Efforts to Reduce SO₂ Emission in Paiton Coal-Fired Power Plant

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Abstract. Several breakthrough methods are needed to reduce the exhaust emissions of coal combustion in the boiler in order to meet the environmental quality standard requirements. The implementation of coal mixing is one of the short-term programs to reduce SO₂ emissions, which is carried out by mixing several types of coal which have different calorific values and sulfur content to obtain the right coal mixture so that coal combustion will produce low SO₂ emissions. Supply of coal with low sulfur content is getting smaller due to limited reserves, which causes the coal switching method will no longer be effective. Installation of flue gas desulfurization (FGD) facilities is an effective way to reduce SO₂ emissions. Considering the condition and location of the Paiton 1-2 coal-fired power plant, the seawater desulfurization system is the most appropriate to be implemented because it is close to abundant seawater sources and the system has high reliability and effective economic value. By implementing flue gas desulphurization, SO removal efficiencies will be more than 95%.

1. Introduction
According to the International Energy Agency (IEA), the total amount of electricity production in Indonesia was 254,868 GWh in 2017. Coal-fired power plant played a role in providing electricity by 58%, then successively followed by natural gas-fired power plants supplying electricity by 21.7%, oil-fired power plants supply electricity by 7.6%, hydroelectric power plants by 7.3%, renewable fuels (wind, solar PV and geothermal) by 5% and a small portion supplied by others fuel-fired power plants (waste & biofuels) by 0.3%.

It shows that petroleum is no longer the main source of fuel in generating electricity, but has been replaced by coal and natural gas. Petroleum reserves in Indonesia are decreasing, while proven reserves of coal and natural gas are quite large. British Petroleum in its Statistical Review of World Energy report 69th edition, states that in 2019, Indonesia has coal resources of 39,891 million tons. Based on coal quality, Indonesian coal reserves are classified into anthracite & bituminous ranks of 28,163 million tons, and sub-bituminous & lignite ranks of 11,728 million tons. In 2019, Indonesia produced 610 million tons of coal, and is the 4th largest coal producing country in the world.

By having a large coal reserve, the Indonesian government's program to build power plants using coal as the main fuel is appropriate. As we all know, coal combustion process will produce pollution to the environment, so an environmental conservation program must be carried out. The sulfur, nitrogen and ash content in low quality coal are quite large so that the flue gas from coal combustion contains SO₂, NO₂, and fly ash.

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A significant use of coal has serious consequences to generate large amount of pollutants. Among the pollutants the main ones are SO₂, a major contributor to acid rain, NO and NO₂, collectively called NOx, which plays an important role for photochemical smog and acid rain.

Table 1. Classification of Coals by Rank

| Coal Type                | Ranks                  | Ranks                  | Ranks                  | Ranks                  | Ranks                  | Ranks                  |
|--------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
|                        | PCIC %                  | WCIC %                  | Stiff                  | MAC %                  | MCT %                  | A. Rank               |
| Anthracite              | ≥ 96.5                 | ≥ 96.5                 | ≥ 96.5                 | ≥ 96.5                 | ≥ 96.5                 |                         |
| Sub-bituminous          | ≤ 85.9                 | ≤ 85.9                 | ≤ 85.9                 | ≤ 85.9                 | ≤ 85.9                 |                         |
| Lignite                  | ≤ 50.8                 | ≤ 50.8                 | ≤ 50.8                 | ≤ 50.8                 | ≤ 50.8                 |                         |

Tabel 2. Range of national emission standards for Sox (mg SO₂/Nm³, 6% O₂)

| Country          | New plants | Existing plants |
|------------------|------------|-----------------|
| Austria          | 200–1500   | 200–2000        |
| Belgium          | 250–2000   | 250–2000        |
| Canada           | 770        | —               |
| Czech/Slovakia   | 500–2500   | 500–2500        |
| Denmark          | 400–2000   | 800             |
| EC               | 400–2000   | —               |
| Finland          | 450–2500   | 620–1540        |
| France           | 400–2000   | 400–2000        |
| Germany          | 400–2000   | 400–2000        |
| Italy            | 400–2000   | 400–2000        |
| Luxembourg       | 400–2000   | —               |
| Netherlands      | 200–700    | 400             |
| New Zealand      | 125        | —               |
| Poland           | 540–1755   | 675–4160        |
| Portugal         | 400–2000   | —               |
| Spain            | 400–2000   | 2400–9000       |
| Sweden           | 160–540    | 160–540         |
| Switzerland      | 430–2145   | 430–2145        |
| Taiwan           | 1430–4000  | 1430–4000       |
| Turkey           | 430–1875   | 430–1875        |
| U.K.             | 400–3000   | 2000–3000       |
| U.S.A.           | 750–1480   | 1480            |

The world has struggle to reduce SO₂ and NOx emissions from power plant. From nation to nation, SO₂ emission reductions range to millions of annual tons in conjunction with use of coal and residual oil fuels. National programs have been successful, particularly in the U.S., Japan, Germany and other western European countries, in limiting ground-level atmospheric concentration of SO₂ by reduction or dispersion of emissions from new and existing coal-burning power plants [2]. Limiting emission is more concerned rather than dispersion in pursuing air quality objectives.
Indonesia has reviewed SO\textsubscript{2} emission standard for coal-fired power plant in 2019 through Minister of Environment and Forestry Regulation No. P.15/MENLHK/SETJEN/KUM.1/4/2019 that decrease the limit of SO\textsubscript{2} emission. For Coal Fired Power Plant that build before this rules applied is 550 mg/Nm\textsuperscript{3} (the previous limit is 750 mg/Nm\textsuperscript{3}), and after this rules applied is 200 mg/Nm\textsuperscript{3}. Considerable effort has been made and many techniques have been developed to reduce the emission SO\textsubscript{2} from the combustion processes. Some of these techniques have been widely used in industry. However, a minimization of the pollutant emissions by these technologies is generally decrease the plant efficiency. New cost-effective methods for further reduction of SO\textsubscript{2} are needed to meet stricter requirements in the future. Worldwide still continuing in pursuing advance control technologies in order to suppress the negative effect of stack emissions of SO\textsubscript{2} and NO\textsubscript{x}.

2. Short Term Program

Options to reduce sulfur dioxide from power plants emissions include, among others, the use of low sulfur coal [1]. In order to generate electricity, currently Paiton 1-2 coal-fired power plant uses coal from several suppliers with different specifications of calorific value and sulfur content. PT Oktasan Baruna Persada supplies 15,000 MT of coal with a calorific value of 4900 GAR and a typical total sulfur content of 0.25% (as received) and a maximum total sulfur content of 0.30% (as received). PT Kaltim Prima Coal supplies 3,120,000 MT ± 30% of coal with a calorific value of 4700 GAR and a typical total sulfur content of 0.50% (as received) and a maximum total sulfur content of 0.7% (as received). PT Adaro Indonesia supplies 380,000 MT ± 30% of coal with a heating value of 4700 GAR and a typical total sulfur content of 0.16% (as received) and a maximum total sulfur content of 0.30% (as received). PT Arutmin Indonesia supplies 2,400,000 MT ± 30% coal with a calorific value of 4200 GAR and a typical total sulfur content of 0.20% (as received) and a maximum total sulfur content of 0.30% (as received). The use of coal mixing with the current composition produces SO\textsubscript{x} emissions which are shown in the graphic 1.

![Graphic 1. Flue Gas Emission SO\textsubscript{x} 2020 Paiton 1 & 2 Without Additional Low Sulphur 4700 GAR](image)

The amount of SO\textsubscript{2} emissions that will result from coal combustion with a specific heating value and sulfur content can be calculated using the following formula:

\[
SO_x = \frac{\% FBS}{100} \times \frac{1000000 \text{ BTU}}{\text{HHV Batubara}} \times 2,00 \times 0.9
\]

The sensitivity of coal heating value and sulfur content in coal combustion to ensure SO\textsubscript{2} emissions do not exceed the quality standards of SO\textsubscript{2} emissions in exhaust gas (550 mg/Nm\textsuperscript{3}) can be shown in the graphic 2:
The graph above shows that the lower the calorific value of coal, the maximum sulfur content limit is getting tighter.

Based on calculations and simulations, coal mixing with a minimum final heating value of 4500 kCal/kg (as received) and a total final sulfur content of 0.275% (as received) is needed to achieve the target quality of SOx emissions in exhaust gases below 550 mg / Nm³. Another advantage gained from the use of coal is the reduction in production costs. To obtain the required coal mixing quality, PLTU Paiton 1-2 requires an additional coal supply of 60,000 MT ± 30% per month with a heating value of 4700 kCal/kg (GAR) and a typical total sulfur content of 0.16% (as received) and a maximum total sulfur content of 0.30% (as received). The implementation of coal mixing will produce SOx emissions which are shown in the graphic 3.

Low sulfur coal is one method could be used to reduce sulfur dioxide emissions form power plants, and this method is being applied on paiton 1 & 2 power plant. The most influential parameter which is the main reason of high price is the incremental fuel cost.
Regarding that low sulfur coal is expensive method to reduce sulfur dioxide emissions, so another kind of method must be considered to be implemented in order to obtain economical ways to reduce sulfur dioxide emissions.

3. Medium term Program

SO₂ reduction in emission also could be achieved by implementing Dry Sorbent Injection (DSI) using lime absorbent or Sodium-based material with technical considerations is easier to apply and does not require large areas compared to the wet and semi-wet system desulfurization method. DSI is still possible to meet the 30% emission reduction target, with products also dried. DSI will be placed on the ESP ducting inlet. ESP has 4 ducting in each unit. This method is still need Laboratory scale studies to be carried out to get the right meshing size and Ca / S ratio. While full scale aims to get an effect on ESP performance.

To ensure effectiveness of this method, a study is needed to be done to get the characteristics of SO₂ reduction using duct sorbent injection technology to meet emission quality standards. The characterization was conducted a review of chemical and physical analysis on coal, sorbent analysis, and observation of the operating parameters of the duct sorbent and ESP in one Paiton PJB Unit. Review SO₂ emission reduction with variations in sorbent dosage and sorbent type. A comprehensive study of SO₂ emission reductions to meet emission quality standards with DSI with an optimal ratio and the effect of increasing particulate emissions to a minimum will be obtained.

The methodology for implementing the study is as follows:

a. Characterize the chemical composition and physics of fuels, and sorbents.
   The purpose of this characterization is to determine the chemical and physical composition in coal fuels and ash analysis. The coal was tested using high %S. The composition of the sorbent was analyzed to determine the alkali content.

b. Characterizing coal combustion and reducing laboratory SO₂ emissions
   PJB Paiton coal will be tested to be burned in a lab scale for a spray sorbent test. The lab scale parameters are cultivated similar to the conditions at ESP ducting, especially the temperature and residence time. The test matrix will vary the sorbent dose based on three variations of the Ca / S ratio (1, 2 and 3) and 3 variations in the size of the lime sorbent meshing. Sodium based variations can be done based on the Na / S ratio.

c. Reviewing the DSI test at PJB Paiton
   The DSI test at Paiton PJB is carried out using injection equipment in UP Paiton and is carried out only on 1 ducting from the 4 ducting in each unit. The effect of injection on SO₂ and particulate gas emissions is carried out at the ducting of the FGD outlet. Tests carried out at a ratio of 3 Ca / S variations according to the ability of the injection tool. Tests using lime sorbent and / or sodium based. Measurements on PM emissions are carried out at ducting outlets using the isokinetic method.

d. Implement conceptual design duct sorbent injection at PJB Paiton
After conducting the above study, the conceptual design of DSI in Paiton PJB was conducted with the aim of being able to estimate the cost of developing the DSI in Paiton.

4. Long Term Program

Environmental quality standards in Indonesia are more stringent every year. Minister of the Environment Regulation No. 21/2008 states that the Sulfur Dioxide (SO$_2$) emission quality standard for stationer source thermal power plants has a maximum content of 750 (mg / Nm$^3$) for coal. Then the standard quality value of Sulfur Dioxide (SO$_2$) emissions is updated to 550 (mg / Nm$^3$) in the Minister of Environment and Forestry Regulation No. P.15/MENLHK/SETJEN/KUM.1/4/2019. If the government sets stricter emissions quality standards each year and coal reserves with low sulfur content are limited, then the implementation of the coal switching program will not be able to reduce SO$_2$ emissions below the emission quality standard provisions. Installing flue gas desulfurization (FGD) facilities to capture SOx is a method for reducing SO$_2$ emissions. Based on its working principle, there are 3 types of FGDs for thermal power plants.

| Tabel 3. Types of FGDs for thermal power plants |
|-----------------------------------------------|
| **Wet System** | **Spray Dryer System** | **Dry Injection System** |
| 1. Coal-fired utility and industrial boilers | 1. Municipal solid waste projects | 1. Small to medium municipal and medical solid waste projects |
| 2. Hazardous and municipal solid waste projects | 2. Hazardous incineration | 2. Coke oven emissions control |
| 3. Refining process | 3. Industrial and utility coal-fired boilers | 3. Aluminum anode bake and pot-line project for fluoride scrubbing |
| | | 4. Secondary non-ferrous emission control |

The review of the pattern of past FGD installations in various parts of the world reveals that wet FGD technologies have been predominantly selected over other FGD technologies. Wet-type desulfurization process is the most appropriate method for the coal-fired power plant because of its reliability and cost effectiveness. One of wet-type desulfurization process is seawater desulfurization system, which is no chemicals such as magnesium hydroxide or limestone are used as absorbents. Instead, alkaline compound naturally contained in seawater are utilized for desulfurization.

This simple framework of a desulfurization system can serve as an alternative method even the plant location makes it difficult to prepare absorbents or handle by-product. Most wet limestone systems can perform 90% SO removal, whereas the wet scrubbers are able to conduct SO$_2$ removal efficiencies of more than 95%. Recently, more advance technologies and methods has been provided so that these technology are capable of achieving SO removal efficiencies of more than 95% [4].

Some studies show a result that using FGD systems is more economical than using low sulfur fuel[1]. So FGD alternative was favored over the fuel alternative.

5. Benefit

5.1. Technic

Effort to reduce SO$_2$ in emission Coal-Fired Power Plant in Paiton have several benefit that related to sustainability operational power plant in Indonesia

a. To Fullfill government regulation No. P.15/MENLHK/SETJEN/KUM.1/4/2019, limit of SO$_2$ emission in stack 550 mg/Nm$^3$

b. Reduce the potential corrosion on the stack and several equipment in power plant, cause SO$_2$. When sulfur-bearing fuel is burned, sulfur is converted to sulfur dioxide (SO$_2$) and sulfur...
trioxide (SO₃). The sulfur trioxide combines with moisture to form sulfuric acid (H₂SO₄) that very corrosive.

5.2. Non Technic
Reducing in SO₂ emission on coal-fired power plant contributed to air quality improvement for environment and health benefit for human. Because SO₂ have have potentially cause acid rain and SO₂ also combines in atmosphere with ammonia to form sulfate – fine particulate (PM₂.₅) – which have been shown in several studies to contribute significantly to premature mortality.

6. Conclusion
Current conditions, based on the results of manual measurements, CEMS measurements, and calculations mass balance, it is known that SO₂ emissions from PLTU Paiton Units 1 and 2 exceed quality standards set in PermenLHK No. 15 of 2019.Unit 1 Paiton power plant requires SO₂ emission control by 34% and unit 2 requires SO₂ emission control by 31%. There are three alternative programs as an effort to reduce SO₂ emissions at the Paiton coal-fired power plant based on the time of implementation, i.e.

a. Short term program : By mixing coal with a minimum final heating value of 4500 kCal / kg (after receipt) with a total final sulfur content of 0.275% (after receipt) is needed to achieve the target quality of SOx emissions in exhaust gases below 550 mg / Nm³

b. Medium term Program : SO₂ emission reduction applies Dry Sorbent Injection (DSI) using lime absorber or Sodium-based material. DSI is still possible to meet the 30% emission reduction target, with products also dried. This method still requires Laboratory scale studies to get the right meshing size and Ca / S ratio. Comprehensive study of SO₂ emission reductions to meet emission quality standards with DSI with an optimal ratio and the effect of increasing particle emissions to a minimum.

c. Long Term Program : install flue gas desulfurization (FGD) facilities to reduce SO₂ emissions. The wet type desulfurization process with sea water is the most appropriate method for coal-fired power plants because of its reliability and cost-effectiveness. Further analysis is needed for the application of this method for handling byproducts.

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