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Research article

Investigation of the deposition characteristics of ammonium bisulfate and fly ash blend using an on-line digital image technique: Effect of deposition surface temperature

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ABSTRACT

The problem of ammonium bisulfate (ABS) deposition blocking and corroding air preheaters and economizers in boilers became severe, as the selective catalyst reduction (SCR) system was widely used in the coal-fired boilers to meet the stringent nitrogen oxide (NO_X) discharge standard. In this study, an online digital image technique was applied to investigate the growth of the deposition of fly ash and ABS blend in a drop tube furnace (DTF). The deposition was measured on a temperature controlled deposition probe. The results of the image technique showed that the surface temperature of the deposition probe had a negative effect on stable thicknesses of the blend depositions and the stable thicknesses for cases 1 (553 K), 2 (513 K), and 3 (473 K) are 4.78, 5.26, and 7.64 mm, respectively. Meanwhile, the relative variation of the heat flux Q_R for Cases 1, 2, and 3 are 17.8%, 33.8%, and 40.2%. The deposition in the lower deposition surface temperature has a greater effect on the heat transfer efficiency. In order to understand the deposition formation of fly ash and ABS blend, the X-ray diffraction (XRD), X-ray fluorescence (XRF), and the scanning electron microscopy (SEM) analysis were undertaken of the blend deposition. The results indicated that the content of ABS in the bottom part deposition increased as the probe surface temperature decreases, and this would result in more agglomerates in the deposition according to the observations of the SEM and the growth behavior of the deposition was influenced. Meanwhile, the results show that the deposition characteristics of ABS and fly ash blend is strongly influenced by the distribution and the condensation behavior of ABS. This work makes a contribution to a deeper understanding of deposition characteristics of ammonium bisulfate and fly ash blend, which is important for boilers to control the blend deposition in air preheaters and economizers.

1. Introduction

In order to meet the stringent NO_X discharge standard, the SCR system has been widely used in coal-fired boilers. Moreover, Chinese government requires ultra-low emission reform of coal-fired power plants. The main reactions in the SCR reactor are as follows [1]:

$$4NH_3 + 4NO + O_2 \rightarrow 6H_2O + 4N_2 \quad (1)$$

$$4NH_3 + 2NO_2 + O_2 \rightarrow 6H_2O + 3N_2 \quad (2)$$

The high stoichiometric ratio of NH_3/NO_X was applied in the reactor for the high NO_X removal efficiency. However, the NH_3 slip tends to increase with this high stoichiometric ratio.

The V_2O_5-WO_3/TiO_2 and V_2O_5-MoO_3/TiO_2 are widely applied in commercial SCR systems as the catalysts [1]. When the fuel gas passes through the catalyst reactor, SO_2 which is a high concentration in the fuel gas is oxidized to SO_3 [2]. The reactions are as follows [3]:

$$SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4 \quad (3)$$

$$2SO_2 + V_2O_4 + O_2 \rightarrow 2VOSO_4 \quad (4)$$

$$2VOSO_4 \rightarrow SO_2 + SO_3 + V_2O_5 \quad (5)$$

ABS and ammonium sulfate (AS) are formed by the SO_3 and the escaped NH_3. The main reactions are as follows [4, 5]:

$$SO_3 + NH_3 + H_2O \rightarrow NH_4HSO_4 \quad (6)$$

$$NH_3 + NH_4HSO_4 \rightarrow (NH_4)_2SO_4 \quad (7)$$

$$SO_3 + 2NH_3 + H_2O \rightarrow (NH_4)_2SO_4 \quad (8)$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad (9)$$

$$NH_3 + H_2SO_4 \rightarrow NH_4HSO_4 \quad (10)$$

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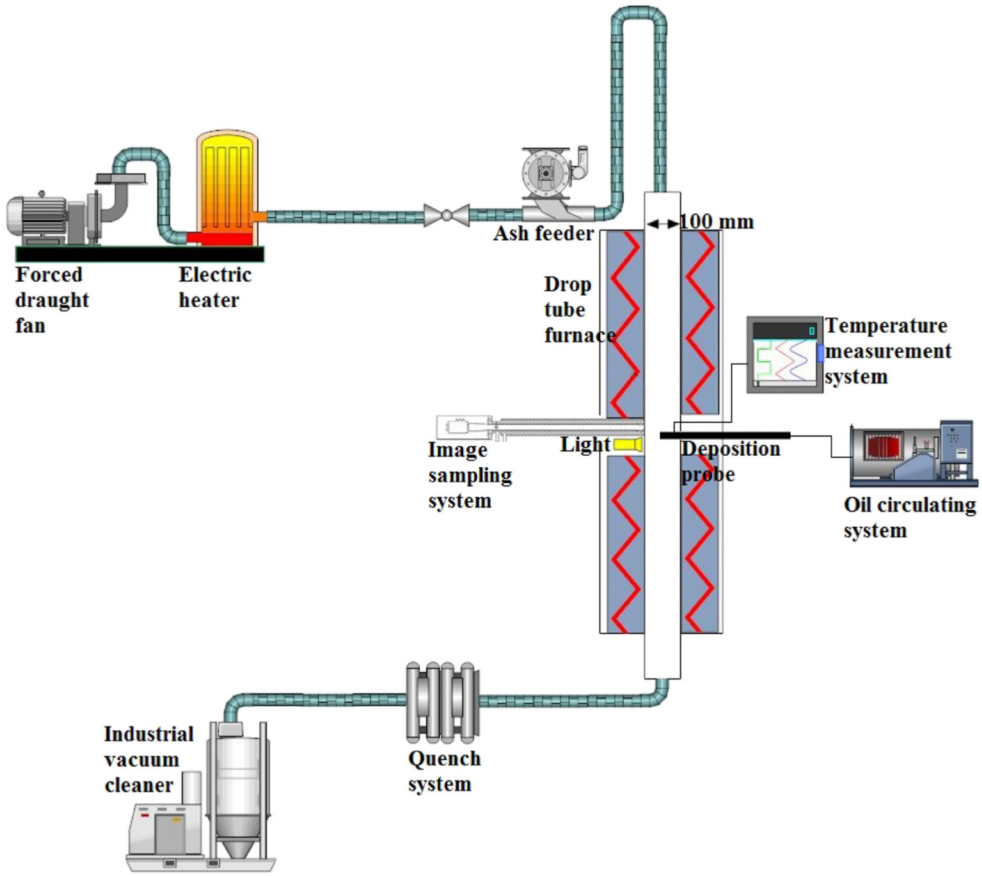

Fig. 1. The schematic diagram of the experimental setup.

Table 1
Experimental conditions.

Feeding rate (kg/h)		2.62
Gas velocity in the DTF (m/s)		9.8
Dust concentration (g/m^3)		9.46
Temperature of the DTF (K)		623
Blending rate (Ash:ABS, wt)		30:1
Temperature of the deposition surface (K)	Case 1	553
	Case 2	513
	Case 3	473
Experimental time (min)		120

The ABS will condense on the surface of the downstream devices, and the ABS is a sticky deposit. The fly ash in the fuel gas is captured by the ABS and the blend deposition grows gradually which causes the pluggage and the corrosion of the downstream devices [3]. It will cause unexpected shutdowns, reduction of the heat transfer efficiency and increasing the replacement and cleaning costs [6].

In recent years, many researchers have investigated the formation mechanism of ABS. The ABS formation rate can be investigated by the thermodynamic and kinetic model developed by Radian in 1982 [7]. Some researchers further developed this ABS formation kinetic model [8–10]. The effect of different factors on the formation of ABS has been investigated, e.g., ammonia slips, SO_3 and ratio of NH_3 to NO_X [3, 6, 10]. Meanwhile, there are also many studies focused on the decomposition mechanism of ABS, and the ABS was directed introduced in the experiments to investigate the reactivity behaviors of ABS in the SCR [11–14]. Shi et al. [11] investigated the decomposition of ABS on the surface of commercial V_2O_5-WO_3/TiO_2 catalysts and found that NO could promote the decomposition on the catalyst by reacting with the NH_4^+ from ABS. Different from the one-step decomposition of pure ABS, the ABS on the catalyst had two steps for decomposition [11].

The formation mechanism and the decomposition mechanism of ABS have been well studied. However, the blend deposition is the ash deposition formed by ABS and fly ash. Even among these references, few studies investigated the formation and the growth of the blend deposition. Most of these studies were focused on the formation of ABS and the fly ash was not taken into consideration. To the authors' knowledge, a few studies only mentioned that the ABS formation could be influenced by the fly ash, because the fly ash could absorb the NH_3 and SO_3 [3, 15]. The growth and characteristics of the blend deposition is still not studied. Vuthaluru et al. [16] investigated the ash deposition in air preheater which contained high amount of sulfate and the chemical and mineralogical analysis had been applied. However, they still did not prove that this ash deposition resulted from the ABS, and the growth of the deposition was not investigated.

In this study, the morphology of blend deposition growth which has not been studied yet is well investigated with an on-line digital technique. Characteristics of the blend deposition, including mineralogy of the deposition, the microstructure of the deposition, chemical composition of the blend deposition, and the heat flux through the deposition are investigated. Meanwhile, the effect of deposition surface temperature on the blend deposition characteristics is studied.

2. Experimental details

2.1. Experimental system

Fig. 1 presents the schematic of the experimental setup. It mainly consists of ash feeder, drop tube furnace (inner diameter 100 mm;