



# Economic Analysis of Absorbent Replacement from NaOH to H<sub>2</sub>O<sub>2</sub> in Scrubber Systems at A Wet Sulphuric Acid Plant

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**Abstract.** In wet sulphuric acid plants, the economic analysis of replacing NaOH with H<sub>2</sub>O<sub>2</sub> as an absorbent in scrubber systems explores the potential cost savings and operational benefits. The primary motivation for this change is the generation of H<sub>2</sub>SO<sub>4</sub> of the reaction between H<sub>2</sub>O<sub>2</sub> and SO<sub>2</sub> that can be reintegrated into the plant's system, thereby reducing effluent treatment cost and raw material cost. A detailed mathematical model was developed based on plant operational data to compare the economic performance of both absorbents. Results indicate potential annual cost savings of approximately 99,515 USD by adopting H<sub>2</sub>O<sub>2</sub>, demonstrating its economic advantage. Further analysis, including environmental impact assessment and operational considerations, is necessary to comprehensively evaluate the overall feasibility of implementing H<sub>2</sub>O<sub>2</sub> as an absorbent in industrial settings. The integration of H<sub>2</sub>SO<sub>4</sub> by-product into the Acid Production Plant for acid dilution when replacing NaOH with H<sub>2</sub>O<sub>2</sub> as the scrubber absorbent offers multiple advantages.

**Keywords:** H<sub>2</sub>O<sub>2</sub>, NaOH, WSA Plant, Economic, Scrubber.

## 1 INTRODUCTION

The Wet Sulphuric Acid (WSA) Plant plays a crucial role in industrial processes that handle sulphurous gases like hydrogen sulphide (H<sub>2</sub>S), ensuring these gases are treated before they are released into the atmosphere. By converting these gases, the plant not only reduces harmful emissions but also recycles sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) as a valuable by-product for use in other industrial applications. Central to the WSA Plant's functionality is the scrubber column, which is vital for absorbing SO<sub>2</sub>, an important intermediary in the transformation of H<sub>2</sub>S into H<sub>2</sub>SO<sub>4</sub>. Each process unit in a WSA (Wet Sulfuric Acid) plant requires specific conditions for optimal operation. For instance, to conduct the combustion reaction safely and effectively, a sufficient amount of air must be supplied. The conversion of SO<sub>2</sub> (sulphur dioxide) to SO<sub>3</sub> (sulphur trioxide) occurs optimally when the temperature of each bed within the reactor is maintained at specific values. Additionally, the optimal condensation of H<sub>2</sub>SO<sub>4</sub> gas occurs at certain temperatures, and the absorption of uncondensed gases in the scrubber column is carefully managed. Therefore, an advanced control structure for the WSA process is crucial to meet the requirements of each unit [1].

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Traditionally, the scrubbing process in WSA Plants has relied on strong alkaline solutions, particularly caustic soda (NaOH), to capture SO<sub>2</sub>. Although this approach is effective, it presents several challenges, including corrosive effects, a significant environmental impact, and high operational costs [2], [3]. These issues have driven the search for alternative absorbents that are both cost-effective and environmentally sustainable.

Hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) has gained attention as a promising alternative to traditional alkaline absorbents. With its strong oxidative properties and reduced environmental impact, H<sub>2</sub>O<sub>2</sub> offers several potential benefits in the scrubbing process. Studies have shown that H<sub>2</sub>O<sub>2</sub> can efficiently absorb SO<sub>2</sub>, converting it into sulfuric acid, which can be reintegrated into the WSA production cycle [4], [5]. Despite these potential advantages, the use of H<sub>2</sub>O<sub>2</sub> for SO<sub>2</sub> scrubbing on an industrial scale remains relatively unexplored, with limited research and pilot projects documented in the literature [6].

This study aims to evaluate the economic implications of using H<sub>2</sub>O<sub>2</sub> as an absorbent for SO<sub>2</sub> in the scrubber column of the WSA Plant, compared to the traditional NaOH method. By analysing the performance and cost-effectiveness of H<sub>2</sub>O<sub>2</sub> against NaOH, this research seeks to uncover the potential benefits of H<sub>2</sub>O<sub>2</sub> as a more efficient absorbent. The findings could lead to significant improvements in industrial emission control practices, contributing to broader environmental sustainability goals. This research will explore the viability of adopting H<sub>2</sub>O<sub>2</sub> for industrial SO<sub>2</sub> scrubbing processes.

## 2 EXPERIMENTAL SECTION

This research was carried out through theoretical methods, involving the development of a detailed mathematical model and simulation specifically designed for the Scrubber Column process unit at the WSA Plant. To accurately determine the mass transfer coefficient, it was necessary to gather detailed equipment datasheets and analyse the operational conditions of both the feed and outlet components of the scrubber. The relevant data was obtained from official plant documentation and was then cross-referenced with the actual conditions observed in the field to ensure accuracy. For the inlet and outlet scrubber calculations, data collection relied on precise readings from field instrumentation. These readings were continuously monitored and transmitted to the Distributed Control System (DCS), where they were securely stored in a data management tool known as the PI Process Book. From there, the necessary data was extracted in the form of Excel files, enabling further analysis and comparison (see Fig. 1). This comprehensive approach ensured that the theoretical model closely reflected real-world operations, providing a robust basis for evaluating the scrubber's performance.

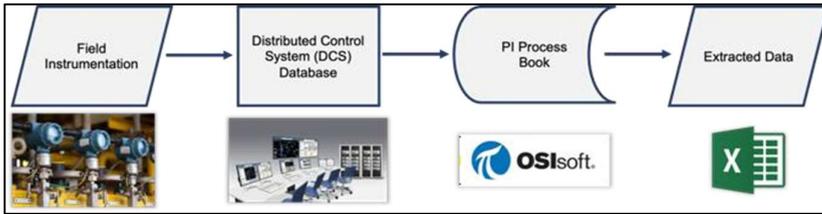


Fig.1. Data Collection and Monitoring Workflow

### 3 RESULT AND DISCUSSION

#### 3.1 Inlet and Outlet SO<sub>2</sub> Gas Concentrations

Sulphur dioxide (SO<sub>2</sub>) concentrations within the chemical industry fluctuate considerably based on the specific industrial processes and the extent of sulphur or sulphur-containing compound utilization. SO<sub>2</sub> gas in the WSA unit is generated from the combustion of H<sub>2</sub>S and liquid sulphur. To ensure compliance with environmental regulations, stringent monitoring and control of SO<sub>2</sub> levels within industrial atmospheres are essential. Implementing gas purification technologies, such as scrubbers within the WSA unit, is a critical strategy to mitigate SO<sub>2</sub> emissions and safeguard air quality. Below is measurement of SO<sub>2</sub> gas concentration emitted from the chimney. Table 1 shows that the SO<sub>2</sub> gas concentration emitted number 2, was the highest. This was due to the lack of catalyst performance and make less conversion that lead SO<sub>2</sub> goes to scrubber very high.

Table 1. Inlet and Outlet SO<sub>2</sub> gas concentration

	Parameter	Unit	1	2	3
Inlet	SO <sub>2</sub>	ppm	303	204	228
Outlet	SO <sub>2</sub>	ppm	0,43	41	14,29

#### 3.2 H<sub>2</sub>O<sub>2</sub> Mass Balance

The diagram Fig. 2 provides a simplified overview of two potential methods for SO<sub>2</sub> removal from gas streams.

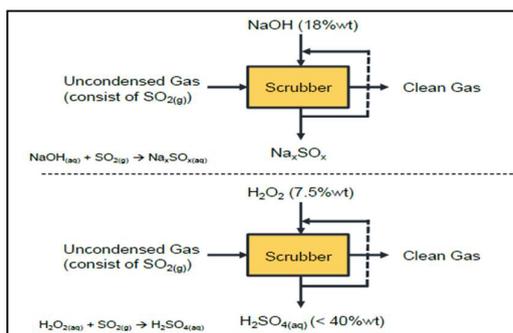
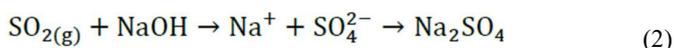
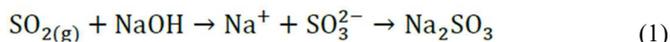
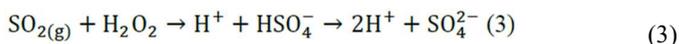


Fig. 2. Diagram of the scrubbing process using NaOH and H<sub>2</sub>O<sub>2</sub>.

In the upper section of the diagram, uncondensed gas containing SO<sub>2</sub> is introduced into the scrubber. Simultaneously, an 18 wt.% NaOH solution is supplied. The SO<sub>2</sub> reacts with the NaOH solution to form sodium sulphite (Na<sub>2</sub>SO<sub>3</sub>) or sodium sulphate (Na<sub>2</sub>SO<sub>4</sub>), depending on the reaction conditions. The cleaned gas, depleted of SO<sub>2</sub>, exits the scrubber.



The lower section depicts a similar process, but with H<sub>2</sub>O<sub>2</sub> as the absorbent. Uncondensed gas containing SO<sub>2</sub> enters the scrubber and interacts with a 7.5 wt.% H<sub>2</sub>O<sub>2</sub> solution. The SO<sub>2</sub> reacts with H<sub>2</sub>O<sub>2</sub> to form sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). The resulting sulfuric acid solution has a concentration below 40 wt.%. Clean gas is subsequently discharged from the scrubber. The reaction that occurs between H<sub>2</sub>O<sub>2</sub> and SO<sub>2</sub> gas is as shown in equation (3).



### 3.3 Design parameter of scrubber with H<sub>2</sub>O<sub>2</sub> as Absorbent

The parameters to be evaluated in this scrubber unit is the scrubber column height, while scrubber diameter and scrubber packing height is constant. The dimensions of the scrubber column are illustrated in Fig.3.

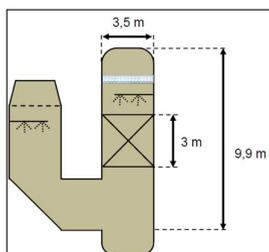


Fig. 3. Scrubber Column's Dimension.

Based on actual design of scrubber column:

1. Column diameter : 3.5 m
2. Column height : 9.9 m
3. Packing height : 3 m

To determine the value of  $K_{GA}$ , equation 4 can be used. However, the equation can be simplified to facilitate the calculation to form the following equation:

$$\frac{G'_m}{K_{GA} P} \times \frac{y_1 - y_2}{Dy_{LM}} \tag{4}$$

The  $Dy_{LM}$  value can be found with the following equation:

$$Dy_{LM} = \frac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln\left(\frac{y_1 - y_1^*}{y_2 - y_2^*}\right)} \tag{5}$$

From equations (4) and (5) we get:

1.  $G'_m = 188.52 \text{ kmol/hr.m}^2$
2.  $Dy_{LM} = 0.0031$

So, the  $K_{GA}$  value is  $4300.41 \text{ kmol/hr.m}^2.\text{atm}$ .

Based on calculation above,  $\text{SO}_2$  removal without modifying the existing scrubber, which stands at 5.75 meters, various  $\text{H}_2\text{O}_2$  concentrations were tested. Initially, a higher concentration of 25%  $\text{H}_2\text{O}_2$  was considered, but this required a shorter contact area than available in the scrubber. Even, if we keep using 25%  $\text{H}_2\text{O}_2$  it will waste so much chemical. To avoid costly modifications, experiments were conducted to identify a suitable  $\text{H}_2\text{O}_2$  concentration that effectively utilizes the existing contact area. Ultimately, a 7.5%  $\text{H}_2\text{O}_2$  solution was determined to be optimal for efficient  $\text{SO}_2$  removal within the constraints of the current scrubber design.

The variation of  $\text{H}_2\text{O}_2$  flow rate when entered with the actual data read by the field instrumentation can be seen in Table 2.

**Table 2.** Inlet and outlet flow rates

	Parameter	Unit	A	B	C
Inlet	$\text{SO}_2$	ppm	303	204	228
	$\text{H}_2\text{O}_2$	kg/hr	209.5	164.2	220.2
	Process Gas	$\text{Nm}^3/\text{hr}$	34212	49789	50814
Outlet	$\text{SO}_2$	ppm	0,43	41	14,29
	$\text{H}_2\text{SO}_4$	kg/hr	239,1	187,4	251,3
	%		18.9%	18.9%	18.9%
Efficiency	%		99.86%	79.90%	93.75%

The Table 3 reflects the calculated amounts of  $\text{H}_2\text{O}_2$  required to achieve the desired reduction in  $\text{SO}_2$  emissions for each scenario. The goal is to lower the  $\text{SO}_2$  concentrations at the scrubber outlet to the levels indicated in the table. Scenario A, with the highest efficiency (99.86%), requires 209.5 kg/hr of  $\text{H}_2\text{O}_2$  to reduce the inlet  $\text{SO}_2$  concentration from 303 ppm to just 0.43 ppm at the outlet. Similarly, scenario C requires 220.2 kg/hr of  $\text{H}_2\text{O}_2$  to lower the  $\text{SO}_2$  concentration from 228 ppm at the inlet to 14.29 ppm at the outlet, achieving an efficiency of 93.75%. Scenario B, which is the least efficient, uses 164.2 kg/hr of  $\text{H}_2\text{O}_2$  to reduce the  $\text{SO}_2$  concentration from 204 ppm at the inlet to 41 ppm at the outlet, with a corresponding efficiency of 79.90%.

### 3.4 Economic Analysis

zz Switching the absorbent from 18% NaOH to 7.5% H<sub>2</sub>O<sub>2</sub> in scrubbers can have a significant impact on both efficiency and operational costs. The following table summarizes these impacts :

**Table 3.** Comparison of Scrubber Efficiency and Operational Costs with 18% NaOH and 7.5% H<sub>2</sub>O<sub>2</sub> Absorbents.

<b>Impact</b>	<b>Explanation</b>
<b>Pollutant Removal Efficiency</b>	<ul style="list-style-type: none"> <li>● H<sub>2</sub>O<sub>2</sub> at 7.5% is generally more effective in removing SO<sub>2</sub> compared to NaOH at 18%.</li> <li>● This can result in lower flue gas emissions and compliance with stricter environmental standards.</li> </ul>
<b>Operational Costs</b>	<ul style="list-style-type: none"> <li>● The operational costs of scrubbers are influenced by absorbent prices, energy consumption, and maintenance.</li> <li>● Switching to H<sub>2</sub>O<sub>2</sub> at 7.5% can lower absorbent costs, as well as potentially reduce energy and maintenance expenses.</li> </ul>
<b>Corrosion and Equipment Damage</b>	<ul style="list-style-type: none"> <li>● H<sub>2</sub>O<sub>2</sub> at 7.5% is generally more corrosive than NaOH at 18%.</li> <li>● Switching to H<sub>2</sub>O<sub>2</sub> at 7.5% requires corrosion-resistant materials and equipment.</li> <li>● Costs associated with corrosion-resistant materials and equipment.</li> </ul>
<b>Environmental Impact</b>	<ul style="list-style-type: none"> <li>● H<sub>2</sub>O<sub>2</sub> at 7.5% does not generate solid waste as NaOH at 18% does.</li> <li>● This can reduce the burden on wastewater treatment systems and minimize environmental impact.</li> </ul>
<b>Safety and Health</b>	<ul style="list-style-type: none"> <li>● H<sub>2</sub>O<sub>2</sub> at 7.5% poses greater hazards compared to NaOH at 18%.</li> <li>● Switching to H<sub>2</sub>O<sub>2</sub> at 7.5% necessitates more stringent safety training and procedures.</li> <li>● Costs associated with safety training and procedures.</li> </ul>

H<sub>2</sub>O<sub>2</sub> at 7.5% offers advantages such as higher pollutant removal efficiency, lower absorbent consumption, and reduced environmental impact compared to NaOH at 18%, it also presents challenges, particularly in terms of corrosion, equipment costs, and safety. The decision to switch to H<sub>2</sub>O<sub>2</sub> must carefully weigh these benefits against the increased operational complexities and potential risks, ensuring that the overall cost-effectiveness and safety of the system are maintained.

The goal of the analysis is to evaluate the economic feasibility of this transition by calculating key financial indicators, including Net Present Value (NPV), Return on Investment (ROI), and Payback Time (POT), based on real-world cost data and operational parameters.

Table 4. provides a comprehensive breakdown of daily and annual costs for essential inputs in a production process. It categorizes expenses into raw materials, comprising hydrogen peroxide and sodium hydroxide, and utilities, including soft water. For each input, detailed information on daily consumption, quantity required per unit of output, and corresponding price is provided.

**Table 4.** Economic Analysis of Switching Absorbent from NaOH 18% to H<sub>2</sub>O<sub>2</sub> 7.5%

Component	NaOH 18%	H <sub>2</sub> O <sub>2</sub> 7.5%	Difference
Cost per ton (USD)	417	350	-67
Consumption (tons/day)	3.0	2.8	-0.2
Annual cost (USD/year)	457,215	357,7	99,515 (Savings)
Capital Expenditures (CapEx)	N/A	19,150(Total)	19,150 (Investment)
- H <sub>2</sub> O <sub>2</sub> Tank (USD)	N/A	3,000	3,000
- 2" Piping (1 km) (USD)	N/A	5,850	5,850
- 1" Piping (1 km) (USD)	N/A	4,900	4,900
- Dosing Pump (USD)	N/A	1,500	1,500
- pH Analyzer (USD)	N/A	700	700
- Acid Mist Analyzer (USD)	N/A	1,200	1,200
- Control Valve 1" (USD)	N/A	1,000	1,000
- Manual Valve 1" (USD)	N/A	150	150
Annual Revenue from H <sub>2</sub> SO <sub>4</sub> (USD/year)	3,942,000	3,942,000	-
Annual Revenue from MP Steam (USD/year)	1,601,209.1	1,601,209.1	-
Soft Water Consumption (USD/year)	5,752.5	5,752.5	-

1. **NPV**, The net present value over one year is calculated as the difference between the savings from using H<sub>2</sub>O<sub>2</sub> and the initial capital expenditures :

$$NPV = 99,515 - 19,150 = 80,365 \text{ USD}$$

2. **ROI**, The return on investment is determined as follows:

$$ROI = \frac{\text{Annual Savings}}{\text{CapEx}} \times 100\% = \frac{99,515}{19,150} \times 100\% = 519.75\%$$

3. **POT**, The payback period is calculated as the time required to recover the initial investment:

$$POT = \frac{\text{CapEx}}{\text{Annual Savings}} = \frac{19,150}{99,515} = 0.19 \text{ years (app. 2.3 months)}$$

### 3.5 Integration of WSA Plant with Acid Production Plant

The produced H<sub>2</sub>SO<sub>4</sub> can be collected and directed to the Acid Production Plant. In many industrial processes, sulfuric acid is used in various concentrations, often requiring dilution with water to achieve the desired concentration. The by-product H<sub>2</sub>SO<sub>4</sub> from the scrubber can be fed into this dilution process, reducing the need to produce or purchase additional concentrated sulfuric acid. This not only lowers raw material costs but also improves the overall efficiency of the plant's acid production

operations. By reusing the sulfuric acid generated in the scrubber, the plant can significantly reduce the cost associated with purchasing or producing sulfuric acid for dilution purposes. This recycling approach makes the operation more cost-effective. From environmental compliance, utilizing the by-product H<sub>2</sub>SO<sub>4</sub> within the plant reduces the volume of waste or effluent that would otherwise need to be treated or disposed of, thereby enhancing environmental compliance and sustainability. This approach supports a more sustainable operation by minimizing waste, reducing the consumption of raw materials, and lowering the plant's overall environmental footprint. The reuse of by-product H<sub>2</sub>SO<sub>4</sub> is an example of a circular economy practice within the plant, where waste from one process becomes a valuable input for another.

## 4 CONCLUSION

Replacing NaOH with H<sub>2</sub>O<sub>2</sub> as the absorbent in scrubber systems allows the wet sulfuric acid plant to generate H<sub>2</sub>SO<sub>4</sub> as a by-product. This sulfuric acid can be seamlessly integrated into the Acid Production Plant for dilution processes, resulting in significant cost savings by reducing the need for additional sulfuric acid production or purchase. The decision to utilize H<sub>2</sub>O<sub>2</sub> at 7.5% or NaOH at 18% as an absorbent in scrubber systems involves a careful evaluation of various factors. While H<sub>2</sub>O<sub>2</sub> offers advantages in terms of pollutant removal efficiency, reduced absorbent consumption, and minimal solid waste generation, it also presents challenges related to corrosion, safety, and operational costs. A comprehensive cost-benefit analysis considering environmental regulations, economic factors, and safety protocols is crucial for selecting the most suitable absorbent for a specific application.

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