DESIGN AND OPERATION OF A MSW AND STRAW CO-FIRING CFB BOILER

JunpingGu[1],HairuiYang[1*], Changlong Li[2], Junfu Lyu[1]

[1] *Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Thermal Engineering, Tsinghua University, Beijing 100084, China*
[2]*GuoFeng New Energy Ltd, Jiangsu 221000, China*

*Email:*yhr@mail.tsinghua.edu.cn*

Abstract–In order to solve the problems of Municipal Solid Waste (MSW) disposal, the Circulating Fluidized Bed (CFB) technology is a promising method to burn MSW to generate electricity. In this paper, a MSW and straw co-firing CFB boiler was investigated. It is the first CFB boiler in China, which purely utilizes MSW and straw as fuel. The boiler structure, design parameters and the mixed fuel properties were introduced. The special design of water-cooled square separators used in this boiler can maintain an excellent mass balance and prevent the heating surface from corrosion and coking. The operating results show that the boiler operates economically and reliably. During actual operation, the temperature in furnace is stable, the dense bed temperature is about 850℃ and the dilute zone temperature is about 810℃.The boiler efficiency can reach 87.25%. By using appropriate pollution control method portfolio, the pollutant emissions are lower than the emission standard. The furnace desulphurization efficiency is about 97%.Moreover, the operating problems, including bottom ash discharge and deposition of the economizer heating surface, were studied, and the solution method was provided.

INTRODUCTION

The amount of Municipal Solid Waste increases rapidly in the past decades, which can lead to many problems including occupation of land resource, environmental pollution and huge economic losses (Arafat H A et al, 2015). The problem of MSW disposal needs to be urgently solved. Fig. 1 shows the amount of MSW clean and harmless treatment in China from 2006 to 2014 (CS Yearbook, 2014). Comparing to landfill and composting, the way to burn MSW to generate electricity provides an economical and innoxious method of MSW disposal and it has had a great development in China since 1980s [Zhang Y et al, 1998; Zhang Y et al, 2016].

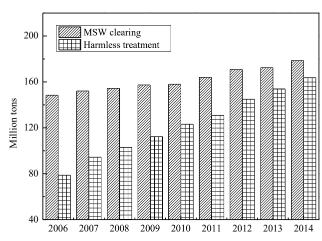

Fig. 1. The amount of MSW clearing and harmless treatment in China from 2006 to 2014.

The property of MSW in China has high moisture, high volatile but low heating value, so that the MSW is used to burn by mixing with coal [Ma Z et al, 2009]. In order to save the operating cost, straw, which is a kind of renewable energy, was considered to be an excellent substitute of coal for co-firing with MSW. The use of straw can improve the efficiency of energy utilization and local environment [Xiong X, 2016]. However, the high content of alkali metals in mixed fuel of MSW and straw can cause sintering, deposition and high temperature corrosion of heating surface at high temperature condition [Zhang Y et al, 2010; Gong B et al, 2015]. Thus, the operating temperature should be carefully controlled. For CFB boiler, it has many advantages at low operating temperature such as high combustion efficiency and low pollutant emissions. The CFB combustion technology becomes a promising method for MSW incineration in China.

To further study the co-firing of MSW and straw, a 75 t/h CFB boiler was designed and manufactured. It is the first CFB boiler in China which purely utilizes MSW and straw as fuel, and it has already been in commercial operation since May 2016 in Xuzhou City, Jiangsu Province, China. In this paper, the boiler design, properties of the mixed fuel as well as the pollutant control technologies were introduced. The operating results were presented and discussed to evaluate the performance of the MSW incineration power plant. In addition, the problems occurred in actual operation of the present CFB boiler, including bottom ash discharge and deposition, were investigated and the solutions were provided as well.

BOILER DESIGN

Main design parameters

The main design parameters of the 75 t/h CFB boiler are listed in Tab. 1.

Table 1: The main design parameters of the CFB boiler

Parameters	Unit	Design value（BMCR）
Main steam flow	t/h	75
Main steam pressure	MPa	5.29
Main steam temperature	℃	485
Bed temperature	℃	850
Exhaust gas temperature	℃	148
Boiler thermal efficiency	%	86
excess air coefficient		<1.4
Fuel flow	t/d	400

General structure

The 75t/h boiler (TG-400-75/5.29-LS), shown in Fig. 2, was designed based on the second generation CFB combustion technology, which is of higher reliability and lower electric power consumption of forced fans(Yue G et al, 2016).The boiler has Π-shape layout, mainly comprises furnace, single drum, two water-cooled square separators and the second pass. The furnace cross section is 3230 mm × 7230 mm. The water wall is membrane. Three circular bottom ash discharging outlets are installed in the lower furnace. ˥-type wind caps are arranged around the discharging outlet to prevent discharge pipe from being blocked. Two feeding inlets are set in the front wall and lifted to a certain height so that the mixed fuel can be dried in the falling process. The platen superheater is hung in the upper furnace. Two water-cooled square separators, which are made of the membrane water walls, are connected with the furnace and the second pass to make the boiler structure more compact, to solve the sealing problem and to increase the heating surface. The temperature of flue gas is reduced by the separators to prevent the heating surfaces in second pass from high temperature corrosion. Moreover, the coking on the high-temperature surface of separators and the material recycle device is avoided as a result of the decrease of the returning ash temperature [Lyu J et al, 1998]. The water-cooled square separators are important to the safe operation and combustion efficiency of the MSW and straw co-firing CFB boiler. In the second pass, a middle-stage superheater, a primary superheater, a final-stage economizer, a primary economizer and an air preheater are arranged along the flow direction of flue gas.

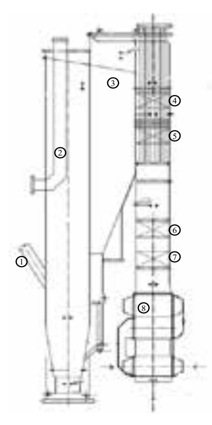

Fig. 2. The arrangement of the 75 t/h CFB boiler.①feeding inlet, ②water-cooled panel, ③water-cooled square separators, ④middle-stage superheater, ⑤primary superheater, ⑥final-stage economizer, ⑦primary economizer and ⑧air preheater.

Properties of design fuel and limestone

This CFB boiler was designed for the mixed fuel of 62% MSW and 38% straw. The ultimate analysis of the design fuel was listed in Tab. 2. It is clearly seen that the design fuel is characterized by a relative high moisture content (31.64% as received), a high volatile content (47.76% as received) and a low heating value. As listed in Tab.2, the low sulfur content can reduce the generation of SO_2, but the high chlorine content will cause corrosion of heating surface which is a crucial challenge of the MSW and straw co-firing CFB boiler.

Table 2: The ultimate analysis of the design fuel.

Car%	Har%	Oar%	Nar%	Sar%
26.1	2.93	17.9	0.51	0.27
Mar%	Aar%	Var%	Clar%	Lower heating value, kJ/kg
31.64	20.49	47.76	0.16	9158.5

The limestone injection method is used for desulfurization in the boiler furnace. Tab. 3 lists the constituents of the limestone.

Table 3: The composition of the limestone.

constituents	unit	value
Calcium carbonate ($CaCO_3$)	%	90.00
Magnesium carbonate ($MgCO_3$)	%	2.15
Water (H_2O)	%	0.15
Others	%	7.70

Due to the special ash formation characteristic of the mixed fuel of MSW and straw, it is difficult to accumulate enough circulating material to maintain the certain solid suspension density distribution in the furnace. Thus, the additional sand is necessary for the MSW and straw co-firing CFB boiler [He H, 2010]. The sand with smaller specific gravity and lower alkali metal content is selected to maintain appropriate pressure drop in the furnace and to prevent bed material coking. The Na_2O and K_2O contents in the selected sand are suggested to be lower than 2.0% and 2.5% respectively. Sand sizes are supposed to be smaller than 6 mm. Since the limestone is used as desulfurizer and circulating material, the limestone particle sizes should be controlled in appropriate range, shown in Fig. 3, to improve the desulfurization efficiency and strengthen the fluidized effect.

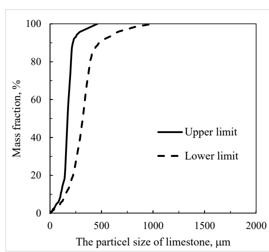

Fig.3. The particle size distribution of the limestone.

Pollution control methods

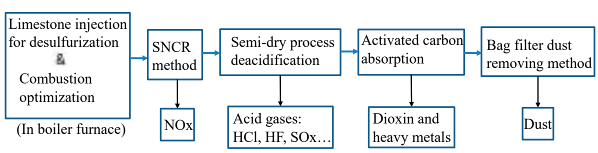

Fig. 4The pollution control process of the MSW incineration power plant.

In order to solve the problem of pollution emission in a power plant, not only the novel pollution control technologies need to be researched, but also the utilization of the existing pollution control method portfolio needs to be carefully studied. The pollution control methods shown in Fig. 4 are used in the present power plant to limit the pollutant emission in the allowed range. In the boiler furnace, the limestone injection method is used for desulfurization and the combustion is optimized to decrease the original generation of pollutant. The bed temperature is designed at about 850℃, the fuel residence time is longer than 2 seconds and the ratio of the primary and secondary air is 6:4 for the Maximum Continues Rate (MCR) condition. As a result, the original generation of pollutant including NO_x, SO_2 and dioxin are reduced. The SNCR technique and semi-dry process deacidification method are used to further remove NO_x and acid gases respectively. The dioxin and heavy metals are removed from the flue gas by activated carbon absorption method. Finally, the bag filter is used to collect the dust.

RESULTS AND DISCUSSION

Operating parameters

The operating parameters listed in Tab. 4 were collected to evaluate the performance of the CFB boiler. Comparing with the design parameters listed in Tab.1, the results show that the operation of the CFB boiler is stable, reliable and economic. However, the exhaust gas temperature is higher than the design value due to the ash deposition on the heating surface of economizer. The problems in the actual operation of the CFB boiler are investigated in the following sections.

Table 4: Operating parameters of the MSW and straw co-firing CFB boiler.

Parameters	Unit	Operation value
Main steam flow	t/h	70-75
Main steam pressure	MPa	5.04-5.21
Main steam temperature	℃	480-485
Feed water temperature	℃	135-141
Bed temperature	℃	845-865
Exhaust gas temperature	℃	166-172
Boiler thermal efficiency	%	87.25
excess air coefficient		1.39
Fuel flow	t/d	MSW:220Straw: 135
Annual availability	h/year	6000

Temperature and pressure distribution

The temperature in furnace is stable when burning the mixed fuel of MSW and straw. Fig. 5 shows the temperature distribution along the furnace. It is clearly seen that the dense bed temperature is about 850℃ and the dilute zone temperature is about 810℃. The temperature difference between the dense bed and the dilute zone is less than 50℃, which indicates the excellent mass balance performance.

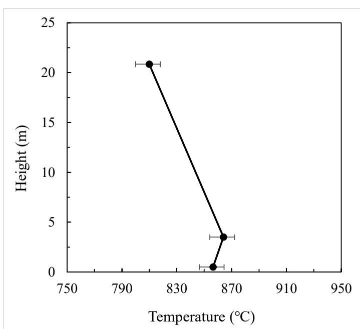

Fig. 5. The temperature distribution along the furnace.

Pollutant emissions

By using appropriate pollution control method portfolio introduced in section 2.4, the pollutant emissions are lower than the emission standard as listed in Tab. 5. The original emissions of NO_x and SO_2 without SNCR and semi-dry process deacidification method were also collected. The results show that the original generation of NO_x and SO_2 is lower than 120 mg/Nm^3 and 35 mg/Nm^3 respectively.

Table 5: The emission standard and the final pollutant emission of the power plant.

pollutants	unit	Emission standard	Final emission
NOx	mg/Nm^3	250	<50
SO_2	mg/Nm^3	80	<47
HCl	mg/Nm^3	50	20-50

Dioxin	ng/Nm^3	0.1	0.02
Dust	mg/Nm^3	20	<4

For the design fuel listed in Tab. 2, the original generation of SO_2 is low due to the low sulfur content. The calculation results present that the original generation of SO_2 without any desulfurization method is 1565 mg/m^3. Thus, the furnace desulphurization efficiency of the MSW and straw co-firing CFB boiler reaches about 97%. Since the property of MSW is different in regions and seasons, the SNCR and semi-dry process deacidification technology are put into operation only when the original emissions are higher than the emission standard. Moreover, the pollutant emissions fluctuated violently during normal operation. That was due to the instable fuel feeding rate as shown in Fig.6. It was clearly seen that the mixed fuel twines together fed into the furnace. Subsequently, the pollutant emission increases especially the emission of CO. Thus, it is of importance for MSW and straw co-firing CFB boiler to control fuel feeding rate by performing preprocessing.

Fig.6. The status of instable fuel feeding.

OPERATION PROBLEMS

Bottom ash discharge problem

Since the garbage sorting process is too simple in China, the component of MSW is complicated. The impurities, such as coarse stones and iron, can cause block of bottom ash discharge. It was found that the circular bottom ash discharging outlets installed in this CFB boiler could not discharge the bottom ash smoothly during operation. Thus, the bottom ash discharging outlets was modified to 300 × 400 mm rectangular outlets as shown in Fig.7, which successfully used in our other MSW incineration CFB boilers. Comparing with circular discharging outlet, wind caps can be more uniformly arranged with the rectangular outlet. Specifically, ˥-type wind caps are uniformly arranged around the rectangular bottom ash discharging outlet, and bell-type wind caps are uniformly installed at the rest region as shown in Fig. 7, to enhance the mass fluidity and increase the bottom ash discharge ability.

Fig.7. The rectangular bottom ash discharging outlet and the arrangement of the wind caps.

Deposition problem

Due to the high content of alkali metals in the fuel, it is easy to cause deposition on heating surface in boiler, particularly on the economizer surface (temperature range of 500~560℃), which is a common problem for the biomass boiler. As discussed in section 3.1, the ash deposit of the economizer heating surface lead to an increase of the exhaust gas temperature and the exhaust gas heat losses, has a significant influence on the efficiency and the safe operation of the boiler. Fig. 8 presents the ash deposit sample of the economizer surface, it was found to be the low-temperature bonded deposition with high hardness. According to the slight differences of the color and hardness, the deposit was divided into three layers (inner layer, middle layer and outer layer). The X-ray diffraction (XRD) and X-ray florescence (XRF) were used to analysis the phase and the elemental compositions respectively.

Fig. 8. The ash deposit sample of the economizer heating surface.

As listed in Tab. 6, the main source of deposits is the high contents of Ca, S, Cl, Al and K in the mixed fuel. At the initial deposition stage, the K/Na alkali metal compounds, which gasified in the high temperature region, condensed on the heating surface. Then, the high calcium sub-micron particles were adhered on the molten adhesive surface to form the firm inner layer. Even though there was no much KCl as expected in the inner layer, KCl still played an important role in the deposit formation due to its high adhesiveness. The mass fraction of Ca, S continued to increase from inner layer to outer. It was found that the higher-density middle layer was made up of the small particles with high Ca, S and Cl contents and the loose outer layer was made up of the captured fly ash. Table 6 presents that the Ca/S of the deposit is much bigger than 1, thus it can be suspected that Ca is deposited not only as the form of $CaSO_4$ but also as the aluminosilicate. It can be clearly seen from Fig. 9 that KCl, Hydroxylellestadite and SiO_2 are the key components of the deposit. With the process of the development of deposition, the types of the deposit components were simplified from inner layer to outer. In addition, the high Cl content in the deposit might cause severe corrosion of heating surface, thus more studies are urgently needed to solve the problems of deposition and corrosion.

Table 6: The X-ray diffraction analysis results of the ash deposit sample.

Elements	Inner layer,		Middle layer,		Outer layer,	
	Wt%	At%	Wt%	At%	Wt%	At%
Ca	27.67	17.15	29.99	18.75	31.54	19.60
Si	9.66	8.55	6.43	5.74	6.95	6.17
Cl	10.09	7.06	11.05	7.80	9.76	6.84
Sx	3.11	2.41	5.14	4.02	6.09	4.73
Al	3.83	3.52	2.73	2.53	2.53	2.33
K	2.6	1.65	3.09	1.98	2.32	1.48
Fe	2.18	0.97	1.98	0.89	1.65	0.73
Mg	1.75	1.81	1.81	1.89	1.2	1.24
Na	1.41	1.52	1.46	1.59	1.11	1.20
Px	0.82	0.66	0.91	0.73	0.54	0.43

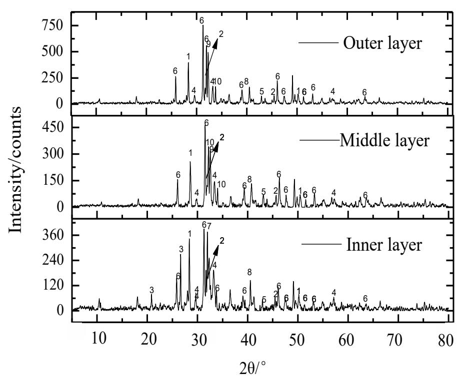

Fig. 9. X-ray diffraction analysis results of the ash deposit sample.1 KCl, 2 NaCl, 3 SiO_2, 4 $Ca_3Fe_2(SiO_4)_3$, 5 MgO, 6 Hydroxylellestadite, 7 $CaSiO_4$, 8 MnO, 9 $Ca_5(PO_4)_3Cl$, 10 Na_2SO_4

CONCLUSIONS

A CFB boiler, which purely burns municipal solid waste and straw as fuel, was investigated in this paper. Due to the particularity of the mixed fuel properties, special arrangement was considered in the boiler design. The main results are as follows:

(1) The mixed fuel of MSW and straw with high moisture, high volatile and low heating value can be effectively and stably burned in the CFB boiler. The special design of water-cooled square separators can maintain material balance of the boiler and prevent the heating surface from corrosion and coking. The operating parameters meet the design range. The temperature in furnace is stable and the boiler efficiency can reach 87.25%.

(2) By using appropriate pollution control method portfolio and combustion optimization, the pollutant emission is limited in the allowed range. The original emission of NO_x and SO_2 without flue gas treatment methods is low. The furnace desulphurization efficiency reaches about 97%.

(3) To solve the problem of bottom ash discharge, the circular bottom ash discharging outlets installed in the CFB boiler are suggested to be modified to rectangular outlets.

(4) The deposition problem on the economizer heating surface becomes a challenge for the safe operation of the MSW and straw co-firing CFB boiler. It was found that the deposit can be divided into three layers, and KCl, Hydroxylellestadite and SiO_2 are the key components of the deposit. More studies are urgently needed to solve the problems of deposition and corrosion.

ACKNOWLEDGMENT

Financial support for this work by the National Program on Key Basic Research Project (973 Program) of China (No. 2014CB744305) is gratefully acknowledged.

REFERENCES

Arafat H A, Jijakli K, Ahsan A.2015. Environmental performance and energy recovery potential of five processes for municipal solid waste treatment[J]. Journal of Cleaner Production, 105: 233-240.

CS Yearbook-Beijing, China, 2014.

Gong B, Yu C, Wang Z. 2015. Characteristic of deposits on different heating surface from a biomass-fired grate boiler. (8): 1578-1584.

He H, Hu N, Lyu J. 2010. Analysis on additional sand size in low-ash fuel fired circulating fluidized bed boilers. (6): 409-414.38(5): 7-10.

Lyu J, Jin X. 1998. Hot test of material balance in a 75 t/h CFB boiler with water cooled square separator. Journal of Tsinghua University (Science and Technology). (5):7-10.

Ma Z, Wu S, Bai Y. 2009. Research on Co-incineration Technology of Municipal Solid Wastes and Coal in China [J]. Thermal Power Generation, 38(4): 9-13.

Xiong X. 2016. Feasibility analysis of using garbage-straw mixture in renewable energy power generation prejects. Energy Research and Management. (3): 65-68.

Yue G, Lyu J, Xu P. 2016. The up-to-date development and future of circulating fluidized bed combustion technology. Electric Power, 49(1):1-13.

Zhang Y, Lyu J. 1998. Development and prospects of Municipal Solid Waste Incineration and energy regeneration technology in the world [J]. Environmental Protection. 7(38): 7.

Zhang Y, Wang L, Meng A. 2010. Experimental study on the slagging of power station incinerator. (29): 1-8.

Zhang Y. 2016. Review and prospect of living garbage incineration technologies in China. Environmental Protection.(13): 20-26.