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The influence of air distribution on gas-fired coal preheating method for NO emissions reduction

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HIGHLIGHTS

- GFCP provides a flexible means of further control of NO emissions for various coals.
- GFCP helps substantial soot to be generated in the preheating chamber.
- Soot functions as reductant in the subsequent furnace to destroy newly formed NO.
- MILD and sufficient air staging also lend hand to promote soot reduction in the major oxidation zones.

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ABSTRACT

A gas-fired coal preheating (GFCP) method was investigated on a 35 kW drop tube furnace with different air distributions, and three coals of various rank were used in the experiments. The results of this investigation show the GFCP provides a flexible means to control NO_x emissions for various coals, which can be used with traditional air staging like close-coupled over fire air (CCOFA), separated over fire air (SOFA) as well as MILD. The principle is that GFCP promotes substantial nitrogen intermediates (HCN and NH_3) and soot to be generated in the preheating chamber. With proper air distribution, the former convert into N_2 and the later function as reductant to destroy newly formed NO in the subsequent furnace. The global denitrification effect is more remarkable for coals of lower rank. While a primary air ratio at intermediate level may obtain the lowest NO emissions for combustion without GFCP, the NO emissions are essentially independent of variations in primary air ratio when GFCP is adopted. Our experiments also find that GFCP reduces fly-ash level by extending residence time for particles traversing high temperature zones.

1. Introduction

Coal is the principal energy source in China and playing dominant role in the economic growth of the country [1]. Coal-firing units account for 78.6% of the total electricity generation in China in 2012. Burning coal is a major source of NO_x emissions and has caused serious air pollution problem. So China adopt tighter limit on NO_x emissions, namely the new standard implemented in 2012 [2] sets a maximum exhaust value of NO_x of 100 mg/m^3 for coal-firing boilers of steam capacity of 65 t/h and above. The situation drives power plants to seek more effective method to reduce NO_x emissions.

A novel de-NO_x combustion method had been proposed to reduce NO emissions, namely gas-fired coal preheating (GFCP) method, which was developed by the All-Russian Thermal Engineering Institute (VTI) and was further improved by the American Gas Technology institute (GTI) under a cooperative agreement with American Department of Energy's National Energy Technology Laboratory (NETL) [3–5]. The essence of this technology is that a stream of concentrated pulverized coal (PC) enters a preheating chamber, where flue gas from gas combustion is used to heat the PC up to temperature high enough to initiate major devolatilization, prior to major oxidation. The thermal pretreatment releases coal volatiles, including fuel-bound nitrogen compounds into oxygen-deficient atmosphere, and these coal-derived nitrogen compounds could be easier to convert to N_2 through the rational organization of combustion. General trend established from lab-scale testing showed the more volatile was generated during coals pyrolysis, the more NO emissions were reduced in air staging. Since preheating promotes volatile release during pyrolysis, usage of simple over fire air in conjunction with preheating may lead to further denitrification. However, it is still unclear about the mechanism why preheating is working in favor of reducing NO, for

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example, whether hydrocarbon or soot plays a dominant role. Besides, modern over fire air on utility units has been developed into complicated but effective system comprised of closed coupled over fire air (CCOFA) and separated over fire air (SOFA) [6]. So it could be useful to study the effects of air distribution to these components when working with preheating.

Moderate and Intensive Low-oxygen Dilution (MILD) combustion has been proven to reduce NO_x emissions significantly for gas and oil burners [7,8]. In recent years, this technology is also used to coal combustion and gets some good results for NO_x emissions reduction [9–13]. The features of MILD can be found in [9,14]. The essence of this technology is that fuel is oxidized in an environment that contains substantial amount of inert gas, so the combustion takes place in almost entire volume of the combustion chamber and the peak of temperature is reduced. The method to implement this technique includes high speed jet of air and fuels entraining various combustion products, long distance between air nozzles and fuel nozzles to delay the mixing and high preheating temperature of air [15]. Our experiment does not resemble every features of MILD defined in [9], but it is still interesting to study the NO_x emissions reduction trend with selected key features of MILD. MILD in our experiments represents combustion where the secondary air is only fed through two nozzles which are far from the fuel nozzle into the furnace. Since the concept of MILD has good reason to lend additional support to GFCP as we discussed below, it would be interesting to see how MILD behaves with GFCP and air staging, a proven effective measure to reduce NO [16,17].

2. Experiment setup

A schematic of the experimental apparatus is shown in Fig. 1. The preheating chamber is made of stainless steel, 980 mm in length and 79 mm I.D., enveloped in refractory fibre. Pulverized coal is fed by a screw feeder on top down into the chamber. Upon entering the chamber coal particles get preheated by heat release from four premixed propane burners that are arranged around primary air tube. To avoid deflagration of the pulverized coal, only the inner primary air surrounded by circular outer primary air, is used to transport coal particles. The outer primary air progressively mixes with the preheated coal cloud. Coal devolatilization and partial oxidation happen in this preheating chamber. The produced mixture is then introduced into the subsequent drop tube furnace of 160 mm I.D. and 2600 mm height, where major combustion occurs. At the top of the drop tube furnace inner secondary air is introduced by axial vanes, and the outer secondary is introduced by two straight pipes located equidistantly on a pitch circle around the inner secondary air. The close coupled over fire air (CCOFA) and the separated over fire air (SOFA) are shown in Fig. 1 and their relative positions are listed in Table 2. Of course, if preheating (GFCP) is not used, coal particles traverse the preheating chamber nearly at surrounding temperature, and then undergo pyrolysis and oxidation in the drop tube furnace. Residence time of coal particles flowing through the drop tube furnace is estimated about 1-second, for all cases.

The flue gas, withdrawn from the furnace exit with a stainless steel water-cooled probe, is continuously analyzed by a gas analyzer (GASMET FTIR Dx4000). NO concentrations are reported on a basis at 6% oxygen. The fly-ash is sampled at stack as shown in Fig. 1. The flow rates of propane, inner and outer primary air, inner and outer secondary air, CCOFA and SOFA, are regulated and measured by rotameters. Thermocouples located on the furnace wall monitor temperature profiles of preheating chamber and drop tube furnace.

Experiments are performed with two high-volatile coals, Shenmu (SM) bituminous coal and Huangling (HL) bituminous coal, and one low-volatile coal from Hejin (HJ). Properties of the coals are listed in Table 1.

Outer secondary air pipe has an I.D. limited to 10 mm, to produce high-speed air injection. This configuration prevents immediate mixing of outer secondary air into the primary combustion zone, but eventually entrains large amount of hot flue gas back into the flamelet. So the chemical reactions occur in a large volume, leading no a distinct flame front of high temperatures found in conventional combustion flame modes.

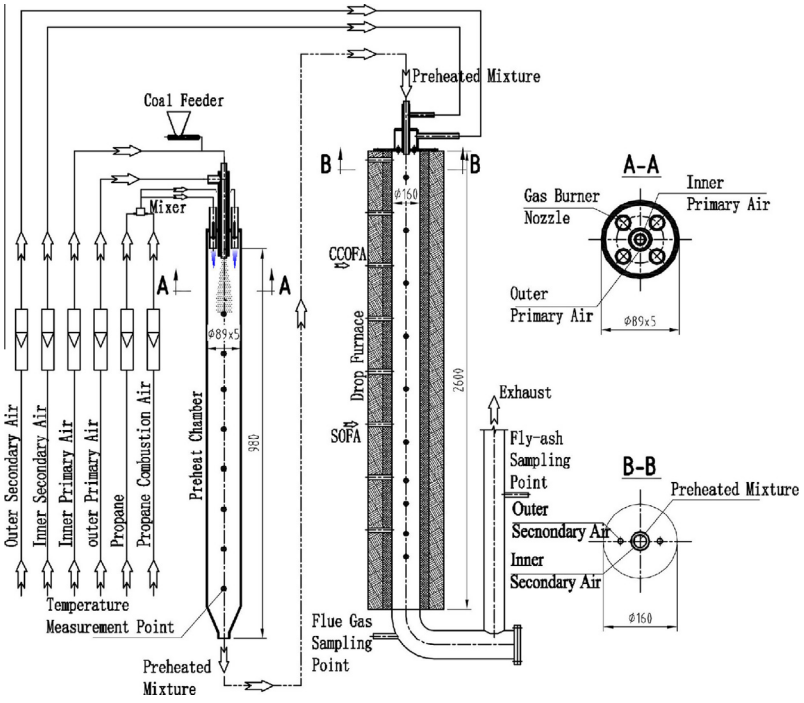

Fig. 1. Schematic diagram of the experimental apparatus.