

Evaluating Thermal Performance and Optimization of Power Generation Boilers Using Process Modelling: A Quantitative Analysis of Air Heater Leakage and Coal Quality Effects

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Abstract

This paper presents a validated ASPEN PLUS process simulation study of a 400 MW coal-fired boiler system, calibrated using five months of high-frequency distributed control system (DCS) data from four operational units (January–May 2023). The research quantifies the combined effect of two concurrent degradation mechanisms coal quality deterioration (8.0% calorific value reduction from design) and excessive air heater leakage (20–35% versus 10–15% design specification)—on boiler thermal performance and steam production capacity. Current operations require a steam flow of 376 kg/s to generate 400 MW, representing a $9.0\% \pm 1.2\%$ increase above the design specification of 357 kg/s. Component capacity analysis reveals that coal flow requirements exceed design limits by 8.3–18.8% across all coal quality scenarios, while milling plant and draught equipment require 25–50% additional capacity to sustain full load under present conditions. Optimisation scenarios demonstrate that reducing air heater leakage to below 15% and restoring economiser performance can recover steam flow rates to 328–357 kg/s, recovering 80–90% of design performance. The proposed interventions offer a projected 12–15% reduction in CO₂ emissions through improved combustion efficiency and reduced fuel consumption. Model validation against independent test data yields a Mean Absolute Percentage Error (MAPE) of 3.2% across key parameters, confirming simulation credibility. This work provides the first systematic, validated assessment of coupled air heater leakage and coal quality effects on boiler performance, offering plant operators and maintenance planners quantitative, actionable guidance.

Keywords

Thermal Performance Analysis, Coal-Fired Boiler, Air Heater Leakage, Coal Quality, Process Simulation