Energy 119 (2017) 392–399

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Co-firing sludge in a pulverized coal-fired utility boiler: Combustion characteristics and economic impacts

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ARTICLE INFO

Article history:
Received 14 October 2016
Received in revised form
10 December 2016
Accepted 15 December 2016

Keywords:
Sludge
Co-combustion
Combustion characteristic
Economic impacts
Coal-fired boiler

ABSTRACT

Co-incineration of sludge in the existing coal-fired utility boilers is a promising sludge disposal approach, but study on the combustion characteristics and the economic impacts of co-firing sludge in full-scale utility boilers is in absence. In this study, a series of full-scale field experiments and numerical experiments were conducted to study the coal-sludge co-combustion characteristic in a 100 MW coal-fired utility boiler. The effects of sludge blending ratio and moisture content in sludge are concerned. Subsequently, the economic impacts of co-firing sludge is presented. The results demonstrate that the combustion characteristics is acceptable when co-firing 10% sludge. The ignition property and the flame stability are significantly affected when the mass content of co-fired sludge is over 10%. Decreasing the moisture content in sludge is beneficial to the combustion characteristics but the improvements are limited. Co-firing sludge is profitable for power plants as the savings from coal and sludge disposal allowance is quite substantial. Considering both the combustion characteristics and the economic impacts, co-firing 10% sludge with moisture content ranging from 40% to 56% is optimal. The annual profit from co-firing sludge can reach 4.2 million to 5.5 million Chinese yuan (CNY), which is remarkable for the power plant.

1. Introduction

Sludge is a residual, semi-solid material that is produced during industrial or municipal wastewater treatment. Due to the rapid industrialization and urbanization, the wastewater produced in China has dramatically increased over the past decades [1]. The discharged wastewater reached about 71.6 billion tonne in 2014. Due to the involved physical-chemical processes in wastewater treatment, the heavy metals and poorly biodegradable trace organic compounds as well as potentially pathogenic organisms (viruses, bacteria etc.) in wastewater are concentrated in sludge [2]. Thus, the sludge must be carefully disposed in an environmentally friendly approach. However, more than 80% of the sludge in China was disposed through improper dumping in 2013 [3]. Many wastewater treatment plants dumped sludge in the suburbs, which causes serious pollution on soil and water resources. The management, treatment, and disposal of sludge is a big issue in China [4].

Generally, the principal sludge disposal methods includes agricultural use, landfill, compost, and incineration [5]. Among these methods, incineration is superior with the advantages of volume reduction, stabilization and harmlessness [6–8]. Besides, the sludge can be regarded as a kind of renewable energy resource [9]. Incineration of sludge can recycle the contained calorie value realizing reduction of fossil fuel consumption and greenhouse gas emissions. Co-firing sludge with coal in the existed power plant boiler utilities, as a kind of incineration disposal method, can not only achieve innocuous sludge disposal, but also save the fuel costs for the power plant.

The co-combustion kinetics of sludge and coal blends have been studied numerously and have laid good foundation on practical applications [10–16]. The volatile of sludge is considered to be emitted at a higher rate at lower temperature when co-fired with coals, which brings an advantage to ignition of the blended fuel [11,13]. The emission of heavy metal from co-firing sludge and coal is a big concern in the co-incineration disposal approach. While several studies have proved that, the emitted heavy metal were below the legal limits and the fly ash fulfills the requirements of the regulation as construction materials when co-firing small percentage of sludge [16–18]. The slagging characteristics of coal-

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http://dx.doi.org/10.1016/j.energy.2016.12.084

sludge blends have also been studied systematically [16,19,20], which have demonstrated that the increase of slagging/fouling potential was limited with small sludge blending ratio. The laboratory-scale studies have provided abundant theoretical basis on co-combustion sludge, while the engineering guidance is still of scarceness. Only a few studies [21–23] have studied the combustion characteristic and feasibility of co-firing sludge in full-scale coal-fired utility boilers. As a kind of biomass, the combustion characteristics of sludge is different from that of coals [24,25]. According to the experience from biomass-coal co-combustion process, the temperature distributions [26,27], gas emissions [28,29] and thermal efficiency [30] will all be influenced when co-firing biomass in coal-fired utility boilers. Thus, a comprehensive study on the combustion characteristics and the economic impacts is urgent to provide engineering guidance on co-firing sludge in coal-fired utility boilers.

The purpose of this study is to obtain an optimum solution for co-firing sludge in pulverized coal-fired utility boilers. A series of full-scale field experiments and numerical experiments were conducted to reveal the co-combustion characteristics of coal-sludge blends. The effects of sludge blending ratio and moisture content in sludge were investigated comprehensively. Furthermore, an economic assessment on the technical potential solutions was made to study the economic impacts of co-firing sludge. An optimum sludge blending ratio and moisture content in sludge was finally acquired considering both the combustion characteristics and the economic impacts. This study provides an engineering guidance on co-firing sludge in coal-fired power plants.

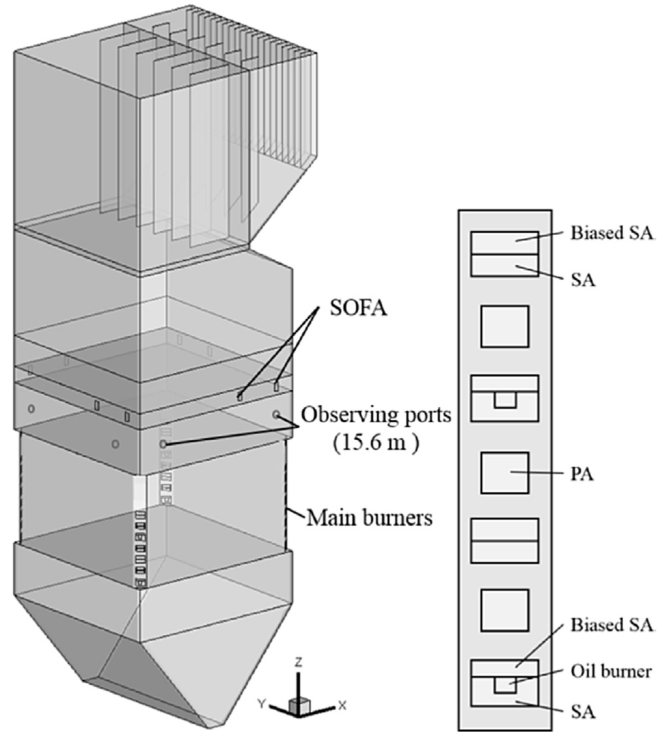

Fig. 1. Schematic diagram of the furnace and arrangement of main burners.

2. Methodology

2.1. Boiler description

The investigation was conducted on a 100 MW tangentially pulverized coal-fired boiler. The schematic structure and dimensions of the boiler, and burner nozzle arrangement is illustrated in Fig. 1. A low NO_X combustion system is equipped to reduce the NO generated in the furnace. A part of the secondary air is directed away from the primary air towards the adjacent furnace wall, realizing horizontal air-staging. Eight separated over-fire air (SOFA) nozzles are equipped on the four walls at about 5 m above the primary combustion zone. Approximately 20% of the total air is injected through the SOFA nozzles to realize vertical air staging. Additionally, a selective catalytic reduction (SCR) flue gas treatment is installed to reduce the NO concentration generated in the furnace. Urea is used as the reductants. The designed denitrification efficiency of SCR system is 85%. The NO_X emission can reach the new pollutant emission standard with NO_X concentration at the furnace outlet less than 330 mg/Nm^3. A wet electrostatic precipitator (WESP) is equipped to remove fine particles in flue gas. The de-dust efficiency is over 80%. After the filter system, a flue-gas desulfurization (FGD) system is equipped to remove SO_2. Limestone slurry is employed as the SO_2 sorbent. The desulfurization efficiency of the system is over 95%.

2.2. Full-scale field experiment

A series of full-scale co-combustion field experiments, e.g. Case 1–3 shown in Table 1, were conducted. The characteristic analysis of the used coal and sludge is summarized in Table 2. The sludge was blended with coal on the belt transport system, pulverized together with coal in mills and finally sent into the furnace. In the experiments, the flue gas temperature was measured using a suction thermocouple (with a measurement error below 30 K) through eight fire-observing ports at the 15.6 m elevation. The measuring points were 1.5 m away from the observed wall and 2 m away from the side wall. The oxygen and NO_X concentration at the outlet of economizer were measured by a MSI EURO-type flue gas analyzer. Fly ash and bottom ash were sampled and analyzed to assess the unburnt carbon content. Each experiment repeated twice.

Table 1
Field and numerical experiment cases.

	Sludge blending ratio (%)	Moisture content in sludge (%)	Experiment type
Case 1	Mono coal combustion	–	Field + numerical
Case 2	5	56	Field + numerical
Case 3	10	56	Field + numerical
Case 4	15	56	Numerical
Case 5	20	56	Numerical
Case 6	10	40	Numerical
Case 7	10	30	Numerical
Case 8	10	20	Numerical

2.3. Numerical experiment

CFD is an effective and reliable technique in revealing detailed combustion characteristics [31,32], and the simulation result from a validated CFD model can be seen as numerical experiments and partly replace the expensive field experiments [32,33]. In this study, a series of numerical experiments were accomplished as supplementation of field experiments to investigate the combustion characteristics of co-firing different ratio of sludge and different moisture content of sludge. In each experiment, the net calorific value of the feeding coal-sludge blend was kept constant. A piece of commercial CFD code, referred as to ANSYS Fluent 16.0, was introduced to conduct the numerical experiments. A high-quality mesh system comprising 1,418,694 hexahedral cells was developed based on grid independence test. The meshes were refined in