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Deposition and corrosion characteristics of liquid-solid droplets on tubular corrosion probes in desulfurized flue gas

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ABSTRACT

In coal-fired boilers, low-temperature corrosion occurring in the back-end is always threatening. Particularly, the desulfurized flue gas from outlet of the flue gas desulfurization (FGD) unit is quite aggressive. The flue gas reheater placed after FGD is usually operating under a much more severe condition than the condensing heat exchangers before FGD. In this paper, field corrosion tests were conducted in a coal-fired heating plant and tubular corrosion probes made of different grades of steels were tested. The total testing period was 6 weeks. The corroded probes were then analyzed by X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscope (SEM) and energy dispersive spectrometer (EDS), and the deposition and corrosion mechanisms were studied. The droplets entrained by the flue gas resulted in deposition and corrosion on the probe, especially on the windward side. During the tests, 2507 and 2205 showed good corrosion resistance, while ND, 304L, 316L suffered considerable corrosion.

1. Introduction

When fossil fuels are burned, atmospheric pollutants such as sulfur oxides, nitric oxides and hydrogen chloride are generated. Wet flue gas desulfurization(FGD) process is usually applied to remove these acid gases by scrubbing the flue gas with absorber slurry. By the use of FGD, more than 95% SO_2 in flue gas could be removed but some corrosion problems then occur. Generally, the flue gas cools down to about 90 °C before the FGD unit and further to about 50 °C in FGD, while then heats up in the flue gas reheater to about 80 °C before being emitted into ambient air through the stack (see Fig. 1). The engineering failures caused by corrosion and degradation of low-temperature heat exchangers have long been a serious problem.

In the back end of a coal-fired plant, the water vapor and acid vapors in the flue gas condense into liquid with the decrease in temperature. And the condensed acid, mainly composed of sulfuric acid and hydrochloric acid, can give rise to extensive corrosion in the devices where the low-temperature flue gas passes through. The flue gas reheater is a tube-type flue gas heat exchanger, which use heat exchange tubes to extract heat from the high-temperature flue gas in the flue gas cooler and heat the low-temperature desulfurized flue gas from outlet of FGD, in order to promote diffusion of the exhaust flue gas from the stack. Limestone slurry is often used in wet FGD as the absorbent. Most of the acid gases and condensates in the flue gas can be absorbed in FGD. However, the flue gas reheater, which is running after FGD, actually suffers much more severe corrosion than the condensing heat exchangers before FGD.

There have been quite a few studies on corrosion in the condensing flue gas of coal before FGD, and many different grades of anticorrosion materials and measures were tested and evaluated [1–4]. The key principle of metal anticorrosion in heater exchangers

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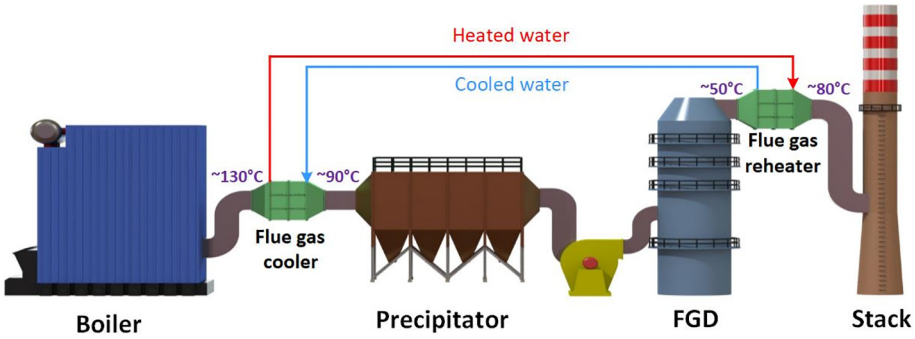

Fig. 1. The back end of a coal-fired heating plant.

before FGD is to keep the surface temperature higher than the sulfuric acid dew point, which is in the range of 70 to 150 °C in flue gas. While the hydrochloric acid dew point is much lower, usually about 50 °C, just around the water dew point. Thus, although there is quite a little hydrogen chloride existing in the flue gas, the effect of hydrochloric acid was always ignored.

Nevertheless, at outlet of FGD, due to the large amount of absorber slurry used in FGD, the flue gas is only about 50 °C and saturated with water vapor, and most of the sulfuric acid vapor and hydrochloric acid vapor in the flue gas have condensed [5–7]. Furthermore, a lot of circulating absorber slurry may be taken by the flue gas in the form of small droplets. These droplets can be very corrosive because there are lots of free ions in the slurry. And the solid content in the slurry is also very high. Therefore, the flue gas reheater is running under an extremely aggressive condition and failures of the heat transfer elements are quite frequent. However, little research has been conducted on the corrosion in the tube-type flue gas reheater since this device was not widely applied until recent years in some countries, and corrosivity of the desulfurized flue gas was once underestimated [8,9]. In China, only some of large-scale coal-fired plants are equipped with flue gas reheaters at present, but more and more flue gas reheaters are coming into operation.

Before FGD, only the sulfuric acid condensation needs to be considered. After FGD, the influence of hydrochloric acid and absorber slurry should also be taken into account. And the impact of numerous liquid-solid droplets in the desulfurized flue gas should be emphasized. In this paper, field tests of tubular corrosion probes made of common corrosion resistant steels were performed in a coal-fired heating plant. Based on these tests, the deposition and corrosion mechanisms of liquid-solid droplets on the corrosion probes were discussed and the testing steels were evaluated.

2. Field tests

2.1. Materials

Five frequently-used steels in the low-temperature flue gases of fossil fuels were tested: ND, 304L, 316L, 2205 and 2507. Since there is little research on the corrosion issues of the flue gas reheater, heat exchanger manufacturers have tried different materials. All of the five steels tested in this work have been used for heat transfer elements in the flue gas reheater in coal-fired plants. Among them, ND, 316L and 2205 are most widely used nowadays. But a lot of severe corrosion failures have also taken place.

ND is a low alloy steel, which was initially developed by a Chinese corporation to cope with sulfuric acid dew point corrosion. Small amounts of chromium and copper are added to enhance its resistance to sulfuric acid to some extent.

304 L and 316L are both austenitic stainless steels with different levels of chromium and nickel contents. In addition, some molybdenum is also added in 316L.

2205 is a duplex stainless steel and 2507 is a super duplex stainless steel, besides chromium, nickel and molybdenum, some nitrogen is also added in these two steels.

The chemical compositions of the five testing steels are listed in Table 1.

Since the heat transfer elements in the flue gas reheater are either tubes or finned tubes. The corrosion probes made of the testing steels were in the form of circular tube, with an outside diameter of 38 mm and an inside diameter of 28 mm.

Table 1
Chemical compositions of the testing steels in wt%.

Steel	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	N	Sb	Fe
09CrCuSb	0.078	0.26	0.48	0.012	0.010	–	0.90	0.37	–	–	0.060	Bal.
S30403	0.019	0.36	1.28	0.029	0.004	8.15	18.14	0.09	–	–	–	Bal.
S31603	0.020	0.40	1.45	0.018	0.002	10.73	16.97	0.12	2.47	–	–	Bal.
S32205	0.016	0.37	1.12	0.026	0.001	5.74	22.06	0.24	3.13	0.17	–	Bal.
S32750	0.018	0.25	0.77	0.015	0.001	7.08	25.18	0.21	3.89	0.27	–	Bal.