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## Process Simulation and Design of Sulfuric Acid Production via Double Contact Process

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**Abstract**

This study examined the production of 98% sulfuric acid using the double contact process, optimized for environmental sustainability and process efficiency. The methodology involved burning sulfur to generate sulfur dioxide ($SO_2$), then catalytically oxidizing it into sulfur trioxide ($SO_3$) using vanadium pentoxide across five fixed-bed reactors. The $SO_3$ produced was absorbed sequentially to form sulfuric acid with intermediate and final absorption stages ensuring optimal conversion and purity. Process simulations conducted via Aspen Plus V11 focus on mass and energy balances, emphasizing energy recovery from exothermic reactions through waste heat boilers and comprehensive heat exchanger networks. The $SO_3$ produced was absorbed sequentially, resulting in a final sulfuric acid concentration of 98%, with an intermediate absorption efficiency of 99.5%. Process simulations conducted via Aspen Plus V11 showed a total energy recovery of 7.5 MW through waste heat boilers and heat exchanger networks, contributing to overall energy efficiency This study, highlighted key environmental strategies, including advanced emission controls such as scrubbers and neutralization pits, to effectively address the release of sulfur oxides and other pollutants. Environmental strategies included advanced emission controlled such as NaOH scrubbers, reducing $SO_2$ emissions to below 200 mg/m³ and mitigating acid mist emissions to less than 10 mg$H_2SO_4$/Nm³. Results showed that strategic process design and rigorous operational controls were crucial for maximizing production efficiency while minimizing environmental footprint, offering insights into scalable and sustainable industrial chemical production.

**Keywords:** Sulfuric acid; Double contact double conversion; Process Design; Energy conservations; Advanced emission controls.

## 1. Introduction

Energy is essential for industrial development and modern life but conventional sources contribute significantly to environmental pollution [1,2]. Renewable energy derived from natural resources such as solar, wind, and biomass, offers a sustainable alternative [3,4]. It supports cleaner production processes, conserves resources, and reduces harmful emissions. Emphasizing energy efficiency and renewables is vital for ensuring both environmental protection and long-term industrial sustainability. Sulfuric acid ($H_2SO_4$) is one of the most widely produced chemicals worldwide, used extensively in various industrial applications, including fertilizer production, mineral processing, petroleum refining, and chemical synthesis. The global demand for sulfuric acid shows its pivotal role in modern industrial economies. Therefore, the efficiency of its production processes critically important not only economically but also environmentally. Numerous studies have explored sulfuric acid production, focusing on efficiency, emission control, and safety. The double contact double absorption (DCDA) process achieves over 99% $SO_2$ conversion, minimizing emissions. The production of sulfuric acid can be achieved through several methods, with the double-contact process being the most efficient in terms of sulfur conversion and acid concentration [5]. This process was developed to enhance the conversion efficiency of sulfur dioxide ($SO_2$) to sulfur trioxide ($SO_3$), utilizes a two-stage catalytic process which allows for a higher production yield and better environmental compliance compared to older single-contact methods. The key to this enhanced efficiency lies in the use of vanadium pentoxide ($V_2O_5$) as a catalyst and the control of process variables such as temperature and pressure, which are critical for maximizing the yield and purity of the final product. The double contact process begins with the burning of sulfur to form $SO_2$, a reaction that is both simple and exothermic. This step is followed by the catalytic oxidation of $SO_2$ to $SO_3$ over a series of catalyst beds. The design of these reactors is crucial as they must facilitate not only the maximum conversion of $SO_2$ to $SO_3$ but also accommodate the

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significant amount of heat released during the reaction. The process is hence typically integrated with heat recovery systems that contribute significantly to the overall energy efficiency of the plant [6].

After the formation of $SO_3$, the gas is absorbed in a series of absorption towers to form sulfuric acid. This step is critical and requires careful control of temperature and concentration to ensure that the $SO_3$ is completely absorbed, minimizing emissions, and maximizing acid strength. The double contact double absorption (DCDA) process, a variant of the double contact process, includes an additional absorption step to capture any unreacted $SO_3$, thereby improving the overall efficiency and environmental performance of the process.

Environmental considerations play a significant role in the design and operation of sulfuric acid plants. The emissions of sulfur oxides ($SO_x$) which are potent environmental pollutants must be controlled to meet stringent global environmental regulations. Modern sulfuric acid plants employ a variety of techniques to reduce these emissions including gas scrubbing and tail gas treatment processes. These systems not only reduce pollution but also improve the safety and sustainability of the operation[7].

Furthermore, the integration of advanced simulation tools such as Aspen Plus for process modeling offers a comprehensive way to design, analyze, and optimize the sulfuric acid production process. These tools allow researchers to simulate different operating conditions and find optimal solutions for material and energy balances, equipment sizing, and system integration which are essential for reducing costs and environmental impact. This study presented a detailed study of the double contact process for sulfuric acid production. It focused on process efficiency and environmental sustainability. Through this study, it was aimed to highlight the critical aspects of process design and operational strategies that can significantly enhance the sustainability and efficiency of sulfuric acid manufacturing. Process simulations using Aspen Plus improved design and energy recovery by 7–10% enhancing sustainability [9]. Emission control strategies including alkali scrubbers and cesium-promoted catalysts, reduce $SO_2$ levels below 200 mg/m$^3$ [10]. Safety remains a key concern, with HAZOP studies highlighting risks and supporting real-time monitoring and automated shutdowns [11,12]. Despite advancements, gaps remain in process integration, emission monitoring, and catalyst optimization. This study addressed these issues by optimizing production efficiency (>99.5% $SO_2$ conversion) while minimizing environmental impact (<10 mg $H_2SO_4$/Nm$^3$ emissions).

## 2. Methodology

Sulfuric acid is necessary for modern industry, agriculture, and infrastructure. Its broad utility in both basic and advanced manufacturing processes makes it a cornerstone of industrial chemistry and global economic progress. A methodological plan was made to design an optimum, feasible, and sustainable method for sulfuric acid. Several software programs were used as means of providing figures and data, including Aspen Plus V11, Edraw max V11, and Cap cost. Table 1 lists the tools used and their main purposes.

**Table 1:** Software Programs Used

| Program | Purpose |
|---|---|
| Aspen Plus V11 | Process simulation. |
| Edraw maxV11 | Block flow diagrams (BFD) and process flow diagrams (PFD) sketching. |
| Capcost (Microsoft Excel macro-enabled file) | Equipment cost analysis. |

The methodology employed Aspen Plus V11 for process simulation, chosen over alternatives like HYSYS and CHEMCAD due to its advanced thermodynamic modeling, reaction kinetics integration, and heat exchanger analysis. Its built-in templates for compressors, separators, and distillation columns make hydrocarbon processing simulations easier.

### 2.2. Process overview

Sulfur combustion and the double contact process are the two primary components of the examined process. Firstly, the combustion furnace receives dry air and molten sulfur as inputs, where the sulfur is burned to create sulfur dioxide. To maintain a proper oxygen concentration in the process gas and guarantee the correct conversion of sulfur dioxide to sulfur trioxide in the next phases, the ratio between the airflow and the sulfur feed rate is regulated. A waste heat boiler in this combustion furnace cools the reaction gas and produces high-pressure steam, which is then supplied to the turbine to produce electricity. Secondly, The $SO_2$ converter receives the cooled reaction product gas where $SO_3$ is produced by oxidizing $SO_2$. Within a single vertical converter, this phase takes place in five catalytic layers. After exiting the reactor through the third layer, the gases go downstream to a medium absorption step where some of the generated $SO_3$ combines with the water in the recycled sulfuric acid, 98% by weight, to produce concentrated sulfuric acid, with a concentration of approximately equal to 99.5%. The gas expelled from the intermediate absorption tower is routed to the fourth and fifth beds in the converter for the last steps of the catalytic oxidation process. The final absorption process, which is comparable to the intermediate absorber, receives the oxidation product to produce further sulfuric acid. Finally, the outputs of these two absorbers are mixed with the sulfuric acids out of the drying tower in the acid circulation tank with water for dilution to produce the ultimate product, which is sulfuric acid at 98% by weight [4].

### 2.2. Process description

Pure sulfur is used in the sulfuric acid plant process. In the melting step, the solid sulfur transforms into a liquid. This part involves feeding the solid sulfur from the storage area into the feed hopper and then into the melting pit. The solid sulfur melts and transforms into liquid sulfur when the coil is heated to a temperature between 135°C and 145 °C. A screw pump feeds molten sulfur to the burner via a jacketed pipe, which keeps the molten sulfur from solidifying inside the pipe. In the burning section, where the temperature ranges from 700 °C to 1040 °C under 1–2 atm pressure with an excess air supply to ensure complete combustion. Unlike later stages in sulfuric acid production, this reaction does not require a catalyst but relies on sufficient residence time in the burner for full conversion. And dried air is directed from the air-drying tower (DRT), the liquefied sulfur is oxidized to $SO_2$. Then the molten sulfur is converted to $SO_2$ gas according to the reaction in Eq1.

$$S_{(L)} + O_{2(g)} \rightarrow SO_{2(g)} \qquad (1)$$

Five fixed catalytic beds with separate heat exchangers are part of the converter component. At the top of the converter, the waste heat boiler's gases are charged to 425 °C, and the drying tower's dried air is likewise sent into the converter. Then, the sulfur dioxide gas is converted to sulfur trioxide in the presence of a vanadium pent oxide ($V_2O_5$) catalyst as Eq 2 demonstrates [5].

$$2\ SO_2(g) + O_2\ (g) \rightarrow 2\ SO_3\ (g) \qquad (2)$$

All the reactions occurring in the converter are both exothermic and reversible. The converters operate within a temperature range of 400°C to 600°C and at a pressure of 1–2 atm.

In the first bed, the gas passes through a catalyst bed containing vanadium pentoxide ($V_2O_5$), where the initial conversion of $SO_2$ to $SO_3$ reaches approximately 64%. The gas exiting the first bed is then directed to the superheater, where it is cooled before proceeding to the next stage.

In the second bed, the gas is directed as given in Eq 2 facilitate the further conversion of unreacted $SO_2$ into $SO_3$.

The conversion efficiency at this stage reaches approximately 88%. The gas exiting the second bed is then transferred to a hot heat exchanger for cooling before the remaining $SO_2$ is sent to the third bed of the converter. The conversion process occurs in multiple stages to maximize $SO_2$ to $SO_3$ conversion. In the first bed, the reaction begins with a 64% conversion, followed by cooling in the superheater. The second bed increases conversion to 88%, and the gas is cooled before moving to the third bed, where conversion reaches 95%. The gas then passes through heat exchangers and the intermediate absorption tower

IAT), with unconverted gases sent to the fourth bed, achieving 99% conversion. Finally, in the fifth bed, dried air is mixed with the gas to reach a 99.9% conversion rate before the $SO_3$ is sent to the final absorption tower (FAT).

the SO3 is sent to the 2nd economizer and then to the final absorption tower (FAT).

In the absorption tower, $SO_3$ gas enters from the bottom while 98% concentrated sulfuric acid is sprayed from the top. The reaction occurs at 50–80°C under 1–2 atm pressure in a packed absorption tower, ensuring maximum gas-liquid contact. The acid is cooled from 80°C to 60°C to enhance absorption efficiency. A rushing ring increases gas-liquid contact while reducing pressure drop. The sulfuric acid, containing 1.5% water, reacts with $SO_3$, resulting in the production of 99.1% concentrated sulfuric acid at 89.3°C.

Dilution Tank: Finally, the oleum enters the circulation tank to reduce the concentration from 99.5% to 98% by adding water or an acid that returns from the drying tower with a concentration of 98% according to Eq. 3.

After mixing in the circulation tank the acid has a concentration of 98% with a temperature of 80 °C [9].

$$SO_3(g) + H_2O\ (L) \rightarrow H_2SO_4 \quad (3)$$

### 2.3. Block Flow Diagram

A block flow diagram typically represents the process shown in Figure 1. The block flow diagram (BFD) illustrates the main stages of sulfuric acid production via the double contact process. It provides a high-level overview of the process including sulfur melting, combustion, catalytic conversion of $SO_2$ to $SO_3$, and absorption to produce concentrated sulfuric acid. The BFD simplifies complex operations into basic blocks. It highlights key inputs like air and sulfur, and outputs such as sulfuric acid and emissions. This diagram supports process understanding and design by offering a clear, streamlined visualization of the overall production sequence.

## 3. Simulation results

Aspen Plus V11 was used to generate simulation results for 98% sulfuric acid production, with an emphasis on stream characteristics, material and energy balances, and process flow diagrams (PFD). Energy use throughout the process, product purity, and sulfur conversion efficiency are all included in the analysis. Datasheets detailing stream temperatures, pressures, and phase compositions were created, and an evaluation of energy recovery in waste heat boilers and heat exchangers was also included.

Process Flow Diagram demonstrates the process flow diagram of a sulfuric acid plant by the double conversion double absorption method. The PFD was drawn by Edraw max Professional V12. This research is aimed at producing a 500 MTDP of sulfuric acid 98% using 6816.9kg/hr. of solid sulfur. The process consists of two main stages: the powdered sulfur conversion to $SO_3$ through a series of steps. Secondly, $SO_3$ absorption occurs in two absorption towers using concentrated $H_2SO_4$ (98%) to produce 99.5% sulfuric acid, which is then diluted back to 98%. To enhance energy efficiency, the plant utilizes a series of cold-water heat exchangers to recover heat from the highly exothermic reactions, generating steam to power a turbine. Exhaust gases from the final absorption tower (FAT) pass through NaOH scrubbers, with the treated effluent sent to a neutralization pit before discharge. Remaining gases are released into the atmosphere in compliance with environmental regulations via a 55-meter chimney.

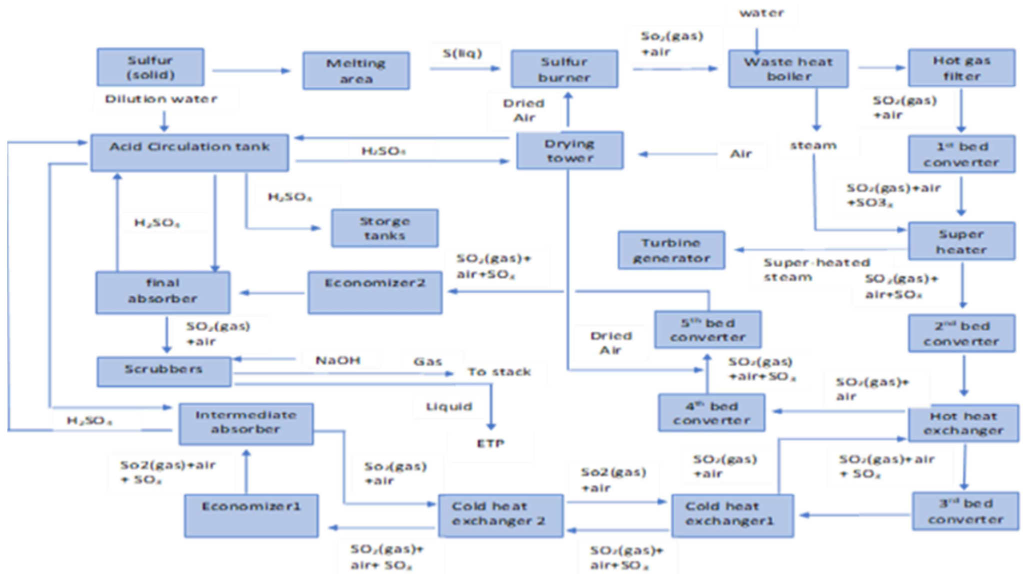


**Figure 1:** A block flow diagram of the sulfuric acid production by double contact process.

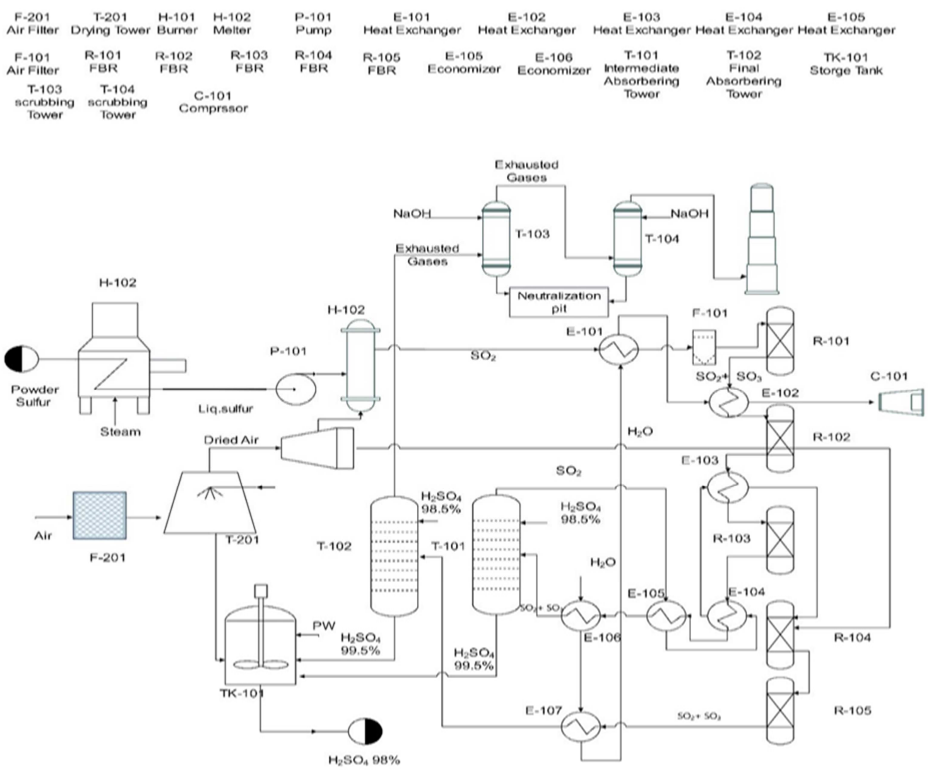


**Figure 2:** A process flow diagram of the sulfuric acid production by double contact process.

Butterfly valves are essential components in sulfuric acid plants, offering reliable flow regulation and throttling for $SO_2$ and $SO_3$ gases. Their superior sealing corrosion resistance, and precise control capabilities support optimal process performance and emission management. Typically used to regulate gas flow and control emissions in tail gas scrubbers, these valves lined with PTFE, Hastelloy, or stainless steel ensure durability, minimal pressure drop, and efficient flow control, particularly within catalytic converters, thus improving conversion efficiency and overall plant operation.

### 3.1. Aspen Plus Simulation

The process efficiency, material balance, and energy balance of a double contact double absorption (DCDA) sulfuric acid plant were evaluated through simulation of 98% sulfuric acid production using Aspen Plus V11. As illustrated in Figure 2, sulfur is combusted to produce $SO_2$, which is then catalytically oxidized to $SO_3$ and absorbed to form $H_2SO_4$. Material balance calculations ensured mass conservation across all process units, while energy balance focused on optimizing utility usage by recovering heat from exothermic reactions via waste heat boilers and heat exchangers. The process design was validated under defined parameters using key outputs such as stream temperatures, pressures, phase compositions, and energy requirements. The results confirm efficient sulfur utilization and effective energy recovery, supporting sustainable plant operation. Figure 3 presents the process flowchart for the production of sulfuric acid at 98% concentration, while detailed process data are summarized in Tables 2 and 3.

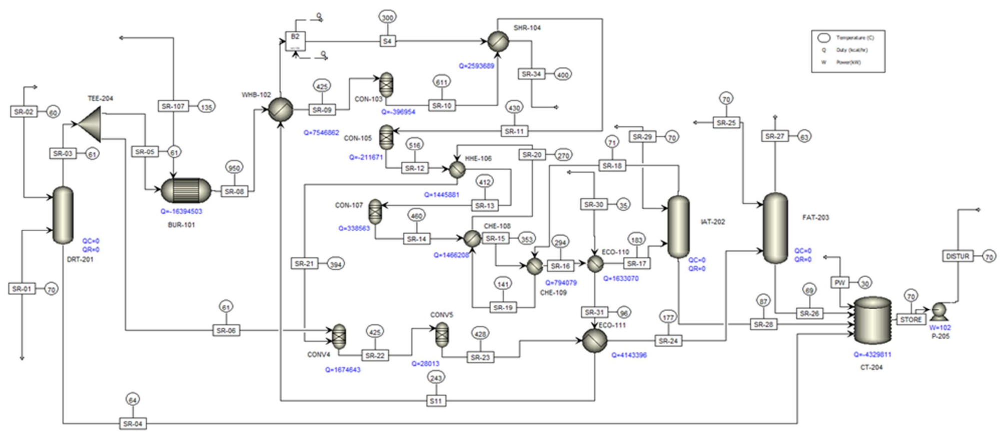


**Figure 3:** Process flowchart of sulfuric acid plant with 98% concentration.

**Table 2:** Inputs and outputs values of the plants

| Stream code | Temperature (C) | Pressure (KPa) | Mass flow (Kg/hr) | Stream code | Temperature (C) | Pressure (KPa) | Mass flow (Kg/hr) |
|---|---|---|---|---|---|---|---|
| SR107 | 135 | 253.3125 | 6816.90 | SR-27 | 63.3 | 7.7 | 62018.21 |
| SR-01 | 70 | 34.335 | 66739.17 | SR107 | 135 | 253.3125 | 6816.90 |
| SR-02 | 60 | 318.8 | 523664.23 | SR-01 | 70 | 34.335 | 66739.17 |
| SR-05 | 60.8 | 34.3 | 49144.86 | SR-02 | 60 | 318.8 | 523664.23 |
| SR-08 | 950 | 39.2 | 55961.76 | SR-05 | 60.8 | 34.3 | 49144.86 |
| SR-09 | 425 | 39.2 | 55961.76 | SR-08 | 950 | 39.2 | 55961.76 |
| SR-17 | 183.25 | 22.7. | 55961.76 | SR-09 | 425 | 39.2 | 55961.76 |
| SR-18 | 70 | 22.7 | 42801.17 | SR-17 | 183.25 | 22.7. | 55961.76 |
| SR-28 | 86.91 | 14.7 | 1009555.31 | SR-18 | 70 | 22.7 | 42801.17 |
| SR-29 | 70 | 318.8 | 996394.72 | SR-28 | 86.91 | 14.7 | 1009555.31 |
| SR-21 | 393.772 | 22.7 | 42801.31 | SR-29 | 70 | 318.8 | 996394.72 |
| SR-06 | 60.84 | 34.3 | 16381.62 | SR-21 | 393.772 | 22.7 | 42801.31 |
| SR-24 | 177 | 22.7 | 59182.81 | SR-06 | 60.84 | 34.3 | 16381.62 |
| SR-25 | 70 | 318.8 | 398934.76 | SR-24 | 177 | 22.7 | 59182.81 |
| SR-26 | 69 | 7.7 | 396099.367 | SR-25 | 70 | 318.8 | 398934.76 |

**Table 3:** Equipment codes, outlet temperature and head duties values

| Equipment | Code | Outlet Temperature (C) | Heat Duty (KW) |
|---|---|---|---|
| **Burner** | **BUR-101** | **950** | **-19066.807** |
| **WHB** | **WHB-102** | **425Hot/300-357Cold** | **7546861.68** |
| **1st Converter** | **CON-103** | **611** | **-461.658** |
| **2ndConverter** | **CON-104** | **516** | **-246.17** |
| **3rdConverter** | **CON-107** | **460** | **393.74** |
| **4thConverter** | **CON-108** | **425** | **1947.60** |
| **5thConverter** | **Con-109** | **428** | **32.57** |
| **Super Heater** | **SHR-104** | **430.47HOT/400 Cold** | **3016.46** |
| **Hot HE** | **HHE-106** | **411.97 HOT/ 393.77** | **1681.56** |
| **Cold HE 1** | **CHE-108** | **353 HOT/270 Cold** | **1705.204** |
| **Cold HE 2** | **CHE-109** | **293.7 HOT/ 141.29 Cold** | **923.51** |
| **Economizer 1** | **ECO-110** | **183 HOT/95 COLD** | **1899.26** |
| **Economizer 2** | **ECO-111** | **176.80 HOT / 242.8 COLD** | **4818.769** |
| **Absorbers** | **IAT, FAT, DRT** | | **QC=0 / QR= 0** |

**4. Hazard and operability study**

This study examined an incident involving the release of sulfur oxide gases from a sulfuric acid manufacturing plant. This article outlines the causes, consequences, and lessons learned, offering recommendations to prevent future occurrences.

**4.1. Hazard Identification**

The first step in any risk assessment is identifying all potential hazards. The significance of each hazard is then evaluated to determine whether it warrants further investigation, typically using a threshold quantity or cut-off. The evaluation assumes that the plant will operate as designed, without accounting for unintended events such as component or material failures, human errors, external incidents, or process uncertainties.

Once a hazard is identified, it must be assessed in terms of the risk it poses to employees and the surrounding community. Ideally, both probability and consequence are considered, but in some cases, decisions can be made based on just one factor if either the probability or consequence is sufficiently low or high[11]

The hazard identification process takes several factors into account. It involves identifying the chemical substances, determining the locations of facilities that use, produce, process, transport, or store hazardous materials, and assessing the types and designs of containers, vessels, or pipelines. Additionally, it considers the quantity of materials that could be released into the air and the specific hazards associated with a spill or release, such as toxic vapors, mists, fire, explosions, or risks related to large-scale storage and handling conditions.

**4.2. Hazard Identification Procedures**

Various techniques are available for identifying and assessing hazards in the chemical processing industry. Some hazards are immediately noticeable, such as the release of $SO_3$ and $SO_2$, which can create dangerous conditions. In India, checklist-based procedures are commonly used, and annual safety audits are mandatory. However, a significant drawback of checklist methods is that they do not account for hazards that are not explicitly listed. These procedures are most effective when there are no modifications to the process or new design implementations. A more flexible and comprehensive approach is the Hazard and Operability Study (HAZOP), which has been applied to the absorption tower, as outlined in Table 4.

**4.3. Quantity of Gas Released**

HAZOP study of the absorption tower. The gas released from the top of the IAT stack was estimated to be 1450 g/s. Modeling the gas dispersion is complex, as $SO_3$ and $SO_2$ are heavier than air, and the emitted gas consists of a mixture of $SO_3$, $SO_2$, $O_2$, and $N_2$. The dispersion model should consider the initial mixing of the gas with air, along with factors like heat and momentum transfer. $SO_3$ reacts with water vapor, forming a white mist. By applying existing dispersion principles, the concentration of acid gas can be estimated both downwind and crosswind.

The following data are used for the model:

Source discharge rate: 1450 g/s.

Composition by weight percentage: $SO_3$ – 8%, $SO_2$ – 0.35%, $O_2$ – 6.2%, $N_2$ – 85.45%.

Wind velocity: 2 m/s.

Atmospheric conditions: Clear day.

Downwind distance for 1ppm concentration (using a neutrally buoyant model):550m. However, the actual downwind distance for a 1ppm concentration is expected to be shorter than the distance predicted by the Gaussian dispersion model. This is due to enhanced turbulence and absorption effects from obstacles in the gas dispersion path [12,13].

**Table 4:** HAZOP study of the absorption tower

| Guide Word | Deviation | Possible Causes | Consequences | Action Required |
|---|---|---|---|---|
| None | No. flow of acid | Insufficient acid pumping due to mechanical issues, such as pump gasket failure, motor coupling shear, or suction line blockage.<br>Acid pump failure caused by electrical faults.<br>Absence of acid in the circulation tank.<br>Leakage in the acid pipeline.<br>Blockage in the acid line. | No absorption of $SO_3$ in the tower and $SO_3$ escaping into the atmosphere | One alarm is to be provided at the acid inlet point to the tower and in the mentioned possible causes, the plant shall trip. |
| More of | More acid flow | The valve of the drying tower/final absorption tower closed. | Acid flooding in the tower caused acid to flow into the $SO_3$ gas inlet pipeline. | An alarm should be installed at the gas inlet point of the tower, and if acid enters the line, the plant will automatically shut down. |
| Less of | Less acid flow | Insufficient acid pumping due to mechanical issues.<br>- Reduced acid flow caused by an electrical fault.<br>- Pipeline leakage resulting in decreased acid supply to the tower.<br>- Partial blockage in the acid line. | Partial absorption of $SO_3$ after $SO_3$ concentration buildup will escape in the atmosphere. | An alarm should be installed at the acid inlet point of the tower, and if any of the identified causes occur, the plant will automatically shut down. |

**4.4. The Problems**

The sulfur oxide gases affected over 21 children at a nearby school, located approximately 500 meters from the source. The children were transferred to a local hospital and provided with first aid, with one child being sent to a nearby medical facility. All were discharged on the same day. The children exhibited symptoms including:

(i) Irritation of the eyes, mucous membranes of the nose, pharynx, and respiratory tract.

(ii) Burning sensations on the skin; and vomiting in some cases, along with the aforementioned symptoms.

To enhance safety, efficiency, and environmental compliance in a sulfuric acid plant, several HAZOP recommendations should be considered. Online $SO_2$ analyzers enable real-time emissions monitoring, while automated flow control optimizes the air/$SO_2$ ratio for efficient conversion. Upgrading to high-efficiency mist eliminators and optimizing absorption tower gas flow rates can reduce acid mist emissions. Automated temperature control with alerts helps prevent heat spikes, while improved maintenance schedules for heat exchangers prevent fouling. Backup cooling systems ensure stability during sudden temperature fluctuations, and regular catalyst regeneration or replacement preserves conversion efficiency. These measures enhance process reliability, minimize risks, and optimize plant performance.

**5. General plant considerations**

Designing a plant involves a lot of critical considerations to ensure its efficient and safe operation. First is the choice of site location, which should factor in geological stability, accessibility to transportation networks and resources, and environmental impact assessments to minimize harm to local ecosystems and communities. The plant layout is equally vital, encompassing equipment spacing to allow for maintenance access and potential expansions, as well as efficient material flow for optimized operations. Safety zones and areas for emergency response and fire protection must also be designated within the layout. Moreover, assessing wind direction and weather patterns is crucial when positioning equipment and emissions stacks to minimize pollutant dispersion and maximize safety, especially in regions prone to extreme weather conditions. Ensuring safety and security measures, including fire prevention and suppression systems and access control, is paramount for protecting critical infrastructure. Thinking ahead, plant designs should incorporate scalability and future expansion possibilities to accommodate growing energy demands or technological advancements. Aesthetic considerations should not be overlooked, as the visual impact on the local community can influence public perception. Finally, operational efficiency should be at the forefront of planning, with a focus on process integration and maintenance accessibility to optimize energy efficiency and reduce operational costs. Thus, these multifaceted considerations, plants can be designed to meet energy needs while minimizing environmental impacts and ensuring long-term sustainability.[14, 15].

### 5.1. Equipment Spacing

Proper spacing of equipment is essential to maintain safe operations and reduce the risk of failures during accident [16]. The equipment Spacing design has been made for the sulfuric acid plant. as shown figure 4.

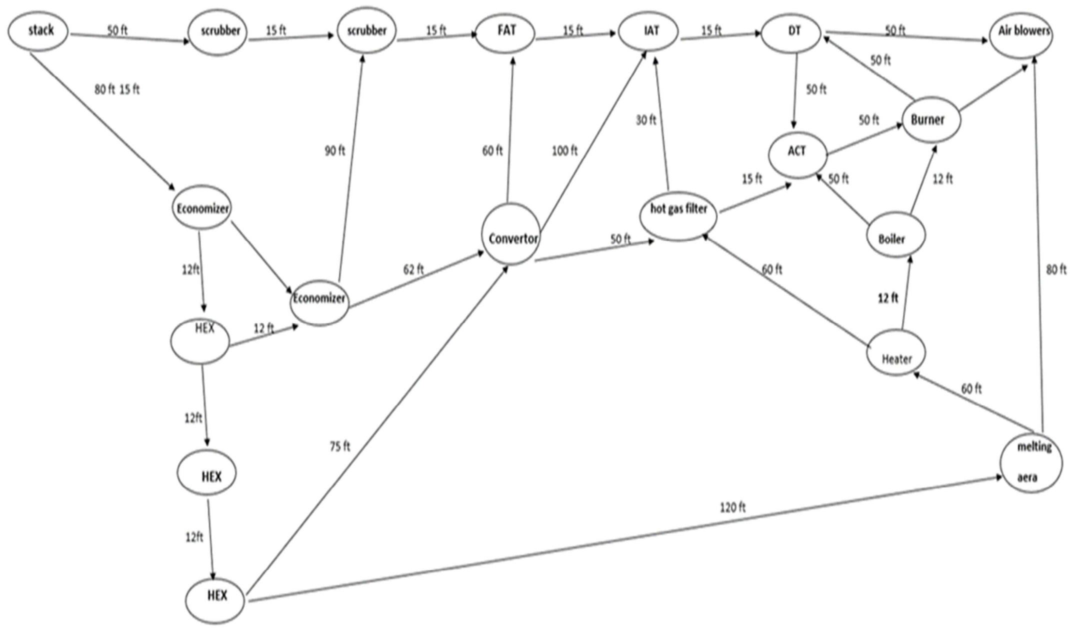


**Figure 4:** Sulfuric acid plant equipment spacing.

### 5.2. Plant Layout

This section will cover the plant layout, focusing on equipment spacing, administrative areas, and potential expansion zones. Considering wind direction and intensity is crucial for determining the plant's orientation, as illustrated in figure 5. Therefore, analyzing the wind atlas or wind rose of Alexandria is recommended [16].

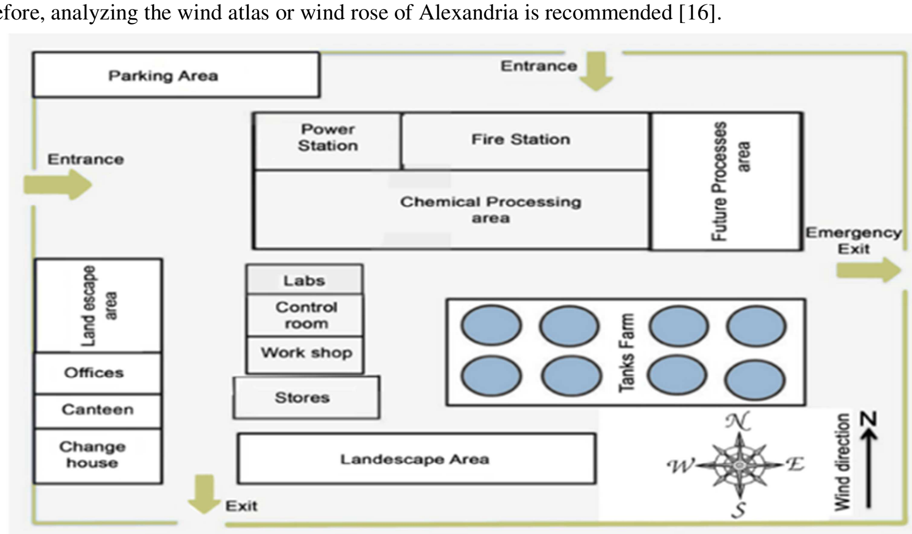


**Figure 5:** Plant layout.

### 5.3. Site Location

Several potential sites were evaluated for the establishment of the sulfuric acid production plant, including the October Industrial Zone, Port Said Industrial Zone, Jamsa Industrial Zone, Alexandria Industrial Zone, Marsa Matrouh, and Ras Ghareb in the Red Sea Governorate. The selection process considered multiple criteria such as proximity to marketing areas, availability of raw materials, transport facilities, labor supply, and utilities including water, fuel, and power. Other important factors included the availability of suitable land, environmental impact and effluent disposal, local community considerations, climate conditions, and political or strategic importance. After thorough assessment, the Alexandria Industrial Zone was identified as the most optimal location for the plant.

## 6. Profitability study

Estimating costs is a specialized field and an occupation in and of itself. However, in order to evaluate projects and choose amongst different designs, the design engineer must be able to quickly and roughly estimate costs. Chemical plants are designed to turn a profit, and before a project's profitability can be evaluated, an estimate of the necessaryinvestment and production costs must be obtained[17]

A profitability study helps the design phase by ensuring the economic feasibility of the sulfuric acid plant. By analyzing fixed and variable costs, operating expenses, and projected revenues, engineers can determine the plant’s financial viability and optimize process efficiency to maximize profits. Cost estimates influence equipment selection, material choices, energy recovery strategies, and emission control investments, ensuring a balance between capital expenditure (CAPEX) and operational expenditure (OPEX). Additionally, profitability assessments guide scalability decisions and investment planning, making the design both technically sound and economically sustainable.

In this study, the fixed and variable costs, for establishing a factory to produce sulfuric acid with a concentration of 98% were calculated according to global readings, known worldwide values, and standards [18]. As tabulated in Table 5-9.

**Table 5: Fixed cost and variable cost**

| | |
|---|---|
| **PCE** | $2969441 |
| **PPC** | $3414857.15 |
| **Fixed Capital Cost** | $5938882 |
| **Total Investment** | $7423602.5 |

**Table 6: Variable cost**

| | |
|---|---|
| **Maintenance** | $148472/yr |
| **Operating Labor** | $1500000/yr |
| **Laboratory costs** | $225000/yr |
| **Supervision** | $300000/yr |
| **Plant overhead** | $750000/yr |
| **Capital charge** | $593888.2/yr |
| **Insurance** | $59388.82/yr |
| **Local taxes** | $118777.64/yr |
| **Royalties** | $16152880/yr |
| **Sub Section B** | $19848406.66/yr |
| **Direct Costs (A+B)** | $944024342.37/yr |

**Table 7: Fixed cost**

| | |
|---|---|
| **Raw Materials** | $807644000/yr |
| **Miscellaneous** | $99052721/yr |
| **Utilities** | $17479214/yr |
| **Shipping and Packaging** | Not applicable |
| **Sub Section A** | $924175935./yr |

**Table 8: Subsection**

| | |
|---|---|
| **Sales expense** | $80764400 |
| **General overheads** | $1050000 |
| **Research and Development** | $80764400 |
| **Sub Section C** | $162578800 |

**Table 9: Profitability**

| | |
|---|---|
| **Annual Production costs (A+B+C)** | $1106603142.37/year |
| **Production Cost** | $137/ton |
| **Net profit** | $508684857/year |
| **Annual revenue** | $1615288000/year |

## 7. Environmental assessment

When selecting a plant location, consideration should be given to the future need for additional waste treatment facilities as well as the permitted tolerance levels for different effluents depending on regulatory requirements. With the assistance of specialized facilities, wastewater disposal must be carried out without endangering the public. Local laws govern toxic and hazardous effluent disposal, and the relevant authorities must be consulted during the first site survey to ascertain the requirements. The creation of an Environmental Impact Assessment (EIA) is also related to this. Fugitive emissions of sulfur oxides and sulfuric acid mist are the two most significant environmental problems that the sulfuric acid manufacturing business faces. Burning sulfur produces $SO_2$, which is one of the main sources of pollution. The majority of the SO2 produced at facilities that adhere to strict sustainability criteria is transformed into sulfuric acid and recovered, although some of the chemical is released into the atmosphere. Because of $SO_2$ emissions, ambient air quality is an issue and needs to be checked on a regular basis. Sulfuric acid can be disposed of by either being absorbed into vermiculite, dry sand, or earth, or by being put in sealed containers. Additionally, sulfuric acid is being neutralized or diluted for disposal[17]. The environmental assessment of sulfuric acid production highlights existing emission control measures, including NaOH scrubbers, DCDA technology, and mist eliminators, but could benefit from alternative technologies. Selective Catalytic Reduction (SCR) can reduce $SO_2$ emissions below 100 mg/m³, while wet electrostatic precipitators (WESPs) effectively capture acid mist and particulates. Activated carbon adsorption provides a cost-effective method for $SO_2$ and $SO_3$ removal, and membrane separation technology shows promise for $SO_2$ recovery. Integrating these advanced methods alongside existing systems can further reduce environmental impact, improve regulatory compliance, and enhance process efficiency.

### 7.1. Environmental consideration

The primary gaseous pollutants found in the production of sulfuric acid are oxides of sulfur (SOx) and acid mist, which, if left unchecked, could have a negative effect on the environment. The catalytic converter and the absorption column can be taken into as a primary source of sulfur oxide emissions and, in the case of the absorption columns, perhaps trace amounts of acid mist, as they can be discharged into the atmosphere as residual air. The primary pollutant that may be released from the IAT, potentially as a result of inadequate absorption, is sulfur trioxide, whereas the catalytic converter may release $SO_2$ a result of inadequate conversion characteristics. While acid spray the dilution tanks and oleum storage tanks are more obvious sources of acid mist emissions, although absorption columns may also release sulfuric acid (i.e., sulfuric acid emission from the interaction of SO3 with water). It should be mentioned that, in general, fugitive emissions are a necessary component of this kind of manufacturing process because the design includes lengthy pipelines with several ancillaries installed on them (pumps, valves, instrumentation, junctions, and bypasses), as well as a variety of equipment with various joints and holes. When the tiny emissions from each of these locations are combined to form fugitive emissions, they may affect the environment, thus the design must make sure that the emissions don't go above the legally allowed discharge limits.

The characteristics of the pollutants negatively impact the ecosystem. as well as public health. When thinking about effect reduction, several methods might be examined [17].

- Equipment design for improved conversion.
- Using catalysts effectively and installing mist eliminators in tanks and columns.
- Enhancing the absorption characteristics of absorption columns.
- Making use of scrubbers.

### 7.2. Pollution Monitoring

Continuous monitoring equipment for $SO_2$ emissions is essential for sulfuric acid plants and should be installed universally. Dual-range instruments are available to measure both low $SO_2$ emissions during stable operation and higher emissions during startup. Records of emission monitoring should be maintained, and authorities should conduct necessary statistical analyses or reporting. Common emissions from sulfuric acid plants include unconverted $SO_2$, unabsorbed $SO_3$, and acid mist escaping from demisters in the FAT. Emission reduction methods using a double-contact double-absorption (DCDA) process with cesium-promoted catalysts in the converter's final pass, strictly controlling $SO_2$ percentages in incoming gas and process temperatures, employing effective hot gas and sulfur filters to minimize ash deposition on catalyst surfaces, automatically adjusting dilution water to maintain optimal circulating acid strength (98.0–98.5%), regulating gas and acid temperatures at the absorption towers' inlets, ensuring adequate acid flow in all towers, using effective candle-type demisters in all acid towers, and providing alkali scrubbers for tail gases to address process disturbances and reduce emissions during startup [19].

### Techniques to Control Emissions of $SO_3$ and $H_2SO_4$

An overview of methods that positively impact, or lower, the emissions of $H_2SO_4$ (calculated as the total of $SO_3$ and $H_2SO_4$) throughout the production of sulfuric acid is tabulated in Tables 10& 11. Most sulfuric acid facilities have employed general primary optimization methods such as process control techniques [19].

**Methods for Reducing $SO_3$ and $H_2SO_4$ Emissions**

An overview of methods that positively impact, or lower, the emissions of H2SO4 (calculated as the total of $SO_3$ and $H_2SO_4$) during the production of sulfuric acid is provided in Error! Reference source not found.. Process control techniques and other broad primary optimization procedures have been implemented in the majority of sulfuric acid plants [19].

**Table 10: Techniques for reduction of sulfur dioxide emissions**

| *Techniques* | *Emission Level (mgSO₂/m³ tail gas)* | *Emission Level (KgSO₂/ton H₂SO₄ 100%)* |
|---|---|---|
| *Single absorption + fifth bed* | *<2,000* | *<6* |
| *Double absorption + fifth bed* | *<1,000* | *<2.5* |
| *Single absorption + cesium catalyst in last bed* | *<2,000* | *<5* |
| *Double absorption + cesium catalyst in the last bed* | *<250* | *<2.3* |
| *Single to double absorption* | *<1,000* | *2.6* |
| *Tail gas scrubbing by:* | | |
| *Sodium hydroxide* | *<200* | *<2* |
| *Ammonium hydroxide* | *<200* | *<2* |
| *Calcium hydroxide* | *<200* | *<2* |
| *Activated carbon* | *<1,000* | *<2* |
| *$H_2O_2$treatment after absorption* | *<200* | *<2* |

**Table 11: Techniques for reduction of sulfur trioxide and sulfuric acid mist**

| **Technique** | **Emission Level (mg$H_2SO_4$ /Nm$^3$ tail gas)** | **Emission Level (kg/ton $H_2SO_4$ 100%)** |
|---|---|---|
| Wire-mesh | <100 | - |
| High-efficiency candle- type filter after absorbers | <50 | <0.03 |
| Scrubbing | <10 | <0.015 |

**8. Conclusion**

In conclusion, the comprehensive study of sulfuric acid production using the double contact process highlights the intricate balance required between operational efficiency and environmental safety. The process described efficiently converts sulfur to sulfuric acid with a high conversion rate of 98%, ensuring minimal waste and maximal output. The use of advanced simulation tools like Aspen Plus V11 has enabled a detailed analysis of the material and energy balances, providing valuable insights into potential areas for optimization. Moreover, the environmental impact assessment indicates significant risks associated with $SO_2$ and $SO_3$ emissions, necessitating stringent control measures including advanced scrubbers and absorption systems to mitigate these impacts. The incident analysis further underscores the importance of robust safety protocols and regular maintenance to prevent and manage potential hazardous events effectively. Future implementations should focus on refining these processes to enhance safety and efficiency, potentially incorporating emerging technologies to reduce environmental impact further. The study serves as a crucial reference point for industrial applications and environmental policymaking, aiming to balance industrial growth with sustainability and safety.

**9. Conflicts of interest**

We declare that we have no financial, personal, or professional interests that could be perceived as a conflict of interest regarding our involvement in research. We are committed to maintaining transparency and objectivity, and will promptly disclose any potential conflicts that may arise. Should any conflicts emerge during the course of our involvement, we will take appropriate steps to address and resolve them.

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No Funding.

**11. References**

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