Development of Emission Factors from Indonesian Coal-Fired Power Plant Using Continuous Emission Monitoring Data

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Abstract. Continuous Emission Monitoring System (CEMS) is generally used for monitoring compliance with emission standards set by the government regulations and has not been optimally used for other additional purposes yet. If operated CEMS can produce reliable and accurate data, they can develop further specific data such as emission factors. These emission factors can be used for estimating pollutant emission loads from coal combustion activity in Coal-Fired Power Plants (CFPPs) without conducting direct source measurements. In this study, hourly 1 yr CEMS data from several units of CFPPs were processed to develop specific emission factors for principal air pollutants (SO2, NOx, particulates) and greenhouse gases (represented by CO2). Emission factors were determined by dividing the emission load of each pollutant by the amount of combusted coal during 1 yr. The results showed that emission factor ratings for this study could not be classified as A ratings due to the limited number of investigated CEMS facilities. According to the variability of the derived emission factor values, SO2 and CO2 emission factors can be rated as B or above average (with fewer variability values). In comparison, NOx and particulate emission factors can be placed as C or average (with more variability values).

Keywords: Emission factors, pollutants, regulations.

1 Introduction

Continuous Emission Monitoring Systems (CEMS) in Coal-Fired Power Plants (CFPPs) are generally used to monitor compliance with air emission standards set by the government regulations [1]. This tool is considered an efficient, real-time, and continuous system
essential to strengthening the enforcement of regulations and emissions compliance with environmental standards.

Developed countries, including United States, European Union (EU) and Japan, have adopted and excelled in the implementation of CEMS. Some developing countries, including Brazil, Chile, Indonesia and China, have also adopted CEMS. To improve the quality of CEMS, the Chinese Government has established regulations and standards that standardize the operation and supervision of the use of CEMS [2, 3]. Over the past 2 yr, India has begun to take steps towards the use of CEMS. India's Central Pollution Control Board has issued directives and mandates the installation of CEMS in highly polluting industries [4].

CEMS installation policy for Indonesian CFPPs today refers to a new regulation issued by the Ministry of Environment and Forestry (MoEF) Number 15/2019, concerning Emission Standards for Thermal Power Plants [5]. Thermal power plant with a capacity equal to or more than 25 MW or less than 25 MW utilizing fuel with more than 2 % of sulphur content CEMS must be installed CEMS. CEMS in CFPPs must monitor main parameters such as nitrogen dioxide (NO$_2$), sulphur dioxide (SO$_2$), particulates, carbon monoxide (CO), and mercury (Hg). These CEMS must also have a specification to monitor O$_2$, CO$_2$, and flue gas flowrate. Results of monitoring must be reported to MoEF every 3 mo. CEMS data can be replaced by manual monitoring if they cannot be operated due to technical difficulties within at least 3 mo or maximum within 1 yr.

Currently, the use of CEMS data for other purposes have not been widespread yet. However, few types of research denoted that CEMS data can be helpful for power plant heat rate determination [6] or emission factor calculations [7, 8]. Emission Factor (EF) is a factor that shows the number of pollutants that will be emitted from a specific activity, e.g., the amount of SO$_2$ that will be ejected from coal combustion at a power plant. It is usually expressed in g SO$_2$ kg$^{-1}$ burned coal, which means a particular gram of SO$_2$ will be emitted from every kg of burned coal. According to Sloss [9] and de Nevers [10], emission factors are beneficial for preparing emission inventories. They provide values that can be applied to estimate emissions from many sources without using exhaustive testing at each plant.

Emission factors as a part of emission inventories have long been fundamental tools for air quality management [11]. Estimating emission loads is essential for establishing the applicability of permitting and control programs, designing emission control strategies, discovering the effects of sources and appropriate techniques of mitigation, and other valuable applications by related stakeholders. Implementing stricter emission regulations for coal-fired power plants, gradually removing high-emission power generation units, and installing air pollution control devices on existing units have led to enhancements in reducing air pollutants through fuel switching and various methods [12, 13].

CEMS and direct source sampling in certain conditions are usually preferred for estimating pollutant emission loads since they can provide an actual representation of tested emission sources. However, not all of the individual sources install CEMS or conduct manual sampling. Although there are still limitations, emission factor application is the simplest way to estimate pollutant emission load, which can help determine policy-making [14], particularly when enforcing environmental regulations [15, 16]. The data from emission monitoring contributes to proposing a proper strategy for reducing pollutants [17].

This study represents specific emission factors for SO$_2$, NO$_x$, particulates and CO$_2$, developed from recorded CEMS data in 2018. 1 yr hourly CEMS data from seven units of CFPPs were collected and processed to produce the PLN specific emission factors, which can be utilized for estimating Indonesian CFPPs emission load without conducting direct measurement.
## 2 Method

CEMS data were collected from several CFPPs located in Java and Sumatra. CEMS in these selected CFPPs is considered to represent the average condition of CEMS performance in Indonesia. Collected data include the physical characteristics of the flue gas (flow rate, temperature, and pressure) and concentrations of measured parameters (CO₂, NOₓ, SO₂, and particulates). All CEMS data might be available in specific temperature and pressure conditions. Therefore, according to Indonesian Regulation, adjustment to a normal state must be made to meet the standard at 25 °C and 1 atm (101 325 Pa).

There are three kinds of CEMS sampling systems commonly applied by the CFPPs: the in-situ system, the dilution probe system, and the direct extractive system. Recorded data from these selected CEMS were utilized to develop the emission factors of SO₂, NOₓ, particulates, and CO₂ in g kg⁻¹ unit. The basic equation of emission factors originates from a general equation for emission load estimation as described in Equation (1) [7]:

\[
E = A \times EF \left(1 - \frac{ER}{100}\right)
\]  

(1)

Where,

- **E**: Emission load
- **A**: Activity rate
- **EF**: Emission factors
- **ER**: Overall emission reduction efficiency (%).

For the case of unknown emission reduction or uncontrolled emission factors, the equation is simplified to be in Equation (2):

\[
E = A \times EF
\]  

(2)

Emission factors in this study can be derived by dividing the emission load by the activity data as follow in Equation (3):

\[
EF = \frac{E}{A} = \frac{\text{SO}_2 \text{ emission load from CEMS data (g year)}^{-1}}{\text{coal use (kg year)}} = \frac{\text{g SO}_2}{\text{kg coal}}
\]  

(3)

Emission loads in this study were derived by multiplying the hourly emission load with hourly flow rate, and adding up all these hourly emissions loads for 1 yr, as expressed in Equation (4):

\[
EF = \frac{\sum_{i=1}^{OP} C \times Q}{\text{coal use (kg year)}} = \frac{\text{g SO}_2}{\text{kg coal}}
\]  

(4)

Where,

- **C**: Hourly concentration of pollutants (g Nm⁻³, at 25 °C and 1 atm)
- **OP**: The last number of the operating hours (if data is complete with total operating hours, OP = 8760)
- **Q**: Hourly flow rates of the stack flue gas (Nm³ h⁻¹, at 25 °C and 1 atm).

Typically CEMS cannot produce 100 % valid data for a whole year period. Therefore, it is necessary to normalize the emission load by applying a correction factor (total operating hours in 1 yr/operating hours without interruption) to the total calculated annual emissions load based on CEMS data. Normalization of emission load is not necessary if CEMS can produce 100 % valid data. Results that are obtained by using this method will depend on the availability, validity, and accuracy of the recorded CEMS data.
The USEPA [7] classifies the ratings of emission factors developments as depicted in Figure 1 and summarized as follows:

(i) A, excellent. The factor is derived from source sampling using CEMS or standardized source sampling, taken from many randomly chosen representative industries to minimize variability.
(ii) B, above average. The factor is derived from source sampling using CEMS or standardized source sampling, taken from a sufficient number of industries to minimize variability.
(iii) C, average. The factor is derived from CEMS, standardized source sampling, or unproven/new technology, taken from a reasonable number of facilities. The facilities tested are not yet clearly representative of a randomized industrial sample.
(iv) D, below average. The factor is derived from CEMS, standardized source sampling, or unproven/new technology, comes from a small number of facilities, and there is a high probability that the facilities tested are not representative of a random sample of the industry.

Fig. 1. Approach to emission load estimation [7].

3 Results and discussion

Coal is a naturally occurring combustible sedimentary rock. Generally, the coal content consists of carbon, hydrogen, ash, nitrogen, sulfur and water, and trace elements such as mercury. Oxidation of carbon and other matter contained within the coal with O₂ with specific excess of air will release principal air pollutants such as SO₂, NOₓ, and particulates. The CO₂ as the ultimate product of complete combustion is emitted in the highest amount of emission load.
The SO₂ emission factors from CFPP-1 (CFPP with a capacity of 400 MW), CFPP-2 (400 MW), CFPP-3 (600 MW), CFPP-4 (600 MW) are classified as uncontrolled emission factors since there is no installation of SO₂ control devices. The SO₂ emission factors from CFPP-5 (660 MW), CFPP-6 (660 MW), and CFPP-7 (100 MW) are the controlled emission factors. CFPP-5 and CFPP-6 have the limestone wet Flue Gas Desulphurizations (FGD) installed after the boiler, while CFPP-7 has the dry FGD system by limestone injection in the boiler. Although, CFPP-5 and CFPP-6 have not optimally utilized FGD's ability to reduce SO₂. With these operating conditions, CFPPs can still meet Indonesian Regulations when the SO₂ emission standard in 2018 was still 750 mg Nm⁻³, at 1 atm, 25 °C, and 7 % O₂. In CFPP-7, although the dry limestone injection was applied within the boiler, it had been known that this dry FGD did not reduce the SO₂ emission effectively. The NOₓ and particulates emission factors are classified as the controlled emission factors since all units applied low NOₓ burner technique for reducing NOₓ and electrostatic precipitator (ESP) for reducing particulates.

The quality of recorded CEMS data strongly influences the emission factor. Determination of emission factors can also be done by selecting a certain period when CEMS can operate properly, i.e., no interference during data recording or no malfunctions of CEMS sensor equipment.

Analysis of CEMS performance from each unit can be summarized as follows:

(i) The sensor of CEMS CFPP-3 recorded many flow rates data that were too small.
(ii) The sensor of CEMS CFPP-4 recorded considerable fluctuation of flow rates and SO₂ concentration.
(iii) The sensor of CEMS CFPP-7 recorded fluctuating data or unstable record.

Based on this performance, for the representative values of PLN emission factors, it is recommended to use emission factors developed from CFPP-1, CFPP-2, CFPP-5, and CFPP-6.

The results of emission factor determinations for these principal air pollutants and CO₂ are shown in Figure 2 and Figure 3 (SO₂), Figure 4 (NOₓ), Figure 5 (particulates), Figure 6 and Figure 7 (CO₂). As shown in Figure 1 to Figure 6, each CFPP has a different emission factor value, but it is still within the acceptable range compared with other published values. It should also be noted that there are not many differences between emission factors developed from units in the same CFPP. Similarly, compared with emission factor values from various literature (Table 1), the derived values are within the same order.

**Table 1.** Values of emission factors from various sources [7].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Emission factor</th>
</tr>
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<tbody>
<tr>
<td>SO₂ ⁺⁺⁺</td>
<td>15.9S g kg⁻¹ (S = sulphur content)</td>
</tr>
<tr>
<td>NOₓ⁺⁺⁺</td>
<td>4.99 g kg⁻¹</td>
</tr>
<tr>
<td>Particulates ⁺⁺⁺</td>
<td>0.17 g kg⁻¹ (CFPPs with particulate control and flue gas desulphurization unit)</td>
</tr>
<tr>
<td>CO₂⁻</td>
<td>1 974.4 g kg⁻¹</td>
</tr>
</tbody>
</table>

⁻ US EPA, 1998, uncontrolled emission factors, A rating
⁻ Research and development Center-Tekmira, Ministry of Energy and Mineral Recources Indonesia, 2009

PLN SO₂ emission factors range between (5.01S to 6.2S) g kg⁻¹, much lower than the US EPA emission factor (15.9S kg kg⁻¹). Compared to Indonesia, according to Wisconsin Centre for Environmental Education [18], the United States generally have higher coal sulphur content, about 51 % of their coal reserves have a sulphur content of 0.8 % to 5.0 %, and 38 % of their coal reserves have a sulphur content of 0.6 % to 1.8 %. While in Indonesia, the PLN CFPPs use coal with sulphur content between 0.47 % to 0.71 % on average. The SO₂ emission factors are greatly influenced by the coal sulfur content, as indicated in Figure 2 and Figure 3. A higher coal sulphur content resulted in a higher SO₂ emission factor.
Fig. 2. SO₂ emission factor (g kg⁻¹) and coal sulphur content (%).

Fig. 3. SO₂ emission factor (g kg⁻¹) incorporating sulphur content (%).

PLN NOₓ and particulate emission factors range between 0.75 g kg⁻¹ to 3.21 g kg⁻¹ and 0.08 g kg⁻¹ to 0.49 g kg⁻¹, respectively (Figure 4 and Figure 5). These values are lower than NOₓ and particulate emission factors from US EPA (Table 1). However, based on the US EPA emission factor classification, the emission factor for NOx and particulates developed from this study has a C rating. In contrast, US EPA emission factors have an A rating. Although created using CEMS data, the lack of some representatives CFPPs made the A rating not accomplished.
Based on Figure 6, PLN CO₂ emission factors range between 1 156 g kg⁻¹ to 2 060 g kg⁻¹, close to the value developed by Tekmira (1 974 g kg⁻¹). The higher CO₂ emission factors denote, the more effective complete combustion occurs within the CFPP plant.
As mentioned before, the determination of emission factor from CEMS data can be chosen from a certain period, where there are no measurement interferences such as sensor malfunctions. Another factor that should be considered is the normal condition of plant operation. The use of data during abnormal condition such as start-up and shut-down must be avoided. Calculation of CO₂ emission factor using uninterrupted 1 mo hourly recorded data compared to a normalized full year recorded hourly data can be seen in Figure 7. Emission factors developed from different data period are very similar (2 059 from 1 yr and 2 086 from 1 mo period). This also proves that the method utilized in this study is accurate.
4 Conclusion

The development of PLN specific emission factors for SO$_2$, CO$_2$, NO$_x$, and particulates have been carried out by processing CEMS data from seven units of CEMS in representatives PLN CFPPs. The emission factor ranges between (5.01S to 6.2S) g kg$^{-1}$ for SO$_2$, (1.156 to 2.060) g kg$^{-1}$ for CO$_2$, (0.75 to 3.21) g kg$^{-1}$ for NO$_x$ and (0.08 to 0.32) g kg$^{-1}$ for particulates. The rating of emission factors developed from this study can be classified as B or above average for SO$_2$ and CO$_2$ (less variability, limited number of CEMS facilities), and C or average for NO$_x$ and particulates (more variability, limited number of CEMS facilities). Improvement of the emission factor rating can be made by collecting more CEMS data from representative CFPPs. Utilization of CEMS data for purposes other than monitoring the compliance to the government regulation is one of the continuous improvement efforts in optimizing CEMS data utilization. Specific emission factors that represent the general conditions of emissions from Indonesian CFPPs are beneficial for supporting the government in developing more accurate estimations of emission loads of air pollutants from Indonesian CFPPs without conducting expensive direct source emission sampling.

References


   https://books.google.co.id/books?id=rc0SAAAAQBAJ&printsec=frontcover&hl=id#v=onepage&q&f=false

   https://doi.org/10.3390/su151511653

   https://doi.org/10.3390/en14185716

   https://doi.org/10.1016/j.scitotenv.2023.166108

   https://doi.org/10.1038/s41597-023-02054-w

   https://doi.org/10.1016/j.jenvman.2022.115081

   https://doi.org/10.1016/j.scitotenv.2023.161817

   https://doi.org/10.1016/j.scitotenv.2023.162851