

Numerical Study on NO_x Emissions of Methane Re-Combustion in a 600 MWe Coal-Fired Boiler

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Abstract

The fuel staging combustion technology is a promising low NO_x combustion technology for coal-fired boiler. In order to reduce NO_x emissions, the burners of a 600 MWe coal-fired boiler are retrofitted in which methane gas is selected as a secondary fuel for re-combustion. The CFD models of combustion process are built to investigate effects of the methane gasratio on combustion process and NO_x emissions. A total of 4 cases are numerically studied, including the pure coal combustion case, the coal combustion with 7.5%, 10%, 12.5% of methane gas re-combustion cases respectively. The results show that the re-combustion of methane can reduce the temperature at primary combustion zone, but increase the temperatures at the re-combustion area and the furnace outlet. The NO_x concentration at the furnace outlet reduces with the increasing methane gas ratio. Methane re-combustion can greatly benefit to the NO_x emissions reduction.

Keywords

Numerical Simulation, Re-Combustion, NO_x Emission Reduction

1. Introduction

The past many years have seen the emergence of a growing desire worldwide to take actions to protect the environment from the degrading effects of all forms of pollution. The gaseous pollutant NO_x is a primary air pollution composition from the combustion of coal for power generation. A broad range of NO_x control technologies have been employed [1]. The low NO_x combustion and the flue gas de-nitrication technologies are the main methods to reduce nitrogen oxide emissions from coal-fired boilers. The fuel staging combustion technology is a promising technology at present [2]. The fuel staging combustion, also known as

re-combustion, has been widely concerned by scholars. This technology reduces NO_x emissions by setting up a less oxygen-burning section in furnace to restore a part of NO_x to N₂ [3] [4]. There are several kinds of material that can be used as re-combustion fuel, such as ultra-fined coal, biomass raw materials and some combustible gases [5]. Gaseous fuels are the first choice for re-combustion because they are easier to be fully mixed and burnt out [6]. Zhang and others carried out the research of a biomass gasification gasifier coupled to a 330 MW coal-fired boiler, it was found that biomass gas has little impact on the normal boiler operation and can effectively reduce the emissions of NO_x, SO₂ and other pollutants [7]. Glarborg *et al.* also carried out a study on the re-combustion characteristics of biomass gas, the results showed that, a higher methane concentration can lead to the greater NO_x reduction rate at the excess air coefficient of 0.9 in re-combustion zone [8]. Shi *et al.* studied the effect of methane on the mixing characteristics of gas re-combustion in a coal-fired boiler [9]. Wu *et al.* studied the effect of biomass volatiles (CH₄, CO, H₂ and CO₂) on NO reduction of re-combustion de-nitrification technology. The results showed that the main positive factors of NO reduction are CH₄ and H₂ [10]. Su *et al.* performed the methane re-combustion de-nitrification test at four different levels of metamorphic coal species, the results showed that methane's stay time in re-combustion area is at 0.7 - 0.9 s range, and the re-combustion de-nitrification efficiency is more than 50% [11]. Lu *et al.* indicated that the excessive air coefficient, the ammonia nitrogen ratio and other parameters at the re-combustion area have a great impact on de-nitrification efficiency [12]. Many early boilers had no re-combustion zone, causing high NO_x emission. In this work, the re-combustion nozzles are added in the burner system to retrofit a 600 MW coal-fired boiler and methane is selected as the secondary fuel. The main objective is to investigate the influences of the methane co-firing ratio on boiler combustion characteristics and NO_x emission. The results can provide a theoretical basis for retrofitting old units in service aiming NO_x emission reduction.

2. Boiler Characteristics

2.1. Research Objects and Burner Renovation Program

A 600 MWe super-supercritical boiler is taken as the research object. This is a single furnace tangential firing boiler with a body of 63.55 m high, 18.816 m wide and 17.696 m deep.

As shown in **Figure 1**, the burner system before transformation is equipped with a total of 15-layer nozzles from bottom to top, including 6 layers of primary air nozzles (*i.e.*, A, B, C, D, E and F), 7 layers of secondary air nozzles (*i.e.*, AA, AB, BC, CD, DE, EF and FG), and 2 layers of separated over fire air nozzles (*i.e.*, SOFA1 and SOFA2). The burner system is retrofitted by adding a layer of methane gas nozzles (*i.e.* G) and a layer of re-combustion air nozzles (*i.e.* GH). The combustion area of the furnace is divided into the primary combustion zone, the re-combustion zone and the burn-out zone after retrofit of burner system.

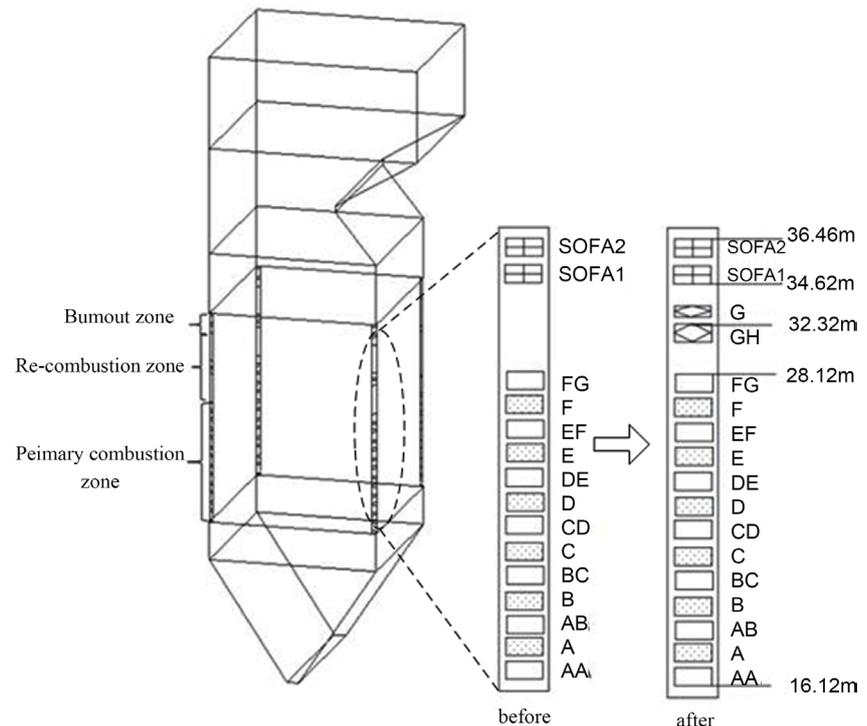


Figure 1. Boiler structure and burner layout before and after transformation.

2.2. NO_x Emissions Reduction Mechanism

NO_x generated in the furnace is divided into thermal type, fuel type and fast type. Its concentration is related to fuel characteristics and combustion conditions. NO_x generated from coal combustion is due to high temperature at the primary combustion zone. As the re-combustion fuel is injected into furnace, a fuel-rich reductive atmosphere is formed. A part of NO_x generated at the main combustion zone produces a reduction reaction in this area, being transformed to N₂, hence the NO_x emission is reduced.

The Methane as re-combustion fuel is broken down and produces a large amount of hydrocarbon root CH_i to enhance the ability of reducing NO_x. Therefore, it is considered one of most ideal re-combustion fuels.

2.3. Input Parameters

In order to study the effect of methane re-combustion ratio on combustion process and NO_x emissions in furnace, four cases are considered. The total heat input to the boiler is constant. The basic case is coal combustion without re-combustion; the other three cases are the coal combustion with 7.5%, 10% and 12.5% methane re-combustion ratio (according to heat input) respectively. The input parameters at 4 cases are shown in **Table 1**.

3. Results and Discussions

3.1. The Temperature Distribution

The mean temperature distributions at horizontal cross-section in the furnace

under different operating conditions are shown in **Figure 2**. The mean temperature gradually increases with furnace height and reaches its peak at the height of 24 m, and then it gradually decreases. With the increase of re-combustion ratio, the temperature at main combustion zone decreases, but increases at re-combustion zone. The peak temperature at case 1 is around 1900 K, 51 - 72 K higher than that of case 2 - 4. Temperature at the furnace outlet of case 1 is about 1300 K, 10 - 36 K less than that of case 2 - 4. This actually revealed the combustion condition and was related to flue gas concentration.

3.2. The Flue Gas Component Field Distribution

In this study, the main components in the flue gas are O₂, CO, CO₂ and NO. The volume fractions of O₂, CO, CO₂ and NO_x mass concentration at each furnace horizontal cross-section under different operating conditions are shown in **Figure 3**.

As seen from **Figure 3**, the changing trend of O₂ volume fraction is similar at different cases. The O₂ volume fraction of case 1 at the primary combustion zone

Table 1. Input parameters under different operating conditions.

case	1	2	3	4
CH ₄ Re-combustion ratio ($\gamma/\%$)	0	7.5	10	12.5
Coal mass flow ($B_0/\text{kg}\cdot\text{s}^{-1}$)	3.09	2.86	2.78	2.70
Primary air speed ($v_1/\text{m}\cdot\text{s}^{-1}$)	25.45	25.13	25.04	24.94
Secondary air speed ($v_2/\text{m}\cdot\text{s}^{-1}$)	57.67	48.67	47.09	45.50
Separated over fire air speed ($v_{\text{SOFA}}/\text{m}\cdot\text{s}^{-1}$)	50.91	50.32	50.12	49.93
Re-combustion methane speed ($v_{\text{CH}_4}/\text{m}\cdot\text{s}^{-1}$)	0	27.90	37.20	46.50
CH ₄ volume flow ($V_{\text{CH}_4}/\text{m}^3\cdot\text{s}^{-1}$)	0	2.86	3.82	4.77
Re-combustion air speed ($v_{r\text{-air}}/\text{m}\cdot\text{s}^{-1}$)	0	31.35	41.80	52.25

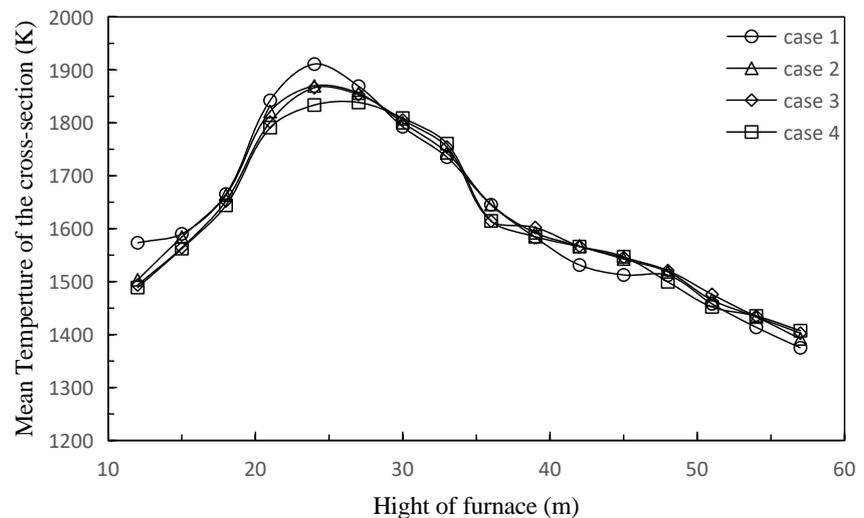


Figure 2. Mean temperature distribution of horizontal cross-section (K).

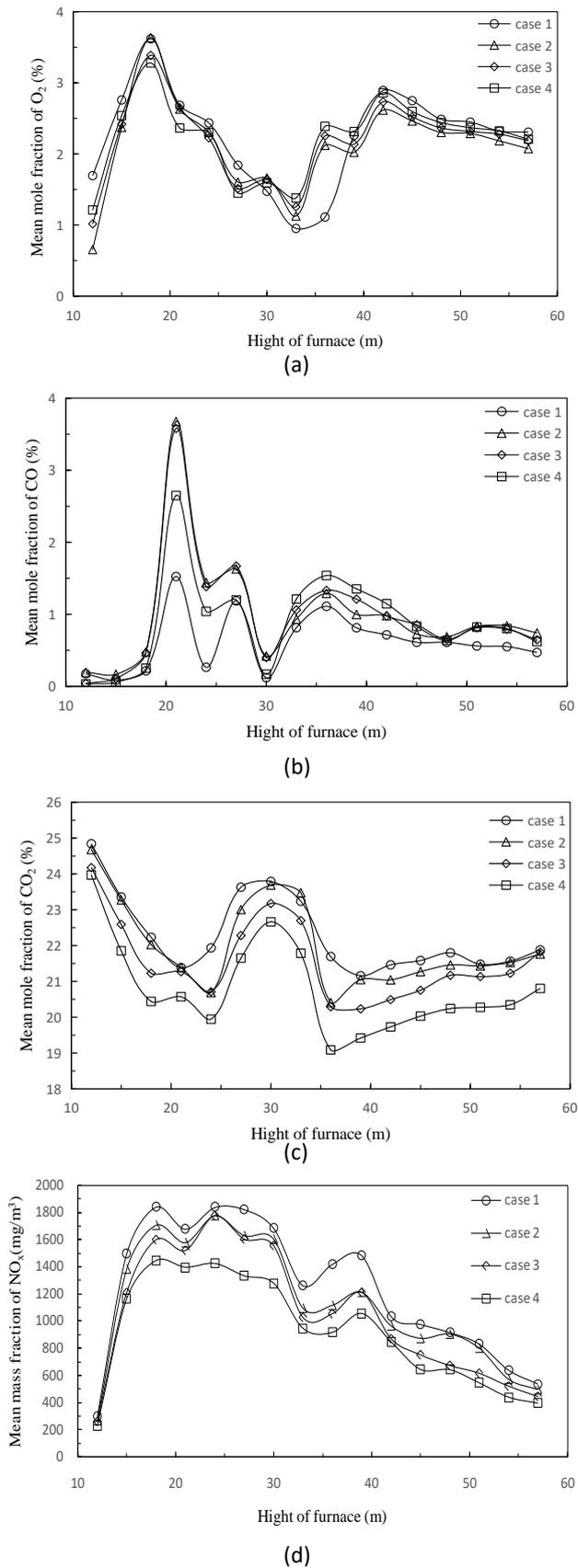


Figure 3. Volume fractions of O₂, CO, CO₂ and NO_x mass concentration.

is higher than that of case 2 - 4, but lower at the re-combustion zone. The CO and CO₂ volume fraction have an inverse trend, being related to the concentration of O₂. When O₂ in flue gas decreases, CO increases, but CO₂ decreases. This indicates that the simulation is reasonable. At the re-combustion area, the NO concentration decreases with the rise of CH₄ volume fraction, in that a part of NO react with CO to generate N₂ and CO₂. At the re-combustion area, the NOx production decreases greatly with the rise of CH₄ re-combustion ratio. Therefore, the productions of NOx at cases 2 - 4 are less than that at case 1. The mean mass concentrations of NOx at furnace outlet are 535.05 mg/m³, 497.48 mg/m³, 446.16 mg/m³, 398.00 mg/m³ respectively, where the NOx emissions decrease by 7.02%, 16.61% and 25.61%, respectively.

4. Conclusions

In this work, the numerical models are built to study the influence of different methane re-combustion ratio on the combustion process and the concentration distributions of the flue gas components in a retrofitted coal-fired boiler. The research work shows that methane gas re-combustion can lead to the temperature at primary zone decrease, reducing NOx formation in furnace. The re-combustion of methane gas can produce reduction atmosphere to further reduce NO to N₂. The NOx concentration at the furnace outlet can be reduced by 7.02%, 16.61% and 25.61% respectively compared to strict coal combustion condition.

In order to ensure safe operation of boiler and effective reduction of NOx emissions from boiler, it is more reasonable to construct a re-combustion zone with 12.5% methane as re-combustion fuel. It is feasible to retrofit the old units in service to reduce NOx emission according to fuel staging combustion technology.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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