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Research Paper

Design of porous wall air coupling with air staged furnace for preventing high temperature corrosion and reducing NOx emissions

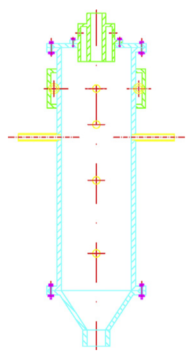
Honghe Ma *, Lu Zhou, Suxia Ma, Huijuan Du

Shanxi Key Laboratory of Circulating Fluidized Bed with High-Efficiency Clean Combustion and Utilization, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China

HIGHLIGHTS

- The problems of air staged are reviewed.
- Porous wall air coupling with air staged combustion furnace is manufactured.
- Highly efficient combustion and low NOx emissions are realized simultaneously.
- High temperature corrosion and slagging are prevented.

GRAPHICAL ABSTRACT



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ABSTRACT

Air staged technology can remarkably reduce NOx emissions during pulverized coal combustion. However, it also may result in the negative impacts of high temperature corrosion, slagging, and high imperfect combustion loss. The porous wall air coupling with air staged (PW&AS) furnace is designed and manufactured to overcome these problems. The preliminary experimental results show that PW&AS furnace could effect a simultaneous realization of prevention of high temperature corrosion, high combustion efficiency, and low NOx emissions.

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1. Introduction

Coal will continue to serve as a main fuel for power generation in many industrial and developing countries, so it is still an important issue for NOx control. Nowadays, many technological methods for NOx reduction are available: low NOx burners [1], fuel/air staged combustion [2], re-burning [3], oxy-fuel combustion [4–7], and new combustion technology (e.g. supercritical water oxidation [8]), etc. Among these solutions, the overall air staged technology is one of the most efficient technologies for reducing NOx emissions and has been widely used in coal-fired power plants [9–11], due to its costs of installation and operation [12]. Here, part combustion air is added as over-fire air (OFA) above the burner belt, thus the stoichiometry is reduced [13]. The furnace is separated as the primary combustion zone (or fuel-rich zone), reducing zone and burnout zone (or oxygen-rich zone) along the axis of the furnace. Firstly, coal is combusted in the primary combustion zone where the generation of NOx is suppressed. Then, NOx is deoxygenated to N_2 by reducing substances (e.g. NH_3,

* Corresponding author.
E-mail address: ma-honghe@163.com (H. Ma).

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HCN) in the reducing zone. Finally, over-fire air is injected into the burnout zone where coal is completely combusted.

Many scholars have investigated the effect of air staged on NOx emissions, and the main conclusions can be summarized as follows. First, the NOx emissions are mainly dependent on the OFA location [14] and the primary combustion zone stoichiometric [15,16]. Second, in a certain NOx reduction limit, the more deeply the air is staged, the further the NOx emissions are reduced [17].Third, the NOx reduction in multi air staged is greater than that in single air staged [18]. Fourth, NOx reduction of superfine pulverized coal is superior to that of regular size because of the further penetration and adsorption of NOx taking place in the inner pores [19]. Based on these conclusions, a 300 MW utility boiler was retrofitted with air staged technology, and NOx emissions could be limited in 500 mg N m^{-3} (6%O_2) [20]. Even though air staged technology can reduce NOx emissions remarkably, it may cause some negative impacts, such as high temperature corrosion [21,22], slagging [23–25], and high imperfect combustion loss [26,27].

In this work, the above problems are summarized on the basis of previous research. A porous wall air coupling with air staged (PW&AS) furnace is designed and manufactured. The preliminary experimental results are presented concisely to test the performance of PW&AS furnace. The information should be valuable for designing and constructing a pilot or commercial scale PW&AS furnace for preventing high temperature corrosion and reducing NOx emissions.

2. Negative impact of air staged

High temperature corrosion. One of the major disadvantages of the air staged combustion is the high temperature corrosion. The corrosion mechanisms can be attributed to the attack from sulfur species such as H_2S and free-state sulfur [S] [28] and chlorine-based species such as HCl and Cl_2, and to the deposition of unoxidized material such as FeS and char [29]. These mechanisms are closely linked to fuel composition (primary the fuels sulfur and chlorine content), and to local combustion conditions (near wall fuel gas composition and stoichiometry, e.g.).

In an air staged combustion furnace, a strong reducing environment is formed in the reducing zone, so the reducing substances are released from coal, such as H_2S, [S], HCl, Cl_2, char, FeS, et al. In the cases of H_2S attack and chlorine-based attack, these substances, H_2S, [S], HCl, Cl_2, diffuse to and react with the bare tube metal forming FeS, Fe_3O_4, $FeCl_2$, FeS_2, etc. In the case of deposition of unoxidized material, metal coated with a FeS layer may experience corrosion rates much higher than those due to the gas phase H_2S, and the presence of char in the coating may increase corrosion rates. Furthermore, when the water cooled wall tube placed in the specific conditions of $O_2 < 0.5\%$ and $CO > 2\%$, just like the atmosphere of reducing zone, the high temperature corrosion rates can be much higher than those due to H_2S or HCl [30].

Slagging. The second disadvantage of the air staged is the slagging near the burners in coal-fired boilers [31], including wall-fired [29], down-fired [32,33], and tangential-fired boiler [34]. Under air staged combustion conditions, the reducing zone is an area with the high temperature and high pulverized coal concentration [24]. Furthermore, a high pulverized coal concentration is easily formed near the water cooled wall, because the pulverized coal flow always deflects and even separates from the main flow [35,36]. Due to the endothermic effect of water cooled wall, the fireside water cooled wall temperature is much lower than the ash melting point temperature. Thus, it is more likely to form slagging under the air staged combustion conditions. Especially for the tangential-fired boiler, the slagging may become even worse because the trend of primary air jet (air-carried pulverized coal) deflection is more easily formed [37].

Imperfect combustion. The third negative impact of the air staged is the high imperfect combustion loss [38], which can be attributed to three reasons. First, because of the low temperature in primary combustion zone, the ignition of the pulverized coal flow is delayed, and the residence time of pulverized coal is reduced due to the space restrictions of furnace [39]. Second, it prevents too much air from mixing into primary air jet at the beginning of combustion. Third, the region near the water cooled wall in the reducing zone is the area with low temperature and high pulverized coal concentration, and this also prevents the burnout of pulverized coal [24]. Therefore, the imperfect combustion loss increases, including CO emissions and unburnt carbon content in fly ash. Currently, the conflict between low NOx emissions and imperfect combustion loss becomes increasingly acute [40].

3. A novel furnace design

How to avoid the disadvantages of the air staged technology has always been the focus of the combustion theory and technology research in recent years. One of the existing technologies is the closing to wall air technology. That is, part of over fired air is deflected in the direction of parallel to the water cooled wall to raise the local oxygen concentration [41]. As expected, the high temperature corrosion and slagging are prevented to some extent. However, closing to wall air can have two other disadvantages. First, because the direction of closing to wall air is parallel with the water-wall surface, the imperfect combustion loss not only does not decrease, but also may increase. Second, the air distribution mode of closing to wall air is a central air supply, which leads to the uneven temperature and velocity distributions at the furnace outlet, and further results in the heating surface thermal deviation. Therefore, the closing to wall air technology is greatly limited for application. How to make better use of its advantages on low-NOx emissions and prevent its disadvantages is the future development direction of air staged combustion technology.

3.1. The novel design ideas

In this work, the porous wall air coupling with air staged (PW&AS) technology is proposed to effect a simultaneous realization of prevention of high temperature corrosion and slagging, highly efficient burning of pulverized coal, and low NOx emissions. The working principle of PW&AS has been briefly mentioned in our previous study [42], and here is summarized in detailed. In the reducing zone of an air staged combustion furnace, several fins of water cooled wall are opened a large number of micro-pores. Part of the air required for coal combustion evenly blows into the furnace from the micro-pores in the direction of perpendicular to the water cooled wall. And then, the air mixes with the burning pulverized coal flow. Obviously, the pulverized coal flow is enwrapped by air, and the outer side of the flow contains more air. This means that the surrounding water cooled wall is separated from the pulverized coal flow and has no chance to contact H_2S, HCl, melting ash etc. Moreover, deposition of unoxidized material cannot occur. So the high temperature corrosion and slagging are prevented. The membrane wall whose fines are opened micro-pores wall is called the porous wall, this part of air is named the porous wall air, and the technology is defined as PW&AS combustion technology. In fact, the porous wall is a part of the water cooled wall, and named porous wall only because it is opened a large number of micro-pores are on the water cooled wall.

Compared with the closing to wall air, the porous wall air is expected to have three advantages. First, because the porous wall

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