

ABSTRAK

Sistem ketenagalistrikan Indonesia masih didominasi oleh pembangkit listrik tenaga uap (PLTU) batu bara yang berkontribusi besar terhadap emisi karbon. Penelitian ini mengevaluasi potensi retrofit PLTU eksisting berkapasitas 54 MW melalui substitusi batu bara dengan serbuk besi sebagai bahan bakar padat bebas karbon. Analisis mencakup efisiensi boiler, kinerja siklus Rankine, karakteristik emisi, serta aspek ekonomi berdasarkan *Capital Expenditure* (CAPEX), *Operational Expenditure* (OPEX), dan *Levelized Cost of Electricity* (LCOE).

Simulasi dilakukan menggunakan Aspen Plus pada kondisi tunak dengan reaktor RGibbs dan pendekatan masukan energi ekuivalen sebesar sekitar 223,10 MW. Dua konfigurasi dianalisis, yaitu direct Fe co-firing dan external Fe combustion. Unit EVAP-FEox dimodelkan sebagai sistem konseptual *heat recovery* untuk memanfaatkan kalor sensibel dari oksida Fe.

Hasil menunjukkan bahwa substitusi Fe mampu mempertahankan kinerja termal sistem, dengan efisiensi boiler sebesar 85,20–85,45% dan efisiensi siklus Rankine sebesar 28,16–28,22%. Peningkatan fraksi Fe menurunkan emisi CO₂ dan SO₂ hingga mencapai nol pada kondisi 100% Fe. Namun, *direct Fe co-firing* menunjukkan peningkatan CO dan NO pada substitusi parsial, sedangkan *external Fe combustion* menghasilkan karakteristik emisi yang lebih stabil. Dari sisi ekonomi, LCOE meningkat seiring peningkatan fraksi Fe, yaitu 0,1091–0,1529 USD/kWh untuk direct co-firing dan 0,1117–0,1582 USD/kWh untuk *external combustion*. Dengan demikian, *retrofit* berbasis serbuk besi berpotensi menjadi opsi transisi dekarbonisasi PLTU eksisting, terutama apabila sistem pemulihan panas, sirkulasi Fe, dan regenerasi rendah karbon dapat dioptimalkan.

Kata Kunci : PLTU baru bara, *iron powder*, retrofit PC boiler, , *thermal efficiency*, emisi CO₂/NO_x, LCOE.

ABSTRACT

Indonesia's power system still relies heavily on coal-fired power plants, which are major contributors to carbon emissions. This study evaluates the retrofit potential of an existing 54 MW coal-fired power plant in Indonesia by substituting coal with iron powder as a carbon-free solid fuel. The analysis focuses on boiler efficiency, Rankine cycle performance, flue gas emissions, and economic impacts through CAPEX, OPEX, and Levelized Cost of Electricity (LCOE).

The simulation was conducted using Aspen Plus under steady-state conditions with an RGibbs reactor. Iron powder substitution was evaluated using an equivalent energy input approach, with total fuel energy maintained at approximately 223.10 MW. Two retrofit configurations were analyzed: direct Fe co-firing and external Fe combustion. EVAP-FEOX was modeled as a conceptual heat recovery unit to utilize sensible heat from hot Fe oxide.

The results show that iron powder substitution maintains system thermal performance, with boiler efficiency around 85.20–85.45% and Rankine cycle efficiency around 28.16–28.22%. Increasing the Fe fraction significantly reduces CO₂ and SO₂ emissions, reaching zero in the 100% Fe scenario. However, direct Fe co-firing increases CO and NO in partial substitution scenarios due to high-temperature equilibrium effects and simultaneous coal–Fe oxidation. External Fe combustion provides more stable emission characteristics because Fe oxidation is separated from the main furnace.

Economically, LCOE increases with Fe fraction. Direct co-firing increases from 0.1091 USD/kWh at 5% Fe to 0.1529 USD/kWh at 75% Fe, while external combustion increases from 0.1117 to 0.1582 USD/kWh. Therefore, iron powder retrofit can be considered a transitional decarbonization option for existing coal-fired power plants, particularly if Fe oxide recovery, heat recovery, Fe circulation cost, and low-carbon regeneration systems are improved.

Key Word : coal-fired power plant, iron powder, PC boiler retrofit, , thermal efficiency, CO₂/NO_x emissions, LCOE.