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Using Seawater to Remove SO$_2$ in a FGD System

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1. Introduction

1.1 Introduction
Sea water contains significant amounts of HCO$_3^-$ and other alkaline compounds that help sulfur dioxide in flue gas dissolve in water. Flue gas desulphurization (FGD) achieves the goals of this system, for sea-water FGD systems. This study conducts a series of simulations or experiments using sea-water at a flue gas combustion plant to identify the advantages and disadvantages of, and related parameters for designing and operating FGD in the future.

1.2 Research objectives
1. Flue gas from a combustion plant is used in a series of experiments. The pre-water method has both advantages and disadvantages associated with relevant parameters.
2. To estimate the amount of tail water and solve the problem of disposing of large amounts of tail-water. To further tail water recycling research and development, one must simultaneously achieve the dual objectives of FGD and the creation of water resources.

2. Literature review

2.1 Flue gas desulfurization processes
Flue Gas Desulphurization is divided into wet, dry, and semi-dry methods (2). The wet method is the most efficient and most commonly used method. The wet method uses absorbent desulfurization processes that differ from other processes, which typically use lime, limestone, magnesium hydroxide, sodium carbonate, water, and double-base.

2.1.1 The seawater method uses sea-water that contains some Trona and SO$_2$ flue gas
The alkalinity of seawater is primarily influenced by calcium, magnesium, carbonate, and other related compounds. The pH of sea-water was 7.5 and 8.5. It can be neutralized with SO$_2$ during a reaction.
During seawater desulfurization, water is the primary absorber. Adding a small amount of NaOH or Mg (OH)$_2$ increases the effect, or alters the process than the final pH of sulfur water. The activity of pure water is as follows.
a. Absorption reaction
Flue gas of \( \text{SO}_2 \) and water vapor from liquid dissolves into sulfite and hydrogen ions, resulting in fluid absorption at a pH of roughly 3.

\[
\text{SO}_2(g) \rightleftharpoons \text{SO}_2(L) \quad (1)
\]

\[
\text{SO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HSO}_3^- + \text{H}^+ \quad (2)
\]

\[
\text{HSO}_3^- \rightleftharpoons \text{SO}_3^{2-} + \text{H}^+ \quad (3)
\]

b. Neutralization reaction
Bicarbonate ions in seawater and hydrogen ions in the carbon dioxide and water reaction, increase the pH of.

\[
\text{HCO}_3^- + \text{H}^+ \rightleftharpoons \text{CO}_2 + \text{H}_2\text{O}
\]

c. Oxidation

\[
\text{SO}_3^{2-} + 1/2 \text{O}_2 \rightleftharpoons \text{SO}_4^{2-}
\]

Although the oxidation reaction at low pH values (roughly \( \leq 4.5 \)) of the low efficiency of water requirement, yet the pH can increase to roughly 5.6. Additionally, aeration functions can eliminate \( \text{CO}_2 \) from the water, thereby increasing pH during the neutralization reaction.

d. Total reaction

\[
\text{SO}_2 + \text{H}_2\text{O} + 1/2 \text{O}_2 \rightarrow \text{SO}_4^{2-} + 2\text{H}^+
\]

\[
\text{HCO}_3^- + \text{H}^+ \rightarrow \text{CO}_2 + \text{H}_2\text{O}
\]

The seawater treatment process resembles the conventional wet process in that water and smoke are in contact in the reverse direction. The kinds of the process are filled with different types, such as the spray-type and layer different types of absorber plate. As water absorbs \( \text{SO}_2 \) after the acidic (pH \( \leq 3 \)), adding large amounts of water before increasing the pH facilitates the following aeration reaction: \( \text{SO}_3^{2-} \) is oxidized to \( \text{SO}_4^{2-} \), and discharge the dissolution of \( \text{CO}_2 \).

3. Seawater desulphurization process assessment

3.1 Business transfer performance
In the 1970s, the University of California at Berkeley first used seawater to remove \( \text{SO}_2 \) from flue gas. In 1978, Fujikasui, a Japanese researcher, used seawater in an FGD system at a chemical plant. In 1988, ABB, a company, used seawater in an FGD system at an oil refinery in Norway.

3.2 System evaluation
Packing and orifice-plate systems in a field simulation test verified that pure seawater can remove up to 90% of \( \text{SO}_2 \) flue gas from combustion-fired units. The two sulfur tower designs have different advantages and disadvantages. For example, a packing system requires an absorber tower with a large volume.
Although the packing system clogs easily happen, the amount of seawater needed is reduced, resulting in energy savings; conversely, the orifice uses an absorber tower with a smaller volume and does not clog easily, however, this requires more seawater (4).

4. Experimental method: The seawater FGD process

4.1 The selection of a seawater FGD system simulation

According to the assessment of in Section 3.2, the processes that use different water desulfurization have both advantages and disadvantages. In this study, the selection of a seawater FGD orifice plate depends on the following factors. Although the FGD system electrostatic precipitators (ESP), a small amount of fly ash flows into the desulfurization tower, such that the desulfurization tower can clog after long-term operation.

4.2 The orifice-plate type seawater FGD simulation system

The primary component of the system is a desulfurization tower tank, which is divided into a demisting zone, an \( \text{SO}_2 \) absorption zone (spray zone), and water oxidation zone. Water from a pump in the water tank tower into the desulfurization tower at the top of the absorption zone, and flue gas driven by a fan enters the bottom of the desulphurization tower tank. Gas from the bottom up, seawater from the top down, Seawater and gas in the orifice of the perforated plate then contact and \( \text{SO}_2 \) is absorbed by the seawater, such that the treated flue gas is emitted from the top side of the demister zone.

4.3 Desulfurization tests results

The concentration of flue gas \( \text{SO}_2 \) is controlled at 50-250ppm, The tested seawater is seawater from the first condenser. Figure 1 shows the simulation device. Figure 2 shows the absorption area in the orifice-plate. During the test, the flue gas flow rate is 1-3 m\(^3\)/min; the water flow rate is 10-40 ft\(^3\)/min; and the gas-to-liquid G/L ratio is controlled at 5 and 20.

Fig. 1. The orifice-plate style seawater flue gas desulphurization simulation system
4.3.1 Batch seawater desulphurization results
To reduce the amount of seawater used (and reduce pumping energy and the amount of waste-water), some seawater can be reused. The design cycle typically depends on the change in seawater pH and desulphurization efficiency. Via the seawater desulfurization circulation test (a batch test was adopted, and no seawater was discharged), one can identify the relationship between changes in seawater pH and desulphurization efficiency. Figure 4 and 5 list experimental results from two desulfurization tests (G/L ratio = 10-20). Experimental results show that desulfurization efficiency and the pH of exiting seawater decreased as reaction time increased. Experimental results also show that the amount of alkaline compounds in seawater decreased as reaction time increased. The alkalinity of the exiting sea-water convert to Fig. 3. Desulfurization efficiency and water pH are positively correlated. This experimental result indicates that a high residual water pH and large amounts of alkaline compounds lead to higher desulfurization efficiency. The exiting seawater can keep desulfurization efficiency at $\geq 90\%$ under a seawater pH $\geq 6.0$ (Fig. 3).

4.3.2 Test results of continuous seawater desulphurization
When the system is operated continuously, the reflux ratio (reflux ratio $R = \text{(water flow recovery / raw water flow)}$) can explain returning water usage. Figure 6 and 7 show the control loop volume from test results. Experimental results show that as the reflux ratio increased, the pH of exiting seawater decreased, and the amount of alkaline compounds in seawater decreased during the reaction. Adding a relatively smaller amount of fresh seawater reduced desulfurization efficiency; thus, the reflux ratio should not be $> 1$ during operation. When the reflux ratio was controlled at $\leq 1$ (inclusive) (Figure 6 and 7), the pH of
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**Fig. 3.** The pH and alkalinity of exit seawater and desulphurization efficiency diagram

- Efficiency\% vs. pH
- Alkalinity (mg/l)

**Fig. 4.** The seawater circulation desulphurization test results

- L/G ratio = 10
- SO₂ concentration in flue gas imports = 120 PPM

- Desulphurization efficiency (%)
- Export seawater pH

Exiting seawater was kept at > 6.0, resulting in a desulphurization efficiency of ≥ 90%. However, the reflux ratio should be < to reduce seawater usage (which can reduce pump energy and the amount of wastewater used). In summary, the orifice-plate seawater FGD system is an effective system.
Fig. 5. The seawater circulation desulphurization test results

Water circulation desulphurization results (L / G ratio = 20, SO2 concentration in flue gas imports = 110 PPM)

- SO2 concentration in flue gas exports (PPM)
- Desulphurization efficiency (%)
- Export seawater pH

(min)

Fig. 6. The results of controlling seawater reflux ratio desulfurization test

In addition to sulfur than the water control test results back (L / G ratio = 10, SO2 concentration in flue gas imports = 110 PPM)

- SO2 concentration in flue gas exports (PPM)
- Desulphurization efficiency (%)
- Export seawater pH

(R : Reflux ratio)
In addition to sulfur than the water control test results back (L / G ratio = 20, SO₂ concentration in flue gas imports = 115 PPM)

Fig. 7. The results of controlling seawater reflux ratio desulfurization test

4.3.3 Tubular seawater desulphurization results
In the tubular (one-through) seawater desulphurization process, original seawater passes directly through the desulphurization tower instead of being recycled. As the tubular process is used for fresh seawater desulphurization, all alkaline compounds in seawater are in the highest state; thus, a good desulphurization result is expected. Table 1 shows simulation test results. Experimental results confirm that the tubular (one-through) seawater desulphurization process yields excellent desulphurization results. With a G/L ratio > 13, the desulphurization rate exceeded 99%. General designs of often recycle seawater, have G/L ratios of 20 and desulphurization efficiency > 90%.

<table>
<thead>
<tr>
<th>The entrance flue gas SO₂ PPM concentration</th>
<th>L / G ratio</th>
<th>The exit flue gas SO₂ PPM concentration</th>
<th>Desulphurization efficiency %</th>
<th>The pH of exit seawater</th>
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</thead>
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<tr>
<td>150</td>
<td>10</td>
<td>5</td>
<td>96.6</td>
<td>6.5</td>
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<tr>
<td>150</td>
<td>13</td>
<td>1</td>
<td>99</td>
<td>6.4</td>
</tr>
<tr>
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<td>17</td>
<td>&lt; 1</td>
<td>&gt; 99</td>
<td>6.5</td>
</tr>
<tr>
<td>150</td>
<td>20</td>
<td>&lt; 1</td>
<td>&gt; 99</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Table 1. The seawater desulphurization tubular (one-through) test results listed as follows

4.3.4 Evaluation and selection of a seawater desulphurization system
The best seawater desulphurization process is orifice-plate type. According to test results, desulphurization rate of the orifice-plate-type easily reached as high as 99%. However, the
tubular (one-through) system has a higher desulfurization efficiency, is easier to design, and has a lower installation cost than other designs. The G/L ratio depends on desulfurization efficiency. When the G/L ratio was 10, was 95%; conversely, when the G/L ratio was 15, desulfurization efficiency exceeded 99%.

5. Conclusions

1. The orifice-plate type simulated seawater desulfurization equipment, toward a coal-fired (EP) unit exit flue gas, proceeding the field simulation tests for seawater desulfurization. The G/L ratio, desulfurization seawater reflux ratio, number of porous plate boards, area of the perforated plate, the porous plate before and after changes in gas pressure, and the influence of changes in the height of the gas-liquid mixing layer are discussed. After appropriate adjustments, the design achieved a desulfurization efficiency of 99%. This experimental result can be used as the basis for designing and seawater desulfurization systems in power plants.

2. According to test results, the orifice-plate desulfurization system clogs less, has a better desulfurization efficiency, and requires a smaller desulfurization tower than the filling. Based on its economic advantages and limited plant area, the orifice-type is the best seawater desulfurization process for combustion power plants.

6. Acknowledgements

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7. References

The steady increase in industrialization, urbanization and enormous population growth are leading to production of huge quantities of wastewaters that may frequently cause environmental hazards. This makes waste water treatment and waste water reduction very important issues. The book offers a collection of studies and findings concerning waste water treatment, minimization and reuse.

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