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INDUSTRIAL MANUFACTURING OF ACIDS AND BASE SYNTHESIS BY PROCESS CHEMISTRY

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ABSTRACT

Industrial manufacturing of acids and bases relies on large-scale catalytic and thermodynamic chemical processes. Key pathways include the Contact Process for sulfuric acid, the Ostwald Process for nitric acid, and the Chlor-Alkali Process for sodium hydroxide. These foundational base and acid building blocks drive global fertilizer, polymer, and metal processing sectors. Industrial Acid Synthesis: Sulfuric Acid [H_2SO_4]: Manufactured via the Contact Process. Sulfur is burned to form sulfur dioxide, catalytically oxidized over vanadium pentoxide [V_2O_5] to sulfur trioxide [SO_3], and absorbed in concentrated sulfuric acid to yield oleum, which is diluted to high-purity acid. Nitric Acid [HNO_3]: Produced through the Ostwald Process. Ammonia [NH_3] is catalytically oxidized over platinum-rhodium gauze at high temperatures to form nitrogen dioxide [NO_2], which is then absorbed in water. Hydrochloric Acid [HCl]: Synthesized via the direct exothermic reaction of hydrogen gas [H_2] and chlorine gas [Cl] recovered as a byproduct from chlor-alkali units, followed by absorption in deionized water. Industrial Base Synthesis: Sodium Hydroxide [NaOH]: Synthesized via the Chlor-Alkali Process using mercury, diaphragm, or membrane cells to electrolyze aqueous sodium chloride [NaCl], co-producing chlorine gas and hydrogen gas. Sodium Carbonate [Na_2CO_3]: Manufactured via the Solvay Process, using readily available brine, ammonia, and limestone to precipitate sodium bicarbonate, which is thermally calcined into soda ash. Ammonia [NH_3]: Synthesized via the Haber-Bosch Process, reacting atmospheric nitrogen and hydrogen gas directly over an promoted iron catalyst at high pressures and temperatures. Process Chemistry Principles: Thermodynamic Control: Many synthesis steps [SO_2] oxidation or Haber-Bosch [NH_3] creation rely heavily on Le Chatelier's principle, balancing high pressure and optimized temperatures to maximize conversion yields. Heterogeneous Catalysis: Solid catalysts, [V_2O_5] platinum gauze, promoted iron) are engineered for high surface-area-to-volume ratios to speed up reaction rates continuously in continuous-flow reactors. Heat Integration: Exothermic steps—such as burner operations [HCl or SO_3] for absorption—are captured via heat exchangers to run secondary plant utility systems or pre-heat incoming reactant feeds.

KEYWORDS: oil of vitriol, sulfur dioxide, sodium carbonate, sulfur trioxide, oleum, vanadium pentoxide, catalyst, corrosive, Le Chatelier's principle, ammonia, hydrochloric acid, nitric acid, acetic acid, haber process, contact process, ostwald process, solvey process, phosphoric acid process, monsanto & cativa processes.

INTRODUCTION

1. Sulfuric acid: It (H_2SO_4) is a clear, thick, and very strong mineral acid. People also call it oil of vitriol. It is a dangerous and corrosive liquid that can burn skin and dissolve many metals. Industries make more of this chemical than almost any other liquid.

Key Properties: Formula: H_2SO_4 (two hydrogen, one sulfur, and four oxygen atoms).

Look: Clear, colorless, and oily liquid.

Reactivity: Mixes easily with water and releases a lot of heat.

Dehydration: Pulls water out of other things like wood, sugar, or paper, often leaving black carbon behind.

Oil of vitriol is an old historical name for sulfuric acid, a strong and highly corrosive mineral acid with the chemical formula H_2SO_4. It is a clear, thick, and oily liquid.

History and Name Origin

Old Name: Medieval chemists called it this because it looked like oil and came from vitriol minerals.

Vitriols: These were sulfate rocks like green vitriol (iron

sulfate).
Making Acid: Heating green vitriol produced the thick, acidic liquid.
Word Roots: The word "vitriolic" (meaning harsh or mean speech) comes from this caustic acid.

Formula: H_2SO_4
State: Dense, colorless, and odorless liquid.
Behavior: Mixes easily with water in a very hot reaction.
Danger: Causes severe burns on skin and materials.

Common Uses
Batteries: Used as car battery acid.
Farming: Helps make plant fertilizers.
Industry: Used to clean metals and make other chemicals.
Sulfuric acid (H_2SO_4) was named *oil of vitriol* by medieval alchemists because it was originally made by distilling green vitriol (iron(II) sulfate heptahydrate), and the resulting concentrated acid fluid had a thick, syrupy, and oily physical appearance.

Historical Origins and Meaning
Vitriol: This was an old alchemical name for sulfate minerals (such as green vitriol for iron sulfate or blue vitriol for copper sulfate) because of their glassy or crystalline look.
The "Oil" Part: Concentrated sulfuric acid does not pour like thin water; it is dense, viscous, and slick, which made early chemists describe it as an oil.
Oleum, or fuming sulfuric acid, is a highly corrosive, oily liquid solution of sulfur trioxide in sulfuric acid ($H_2SO_4 \cdot xSO_3$). It releases dense toxic fumes in moist air and is widely used in industrial manufacturing, petroleum refining, and making dyes and explosives.

Physical and Chemical Properties
Appearance: Colorless to dark brown viscous, oily liquid.
Formula: Commonly represented as disulfuric acid ($H_2S_2O_7$) or general mixtures ($H_2SO_4 \cdot SO_3$).
Reactivity: Reacts violently with water to release extreme heat and generate standard sulfuric acid.
Sulfuric Acid Production: Diluted safely with water to produce high-purity, concentrated sulfuric acid on a massive scale.
Sulfonation: Acts as a powerful agent to introduce sulfonic groups into organic compounds for detergents and pharmaceuticals.
Synthesis: Utilized in the creation of synthetic dyes, intermediates, and military or commercial explosives.
Safety Hazards
Corrosively: Causes severe, immediate chemical burns and permanent tissue damage on contact with skin or eyes.
Inhalation Risks: Releasing sulfur trioxide fumes causes acute, choking irritation and severe damage to the respiratory tract.
The specific chemical formula for pure disulfuric (pyrosulfuric) acid is $H_2S_2O_7$. However, because oleum is a solution of varying amounts of sulfur trioxide dissolved in sulfuric acid, it is more accurately represented by the general formula
Or H_2SO_4. xSO_3 or ySO_3. H_2O.

Chemical Composition
Specific Compound: $H_2S_2O_7$ represents oleum where x=1 (disulfuric acid).
Mixture Representation: $H_2S_2O_7$. xSO_3, where x is the molar amount of free sulfur trioxide (SO_3) dissolved in the sulfuric acid.
Also known as fuming sulfuric acid. Appears as a colorless or light-colored fuming liquid that reacts strongly with air and moisture. Used heavily in industrial manufacturing, including the production of standard sulfuric acid and various organic sulfonation processes.
Sulfuric acid (H_2SO_4) is industrially manufactured via the Contact Process, which involves burning sulfur to create sulfur dioxide, oxidizing it into sulfur trioxide using a catalyst, and reacting it with water.

Industrial Manufacturing (The Contact Process)
Step 1: Burn Sulfur: Melted elemental sulfur is burned in the presence of dry air (oxygen) to produce sulfur dioxide (SO_2): $(S(s)+O_2(g)= SO_2(g)$
Step 2: Catalytic Oxidation: Sulfur dioxide is mixed with more oxygen and passed over a vanadium(V) oxide (V_2O_5) catalyst at about 450°C and 1–2 atm to form sulfur trioxide (SO_3): $(2SO_2(g)+O_2(g)\rightarrow 2SO_3(g)$
Step 3: Absorption and Dilution: Sulfur trioxide is dissolved directly in concentrated sulfuric acid to form oleum (pyrosulfuric acid, $H_2S_2O_7$), because dissolving SO_3 straight into water creates an unmanageable, highly corrosive acid fog. Oleum is then carefully mixed with water to yield concentrated sulfuric acid: $(H_2SO_4+SO_3\rightarrow H_2S_2O_7)\backslash(H_2S_2O_7+H_2O\rightarrow 2H_2SO_4)$

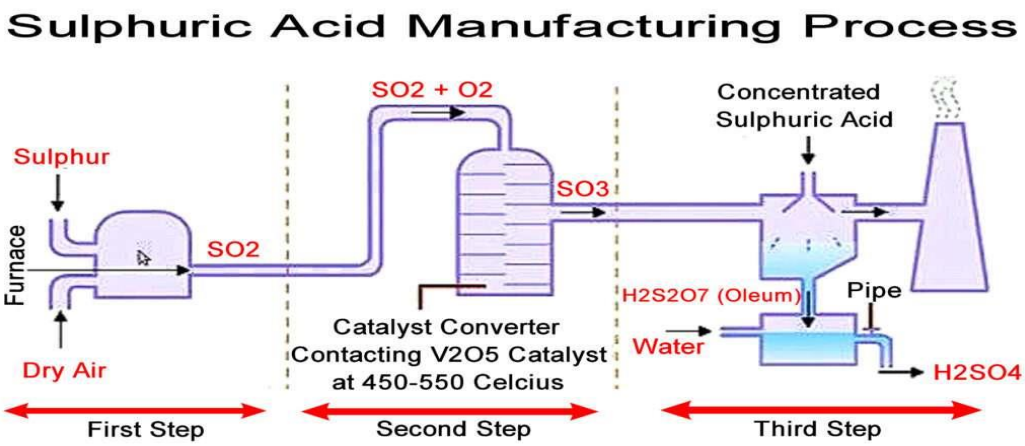

Figure-1: Contact Process Flow-Chart of Sulfuric Acid.

The Contact Process manufactures sulfuric acid through four primary steps: burning sulfur to make sulfur dioxide, purifying the gas, catalytically oxidizing it into sulfur trioxide using vanadium pentoxide at 450°C and 1–2 atm, absorbing it in concentrated sulfuric acid to form oleum, and diluting the oleum with water.

Production and Purification of Sulfur Dioxide

Combustion: Melted elemental sulfur or iron pyrite burns in dry air or oxygen to create sulfur dioxide.

$S(s)+O_2(g)\rightarrow SO_2(g)$

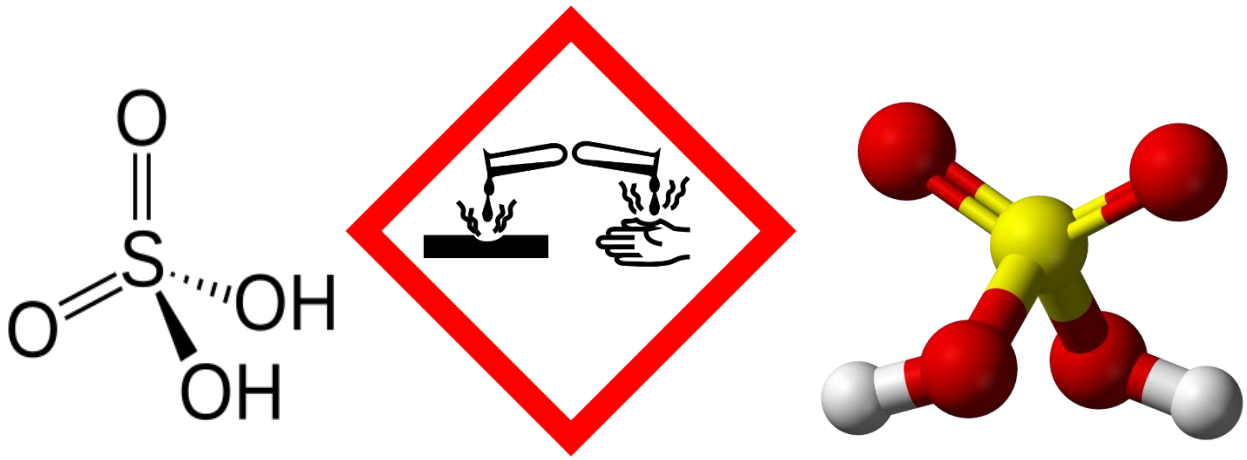

Figure-2: Sulfuric acid structure, hazard & 3D structure.

Purification: The raw SO_2 gas passes through dust removers, water scrubbers, drying towers (concentrated H_2SO_4), and arsenic purifiers to eliminate solid and moisture impurities that can poison the catalyst.

Catalytic Oxidation to Sulfur Trioxide

Reaction: Purified sulfur dioxide mixes with excess air and passes over a porous vanadium pentoxide (V_2O_5) catalyst.

Conditions: Maintained at an optimum temperature of 400°C–450°C and low pressure of 1–2 atmospheres because the forward reaction is exothermic and involves a decrease in volume. $2SO_2(g)+O_2(g)\rightarrow 2SO_3(g)$ [Δ= -197kJ/mol]

Absorption and Dilution

Oleum Formation: Sulfur trioxide gas is absorbed directly into concentrated (98%) sulfuric acid rather than water to prevent creating a hazardous, uncollectible acid mist. This produces pyrosulfuric acid, known as oleum.

$SO_3(g) + H_2SO_4(l)=H_2S_2O_7(l)$

Final Dilution: Oleum is carefully mixed with calculated amounts of pure water to yield commercial-grade concentrated sulfuric acid.

$H_2S_2O_7(l)+H_2O(l)\rightarrow 2H_2SO_4(l)$

CAS: 7664-93-9

Central Atom: Sulfur (S) sits in the middle.

Shape: Tetrahedral arrangement.

Bond Types: Two double-bonded oxygen atoms (S=O) and two single-bonded hydroxyl groups (-OH).

Angles: O-S-O bond angles deviate from ideal tetrahedral angles due to double-bond repulsion.

Atom Color Codes

Yellow: Sulfur atom (1)

Red: Oxygen atoms (4)

White: Hydrogen atoms (2)

Physical Properties

State & Appearance: Clear, thick, oily, and colorless

liquid.
Density: Specific gravity of 1.84 at 25 °C (dense and heavy).
Melting Point: Freezes into crystals at 10.37 °C (50.7 °F).
Boiling Point: Boils at 338 °C (640 °F).
Solubility: Mixes completely with water, releasing a huge amount of heat (exothermic).

Chemical Properties
Strong Acid: Acts as a diprotic (dibasic) acid, ionizing completely in water to release hydronium ions.
Dehydrating Agent: Pulls water out of organic compounds like sugar and paper, leaving a black carbon residue.
Oxidizing Agent: Concentrated hot acid oxidizes many metals and non-metals while reducing itself to sulfur dioxide. **Hygroscopic:** Readily absorbs water vapor directly from the surrounding air.

2. Nitric acid: It is prepared industrially on a large scale via the **Ostwald Process**, which involves the catalytic oxidation of ammonia (NH_3) with air to form nitric oxide, subsequent oxidation to nitrogen dioxide, and final absorption of the gas in water to yield aqueous (HNO_3).

Key Stages of the Ostwald Process.
Catalytic Oxidation of Ammonia
Ammonia gas is mixed with excess air and heated at ($700^{O}C$) to ($900^{O}C$) under pressures of 4 to 10 atmospheres in the presence of a platinum-rhodium catalyst. ($4NH_3+5O_2 \leftrightarrow$ catalyst (Pt-Rh) $4NO+6H_2O$.

Oxidation of Nitric Oxide: The resulting nitric oxide (NO) gas is cooled and reacted with additional oxygen (O_2) at lower temperatures to produce nitrogen dioxide (NO_2). ($2NO+O_2 \rightarrow 2NO_2$.

Absorption in Water: Nitrogen dioxide is passed through an absorption tower against a downward flow of water in the presence of air. This produces approximately 60% to 65% pure aqueous nitric acid. $3NO_2 + H_2O \leftrightarrow 2HNO_3 + NO$. The recovered (NO) is recycled back into the second step. Further concentration up to 98% can be achieved via fractional distillation with concentrated sulfuric acid.

Nitric Acid: CAS: 7697-37-2. Aqua Fortis. Nitric acid (HNO_3) is a highly corrosive, toxic, and colorless mineral acid that turns yellow over time due to light exposure and breakdown into nitrogen oxides. It acts as a strong acid and a powerful oxidizing agent, and is widely used to make fertilizers and explosives. The industrial preparation of nitric acid via the Ostwald Process involves three main chemical stages: catalytic oxidation of ammonia to nitric oxide ($700–900^{O}C$) over a platinum-rhodium catalyst), oxidation of nitric oxide to nitrogen dioxide, and absorption of nitrogen dioxide in water with excess air to yield roughly 65–68% pure nitric acid.

Raw Materials and Operating Conditions
Reactants: Ammonia (NH_3), air (O_2), and water (H_2O).
Catalyst: Platinum-rhodium gauze (9:1 ratio) to promote rapid oxidation. Temperature: ($700–900^{O}C$) in the catalytic chamber. Pressure: (1–9 atmospheres).

Key Properties
Formula: HNO_3
Appearance: Clear liquid that yellows with age; concentrations over 86% are called fuming nitric acid.
Acidity: Strong acid that dissociates completely in water.
Reactivity: Reacts with most metals, organic compounds, and bases.

Main Uses
Fertilizers: Used to produce ammonium nitrate for farming.
Explosives: Used to manufacture compounds like TNT and nitroglycerin.
Industry: Used for metal etching, cleaning stainless steel, and making nylon precursors.
Laboratory: Used as a common reagent and mixed with hydrochloric acid to form ***aqua regia*** for dissolving noble metals like gold.

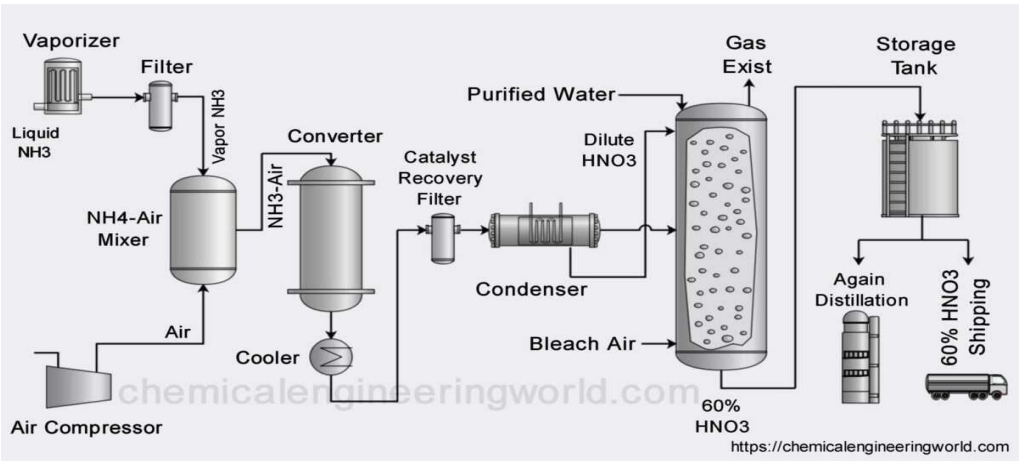

Figure-3: Flow Chart of Nitric Acid preparation in Industry by Ostwald Process.

Step 1: Catalytic Oxidation of Ammonia: Ammonia is mixed with excess air and passed through a catalytic converter chamber containing a platinum-rhodium catalyst at high temperature (700–900^{O}C). Ammonia is oxidized into colorless nitric oxide gas. This reaction is highly exothermic Reaction: ($4NH_3(g)+5O_2(g)\rightarrow$Pt-Rh catalyst 700–900^{O}C $4NO(g)+6H_2O(g)$ (ΔH = -905.2kJ/mol).

Step 2: Oxidation of Nitric Oxide to Nitrogen Dioxide: The hot nitric oxide gas is cooled down using a cooler or heat exchanger and then mixed with more oxygen (air) at a lower temperature (<50^{O}C) to form reddish-brown nitrogen dioxide gas.
Reaction: $2NO(g)+O_2(g)\rightarrow 2NO_2(g)$

Step 3: Absorption in Water: The nitrogen dioxide gas is passed into an absorption tower where water is sprayed from the top against a rising flow of gas in the presence of excess air. This produces aqueous nitric acid (HNO_3). Reaction: $4NO_2(g)+2H_2O(l)+O_2\rightarrow 4HNO_3(aq)$. The resulting acid is about 65% to 68% concentrated by mass and can be further concentrated via distillation with concentrated sulfuric acid if anhydrous or fuming nitric acid is required.

Fuming nitric acid (HNO_3) is a highly concentrated form of nitric acid containing over 86% to 99% HNO_3. It emits toxic, suffocating red-brown nitrogen dioxide fumes, acts as an extremely powerful oxidizing agent, and causes severe tissue damage on contact.

Properties and Types: Concentration: Greater than 86% HNO_3 by weight, with the remainder being dissolved nitrogen oxides and minimal water.

White Fuming: Contains less than 2% water and very low dissolved NO_2 (>95% pure HNO_3), appearing as a clear or pale liquid that fumes heavily in moist air.

Red Fuming: Contains significant dissolved nitrogen dioxide (5-10% or more NO_2), giving it a distinct reddish-brown color and dense choking vapors.

Boiling Point: Approximately 120.5° C.

Density: 1.48 g/mL at 20° C.

Primary Uses
Rocket Propellants: Used as a storable liquid oxidizer in rocket engines and missiles.

Organic Synthesis: Essential for multiple or difficult nitrations, such as manufacturing high explosives (e.g., TNT).
Analytical Chemistry: Employed as a potent oxidizing reagent in specialized laboratory testing and sample digestion.

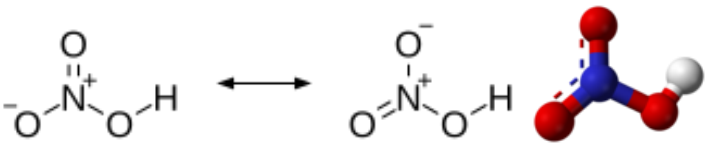

Figure-4: Nitric Acid and 3D Structure.

Safety Hazards
Reactivity: Highly corrosive to metals and organic tissue. It can spontaneously ignite organic materials, fuel, and standard nitrile or latex laboratory gloves.

Inhalation: Vapor is extremely toxic and causes severe irritation or pulmonary edema.

Skin Contact: Causes immediate yellow staining (xanthoproteic reaction with proteins) and deep chemical burns. Must be handled exclusively inside a certified fume hood with specialized personal protective equipment.

Fuming nitric acid (concentration >86% up to 99%+) is produced industrially by upgrading standard weak or concentrated nitric acid (68%) via extractive distillation with concentrated sulfuric acid (H_2SO_4) or by direct absorption of excess nitrogen dioxide (NO_2) in anhydrous nitric acid.

The Industrial Process Steps
Base Production (Ostwald Process): Ammonia is catalytically oxidized to nitric oxide (NO), oxidized further to nitrogen dioxide (NO_2), and absorbed in water to yield standard commercial nitric acid (~68%) concentration).

Dehydration/Concentration: Because (68%) nitric acid forms a maximum-boiling azeotrope, water cannot be removed by simple boiling. Concentrated sulfuric acid (98%) is mixed with the aqueous nitric acid as a dehydrating agent.

Extractive Distillation: The mixture is fed into a distillation column. Sulfuric acid binds the water molecules, forcing pure anhydrous nitric acid vapor to overhead-distill at high concentrations (>95%). Diluted sulfuric acid is simultaneously drawn from the bottom and sent to a concentrator to recover the (H_2SO_4).

Type Differentiation (Red vs. White)
White Fuming Nitric Acid (WFNA): Contains (>95%) (HNO_3) and minimal dissolved gases; produced by

stripping out dissolved oxides.

Red Fuming Nitric Acid (RFNA): Contains high concentration (HNO_3) with dissolved toxic nitrogen dioxide (NO_2) gas (86% - 95%+) concentration); produced by adding or retaining excess (NO_2) directly inside the liquid.

3. Ammonia: CAS: 7664-41-7. Ammonia is a colorless, pungent gas with the chemical formula NH_3. Roughly 80% of manufactured ammonia is used in agricultural fertilizers. It is also utilized in household cleaning products, industrial manufacturing, and refrigeration systems.

Key Properties & Production
Chemical Formula: NH_3 (one nitrogen atom and three hydrogen atoms).

Odor: Strong, sharp, and fishy or suffocating smell.

Creation: Produced industrially via the Haber-Bosch process from nitrogen and hydrogen gases. It also occurs naturally from decaying organic matter.

Solubility: Dissolves easily in water to form an alkaline (basic) solution called ammonium hydroxide.

The **Haber-Bosch process** combines nitrogen gas from the air with hydrogen gas from natural gas at temperatures of 400–450°C and pressures of 150–200 atmospheres over an iron catalyst. This catalytic reaction creates liquid ammonia used largely for global agriculture and fertilizers.

Uses
Agriculture: Applied directly to soil or processed into urea and ammonium nitrate fertilizers.

Cleaning: Diluted solutions (5% to 10%) are common in glass and surface cleaners.

Industry: Acts as a coolant in industrial refrigeration and a building block for plastics, fibers, and explosives.

Safety: High concentrations of ammonia gas are toxic and corrosive to skin, eyes, and lungs. Never mix ammonia with bleach, as this creates toxic and dangerous chloramine gases.

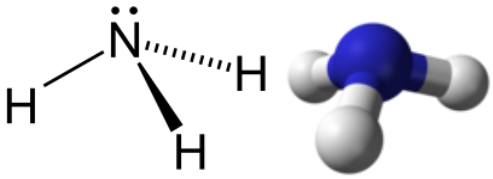

Figure-5: Ammonia and 3D Structure.

Raw Material Preparation
Nitrogen: Sourced directly from atmospheric air, typically via fractional distillation or by reacting out oxygen.

Hydrogen: Produced primarily through the steam reforming of methane found in natural gas, followed by a water-gas shift reaction to clear out carbon oxides.

Ratio: Mixed in a strict 3:1 volumetric ratio of hydrogen to nitrogen ($3H_2+N_2 \rightarrow 2NH_3$).

Reaction Conditions and Equilibrium
Temperature (400–450°C): The forward reaction is exothermic, meaning lower temperatures favor high yield. However, a moderate temperature is used to ensure a practical reaction rate.

Pressure (150–200 atm): High pressure drives the equilibrium toward the product side because four total moles of gas turn into two moles of ammonia.

Iron Catalyst: Finely divided iron promoted with potassium hydroxide speeds up the slow breaking of the strong nitrogen-nitrogen triple bond.

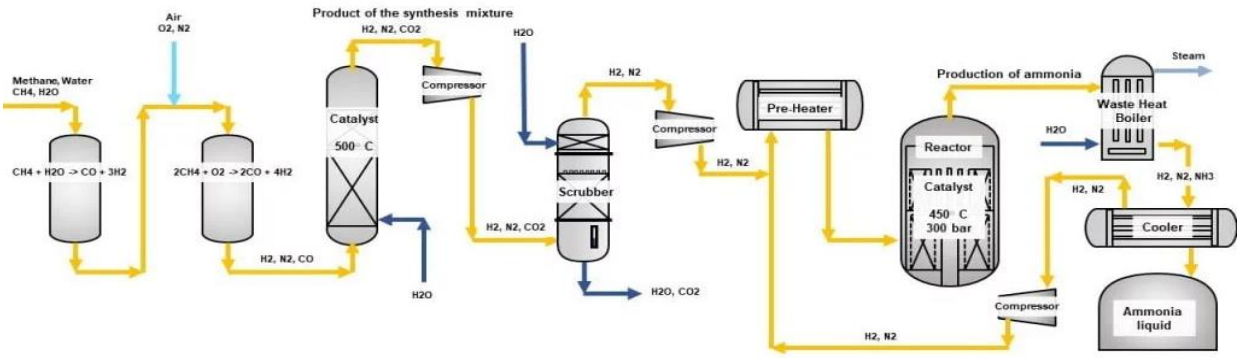

Figure-6: Ammonia production in Industry Flow Chart.

Separation and Recycling

Condensation: The outgoing gas mixture is cooled so that ammonia liquefies and separates out while leaving unreacted gases behind.

Recycle Loop: Unreacted nitrogen and hydrogen gas are compressed and fed back into the main catalyst reactor chamber to maximize overall conversion efficiency.

4. Hydrochloric acid: CAS: 7647-01-0. It is a strong, corrosive chemical compound defined by the formula HCl, clear colorless appearance, and pungent odor. It is an aqueous solution of hydrogen chloride gas, functions as a key component of human stomach acid, and serves major industrial roles.

Formula: HCl. Muriatic acid.

Molar Mass: 36.46 g/mol.

Classification: Strong mineral acid that dissociates completely in water.

Physical Traits: Clear, colorless liquid with a sharp, irritating smell and a boiling point of 110°C for a standard 37% solution.

Common Uses

Steel and Metal Cleaning: Used in pickling to remove rust or iron oxide scale from steel before processing.

Industrial Manufacturing: Used to produce organic compounds like PVC (vinyl chloride) and polyurethane, as well as inorganic chemicals like calcium chloride.

Pool and Household Maintenance: Used for pH control in swimming pools and found in lower concentrations in commercial scale and masonry cleaners.

Digestion: Produced naturally in vertebrate gastric glands to aid food breakdown.

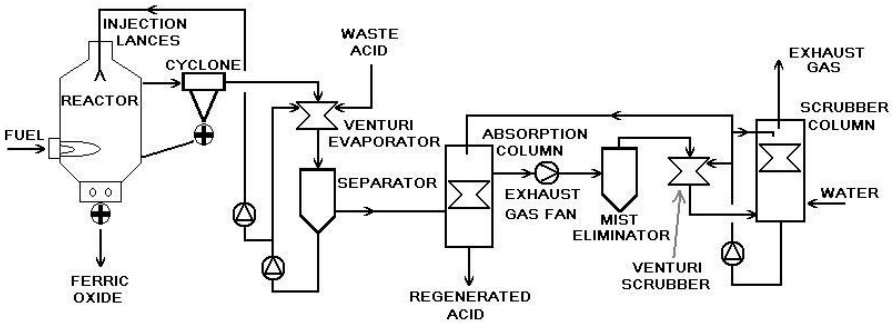

Figure-7: Hydrochloric Acid preparation Flow Chart in Industry.

Hydrochloric acid (HCl) is processed chemically by first producing hydrogen chloride (HCl) gas—via direct element synthesis, salt-acid reactions, or organic chlorination—and then dissolving that gas safely into water.

Le Chatelier's principle states that if a system at dynamic equilibrium is disturbed, the position of equilibrium shifts to counteract the change and reestablish equilibrium. The three main factors that cause a shift are concentration, pressure, and temperature.

How the Factors: Work Concentration: Adding reactants or removing products shifts the equilibrium to the right (toward products).

Removing reactants or adding products shifts the equilibrium to the left (toward reactants).

Pressure (for gases): Increasing pressure shifts the equilibrium to the side with fewer moles of gas. Decreasing pressure shifts the equilibrium to the side with more moles of gas.

Temperature: Increasing temperature shifts the equilibrium in the endothermic (heat-absorbing) direction. Decreasing temperature shifts the equilibrium in the exothermic (heat-releasing) direction.

Catalysts: Catalysts speed up both forward and reverse reactions equally, meaning they have no effect on the position of equilibrium.

5. Sodium carbonate: It is (Na_2CO_3), or soda ash, is produced commercially using the **Solvay Process**. This method reacts cheap salt brine (NaCl) with ammonia (NH_3) and carbon dioxide (CO_2) to precipitate sodium bicarbonate, which is then heated to form sodium carbonate while recycling the ammonia and carbon dioxide.

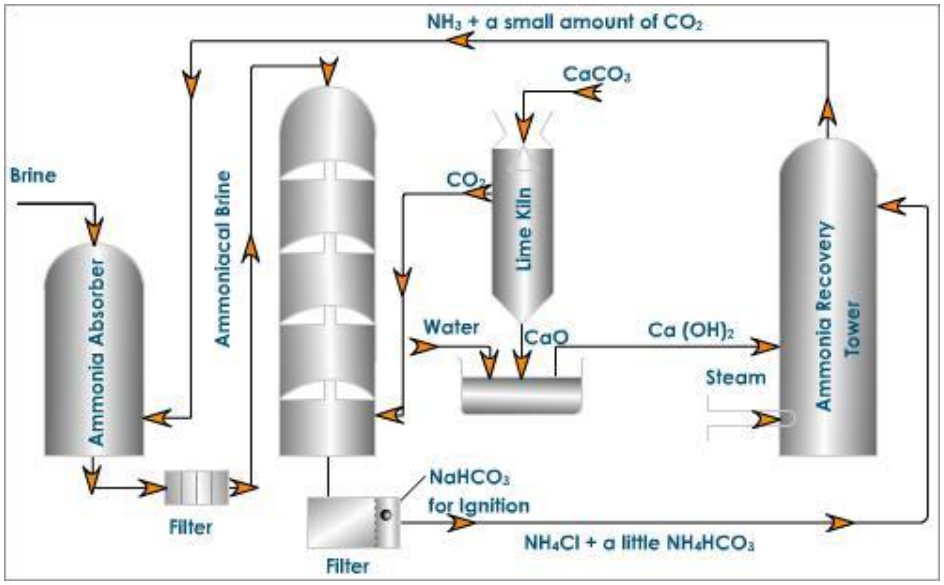

Figure-8: Sodium Carbonate preparation Flow Chart in Industry.

Core Chemical Reactions: Ammonia Saturation: Ammonia dissolves in concentrated sodium chloride brine: ($NaCl+H_2O+NH_3 \rightarrow NaCl+NH_4OH$) Carbonation: Carbon dioxide (from heated limestone) bubbles through the ammoniated brine to precipitate sodium bicarbonate: $NaCl+NH_3+CO_2+H_2O \rightarrow NaHCO_3+NH_4Cl$.

Calcination (Thermal Decomposition): Separated sodium bicarbonate is heated to yield soda ash: ($2NaHCO_3 \rightarrow Na_2CO_3+H_2O+CO_2$. Ammonia Recovery: Ammonium chloride byproduct reacts with lime to recover ammonia: ($2NH_4Cl+Ca(OH)_2 \rightarrow 2NH_3\uparrow+CaCl_2+H_2O$).

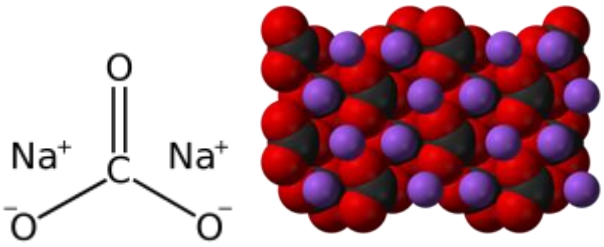

Figure-9: Sodium carbonate & 3D Structure.

CAS: 497-19-8 (anhydrous), 5968-11-6 (monohydrate), 6132-02-1 (decahydrate)

Key Process
Steps
Brine Preparation: Salt water is purified to remove calcium and magnesium impurities.

Absorption Tower: Ammonia gas is absorbed into the purified cold brine.

Carbonator: (CO_2) is injected, causing sparingly soluble ($NaHCO_3$) to drop out of the cooled solution.

Filtration: Solid sodium bicarbonate crystals are separated via vacuum or rotary filters.

Byproduct Regeneration: Limestone ($CaCO_3$) is burned to supply (CO_2) and generate (CaO), which is slaked into ($Ca(OH)_2$ to recycle ammonia.

6. Acetic Acid: Industrially, acetic acid is primarily prepared via methanol carbonylation, reacting methanol with carbon monoxide at high pressures and temperatures using a metal catalyst. Secondary methods include the liquid-phase oxidation of acetaldehyde or butane, and biological fermentation for food-grade vinegar.

Main Industrial Methods
Methanol Carbonylation (Monsanto & Cativa Processes)
The Reaction: Methanol reacts with carbon monoxide ($CH_3OH+CO \rightarrow CH_3COOH$).

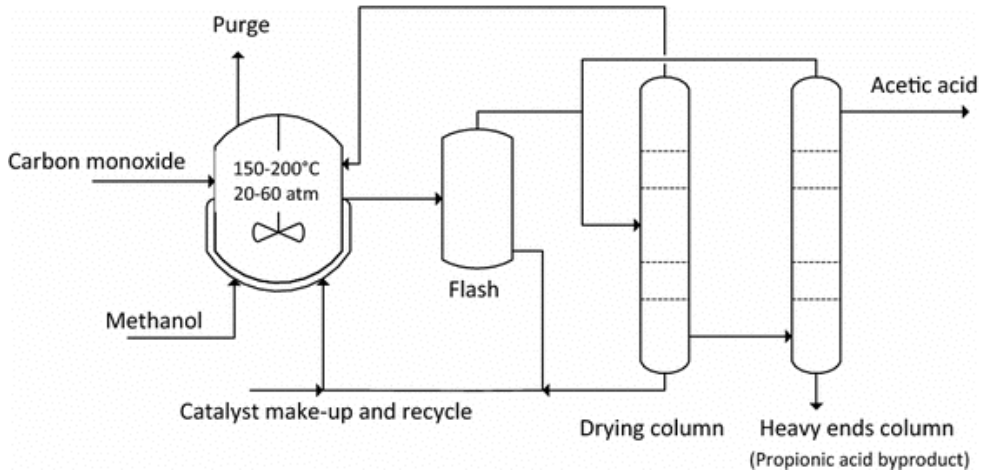

Figure-10: Acetic Acid preparation in Industry.

Catalysts: Uses a rhodium-based catalyst (Monsanto process) or a more efficient iridium-based catalyst (Cativa process) with iodine promoters.

Significance: Dominates global commercial production due to high efficiency and low raw material costs.

Acetaldehyde Oxidation

The Reaction: Acetaldehyde is oxidized by oxygen or air in the liquid phase at 60–70°C.

Catalysts: Transition metal acetate catalysts (like manganese or cobalt) are used to manage intermediate peracetic acid breakdown into acetic acid.

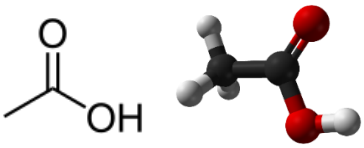

Figure-11: Acetic Acid & 3D Structure.

Alkane Oxidation:

The Reaction: Light petroleum alkanes, primarily butane, are oxidized with air at elevated temperatures and pressures to yield acetic acid alongside byproducts.

Fermentation (Biosynthesis)

The Process: Utilizes Acetobacter bacteria to aerobically convert dilute ethanol (from wine, cider, or grain mash) into acetic acid and water ($C_2H_5OH+O_2 \rightarrow CH_3COOH+H_2O$).

Usage: Reserved specifically for dietary vinegar production rather than large-scale industrial chemical synthesis.

7. Phosphoric acid: CAS: 7664-38-2. It is also called Orthophosphoric acid manufactured industrially through two primary methods: the Wet Process, which treats phosphate rock with sulfuric acid to produce agricultural-grade acid, and the Thermal (Electric Furnace) Process, which reduces phosphate ore to high-purity elemental phosphorus for food and industrial applications.

The Wet Process (Agricultural Grade)

Raw Materials: Finely ground phosphate rock ($Ca_5(PO_4)_3F$ fluorapatite) and concentrated sulfuric acid (H_2SO_4).

Reaction: Rock is digested in a mixture of sulfuric acid and recycled weak phosphoric acid. This exothermic reaction yields phosphoric acid and calcium sulfate (gypsum).

Crystallization Control: Operating conditions dictate whether gypsum precipitates as a dihydrate (70–80°C) or hemihydrate (90–110°C).

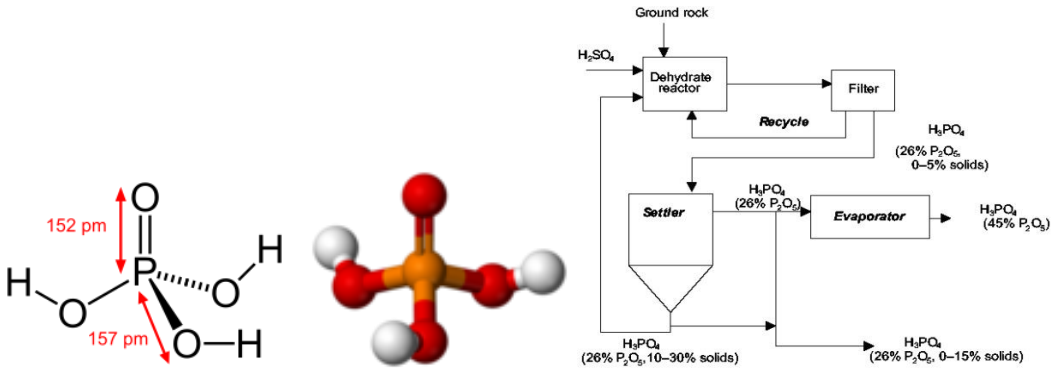

Figure-12: Phosphoric Acid, 3D and Industrial Process.

Separation & Concentration: Slurry goes to filtration units (like rotating pan filters) to separate the gypsum byproduct. The resulting weak acid (26–32% P_2O_5) is concentrated via vacuum evaporators to roughly 54% P_2O_5 for commercial use.

The Thermal Process (High Purity / Food Grade): Reduction: Crushed phosphate rock is mixed with silica (sand) and coke (carbon) and fed into an electric arc furnace at 1400–1500°C.

Vaporization: The reaction releases elemental yellow phosphorus (P_4) vapor and carbon monoxide gas, leaving behind a calcium silicate slag.

Combustion & Hydration: Liquid elemental phosphorus is burned with air to create high-purity phosphorus pentoxide (P_4O_{10}), which is subsequently dissolved in water to yield high-purity phosphoric acid (85% concentration).

ACKNOWLEDGEMENT

*This article is dedicated to **Shri Chiranjib Sen** [Father of Prof Dr Dhrubo Jyoti Sen] who had taught process chemistry of inorganic acids and bases by contact process during in Class X-XII [1980-83], so pray homage to Shri Sen who was the mastermind of chemistry.*

CONCLUSION

The Contact Process is the primary industrial method for manufacturing concentrated sulfuric acid (H_2SO_4). Its importance lies in the massive, cost-effective production of sulfuric acid—often called the "king of chemicals"—which serves as a fundamental backbone for global agriculture, manufacturing, and industrial chemical sectors. Key Uses and Economic Impact: Fertilizer production: Large quantities go into making ammonium sulfate and superphosphate fertilizers. Chemical manufacturing: Used to produce other acids, sulfate salts, dyes, and pigments. Energy storage: Acts as the essential electrolyte solution inside automotive lead-acid storage batteries. Processing and refining: Vital for petroleum oil refining, metal and mineral processing, and wastewater treatment. Economic barometer: A nation's overall production volume of sulfuric acid is widely regarded as a key indicator of its industrial strength and economic growth. Efficiency and Optimization: High purity yield: Yields roughly 97% conversion efficiency of sulfur dioxide to sulfur trioxide using a vanadium pentoxide (V_2O_5) catalyst. Controlled equilibrium: Operates under optimized compromise conditions (temperatures around 450°C and low pressures near 1–2 atm) to balance reaction speed, equipment safety, and economic feasibility. Industrial nitric acid (HNO_3) is a vital mineral acid and strong oxidizing agent produced primarily via the Ostwald process through the catalytic oxidation of ammonia. It is predominantly used to manufacture ammonium nitrate for fertilizers (consuming 75–80% of production), as well as explosives, nylon precursors, and metal-etching solutions. Raw materials: Synthetic ammonia (NH_3) and filtered air (O_2). Ammonia oxidation: Ammonia and air mix and pass over a platinum-rhodium gauze catalyst at 810–930°C to produce nitric oxide (NO) and steam. Nitric oxide oxidation: Nitric oxide cools and reacts with oxygen to form nitrogen dioxide (NO_2) gas. Absorption: Nitrogen dioxide is absorbed in water inside absorption towers to yield aqueous nitric acid, typically at 60–68% concentration. Concentration: Higher purities (up to 98%) are achieved via extractive distillation using concentrated sulfuric acid or dehydration methods. Key Industrial Applications: Fertilizers: Neutralized with ammonia to create ammonium nitrate for rich crop nutrition. Explosives & Propellants: Used in making compounds like TNT, nitroglycerin, and rocket propellants. Chemical Synthesis: Acts as a key nitrating agent for producing adipic acid, nitrobenzene, and nylon precursors. Metal Processing: Applied in the pickling, etching, and passivation of stainless steel. Electronics: Utilized for microchip and semiconductor surface cleaning and etching. The Haber process, also called the Haber–Bosch process, is the main industrial procedure for the production of ammonia. It converts atmospheric nitrogen (N_2) to ammonia (NH_3) by a reaction with hydrogen (H_2) using finely divided iron metal as a catalyst.

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