FLUE GAS DESULFURIZATION FOR 2 X 6 MW COAL FIRED POWER PLANT

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Abstract
A study on a mine mouth coal fired power plant has been done and showed that a 2x6 MW electricity output coal fired power plant is feasible to be installed when it uses rejected coal. The rejected coal mostly contains high sulfur (~3% dry basis), and has low calorific value (4700 Kcal/kg). From an environmental point of view, the SO\textsubscript{2} emission from the combustion of high sulfur containing coal has to be controlled in order to comply with the government regulation. Besides, ash content of the coal which produces the particulates need to be captured by cyclones to have particle concentration below the standard. This paper calculates the particulate and SO\textsubscript{2} emissions and estimates the size and number of cyclones used as well as the amount of lime slurry utilized in the in Flue Gas Desulfurization using a spray-dry scrubber type. Utilizing a 4.7% ash content and a 3% sulfur content of coal as a fuel, the prediction of particulate and SO\textsubscript{2} emission are about 570 mg/m\textsuperscript{3} and 2580 mg/m\textsuperscript{3}, respectively. In order to meet the respective particulate and SO\textsubscript{2} emission standards of 150 and 750 mg/m\textsuperscript{3}, it could employ a 4-conventional type cyclones with a 0.5 m\textsuperscript{2} each of inlet area having around 80% efficiency, and a SO\textsubscript{2} control device of spray-dry scrubber type with a capture efficiency of at least 75%. The scrubber has to utilize lime between 376 and 504 kg Ca(OH)\textsubscript{2}/hour, with continuous addition between 23% and 30%, and re-cycled between 77% and 70% of it.

Key words: coal, desulfurization, SO\textsubscript{2} emission

1. INTRODUCTION
1.1. Background of Study

Sulfur dioxide (SO\textsubscript{2}) and sulfur trioxide (SO\textsubscript{3}) are two sulfur oxides that are formed when the sulfur containing material is burned. More than one half of the world sulfur oxides is released from coal combustion. The effects of sulfur oxides released into the atmosphere are very serious. Acid rain is one result that is very dangerous to the environment and life. Also, particulates are commonly released from the plant into the atmosphere. Therefore, the control of particulates and sulfur oxides emissions must be done.

The particulate and SO\textsubscript{2} emission standard for coal power plant in Indonesia has been regulated by the Government of Indonesia through Environment Minister Decree No.13/MEN-LH/3/95, as shown in Table 1.

Capturing the particulate after combustion commonly uses cyclone. It is a well known particulate control device that is used for pre-cleaner. Figure 1 is typical conventional cyclone.
Figure 1. Schematic diagram of conventional cyclone.

Note: ratio of
\[ D : H : W : De : S : Lb : Lc : Dd = 1 : 0.5 : 0.25 : 0.5 : 0.625 : 2 : 2 : 0.25. \]

After the cyclone, another air pollution control device needs to be installed. In this case, flue gas desulfurization is chosen to capture SO\(_2\) emission in order to comply with the Government regulation. Table 2 shows the summary of SO\(_2\) emissions control alternatives that are employed at many industries. It basically consists of 2 (two) groups of systems: throwaway and regenerative systems at wet or dry conditions.

The throwaway system refers to the process of reducing SO\(_2\) from the flue gas and deposits the final product (sulfate and sulfite ash) as it is. The regenerative system refers to the process of SO\(_2\) reduction when the final product of solid or liquid waste is converted to valuable ones. "Wet" or "dry" indicates the level where the main reaction occurs. Either "wet" or "dry" could use "throwaway" or "regenerative" processes.

In limestone scrubbing process, limestone slurry is contacted with flue gas in the spray tower. SO\(_2\) is absorbed, neutralized, and some of it oxidized to become calcium sulfite and sulfate. The primary advantage of limestone scrubbing is that the adsorbant material is abundantly available and relatively cheap, as well as has commercially large application. The disadvantages are scale occurring on the tower, plugging on the equipment and corrosion.

<table>
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<th>Emissions</th>
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<tr>
<td>SO(_2) * ((\text{mg/M}^3))</td>
<td>750</td>
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<tr>
<td>NO(_2) * ((\text{mg/M}^3))</td>
<td>850</td>
</tr>
<tr>
<td>Particulate, ((\text{mg/M}^3))</td>
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<td>Opacity, %</td>
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Note: (*) Based on a discussion with the authority it is corrected at 7% O\(_2\), 1 atm, 25°C.

Table 2. Some of SO\(_2\) Scrubbers

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<th>Main Option</th>
<th>Sub-option</th>
<th>Process Example</th>
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<td>Throwaway</td>
<td>Wet scrubbing</td>
<td>Lime Limestone Dual alkali</td>
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<td>Dry scrubbing</td>
<td>Lime spray drying Lime injection</td>
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<tr>
<td>Regenerative</td>
<td>Wet processes</td>
<td>Wellman-Lord</td>
</tr>
<tr>
<td></td>
<td>Dry processes</td>
<td>Spray atomizer dry scrubber</td>
</tr>
</tbody>
</table>

Lime scrubbing is very similar in equipment and process flow to limestone scrubbing, except that lime is a much more reactive reagent than limestone.
The advantages of lime scrubbing include better utilization of the reagent and more flexibility in operations. The major disadvantage is the high cost of lime relative to limestone. Whereas limestone scrubbing systems are capable of 90% removal of SO$_2$, lime scrubbing systems can routinely achieve 95% removal of SO$_2$ (Jahnig and Shaw, 1981 in Cooper, C. D. and Alley, F. C. (1986).

The dual alkali system was developed to eliminate the main problems encountered with lime and limestone scrubbing (namely, scaling and plugging inside the scrubbing tower). The dual alkali system uses two reagents and two process loops to remove the SO$_2$.

Lime-spray drying could be termed a wet/dry process. In lime-spray drying, lime slurry is sprayed into the absorption tower, and SO$_2$ is absorbed by the slurry, forming CaSO$_3$/CaSO$_4$. However, the liquid-to-gas ratio is such that the water evaporates before the droplets reach the bottom of the tower. The dry solids are carried out with the gas and collected in a bag house with the fly ash. The advantages of lime-spray drying include fewer maintenance problems, lower energy usage, and lower capital and operating cost. A disadvantage is the potential to blind the fabric if the temperature of the flue gas approaches the dew point.

The direct injection of pulverized lime or limestone into the furnace/boiler is a dry variation of lime-spray-drying. Sorption of the SO$_2$ occurs on the solid particles, and the particulate matter is collected in the bag house. The main disadvantage of direct injection is that large quantity of reagent is necessary because only the surfaces of the particles are reactive.

For regenerative process, the cost is generally higher than throwaway process. It is chosen if the place for equipment installation is limited, the waste disposal is difficult to be done, and the recovered material has a potential market.

Wellman-Lord (W-L) process is one of known technologies of this process. This process principally consists of 4 (four) processes: (1) flue gas pre-treatment, (2) SO$_2$ absorption by sodium sulfite, (3) purge, and (4) sodium sulfite regeneration.

In regenerative-dry processes, a spray atomizer dry scrubber as shown in Figure 2 is currently being used for certain SO$_2$ producing industries. In dry scrubbers, a calcium hydroxide slurry (quicklime mixed with water) is introduced into a spray dryer tower. The slurry is atomized and injected (close to saturation) into the flue hot gas stream at a point upstream from the particulate control device. As the slurry droplets are evaporating, they absorb and react with SO$_2$. The resulting dry by-product is collected in the bottom of the spray dryer and in the particulate removal equipment (ESP or bag-filter).

Figure 2 shows how lime and water (calcium hydroxide slurry) are introduced into the spray dryer tower, where they mix with the flue gas to form CaSO$_4$. Fly ash (CaSO$_3$, CaSO$_4$) and un-reacted lime are removed by a fabric filter down stream of the spray dryer absorber. Part of these solid waste is recycled into the tower, the remainder is sent to a disposal site.

A portion of the dry by-product is recycled to the spray dryer to enhance removal of SO$_2$ and use of alkali. Chloride injection or high chloride coals improve the performance of the spray dryer.
Large spray dryer chambers are used to ensure that all of the slurry droplets evaporate to dryness prior to going to a high efficiency particulate control system. The term "dry scrubber" refers to the condition of the dried particles approaching the particulate control system. Fabric filters or electrostatic precipitators are often used for high efficiency particulate control. The system shown in Figure 1 has a fabric filter.

Spray-dryer-type absorption systems have efficiencies that are similar to those for wet-scrubber-type absorption systems. These generate a waste stream that is dry and, therefore, easier to handle than the sludge generated in a wet scrubber. However, the equipment used to atomize the alkaline slurry is complicated and can require considerably more maintenance than the wet scrubber systems. Spray-dryer-type absorption systems operate at higher gas temperatures than wet scrubbers do and are less effective for the removal of other pollutants in the gas stream such as condensable particulate matter.

The choice between a wet-scrubber absorption system and a spray-dryer absorption system depends primarily on site-specific costs. The options available for environmentally sound disposal of the waste products are also an important consideration in selecting the type of system for a specific application. Both types of systems are capable of providing high efficiency SO$_2$ removal.

1.2. Objective of Study

The objective of this study is to estimate the amount of lime slurry utilized in Flue Gas Desulfurization (FGD) with a spray-dry scrubbing type for a 2 x 6 MWe Coal Fired Power Plant. Prior to FGD, the cyclone is usually employed to catch and separate the generated particles. Thus, the second objective of the study is to calculate the particulate concentration for whether or not the cyclone is also employed.

2. METHODOLOGY

The methodology of this study is as follows:

- Calculation of pollutants concentrations, namely particulate and SO$_2$.
- Based on these resulted pollutants, the calculation of the cyclone efficiency (if required) and the amount of lime used in the scrubber will be carried out.

The 2x6 MWe Coal Fired Power Plant is estimated to use 7000 kg per hour of coal in average. With coal ash content of approximately 5% (see Table in Appendix) and conversion efficiency of 90%, the amount of particulate will be around 54 kg per hour.

The estimation of SO$_2$ concentration is based on the coal sulfur content of 3.07% (see Appendix). It results about 6.14% kg of SO$_2$ per kg of coal fuel.

3. CALCULATION

3.1. Particulate Capture Calculation

From the calculation with 30% excess air, the gas flow rate is approximately 100,000 m$^3$/hour or 1667 m$^3$/min. It results about 540 mg/m$^3$ of particle concentration. Since the standard for particulate emission is only 150 mg/m$^3$, the cyclone needs to be employed.

The size of the smallest particle that will be collected ($D_p$) can be calculated using the following equation.

$$D_p = \left[ \frac{9 \mu W}{2 \pi N_s V_r (p_r - p_p)} \right]^{1/2} \quad \ldots \quad (1)$$

where;
D_p = the smallest particle diameter  
V_i = initial velocity, m / s  
ρ_p = particle density, kg / m$^3$  
ρ_g = gas density, kg / m$^3$  
μ = gas viscosity, kg / m·s  
Ne = number of effective turns  
W = width of cyclone inlet (m)

The flow rate of stack flue gas is calculated to be 101,300 m$^3$/hour or around 1667 m$^3$/min. It is assumed that the number of gas turns entering the body of the cyclone is 6 times. Density of particulate is estimated to be 1600 kg/m$^3$ and gas viscosity (μ) is 0.075 kg/m·hr.

If it is assumed that D_p is 10 µm (the minimal particle size that is captured by the cyclone) with linear velocity of 14 meter per second or 840 m/min., using equation (1), the value of inlet width (W) can be calculated; that is about 0.5 m. Height of conventional cyclone inlet is 2 x W or 1 m, so that the area of inlet (WXH) is 0.5 m$^2$. Total inlet area of cyclone can be calculated; that is done by dividing total gas flow rate (1667 m$^3$/min) with linear inlet velocity (840 m/min) resulting around 2 m$^2$. Thus, the number of cyclone used can be found; that is by dividing total inlet area (2 m$^2$) with the individual inlet area (0.5 m$^2$) resulting 4 units of cyclones.

The particle size distribution from coal combustion is typically 80% by mass above 10 µm, so that the capture efficiency of the cyclone in this case will be around 80%.

### 2.2. SO₂ and Lime Calculation

Based on the condition of stochiometric coal combustion, it is found that the requirement of combustion air for 1 kg coal with excess air of 30% is about 11.8 kg. The prediction of SO₂ gas emission based on emission factor estimation (AP-42 US-EPA) for coal fired power plant with traveling grate stoker (30 S lb/ton) is found to be 2579 mg/m$^3$ or 1592 ppm of SO₂ at 25 °C, 1 atm, and 7% O₂.

Reaction of lime slurry, Ca(OH)$_2$ and sulfur dioxide, SO₂ in spray dryer scrubber can be described as follow:

\[
\text{Ca(OH)}_2 + \text{SO}_2 \rightarrow \text{CaSO}_3 + \text{H}_2\text{O} \quad (2)
\]

The amount of water required for gas absorption at scrubber inlet is calculated using the following equation:

\[
\frac{n_{\text{water}}}{n_{\text{gas}}} = \frac{(Cp\Delta T)_{\text{gas}}}{(\lambda + Cp\Delta T)_{\text{water}}} \approx \frac{Cp\Delta T}{\lambda} = 0.047 \text{ lb water/ lb gas} \quad \ldots \ldots \ldots (3)
\]

Assumption for gas temperature at the scrubber inlet and outlet are 260°C and 150°C, respectively.

Given the coal flow rate (LHV) is about 7000 kg/hour, the combustion air is calculated to be 82,600 kg air/hour or 183,555 lb air/hour. (i.e. 7000kg/hour x 11.8 kg air/kg coal). The quantity of lime Ca(OH)$_2$ is calculated based on the mole ratio of Ca(OH)$_2$ and SO$_2$ (usually called stochiometric ratio). Based on technical specification of scrubber manufacturer, this stochiometric ratio varies between 1.1 and 1.5 for capture efficiency between 75% and 80%).

The ratio between lime and treated SO$_2$ gas is calculated using the following equation:

\[
\frac{n_{\text{Ca(OH)}_2}}{n_{\text{SO}_2}} = \begin{cases} 
1.1 \frac{64}{29} & \text{lime, Ca(OH)$_2$ feed rate at stochiometric ratio of 1.1 with SO$_2$ capture efficiency of 75% is 185,555 lb air/hour x 0.0045 lb Ca(OH)$_2$/lb air = 835 lb Ca(OH)$_2$/hour} \\
1.5 \frac{64}{29} & \text{lime, Ca(OH)$_2$ feed rate at stochiometric ratio of 1.5 with SO$_2$ capture efficiency of 80% is 185,555 lb air/hour x 0.0061 lb Ca(OH)$_2$/lb air = 1120 lb Ca(OH)$_2$/hour}
\end{cases}
\]

Lime, Ca(OH)$_2$ feed rate at stochiometric ratio of 1.1 with SO$_2$ capture efficiency of 75% is 185,555 lb air/hour x 0.0045 lb Ca(OH)$_2$/lb air = 835 lb Ca(OH)$_2$/hour

Lime, Ca(OH)$_2$ feed rate at stochiometric ratio of 1.5 with SO$_2$ capture efficiency of 80% is 185,555 lb air/hour x 0.0061 lb Ca(OH)$_2$/lb air = 1120 lb Ca(OH)$_2$/hour
\[ \frac{m_{\text{solids}}}{m_{\text{gas}}} = \frac{0.3}{0.7} \approx 0.4286 \text{ lb solid/lb gas} \] ....(6)

Based on the result of calculation through equations (4) and (5), it is shown that the capability of slurry carrying the solids is still higher than the quantity of lime for capturing SO\(_2\) gas emission. Therefore, solid re-cycling from the bottom of scrubber and bag-filter or electrostatic precipitator (EP) is needed for optimizing the use of lime slurry.

The amount of fresh lime needed and re-cycled lime could be calculated, and the results are as follows.

- For stochiometric ratio 1.1, there are 23% \((0.0045/0.02)\) fresh lime material, and 77% re-cycled one from bag-filter or the bottom spray-dryer scrubber.
- For stochiometric ratio 1.5, there are 30% \((0.0061/0.02)\) fresh lime material, and 70% re-cycled one from bag-filter or the bottom spray-dryer scrubber.

4. RESULT AND DISCUSSION

From the calculation with 30% excess air, the gas flow rate is approximately 100,000 m\(^3\)/hour or 1667 m\(^3\)/min. It results about 540 mg/m\(^3\) of particle concentration. Since the standard for particulate emission is only 150 mg/m\(^3\), the cyclone needs to be employed.

The number of cyclone used is 4 units with the inlet area of 0.5 m\(^2\) each. The capture efficiency of the cyclone in this case is estimated to be around 80%, and therefore it could reduce concentration of particle from 540 mg/m\(^3\) to 108 mg/m\(^3\), which is already below the standard.

Based on coal fuel with around 3% sulfur content (as received), the prediction of SO\(_2\) gas emission is about 2580 mg/m\(^3\) at 25 °C, 1 atm and 7% O\(_2\). If this emission has to be treated with a spray-dryer scrubber, it requires the capture efficiency between 75% and 80% in order to meet the national emission standard of 750 mg/m\(^3\) (at 25 °C, 1 atm and 7% O\(_2\)). Lime feed rate for spray dryer scrubber with capture efficiency between 75% and 80% is between 376 and 504 kg/hour. About 70 to 77% lime containing solid waste needs to be re-used, and it means that there would be about 23 to 30% of fresh lime needed.

5. REFERENCES

1. IEA-Coal, Sorbent Injection Systems for SO\(_2\) Control.
2. LIFAC Sorbent Injection Desulfurization Demonstration Project. Final Report,
## Coal Analysis

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