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Experiment Study and Industrial Application of Slotted Bluff-Body Burner Applied to Deep Peak Regulation

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ABSTRACT

During the deep peak shaving period, the boiler needs to operate at a lower load, so higher requirements were set for the boiler's stable combustion. In order to better evaluate and compare the stable ignition capacity of bluff-body burners and slotted bluff-body burners, guidance and calculation support for the design of boiler deep peak shaving were needed. This study adopted the reflux heating chain ignition analysis method to study the differences in the steady combustion mechanism between the bluff-body burner and the slotted bluff-body burner. A thermal combustion experiment was conducted in employing the single angle coal powder combustion furnace. The experimental results were compared against the theoretical analysis results. In addition, a study was conducted on the application of slotted bluff-body burners in the deep peak shaving of a 330MW unit power plant boiler. The results showed that as long as the small slot flow can catch fire, the mixed temperature of the reflux fluid of the slotted bluff-body burner will be higher than that of the bluff body burner. This will enhance its steady combustion ability. The combustion test results were found to be consistent with the analysis results, indicating that when the slotted bluff-body burner is used on the 330MW unit, the boiler combustion is in good condition. In this case, it has a stable combustion capacity of 66MW (20% economic continuous rating) without oil injection at low loads. This study revealed the advantages of the slotted bluff-body burner in terms of its steady combustion mechanism compared to traditional bluff-body burners. It verified the feasibility for boiler deep peak shaving in practical applications. This is of great significance for improving the flexibility of coal-fired power generation units, enhancing the flexibility of the power system, and promoting carbon reduction.

KEYWORDS

Bluff Body Burner, Boiler Deep Peak Shaving, Ignition Analysis, Reflux Heating Chain, Slotted Bluff-Body Burner, Steady Combustion Mechanism

INTRODUCTION

With the large-scale deployment of intermittent renewable energy, represented by wind and solar energy, the demands for flexibility in the power system are continuously increasing (Dai, H. et al.,

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2016; Johansson, T. et al., 2012), China relies on coal as its primary energy source (Qi, Y. et al., 2016). Thus, the implementation of a flexible transformation of the thermal power has become the most realistic and feasible choice to improve the power system flexibility (Chen, H. et al., 2021; Xiao, D. et al., 2014; Gong, S. et al., 2017; Ding, Y. et al., 2014). On this basis, in-depth research on the peak shaving technology of large-scale coal-fired units has become necessary. Grid peak shaving involves many aspects such as boilers, turbines, generators, auxiliary equipment, and transmission systems (Gu, Y. et al., 2016; Gao, Z. et al., 2021; Xue, Y. et al., 2019; Manojkumar, R. et al., 2022; Wang, J. et al., 2021). In terms of boilers, the stable combustion under low-load is a key issue, and the main solution is the development of stable combustion technology (Cheng, H. et al., 2021). Researchers have developed stable combustion technologies, including bluff bodies, ship types, pre-combustion chambers, large differential speeds, asymmetric jets, reverse blowing, and coal concentration (Zhang, H. et al., 2007; Tsumura, T. et al., 2003; Zeng, G. et al., 2017; Hu, F. et al., 2022; Wang, J. et al., 2009; Chayalakshmi, C. et al., 2009). Among them, the bluff-body stable combustion technology integrates a bluff body at the nozzle of the burner to form a recirculation zone at the nozzle outlet. This allows the fuel to ignite and burn stably under conditions of high-speed airflow. During combustion, the reflux behind the bluff body heats the fuel-air mainstream at the root of the air mass by entraining a high-temperature flue gas, thereby accelerating the exchange of momentum, mass, and energy. This is conducive to flame stability (Zhang, L. et al., 2011). However, the unburned fuel flow can only enter the recirculation zone through the boundary layer. This prevents the beneficial effect of the high-temperature recirculation zone behind the bluff body from being fully harnessed. In comparison, the slotted bluff-body stable combustion method sets a gap in the middle of the bluff body to directly introduce a small amount of fuel flow into the high-temperature recirculation zone. In this case, this fuel can be ignited first in a favorable environment before igniting the mainstream. This allows for a staged ignition mechanism in the recirculation zone and further improves the stability of combustion. At the same time, it does not destroy the basic structure of the recirculation zone behind the bluff body. (Du, Y. et al., 2006; Liao, Y. et al., 2022; Yan, Y. et al., 2019). However, there is a lack of in-depth analysis on why the slotted bluff-body combustion has good stability.

This study addressed the question by analyzing the thermal balance equation. Also, practical application research was conducted on a 330MW unit, and the application effect of slotted bluff-body burners in deep peak shaving of boilers was verified. The research results showed that in practical applications, the slotted bluff-body burner exhibits a good low-load stable combustion ability without oil injection, proving its feasibility and practicality in actual power systems. The innovative aspects of this study are characterized by the following: (1) the reflux heating chain ignition analysis method was used to construct the thermal balance equation, explaining the differences in the steady combustion mechanisms between the bluff-body burner and the slotted bluff-body burner; (2) the difference between the two burners in steady combustion was evaluated and highlighted through an experimental study; (3) the slotted bluff-body burner was applied in a practical application and improved the boiler's ability to achieve deep peak shaving, reducing the minimum steady combustion load of the boiler from the original 45% ECR to 20% ECR.

RESEARCH METHODS

Comparative Analysis of Theoretical Foundations

According to the traditional recirculation zone fire theory, a high-temperature flue gas that has already ignited flows back to the root of the main airflow in the recirculation zone to mix and heat the main flow. This causes the gas to reach ignition temperature and combust. When stable combustion is achieved, a closed reflux heating ignition chain is formed.

As shown in Figure 1, the unburned mainstream in the bluff-body flame stabilizer gathers a portion of the fresh fuel-air flow near the recirculation zone. At location 1, it mixes with the hot gas