a crucial compound in various industrial processes, is the foundation for numerous derivatives that play essential roles in food production, agriculture, and chemical manufacturing. Among these derivatives are sodium phosphates, metaphosphates, and ammonium phosphates, each offering unique properties and applications.

1. **Sodium Phosphates:** Sodium phosphates are salts derived from phosphoric acid and sodium compounds. Common types include monosodium phosphate **(NaH_2PO_4)**, disodium phosphate (**Na_2HPO_4**), and trisodium phosphate **(Na_3PO_4)**. They are used extensively in food processing as emulsifiers, acidity regulators, and stabilizers. Additionally, they have applications in water treatment, detergents, and as buffering agents in various chemical processes.

- *Tetrasodium pyrophosphate,* or **Na4P2O7·10H2O**, is one example of an alkali metal pyrophosphate.
- The alkali metal orthophosphates **NaH2PO4·H2O, Na2HPO4·7H2O**, and **Na3PO4·12H2O** are a few examples.
- ***Molecular Dehydrated Phosphates:*** Originates from orthophosphates, commonly found in detergents, like sodium tripolyphosphate.
- ***Production Process for Sodium Tripolyphosphate:*** Conversion requires exact temperature control between 300 and 500°C.
- ***Heating and Cooling:*** Tripolyphosphate is produced by heating the proper amounts of mono- and disodium phosphates and then slowly cooling them.
- ***Fusion and Cooling:*** Meta- and pyrophosphates are produced as a mixture following fast cooling following fusion.
- Manufacturing tetrasodium pyrophosphate involves reacting phosphoric acid with soda ash and then calcining the result in a rotary kiln.

Applications: Because of its potent building agent, it is frequently incorporated into detergent formulas. Because of its chemical makeup, it is a great soap and detergent builder.

2. Metaphosphates:

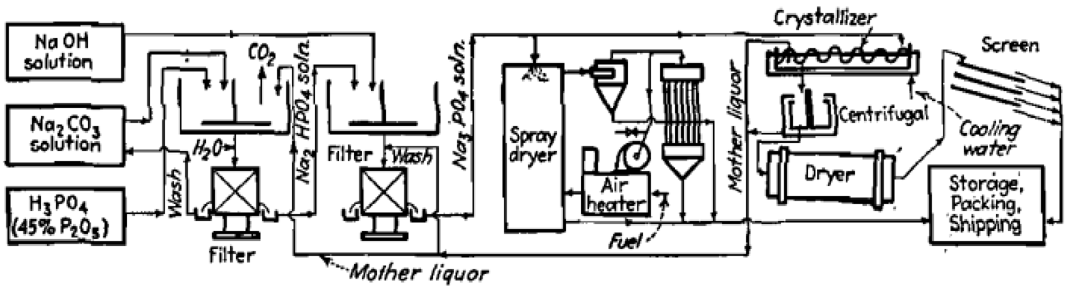
Metaphosphates are soluble, glassy sodium metaphosphate (NaPO3)n, made by fusing pure monosodium phosphate at 760°C. The molten product is then chilled, flaked, packaged, and shipped for various applications, including water treatment.

$$2H_3PO_4 + Na_2CO_3 \rightarrow 2NaH_2PO_4 + CO_2 + H_2O$$
$$nNaH_2PO_4 \rightarrow (NaPO_3)_n + nH_2O$$

Reaction for the Production of Metaphosphates

- ***Production Process -*** The production involves fusing monosodium phosphate at a high temperature to create a glassy, soluble sodium metaphosphate. This product is then processed further, including chilling, flaking, packaging, and shipping for commercial use.

- ***Industrial Significance -*** Metaphosphates have unique properties that make them valuable in water treatment. They can solubilize or repress calcium and magnesium precipitates, even in the presence of soaps, which is crucial for effective water softening and conditioning.
- ***Applications -*** Metaphosphates find applications in various industries, primarily in water treatment, for their ability to bind calcium and magnesium into complexes, stabilize solutions, reduce metal-ion concentrations, and form adsorbed films on metal surfaces. Their versatility makes them essential in practical water treatment processes.
- ***Trisodium Phosphate (TSP)*** is a compound used as a water softener and detergent. It was a significant product of phosphoric acid, known for its water-softening properties. Polyphosphates have largely replaced TSP due to their superior detergency, softening, lower alkalinity, and sequestering ability. Despite this, TSP remains in use due to its cost-effectiveness in manufacturing.



Flow Sheet for Trisodium Phosphate

$$Na_2CO_3 + H_3PO_4 \rightarrow Na_2HPO_4 + CO_2 + H_2O$$
$$Na_2HPO_4 + NaOH \rightarrow Na_3PO_4 + H_2O$$

Reaction for the production of Trisodium Phosphate

- ***Polyphosphates****:* Polyphosphates like sodium tripolyphosphate are widely used in detergents as builders, with about 85% employed for this purpose. They are produced by heating mono- and disodium phosphates or other phosphate mixtures between 300 and 500°C, then slowly cooling to obtain the desired form.

- ***Pyrophosphates:*** Tetrasodium pyrophosphate is a versatile builder for detergents and soap due to its excellent properties. It is manufactured by reacting phosphoric acid and soda ash to yield different forms like anhydrous Na2HP04 or crystallized Na2HP04·2H20 or Na2HP04·7H20, which are then calcined at high temperatures to yield tetrasodium pyrophosphate.

$$2Na_2HPO_4 \rightarrow Na_4P_2O_7 + H_2O$$
$$2Na_2HPO_4 \cdot 2H_2O \rightarrow Na_4P_2O_7 + 5H_2O$$

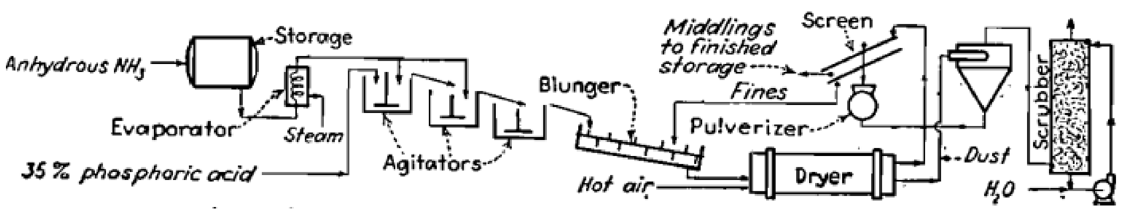
Reaction for the Production of Pyrophosphates

$$2NaH_2PO_4 \rightarrow Na_2H_2P_2O_7 + H_2O$$

Reaction for the Production of Non-Hygroscopic Sodium Acid Pyrophosphate

3. <u>Ammonium Phosphates:</u>

- ***NH4H2PO4 (monoammonium phosphate):*** They are utilized as a flameproofing agent, fertilizer, and yeast nutrient and are produced by absorbing ammonia gas in 75% H3PO4, which yields white crystals of superior quality.
- ***Phosphate of ammonium ((NH4)2HPO4):*** Also known as diammonium phosphate, it is utilized as a flameproofing agent, yeast nutrient, and fertilizer. These are made from phosphoric acid and ammonia in two stages to remove impurities and produce a pure solution of monoammonium phosphate.



Flow Sheet for Diammonium Phosphate

Overall, phosphoric acid derivatives such as sodium phosphates, metaphosphates, and ammonium phosphates play diverse and critical roles across industries, showcasing the versatility and importance of phosphorus compounds in modern applications.

Industrial Applications of Phosphoric Acid and Its Derivatives-

- ***Water Treatment:*** Phosphorus derivatives are used in water treatment processes to precipitate or sequester lime and magnesia, aiding in water softening.
- ***Detergents:*** Sodium phosphates derived from phosphoric acid are utilized in detergents as soap builders or detergent synergists due to their ability to emulsify solids and enhance detergent properties.
- ***Food and Medicine:*** Phosphorus derivatives find applications in food and medicine industries, serving various purposes such as inorganic salts and additives.
- ***Phosphate Esters:*** Organic derivatives of phosphorus, such as alkyl alkali phosphates, are employed as nonflammable hydraulic fluids and humectants in industrial applications.

Environmental Impacts-

Phosphoric acid and its derivatives have an influence on the environment in several additional ways outside water contamination, such as:

- ***Soil Degradation:*** An excess of phosphate fertilizers can cause nutrient imbalances and soil degradation, which can hurt the health of the soil and long-term agricultural output.
- ***Eutrophication:*** Excessive phosphorus discharge from wastewater treatment plants and agricultural fields can deplete oxygen in water bodies, induce algal blooms, and alter aquatic ecosystems.
- ***Biodiversity Loss:*** Aquatic flora and fauna can be harmed by water pollution and eutrophication brought on by phosphorus discharge, which can cause disturbances to ecosystem dynamics and a loss of biodiversity.

- ***Air Pollution:*** The manufacturing of phosphoric acid has the potential to emit nitrogen oxides (NOx) and sulfur dioxide (SO2) into the atmosphere, which might pose health risks.
- ***Climate Change:*** Greenhouse gas emissions from phosphate mining, processing, and transportation contribute to climate change and environmental effects.

Conclusion-

Phosphoric acid and its derivatives are indispensable in diverse industries, from agriculture to chemicals. These compounds, derived through meticulous processes, underpin agricultural fertilizers, food additives, and flame retardants. They bolster crop yields, food preservation, and industrial safety. However, environmental concerns like water pollution necessitate sustainable practices. Despite challenges, phosphoric acid's versatility fuels innovation and economic growth. Continued research and responsible management are vital for maximizing benefits while mitigating environmental impact. Ultimately, phosphoric acid and its derivatives exemplify the delicate balance between industrial advancement and ecological stewardship, shaping a sustainable future for the chemical process industries.

References-

- Shreve's Chemical Process Industries, 2nd Edition.
- Dryden’s Outline of Chemical Technology.
- https://en.wikipedia.org/wiki/Phosphoric_acid