Decarbonization of Indonesian Power Plants through Ammonia Co-Firing: NUMERICAL ANALYSIS OF AMMONIA CO-FIRING AND NOx EMISSION MANAGEMENT WITH FLUE GAS RECIRCULATION IN A TANGENTIALLY FIRED COAL BOILER

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ABSTRACT

Coal–ammonia co-firing is a promising pathway to decarbonize existing coal-fired power plants without replacing the entire asset. However, it also introduces higher NOx emissions and more complex combustion behavior. This study numerically investigates a retrofit strategy that combines coal–NH_3 co-firing with flue gas recirculation (FGR) in a 350 MWe subcritical Carolina-type tangentially fired boiler. Under 20% NH_3 co-firing, the simulations predict a CO_2 reduction at the economizer outlet of about 23% and a slight decrease in furnace temperature without compromising burnout or excess O_2. Applying external FGR between 0 and 20% further reduces peak furnace temperature by roughly 100 ◦C and lowers NO at the economizer outlet by up to about 31%, with burnout remaining above 96% and only modest CO increases.

Keywords: Ammonia co-firing; Flue gas recirculation; NOx mitigation; Computational Fluid Dynamic

INTRODUCTION

- **Coal Decarbonization:** Coal generates ~60% of Indonesia's power. Immediate retirement is economically difficult, co-firing clean fuels provides a practical near-term retrofit pathway.
- **Ammonia (NH_3) Carrier:** Zero-carbon fuel with LHV of 18.8 MJ/kg (similar to Indonesian coal). A 20% heat substitution cuts direct CO_2 by ~23%.
- **The NOx Challenge:** High fuel-bound nitrogen in NH_3 leads to severe NOx spikes (up to 95% in utility boilers).
- **Objective:** Develop a calibrated 3D CFD framework to evaluate 20% NH_3 co-firing and optimize Flue Gas Recirculation (FGR) for effective NOx control.

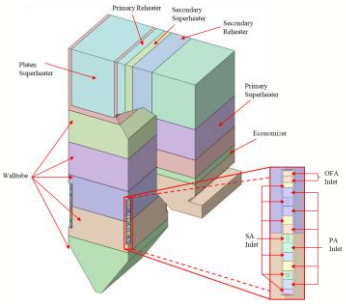


Figure 1. 350 MWe Carolina-type tangentially fired boiler & mesh

RESEARCH METHOD

- **Numerical Setup:** Realizable k-epsilon turbulence, Lagrangian DPM (mean coal size 75 um), and Discrete Ordinates (DO) radiation in 1.8M polyhedral cells.
- **Plant Data Validation:** Pure coal baseline agrees within 5.3% error (Eco Temp: 643 vs 646 K; O2: 4.87 vs 4.70%; NO: 358 vs 340 mg/Nm^3).
- **EDM Limitation:** Default eddy-dissipation model (A=4.0) yields severe NO overprediction and unrealistic NH_3 slip in gaseous utility flames.
- **Reynolds-Scaled Tuning:** Kinetic constant A is selectively adjusted using local turbulent Reynolds numbers in near-burner wall zones, eliminating slip while preserving coal validation.

Table 1. Operating : Baseline coal vs 20% NH3 co-firing

Operating Parameter	Baseline Coal	20% NH_3
Coal Mass Flow (kg/s)	57.3	45.9
NH_3 Mass Flow (kg/s)	0.0	9.8
Combustion Air (kg/s)	407.9 (PA+SA)	407.9 (PA+SA)
Eco-Outlet CO_2 (vol%)	13.8%	10.6%

RESULTS

20% NH3 THERMAL IMPACT

- Furnace exit gas temperature (FEGT) slightly decreases from 1176 °C to 1161 °C, while economizer outlet drops from 370 °C to 318 °C.
- NH_3 combustion increases flue gas H_2O content from 9.2% to 12.6%. The higher specific heat of H_2O acts as an internal thermal sink.
- Carbon dioxide concentration at the economizer outlet decreases by 23% (from 13.8% to 10.6%), confirming substantial decarbonization.
- Excess O_2 remains steady at 4.9% with excellent combustion stability.

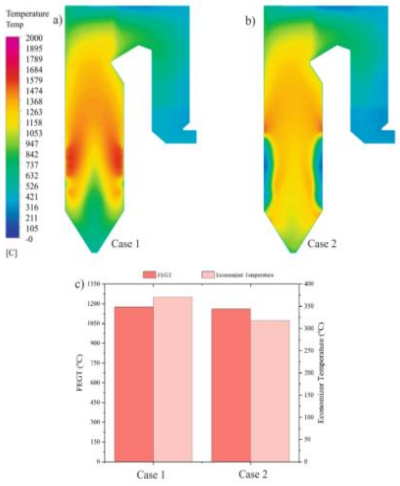


Figure 2. Temperature distribution: (a) Pure coal; (b) 20% NH_3 co-firing; (c) FEGT and Economizer outlet temperature

FGR RETROFIT MECHANISMS

- Flue gas is extracted from economizer outlet and recycled back into primary air nozzles at ratios of 0%, 5%, 10%, 15%, and 20%.
- Triatomic CO_2 and H_2O absorb combustion heat, dropping peak furnace temperature by ~100 °C (1393 °C to 1297 °C) to halt thermal NOx.
- Recirculated gas dilutes local O_2 around burners, slowing fuel-N oxidation and promoting conversion of nitrogen intermediates to N_2.
- Captured NO in recycled flue gas encounters fresh NH_2 radicals in the burner core, triggering active NO destruction: $NH_2 + NO \rightarrow N_2 + H_2O$.

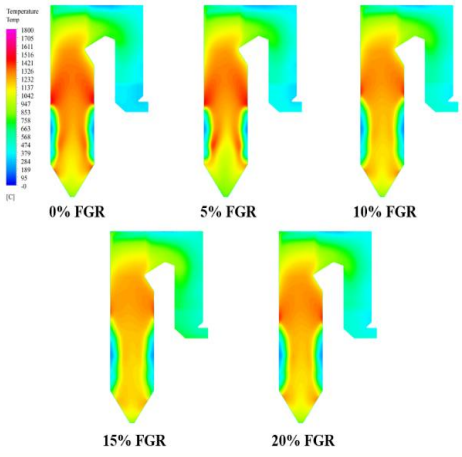


Figure 3. Flame temperature contours across FGR ratios (0%, 5%, 10%, 15%, 20%)

NOX & BURNOUT PERFORMANCE

- Increasing FGR from 0% to 20% drops economizer NO from 589 mg/Nm^3 down to 406 mg/Nm^3 (a 31% reduction).
- An FGR ratio of just 5% brings NO below the Indonesian regulatory limit (550 mg/Nm^3), providing an immediate compliance pathway.
- Fuel burnout efficiency experiences only a nominal 0.7% decrease (from 97.6% to 96.9%), easily meeting utility criteria.
- Minor localized CO rise due to shorter residence time, remaining well within industrial safety envelopes.

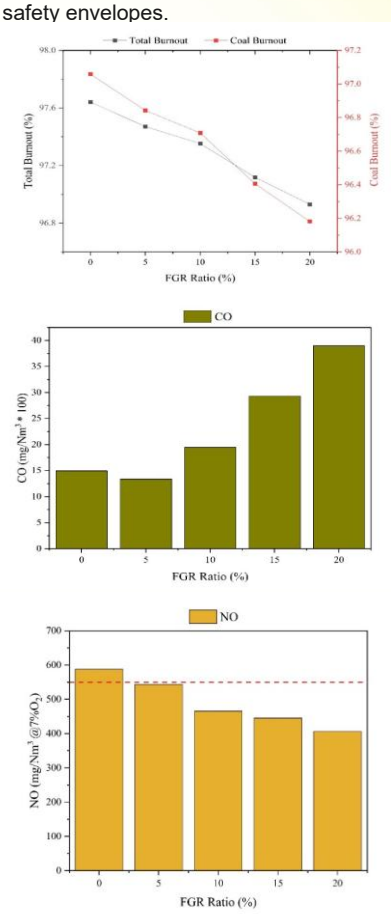


Figure 5. Economizer burnout, CO, and NO concentration vs. FGR ratio

CONCLUSIONS

- **Feasible Decarbonization:** 20% NH_3 co-firing delivers **~23% net CO_2 reduction** with stable combustion and flame attachment.
- **FGR is Highly Effective:** Flue gas recirculation successfully **curbs NO emissions by up to 31%**. Just 5% FGR achieves legal compliance (**<550 mg/Nm3**).
- **Calibrated Modeling Tool:** The Reynolds-scaled EDM closure prevents severe NO overprediction and provides a transferable design method.
- **Engineering Trade-offs:** Higher gas velocities shift peak temperatures upward; superheater heat absorption and tube erosion must be managed in retrofit designs.

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