

Effect of Burner Outage Configuration and MRC-LRC Segregated Firing on the Thermal Performance of A 660 MW Tangentially Fired Boiler: A CFD Study

Feina Faizah Nabila ^{1✉}, Prabowo ²

(1,2) Department of Mechanical Engineering, Institut Teknologi Sepuluh Nopember, Indonesia

Abstract: Pulverized coal boilers commonly use medium-rank coal (MRC) and low-rank coal (LRC), which are blended before combustion. This study evaluated segregated firing, in which both coal types are allocated to different burners without prior blending. Computational fluid dynamics (CFD) simulations examined four configurations in a 660 MW tangentially fired boiler at a constant fuel energy input of 1,840.19 MW. Case 1 represented the existing blended-fuel configuration, while Cases 2–4 applied segregated firing with different burner outage positions. Four criteria were used to evaluate thermal performance: FEGT proximity to the field reference, local maximum temperature, outlet temperature within the design range, and temperature uniformity in the Main Combustion Zone. Case 2, with burner A deactivated, showed the most favourable overall performance. Its furnace exit gas temperature (FEGT) was 1,304.11 °C, close to the field reference of 1,320 °C. Its local maximum temperature was 1,955.81 °C, 171.97 °C lower than Case 1. The Main Combustion Zone temperature standard deviation decreased from 232.18 °C in Case 1 to 100.43 °C in Case 2. Its outlet temperature of 384.68 °C remained within the design range of 320–391 °C. Although outlet CO concentrations were near zero in all scenarios, average CO mass fractions in the Overfire Air Zone varied substantially. These findings suggest that segregated firing may improve thermal performance under simulated conditions. Further field validation and technical and economic assessments are required to establish its operational feasibility and potential cost benefits.

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INTRODUCTION

Coal-fired power plants remain a major source of electricity in Indonesia, with boilers serving as a key component of the Rankine cycle. The boiler converts the chemical energy of coal into thermal energy to generate superheated steam that drives the turbine. Temperature distribution within the furnace and combustion stability are critical to this process because they directly affect the Furnace Exit Gas Temperature (FEGT), which must remain within the design operating range. Uneven temperature distribution can create localised hotspots that lead to tube overheating, material degradation and slagging (Speight, 2021).

In pulverised coal boilers with multiple burners, thermal performance depends not only on the total heat input but also on the spatial distribution of heat release across burners at different elevations. During operation, one burner may be deactivated as part of a standby strategy. However, selecting the position of the inactive burner based on immediate operational considerations may overlook its effects on furnace temperature distribution and flow characteristics. These effects may become more complex when two coal types with different properties are used, namely Medium Rank Coal (MRC) and Low Rank Coal (LRC). Differences in calorific value, moisture content and volatile matter can influence combustion behaviour and heat release. In the operating practice examined in this study, MRC and LRC are burned as a mixture and distributed evenly among the active burners.

Alternative allocation patterns may change the spatial distribution of heat release even when the total fuel energy input remains constant.

Previous research has examined several aspects of burner configuration and combustion performance in tangentially fired pulverised coal boilers. Chen et al. (2017) investigated burner composition and geometry, providing a basis for examining how burner arrangements relate to furnace combustion behaviour. Li et al. (2021) also examined burner composition and geometry, contributing to the discussion of burner configuration as a factor in boiler performance. These studies establish the relevance of burner arrangement to furnace operation, although the information available for the present review does not establish whether they considered the combined effects of burner deactivation and the allocation of different coal types among individual burners.

Research has also considered the effects of operating conditions on burner performance. Gu et al. (2024) examined active burner groups under different operating load conditions. Jiang et al. (2021) investigated burner configurations under varying loads, while Lu et al. (2023) also addressed active burner groups under different operating load conditions. These studies indicate that burner operation needs to be considered in relation to the conditions under which the boiler operates. However, the focus on operating load and active burner configurations does not, based on the information available, establish how the position of a deactivated burner interacts with the allocation of MRC and LRC among the remaining active burners.

A more specific aspect of burner operation was examined by Yildizay et al. (2023), who simulated burner deactivation and validated the simulation against field data. This study is relevant because it connects burner deactivation with actual operating conditions. Nevertheless, the available information does not establish whether the study also examined the allocation of different coal types among individual burners. The influence of fuel properties and distribution has been addressed in more recent research. Samantaray et al. (2026). examined the influence of fuel distribution and characteristics on combustion performance. Saputra et al. (2025) also investigated the relationship between fuel distribution, coal characteristics and combustion performance. These studies highlight the importance of fuel-related factors in understanding combustion behaviour, but the information available does not establish whether they simultaneously evaluated burner deactivation positions at different elevations in a 660 MW tangentially fired boiler.

Taken together, the studies discussed above address burner composition and geometry, operating load, burner deactivation, and fuel distribution and characteristics. However, based on the available literature information, the combined effects of burner deactivation position at different elevations and MRC–LRC allocation among individual burners remain insufficiently established for the specific boiler operating conditions examined in this study. This research gap concerns the interaction between burner arrangement and fuel allocation rather than the influence of either factor in isolation. When the total fuel energy input remains constant, redistributing coal types among active burners may change the spatial distribution of heat release and furnace temperature. Similarly, changing the position of a deactivated burner may affect the distribution of combustion zones within the furnace. Evaluating these factors together is therefore necessary to compare their effects on thermal performance under alternative operating configurations.

This study aims to analyse the effects of burner deactivation position and MRC–LRC fuel allocation on furnace temperature distribution, combustion characteristics and FEGT in a 660 MW tangentially fired pulverised coal boiler. Four operating scenarios are evaluated using computational fluid dynamics (CFD) simulations and compared with actual field FEGT data. The evaluation focuses on differences in temperature distribution, combustion characteristics and FEGT relative to the design operating range. These indicators are used to compare the thermal responses of the scenarios and identify the most favourable configuration among those investigated. The contribution of this study lies in the combined assessment of burner deactivation position and the allocation of MRC and LRC among individual burners while maintaining the same total fuel energy input and furnace geometry.

The findings are expected to provide an operational basis for evaluating burner configurations and fuel allocation strategies without requiring changes to the furnace structure or total fuel energy input.

RESEARCH METHOD

Object and Scope of Research

This research was conducted on a pulverized tangentially fired coal type boiler with a capacity of 660 MW with a configuration of six burner levels (A, B, C, D, E, and F) arranged vertically (multi-burner multi-burner). Burner A is at the lowest elevation, burner C at medium elevation, and burner F is at the highest elevation. This elevation difference is the basis for a systematic evaluation of the effect of burner outage position on thermal distribution. The study did not consider changes in furnace geometry design; The focus of the analysis is limited to variations in burner operational configurations and fuel allocation strategies. The main parameters analyzed include temperature distribution and FEGT, with combustion gas species (CO, CO₂, H₂O) as well as flue gas flow characteristics as supporting parameters to explain the heat diffusion mechanism.

Simulation Scenarios

The four scenarios are simulated at the identical fuel energy rate (Q fuel), which is 1,840.19 MW. This is done so that the difference in results between scenarios is purely due to the spatial distribution of heat sources, namely the position of burner outage and the allocation of coal type. Case 1 represents the actual operating conditions in the field as a baseline: burner A is in standby (outage), while burners B, C, D, E, and F are actively receiving a mixture of MRC and LRC evenly. Three alternative scenarios apply segregated firing strategies, namely the allocation of MRC and LRC on different burners without the blending process in the coal yard, with varying burner outage positions.

Table 1. Burner Outage Configuration and Fuel Allocation in Each Case

Burner	Case 1 (Baseline)	Case 2	Case 3	Case 4
A	Off	Off	MRC	LRC
B	Mixed	MRC	MRC	LRC
C	Mixed	LRC	Off	MRC
D	Mixed	LRC	MRC	MRC
E	Mixed	MRC	LRC	MRC
F	Mixed	MRC	LRC	Off

Blend = MRC+LRC mixture evenly. Fuel energy rate of the whole case = 1,840.19 MW.

The three outage positions (burners A, C, and F) were chosen to represent three strategic points along the elevation of the active burner zone, all of which are within the range of the Main Combustion Zone. Burner A is at the lower limit of the Main Combustion Zone, closest to the Hopper Zone; burner C is right at the midpoint of the Main Combustion Zone; while burner F is at the upper limit of the Main Combustion Zone, closest to the OFA Zone while at the same time playing a role in maintaining the rotational momentum of the flow towards the overfire water field. By selecting the outage position at the lower limit, midpoint, and upper limit of the active burner zone, the effect of the outage position on heat distribution can be systematically evaluated along the furnace elevation, not just at one point.

The optimal criteria in this study were defined as the conditions with the most even temperature distribution in the furnace (quantified by the standard temperature deviation per zone) and the FEGT that was closest to the actual field operating average value (1,320 °C), as well as the outlet temperature in the design range of 320–391 °C.

Governing Equations and CFD Modelling

The flow pattern and temperature distribution within the furnace are modeled using three fluid conservation equations, solved under steady-state conditions; the transient term $\partial/\partial t$ in each governing equation is therefore equal to zero. The continuity equation for steady flow with nonconstant density is expressed as:

$$\nabla \cdot (r\vec{v}) = 0 \quad (1)$$

The momentum equation (Newton's second law mathematical form of a fluid) is expressed as:

$$\rho(\partial\vec{v}/\partial t + \vec{v} \cdot \nabla\vec{v}) = -\nabla p + m\nabla^2\vec{v} + \vec{F} \quad (2)$$

with ρ fluid density (kg/m^3), $\vec{v}$ velocity vector (m/s), p pressure (Pa), dynamic viscosity μ ($Pa \cdot s$), and $\vec{F}$ body force (N/m^3). The energy equation describing the temperature distribution is expressed as:

$$\rho c_p(\partial T/\partial t + \vec{v} \cdot \nabla T) = \nabla \cdot (k\nabla T) + S_h \quad (3)$$

with specific heat capacity c_p ($J/kg \cdot K$), T temperature (K), k thermal conductivity ($W/m \cdot K$), and S_h heat source (W/m^3). Radiant heat transfer is modeled with Discrete Ordinates; blackbody radiation flux follows Stefan-Boltzmann's law:

$$E_b = \sigma T^4 \quad (4)$$

with the Stefan-Boltzmann constant σ ($5.67 \times 10^{-8} W/m^2 \cdot K^4$). The character of a turbulent flow is characterized by Reynolds numbers:

$$Re = \rho v D / \mu \quad (5)$$

The high Re value in the furnace justifies the use of the k- ϵ standard turbulence model. The simulation was carried out in steady-state conditions. Coal combustion reaction modeling using a species transport model is equipped with a Discrete Phase Model (DPM) for coal particle injection through the drying, devolatilization, and char combustion stages. The Discrete Ordinates radiation model is used for the transfer of radiant heat to the waterwall wall.

Boundary Conditions and Operational Data

The boundary condition of the inlet on each active burner is determined based on the mass flow rate of primary air, secondary air, Over Fire Air (OFA), and coal injection rate according to actual operational data in the field. The speed profile on the inlet is assumed to be uniform. The furnace wall is treated as a wall with heat conditions that represent heat absorption by the waterwall. The simulation domain covers the entire volume of the furnace from the hopper to the FEGT outlet, with the analysis zone divided into the Hopper Zone, Main Combustion Zone, OFA Zone, and FEGT Zone to facilitate the systematic evaluation of temperature distribution.

Model Validation

Simulation validation is carried out through two approaches. First, the principle of energy conservation at volume control with a steady-state approach: the simulation is declared valid if the deviation between the incoming chemical energy of the fuel and the total energy absorbed by the boiler components is below 5%. Second, validation of actual FEGT data in the field, where the average FEGT value of actual operation measurement results of 1,320 °C (range 1,236.4–1,364 °C) is used as

a reference. Validation of the field FEGT data resulted in a deviation of 4.50%, which is below the 5% threshold and confirms that the CFD model accurately represents actual operating conditions. This validation approach to actual operating conditions is in line with the practices emphasized by (Xue et al., 2024; Yildizay et al., 2023)

RESULTS AND DISCUSSION

Effect of Burner Configuration and MRC-LRC Allocation on Temperature Distribution and FEGT

The simulation results showed that burner outage position and coal allocation strategy influenced temperature distribution, flow pattern, combustion characteristics, and thermal load distribution along the furnace. The difference in Higher Heating Value (HHV) of 805 kcal/kg between MRC and LRC causes different heat dissipation patterns. The burner that receives MRC becomes a source of strong but delayed heat release and extends in the direction of the flow because the char needs a long trajectory to burn out. Meanwhile, burners with LRC produce early ignition with lower intensity because some of the energy is used for moisture evaporation. Changing the allocation of MRC and LRC between burner elevations means moving the heat discharge points within the furnace chamber, which further affects the temperature distribution, gas species, as well as thermal performance parameters.

In Case 1, the entire active burner receives blended coal with the same composition. The four angles at the six elevations release heat with uniform behavior, so there is no characteristic contrast between the elevations. This condition eliminates the ability to regulate heat placement vertically; The entire burner reaches its maximum intensity at the same elevation range, so that heat accumulates in one region and forms a concentrated fireball in the center of the main combustion zone. Case 2 places MRC on burners B, E, and F and LRC on burners C and D, with burner A in standby condition. This distribution results in a vertically dispersed heat release pattern, where strong heat sources are at the lower, upper middle, and upper elevations, while the middle elevation is filled with burners of lower intensity. As a result, the fireball extends vertically, rather than centers, and the peak temperature shifts upwards with a decreasing value as the same energy is dispersed over a larger volume.

Case 3 groups the MRC at the lower and middle elevations (A, B, D) with burner C off, so that heat discharge is concentrated in the lower half of the main combustion zone. Case 4 places the MRC on burners C, D, and E with burner F off, which means that the most powerful heat source is just below the water overfire injection field, while the top burner jet that is supposed to help with mixing is missing. The mechanism of moving the heat release location due to changes in burner allocation is consistent with the findings (Chen et al., 2017). on 600 MW boilers and (Li et al., 2021, 2023).) in a 660 MW boiler, which indicates that the arrangement of the burner determines the aerodynamic field and uniformity of heat dissipation within the furnace. The difference is that the study modifies the arrangement or geometry of the burner with homogeneous fuel, while this study shows that a similar effect can be achieved through the allocation of coal types to burner elevations without changing the geometry at all.

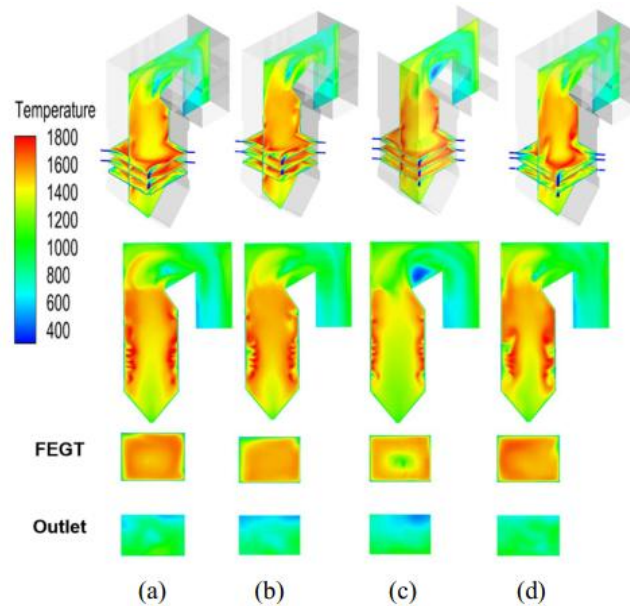


Figure 1. 3D temperature contours of the furnace: (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4.

Table 2. Local Maximum Temperature in Every Scenario

Case	Temp. Maximum Local (°C)	Elevation (m)	Area
Case 1	2.127,78	31,12	Main Combustion Zone
Case 2	1.955,81	42,49	OFA Zone
Case 3	2.112,01	33,53	Main Combustion Zone
Case 4	2.103,64	39,42	OFA Zone

The highest local maximum temperature was obtained by Case 1 at 2,127.78 °C at an elevation of 31.12 m, while the lowest was obtained by Case 2 at 1,955.81 °C at an elevation of 42.49 m. Case 1 and Case 3 reach peak temperatures within the Main Combustion Zone, while Case 2 and Case 4 are within the OFA Zone

Temperature Distribution per Furnace Zone

The uniformity of temperature distribution was quantified using standard temperature deviations in each furnace zone. A smaller deviation value indicates a more even distribution.

Table 3. Standard Temperature Deviation per Furnace Zone (°C)

Area	Case 1	Case 2	Case 3	Case 4
Hopper Zone	238,20	203,13	167,79	217,63
Main Combustion Zone	232,18	100,43	180,23	215,81
OFA Zone	134,23	164,30	91,86	93,57
FEGT Zone	175,92	81,24	87,82	60,22

The smallest (most even) value in the Main Combustion Zone is achieved at Case 2 (100.43 °C), less than half the value of Case 1 (232.18 °C).

Table 4. Average Temperature per Furnace Zone (°C)

Area	Case 1	Case 2	Case 3	Case 4
Hopper Zone	1.589,44	1.684,48	1.519,88	1.592,55
Main Combustion Zone	1.665,41	1.696,43	1.852,75	1.598,18
OFA Zone	1.702,95	1.776,85	1.927,62	1.938,48
FEGT Zone	1.538,61	1.681,76	1.816,00	1.890,13

Case 4 is the only configuration with an average FEGT Zone temperature higher than the Main Combustion Zone (291.95 °C difference), indicating follow-up combustion in the heat absorption zone.

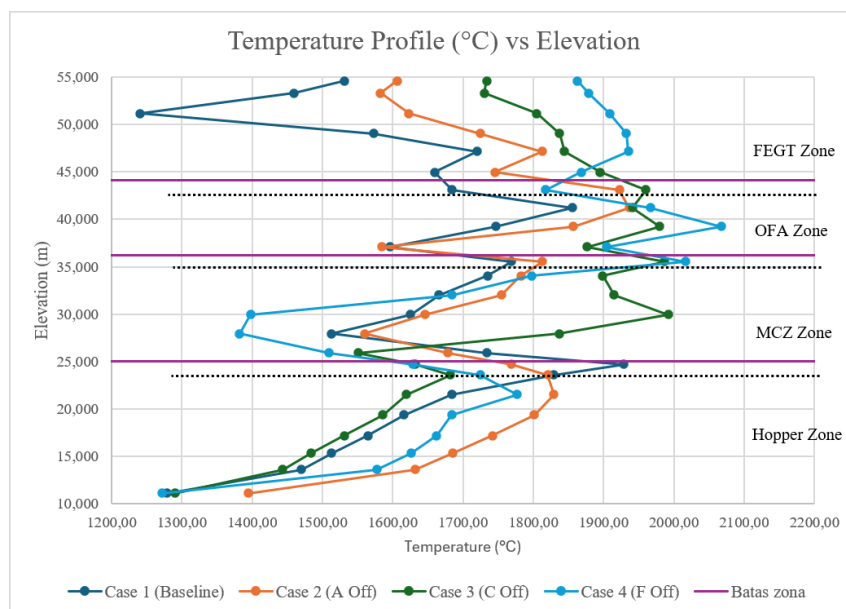


Figure 2. Graph of Temperature Distribution to Furnace Elevation in Each Scenario

There is no one configuration that is absolutely superior to all zones. Case 3 is most evenly distributed in the Hopper Zone and OFA Zone, Case 2 in the Main Combustion Zone, and Case 4 in the FEGT Zone. However, the advantage of Case 2 in the Main Combustion Zone has greater physical weight because it is this zone where the fireball is formed and where the heat flux of radiation to the waterwall wall reaches its highest value. The standard deviation of Case 2 in this zone is 100.43 °C, less than half the value of Case 1 (232.18 °C), indicating that the allocation of the vertically dispersed MRC successfully prevents heat concentration at a single elevation.

Case 4 shows the deviant behavior: The Main Combustion Zone is the coldest, but the FEGT Zone is the hottest. The physical explanation lies in the placement of MRCs in burners C, D, and E (elevation 30–34 m). The char from MRC takes a long stay to burn out; When the CH source is placed near the water overfire field, most char combustion reactions only reach their peak after the gas moves upwards through the OFA field. As a result, heat release occurs in zones that are designed for heat absorption. These findings are in line with Jiang et al. (2021), which explains that the middle burner group on a 550 MW boiler produces the most stable flow and combustion field due to the availability of space above the main combustion zone to complete the burnout process.

FEGT and Outlet Temperature

The FEGT reference value of 1,320 °C was obtained from the average FEGT from actual field operations measurements (range 1,236.4–1,364 °C). The evaluation of the FEGT is based not only on whether the simulated values are within or outside the actual operating range, but mainly on how close the configuration generates the distribution of the thermal load to the representative operating conditions of the boiler.

Table 5. FEGT and Outlet Temperature per Case

Parameter	Case 1	Case 2	Case 3	Case 4
FEGT (°C)	1,260.59	1,304.11	1,286.07	1,354.92
Difference From 1,320°C	-59.41	-15.89	-33.93	+34.92
Maximum Local Temperature (°C)	2,127.78	1,955.81	2,112.01	2,103.64
Outlet Temperature (°C)	391.00	384.68	392.52	403.81
Outlet Temperature Status	Upper Limit	Within Range	Exceeds by 1.52°C	Exceeds by 12.81°C

Outlet temperature design range = 320–391 °C. Case 2 excels at FEGT (closest to the reference), local max T (lowest), and T outlet (safe margin within the range).

Case 2 is the configuration that results in the thermal load distribution closest to the representative operating conditions, with the FEGT closest to the reference value. Case 4 produces a relatively high FEGT and is close to the upper limit of the actual operating range, indicating that the temperature of the gas leaving the furnace towards the convective section is higher, so the thermal load on the convective component has the potential to increase, consistent with Jin et al. (2023), who demonstrated that gas temperature distribution entering the convective section directly governs platen superheater tube temperature using a coupled combustion–hydrodynamic model.

Analysis of temperature gradients within the FEGT Zone reveals the mechanisms underlying these differences. In a boiler that operates normally, the gas temperature decreases monotonous when moving through the FEGT Zone as heat is released to the heating surface. Case 1, Case 2, and Case 3 decreased, while Case 4 actually had gas temperatures increase throughout the zone (an increase of 222 °C, from 1,635 °C to 1,857 °C). The increase in temperature in the absorption zone can only be explained by the ongoing unfinished combustion reaction, according to the concentration of CO Case 4 in the OFA Zone which reaches 2.42×10^{-4} . This series of phenomena suggests that the deactivation of burner F shifts part of the burnout process to the convective zone, so that the distribution of thermal load between the furnace and its downstream components deviates from the design.

Once the gas has passed through the entire heating surface, the outlet temperature should fall within the design range of 320–391 °C. A value below the range signifies overabsorption that has the potential to cause acid condensation in the preheater water, while a value above the range indicates wasted energy along with exhaust gases. Case 1 and Case 2 are within the design range; Case 2 (384.68 °C) provides a looser operating margin than Case 1, which is right at the upper limit. Case 3 (392.52 °C) and Case 4 (403.81 °C) crossed the upper limit, with Case 4 being the furthest away (12.81 °C above the limit).

Characteristics of Gas Flow

All four configurations maintain the typical rotational flow pattern of tangentially fired boilers, with four jets from the angle of the furnace forming a centralized vortex that produces fireballs, but the intensity and vertical position of the vortex differ in each configuration. In Case 3, the deactivation of burner C in the middle of the burner row removes the flow support at the middle elevation, so that the jet momentum from the burner below and above is pushed towards the furnace wall instead of being concentrated in the center. This pattern shortens the gas residence time and contributes to the highest average main combustion zone temperature among the four configurations (1,852.75°C), while increasing the risk of slagging as high-temperature gases move against the wall. In contrast, Case 2 keeps the burner F active, so that the rotational momentum is maintained until the overfire field of water and additional oxygen is effectively mixed into the flow core, which is the basis for the Case 2's advantages in temperature uniformity and CO concentration.

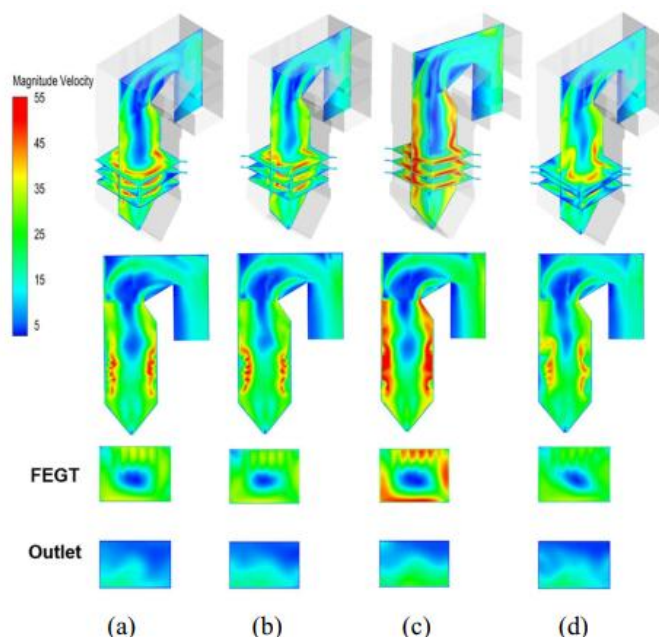


Figure 3. 3D velocity magnitude contours of the furnace: (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4.

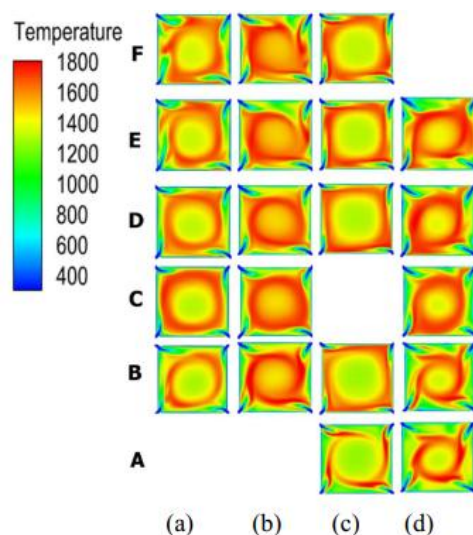


Figure 4. Temperature Contours of Horizontal Sections (XZ Plane) at Different Elevations Burner Configuration for Each Scenario: (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4.

Characteristics of Combustion Gas Species

Carbon monoxide is formed as an intermediate product when carbon is oxidized under conditions of limited oxygen. As the gas moves upwards and meets the overfire of the water, the CO is further oxidized into CO_2 , while water vapor is formed from the hydrogen fuel and from the evaporation of coal moisture. The CO profile to elevation shows a consistent pattern for all four configurations: concentrations increase sharply in the Main Combustion Zone, decrease dramatically after the water overfire field, and near zero at the outlet (order 10^{-12} to 10^{-13}). The CO value at the outlet practically means zero and confirms that combustion is complete in all configurations; There is no unburned carbon loss.

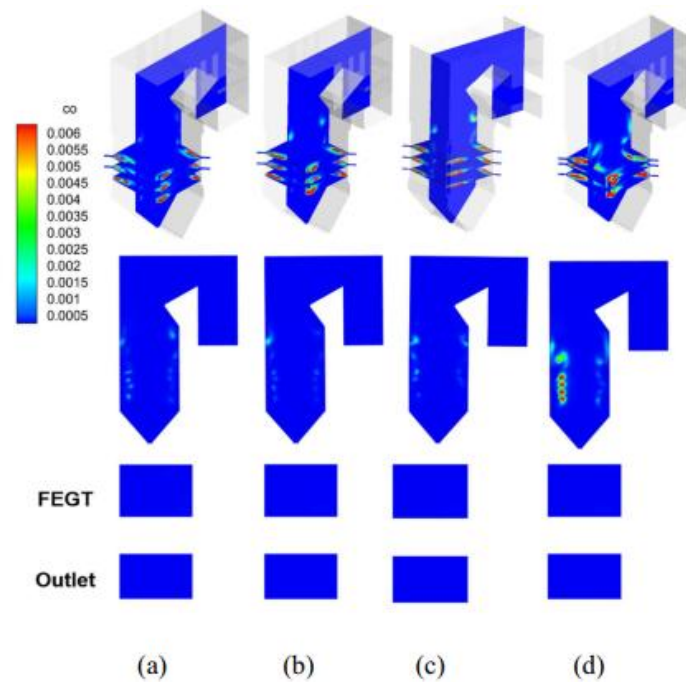


Figure 5. Distribution of CO mass fraction to furnace elevation in each scenario: (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4

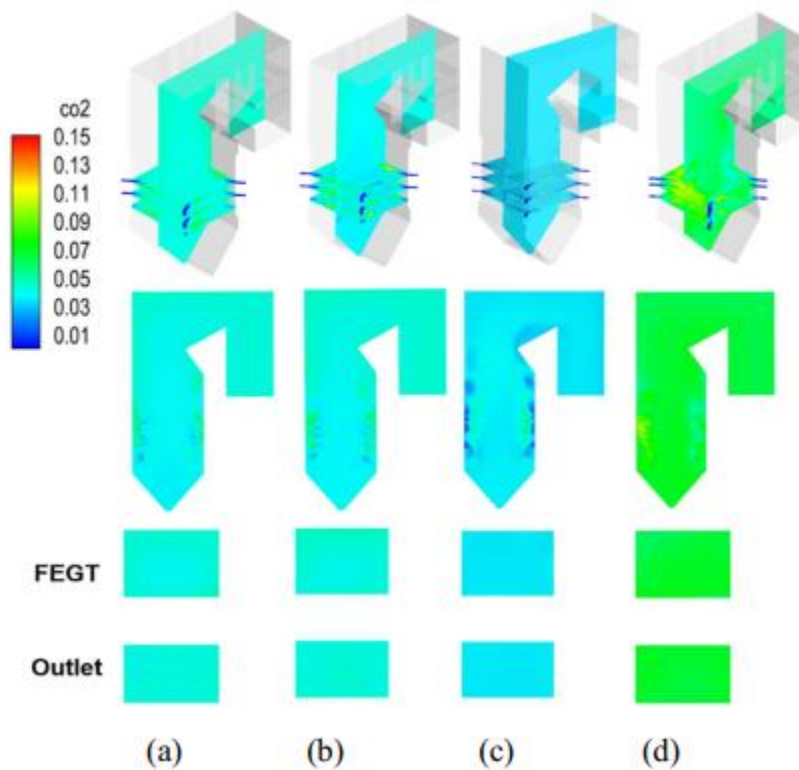


Figure 6. Distribution of CO₂ mass fraction to furnace elevation in each scenario: (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4

The difference between configurations lies not in whether the combustion is complete, but in where the completeness is achieved. The average CO concentration in the OFA Zone shows that Case 2 has the lowest value of 3.69×10^{-6} , while Case 4 reaches 2.42×10^{-4} (about 65 times). This difference of two orders of magnitude is the most direct quantitative evidence that the overfire mixing of the water in Case 4 was disrupted by the loss of the top burner jet. Gases that have not burned completely remain until much higher elevations before finding enough oxygen. Case 4's maximum CO concentration is at an elevation of 42.29 m (within the OFA Zone), while Case 2 reaches its maximum with much lower values.

CO₂ as the final product of carbon oxidation has an inverse distribution to CO. CO₂ at the highest outlet is obtained Case 4 (0.06533) because the oxidation of CO is most delayed, so the conversion of CO to CO₂ takes place at high elevations and the product accumulates in the outflow. Case 3 recorded the lowest outlet CO₂ (0.03406). The H₂O distribution is determined by the composition of the fuel: LRCs carry larger portions of hydrogen and moisture than MRCs. Case 1 has the highest H₂O outlet (0.22156) because the LRC is evenly distributed throughout the burner through the mix, while Case 4 has the lowest value (0.19346), consistent with the placement of the LRC on only the bottom two burners.

Evaluation of the Optimality of Existing Configurations

The second formulation of the problem questions whether the existing operating configuration (Case 1) is the most optimal configuration. Based on the four evaluation criteria in Table 6, Case 2 consistently excels in all criteria compared to the existing configuration and the other two alternatives.

Table 6. Summary of optimization criteria comparison

Criteria	Case 1	Case 2	Case 3	Case 4	Best
Difference of FEGT vs 1,320 °C	-59,41	-15,89	-33,93	+34,92	C2
Local max T (°C)	2.127,78	1.955,81	2.112,01	2.103,64	C2
T outlet vs design range	Upper limit	In the range	Passing	Passing	C2
SD Main Comb. Zone (°C)	232,18	100,43	180,23	215,81	C2

Case 2 consistently excels on all four criteria.

Case 1 as a representation of the existing operating conditions occupies a middle position: the outlet temperature is still within the design range but right at the upper limit, while the local maximum temperature and the standard deviation of the Main Combustion Zone are the highest among all cases, indicating the greatest risk of uneven heat distribution. Case 3 and Case 4 do not meet the outlet temperature criteria because they exceed the upper limit of the design range, with Case 4 being the weakest performing configuration in almost all criteria.

Case 2's advantage over the four criteria is not four separate advantages, but rather a consequence of the same principle. The characteristics of the fuel determine the heat release map, the heat release map shapes the temperature distribution and location of the fireball, the temperature distribution drives the evolution of combustion gas species, and the accumulation of this whole process boils down to FEGT as well as outlet temperature. In Case 2, the vertically dispersed MRC allocation of burners B, E, and F prevents the centralization of heat release, while keeping burner F active maintains the rotational momentum of the flow to the water overfire field, so that air-fuel mixing remains effective. Instead, Case 4 deactivates the F-burner that is responsible for maintaining that momentum, while placing the strongest heat source just below the water overfire field, allowing combustion to continue all the way to the heat absorption zone and resulting in the weakest thermal performance among all scenarios.

The implications for operational reliability can be traced through the thermal risk chain. The concentrated heat distribution, as occurred in Case 1 with a maximum temperature of 2,127.78°C and a standard Main Combustion Zone deviation of 232.18°C, resulted in an uneven radiant heat flux on the waterwall wall. This unevenness causes thermal stress in the tube due to the difference in expansion between sections and, if it continues continuously, encourages the creep mechanism and thinning of the tube wall to potentially lead to tube failure. High peak temperatures also increase the risk of slagging because ash particles have the potential to pass through their softening temperatures before reaching the walls. Case 2 breaks the chain of risk from the first link: with a maximum temperature of 171.97°C lower and the standard deviation of the Main Combustion Zone temperature less than half the value of Case 1, the heat flux to the wall becomes more evenly distributed, so the thermal stress on the tube is reduced. This more even heat absorption also results in FEGT and outlet temperatures as designed, so that convective components downstream work under the planned conditions.

The finding that the distribution of heat sources, not just the total heat load, determines the uniformity of furnace temperature is in line with the results of Chen et al. (2017) on 600 MW boilers and Li et al. (2021, 2023) on 660 MW boilers, suggesting that rearrangement of burner arrays can improve heat distribution without changing furnace geometry. The study expands on the findings by showing that a similar effect can be achieved without changing the geometry or arrangement of the burner at all, simply through the reallocation of fuel types to the same burner arrangement. The pattern of temperature deviation due to the concentration of heat load in this study is also in line with Ma et al. (2021) and Yuan et al. (2025), which show that the gas temperature deviation in tangentially fired boilers is closely related to the division of heat load between burner elevations. Meanwhile, the role of burner F in maintaining the rotational momentum of the flow to the water overfire field is consistent with the findings of Jiang et al. (2021) as well as Xu and Li (2022) and Wang and Yang (2024), which show that disturbances in the mixing momentum of overfire water affect the balance between the radiative and convective components of heat transfer in the furnace.

Overall, these findings recaps the fundamental problem outlined in the Introduction: the best thermal performance (Case 2) is achieved without the need for coal blending using heavy equipment in the coal yard, as MRC and LRC are simply injected directly into the burner according to their allocation through separate silos. Blending practices that have been increasing handling time, heavy equipment costs, and do not guarantee mixing consistency have the potential to be eliminated, with better thermal performance than existing operations. The findings regarding the interaction between burner outage position and fuel type are in line with the direction of recent research on the combustion of mixed fuels in tangentially fired boilers (Samantaray et al., 2026; Saputra et al., 2025) as well as the influence of burner angle and position on flow patterns and heat transfer (Abdul Jameel et al., 2022; Chang et al., 2021, 2022), while expanding on the findings of Yildizay et al. (2023) regarding the effect of burner outage on temperature homogeneity – this study shows that these influences also interact with fuel allocation strategies, not solely determined by burner position. The difference between this study and the other studies lies in the simultaneous evaluation of burner position and fuel type – this is the study's main contribution to the gap outlined in the Introduction.

CONCLUSION

The results demonstrate that burner outage position and MRC–LRC allocation influence temperature distribution, Furnace Exit Gas Temperature (FEGT), outlet temperature, gas species distribution and flow characteristics in the 660 MW tangentially fired pulverised coal boiler. Among the four scenarios evaluated, Case 2, in which burner A is deactivated, burners B, E and F use Medium Rank Coal (MRC), and burners C and D use Low Rank Coal (LRC), provides the most favourable overall thermal performance based on the evaluation criteria applied in this study. Case 2 achieves an FEGT of 1,304.11 °C, which is 15.89 °C below the actual operating reference of 1,320 °C, and the lowest local maximum temperature of 1,955.81 °C. It also produces a more uniform temperature distribution in the Main Combustion Zone, an outlet temperature of 384.68 °C within the design range, and the lowest CO concentration in the OFA Zone among the evaluated configurations. In comparison, the existing configuration (Case 1) produces an FEGT of 1,260.59 °C, a local maximum temperature of 2,127.78 °C and an outlet temperature of 391 °C. These results indicate that Case 2 offers a more favourable thermal response than the existing configuration under the simulated conditions. However, this finding applies only to the four scenarios investigated and does not establish that segregated firing is universally superior to coal blending under all boiler operating conditions.

The findings are subject to the limitations of the CFD modelling approach, particularly the applied boundary conditions, combustion model, fuel properties and modelling assumptions. Further validation under a wider range of actual operating conditions is therefore required before the proposed configuration can be adopted for routine operation. Although segregated firing may reduce the need for coal blending in the coal yard, its potential benefits in terms of operating costs, fuel handling and boiler reliability have not been confirmed through a dedicated technical and economic assessment. Future research should include broader validation against field measurements, simulations and tests at different boiler loads, and further evaluation of NO_x and SO_x emissions, unburned carbon and other relevant combustion performance indicators. Technical and economic assessments of fuel allocation, coal handling, operational reliability and maintenance requirements are also recommended to determine the feasibility of implementing Case 2 in industrial operation.

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