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Correlation Analysis Between Power Output and Exhaust Gas Emissions in a Coal-Fired Power Plant

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Abstract

Coal handling operations play a critical role in ensuring stable fuel supply and maintaining environmental performance in coal-fired power plants. This study investigates the relationship between coal flowrate variability in the coal handling system and exhaust gas emission characteristics at PT. PLN Nusantara Power, Paiton Power Plant Units #1–2. Coal flowrate data from Belt Conveyor J2 and exhaust gas emission data (NO_x and SO₂) were collected under real operating conditions during March–May 2025. The results show that average coal flowrates were 738.72, 732.72, and 717.16 for the morning, afternoon, and night shifts, respectively, indicating moderate inter-shift variability. Despite these variations, exhaust gas emissions remained stable, with NO_x concentrations ranging from 350.69 to 419.95 mg/Nm³ and SO₂ concentrations from 265.81 to 394.18 mg/Nm³. Monthly average emission values were consistently maintained within 387.55–389.14 mg/Nm³ for NO_x and 356.91–361.85 mg/Nm³ for SO₂, all of which were below the regulatory limit of 550 mg/Nm³ stipulated by Indonesian environmental standards. These findings demonstrate that stable coal handling operations contribute significantly to maintaining consistent combustion conditions and effective emission control. The study highlights the importance of optimizing upstream operational systems as an integrated strategy to enhance both operational reliability and environmental compliance in coal-fired power plants.

Keywords: Coal handling system; Coal flow rate; Exhaust gas emissions; Coal-fired power plant; Operational efficiency

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1. Introduction

Coal-fired power plants remain a critical component of electricity generation systems in many developing countries, including Indonesia, due to their ability to provide stable and large-scale power output [1]-[3]. However, the level of electrical power generated by a coal-fired power plant is intrinsically linked to the amount of coal consumed during operation, which consequently influences the magnitude of flue gas emissions such as carbon dioxide (CO₂), sulfur dioxide (SO₂), and nitrogen oxides (NO_x) [3]-[5]. Understanding the relationship between power output and exhaust gas emissions is therefore essential for evaluating plant performance from both efficiency and environmental perspectives [6]-[7].

As the power output of a coal-fired power plant increases, the operational load on auxiliary systems—including coal handling, combustion systems, and electrical drives—also intensifies [8]-[9]. This increase in auxiliary power consumption contributes indirectly to higher fuel usage and elevated emission levels [10]-[11]. Although extensive studies have examined emissions from coal-fired power plants, most have focused on emission inventories or control technologies, while limited attention has been given to quantitative analyses of the correlation between variations in power output and resulting exhaust gas emissions under real operating conditions [12]-[14].

Identifying the correlation between power output and emission characteristics is crucial for optimizing plant operation without compromising environmental compliance [15]-[16]. Variations in load conditions can significantly affect combustion efficiency, heat rate, and emission formation mechanisms. Consequently, a detailed analysis of power output–emission relationships can provide valuable insights into optimal operating ranges that minimize emissions while maintaining reliable power generation [17]-[18].

This study aims to investigate the correlation between power output and exhaust gas emissions in a coal-fired power plant through systematic analysis of operational data [19]-[20]. The findings are expected to contribute to the development of more efficient and environmentally sustainable operational strategies by supporting data-driven decision-making for emission reduction. Furthermore, the results may serve as a reference for future research on integrating advanced control systems and cleaner technologies to reduce the environmental impact of coal-based power generation.

2. Methods

2.1 Coal Flowrate Measurement on Belt Conveyor J2

Coal flowrate measurements on Belt Conveyor J2 were conducted to evaluate the relationship between conveyor motor electrical load and the mass flow rate of coal transported within the coal handling system. The electrical current supplied to the conveyor motor, expressed in amperes, was used as an indicator of motor loading, while the coal flowrate data were obtained from the conveyor's built-in monitoring system.

Data acquisition was performed continuously under normal operating conditions during three consecutive months, namely March, April, and May 2025. Measurements were recorded across different operational shifts to capture variations in conveyor loading and coal transfer rates. The collected data were subsequently processed to support correlation analysis between motor electrical consumption and coal flowrate behavior.

2.2 Exhaust Gas Emission Measurement

Exhaust gas emission measurements were conducted to characterize the environmental impact associated with coal combustion during power generation. The analyzed emission parameters included nitrogen oxides (NO_x) and sulfur dioxide (SO₂), which are the primary regulated pollutants in coal-fired power plants. Emission data were obtained from the Continuous Emission Monitoring System (CEMS) installed at PT. PLN Nusantara Power, Paiton Power Plant Units #1–2. The monitoring period covered March to May 2025, ensuring sufficient temporal coverage to observe operational consistency and variability. The acquired emission data were used to assess emission stability and compliance with national environmental regulations.

Data were obtained using multiple sources to ensure reliability and completeness:

- Supervisory Control and Data Acquisition (SCADA – Citect) system for real-time coal flow rate and motor current measurements,
- Continuous Emission Monitoring System (CEMS) for stack emission data (NO_x and SO₂),
- Internal operational logs and historical records provided by the power plant,
- Supporting technical references and regulatory documents from peer-reviewed literature.

The independent variable in this study is the coal flow rate within the coal handling system, while the dependent variables are the concentrations of nitrogen oxides (NO_x) and sulfur dioxide (SO₂) emissions measured in mg/Nm³. To ensure analytical consistency, unit load, coal type and quality, conveyor configuration,

boiler operating parameters, and ambient environmental conditions were treated as controlled variables. The collected operational data were processed using descriptive statistical analysis, including mean, minimum, maximum, and standard deviation, to characterize system performance and emission variability. Correlation analysis was subsequently applied to evaluate the relationship between coal flow rate fluctuations and changes in emission concentrations, supported by shift-based trend analysis to assess operational consistency across different working periods. Data reliability and validity were ensured through the use of calibrated SCADA and Continuous Emission Monitoring System (CEMS) instruments, cross-verification with official operational records, and the exclusion of anomalous data caused by non-operational disturbances.

3.Results and Discussion

3.1 Coal Flowrate Characteristics on Belt Conveyor J2

Figure 1-3 illustrate the coal flowrate behavior on Belt Conveyor J2 during March, April, and May 2025. The results indicate notable flowrate fluctuations across different operational shifts. During the morning shift, the highest recorded flowrate reached 898.36, while the lowest value was 602.31, resulting in an average flowrate of 738.72. These values suggest relatively stable conveyor operation despite observable variations.

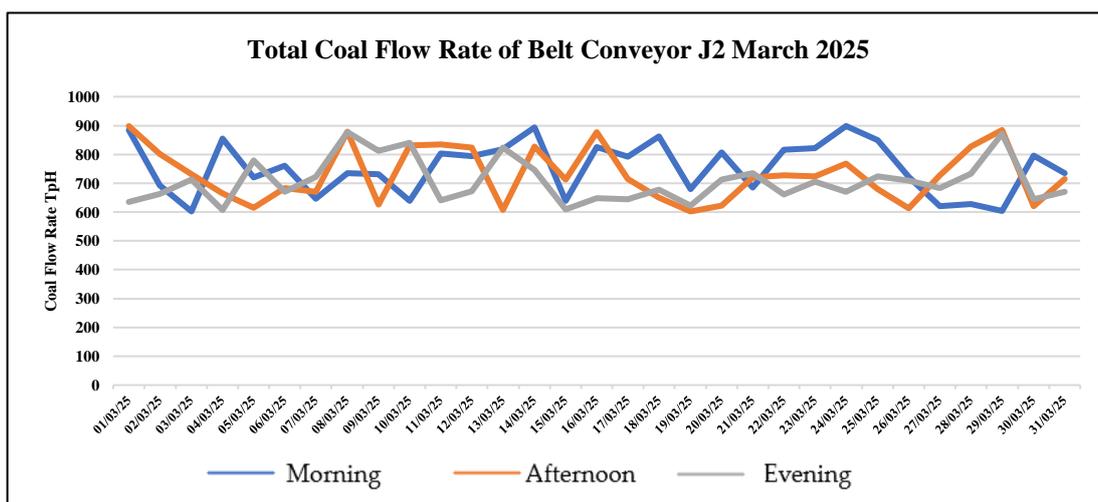


Figure 1. Coal Flow Rate Graph on Belt Conveyor J2 March 2025

A similar pattern was observed during the afternoon shift, with a maximum flowrate of 898.89 and a minimum of 602.20. The average flowrate during this shift was 732.72, slightly lower than that of the morning shift. In contrast, the night shift exhibited a lower overall performance, with an average flowrate of 717.16, although the maximum and minimum values remained within comparable ranges.

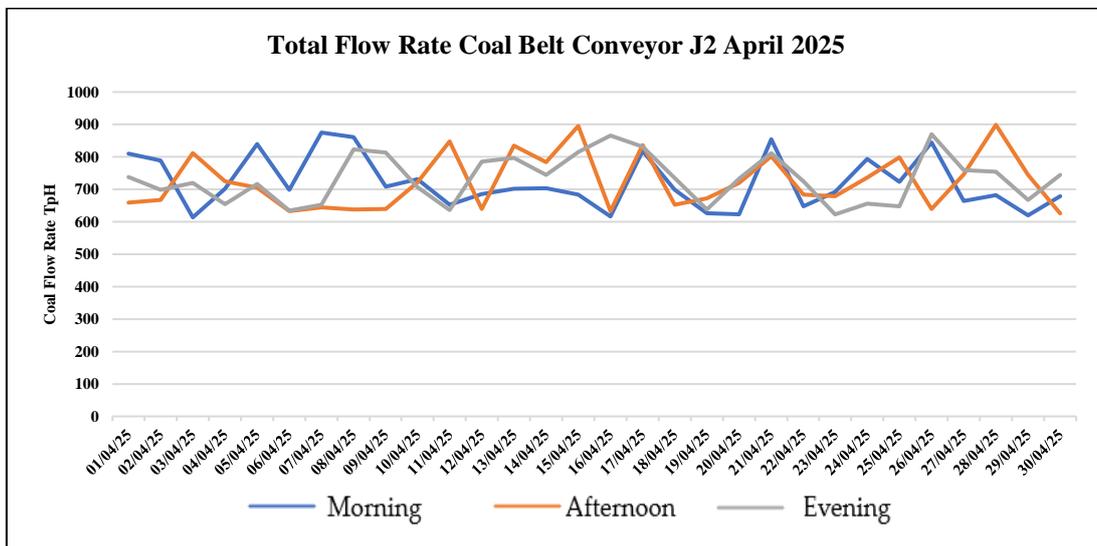


Figure 2. Coal Flow Rate Graph on Belt Conveyor J2 April 2025

The lower average flowrate during the night shift may be attributed to operational scheduling, reduced coal demand, or load management strategies. Nevertheless, the overall flowrate trends demonstrate that the conveyor system maintained stable performance across all shifts, indicating reliable coal transfer operations.

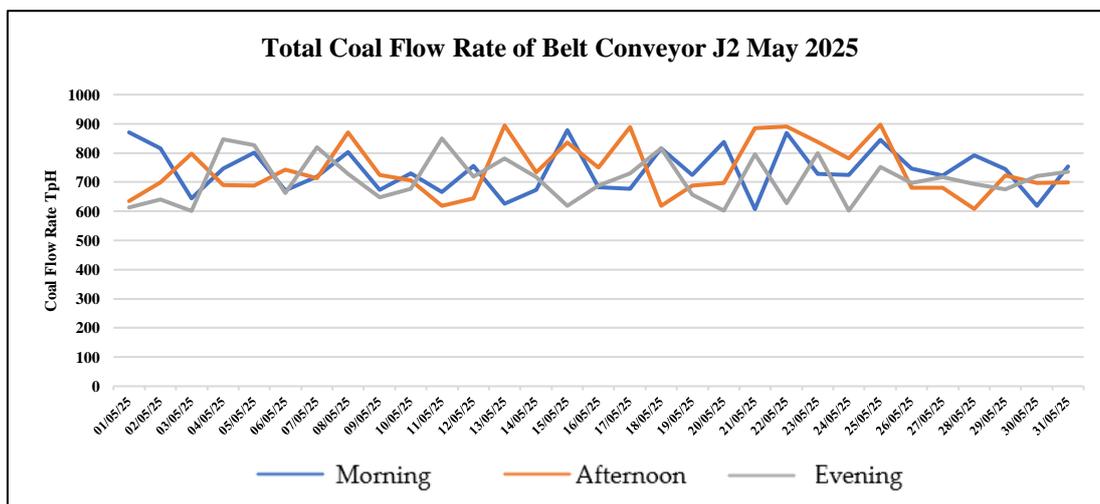


Figure 3. Coal Flow Rate Graph on Belt Conveyor J2 May 2025

3.2 Exhaust Gas Emission Characteristics of the Power Plant

Figure 4-6 present the exhaust gas emission profiles of PLTU Paiton Units #1–2 over the monitoring period. The measured NO_x concentrations ranged from 350.69 to 419.95 mg/Nm³, while SO₂ concentrations varied between 265.81 and 394.18 mg/Nm³. Monthly average emission values remained relatively stable, with NO_x averages between 387.55 and 389.14 mg/Nm³ and SO₂ averages between 356.91 and 361.85 mg/Nm³.

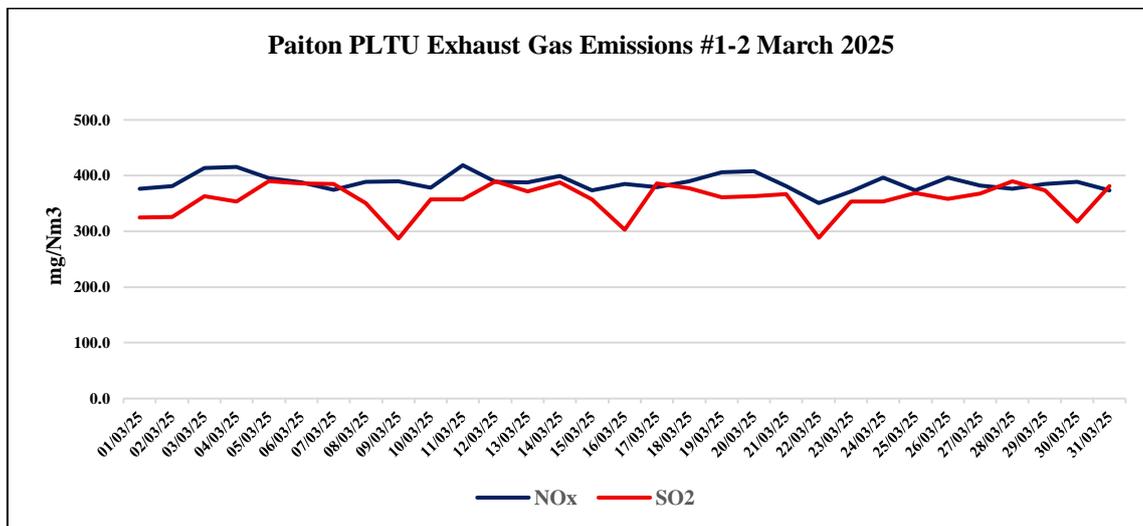


Figure 4. Paiton PLTU Exhaust Gas Emission Graph #1-2 March 2025

The absence of significant emission spikes indicates consistent combustion conditions and effective emission control during the observation period. Furthermore, all recorded emission values were well below the emission limits stipulated in the Indonesian Ministry of Environment and Forestry Regulation No. 15 of 2019 for existing coal-fired power plants, which sets a maximum allowable concentration of 550 mg/Nm³ for both NO_x and SO₂.

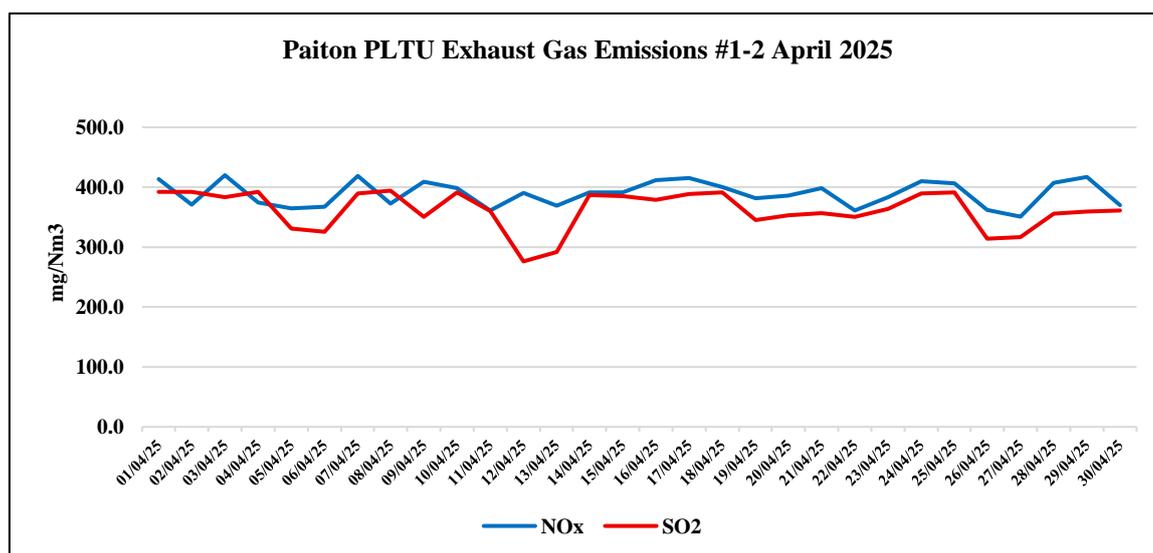


Figure 5. Paiton Steam Power Plant Exhaust Gas Emission Graph #1-2 April 2025

These findings confirm that the operational performance of PLTU Paiton Units #1–2 not only meets regulatory requirements but also reflects stable environmental management practices. The consistency in emission levels further suggests that variations in coal flowrate and operational load did not result in adverse environmental impacts during the study period.

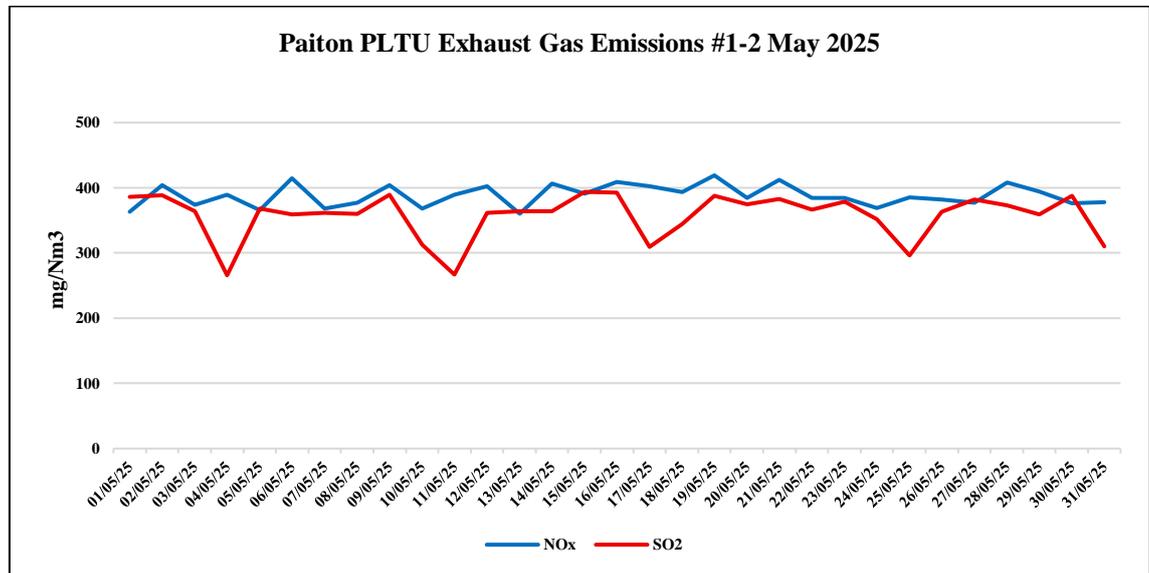


Figure 6. Paiton Steam Power Plant Exhaust Gas Emission Graph #1-2 May 2025

3.3 Operational Stability of Coal Handling and Its Implication on Exhaust Gas Emissions

The coal flowrate data recorded at Belt Conveyor J2 during March–May 2025 reveal consistent operational variability across different working shifts, with moderate differences in average values. The morning and afternoon shifts exhibited higher average flowrates compared to the night shift, indicating that coal supply patterns were aligned with daily power demand profiles. Despite noticeable fluctuations between maximum and minimum values, the relatively narrow operating range suggests that the conveyor system maintained stable and controlled performance throughout the observation period.

Notably, variations in coal flowrate were not accompanied by significant changes in exhaust gas emissions. The measured concentrations of NO_x and SO₂ remained relatively stable on a monthly basis, with no abrupt increases observed during periods of higher coal flowrates. This finding indicates that the combustion system and emission control mechanisms were capable of adapting effectively to variations in fuel supply without compromising environmental performance.

The indirect relationship observed between coal flowrate and exhaust gas emissions highlights the critical role of upstream operational stability in maintaining overall plant environmental performance. A consistent and well-regulated coal supply contributes to stable combustion conditions, thereby reducing the likelihood of emission spikes associated with transient operating states or incomplete combustion. These results emphasize that optimization of auxiliary systems, such as coal handling, can significantly influence emission behavior despite their indirect involvement in the combustion process.

Furthermore, all recorded emission values during the study period remained well below the regulatory thresholds established by the Indonesian Ministry of Environment and Forestry Regulation No. 15 of 2019. Sustained regulatory compliance over multiple months reflects not only the effectiveness of emission control technologies but also the robustness of operational management practices. This demonstrates that maintaining stability across interconnected plant subsystems is a practical and effective approach to achieving both operational efficiency and environmental sustainability.

4. Conclusion

This study demonstrates that variations in coal flowrate within the coal handling system do not necessarily lead to increased exhaust gas emissions when operational stability is maintained. During the observation period (March–May 2025), Belt Conveyor J2 operated with average coal flowrates of 738.72, 732.72, and 717.16 for the morning, afternoon, and night shifts, respectively, indicating moderate inter-shift variability while remaining within a stable operational range. Despite these variations, exhaust gas emissions remained relatively constant, with NO_x concentrations ranging from 350.69 to 419.95 mg/Nm³ and SO₂ concentrations between 265.81 and 394.18 mg/Nm³. The monthly average emission levels further confirm this stability, with NO_x values maintained within 387.55–389.14 mg/Nm³ and SO₂ within 356.91–361.85 mg/Nm³ throughout the study period. Importantly, all measured emission values were well below the regulatory limit of 550 mg/Nm³ stipulated by the Indonesian Ministry of Environment and Forestry Regulation No. 15 of 2019. These findings indicate that consistent coal supply management through the coal handling system contributes to stable combustion conditions and effective emission control.

Overall, the results highlight that optimizing upstream operational systems, such as coal handling and conveyor performance, plays a critical role in sustaining both operational efficiency and environmental compliance in coal-fired power plants. The quantitative evidence presented in this study supports the conclusion that operational stability, rather than absolute fuel throughput, is a key factor in maintaining low and consistent exhaust gas emissions.

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