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10th International Conference on Circulating Fluidized Beds and Fluidization Technology - CFB-10

Refereed Proceedings

Spring 5-3-2011

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DESIGN AND OPERATION OF BIOMASS CIRCULATING FLUIDIZED BED BOILERS WITH HIGH STEAM PARAMETERS

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ABSTRACT

Two circulating fluidized bed(CFB) boilers with capacity of 12 MW_e and 25 MW_e, respectively, with biomass as fuel, adopting the basic technology independently developed by Institute of Engineering Thermophysics (IET), Chinese Academy of Sciences, have been in commercial operation since March 2010 in China. This paper focuses on the design principles, the design specifications and operating results of the two CFB boilers.

INTRODUCTION

Power demand has been mostly met by consuming fossil fuels for a long time in China. However, fossil fuels are limited and results in severe air pollution. Due to the increasing environmental concerns, especially on greenhouse gas emissions related to the use of fossil fuels, new solutions to limit the greenhouse gas are continuously sought. The available alternative energy sources are hydro, solar and wind etc. In order to mitigate greenhouse emissions, biomass is the only carbon-based sustainable option, which is potentially CO_2-neutral and a renewable energy source. At present, biomass has been converted into heat and electricity on a large scale most often by combustion. Over the past five years, more than 20 commercial biomass boilers have been put into operation in China. These boilers are all for 100% biomass combustion because the government has a policy of providing a subsidy for this kind of combustion. Most are grate boilers with electrical capacity from 6 MW_e to 25 MW_e. Recently, since the CFB combustion technology develops quickly in China, circulating fluidized beds which can be used for a broad variety of biomass inputs have been gradually accepted by the Chinese market. Furthermore, the cost of fluidized beds is also its strength compared with other combustion technologies for biomass fuels. In recent years, some biomass CFB boilers have been put into operation for power generation with the capacities from 6 MW_e to 25 MW_e and at the highest steam parameters of 9.8 MPa and 540 ^oC. However, to some extent the technology of biomass CFB boilers is still immature and in the demonstration phase in China.

This paper reports two CFB boilers with capacity of 12 MW_e and 25 MW_e, respectively, for 100% biomass as fuel using basic technology independently developed by Institute of Engineering Thermophysics (IET), Chinese Academy of Sciences. The paper focuses on the design principles applied to the two boilers and presents commercial operation results.

DESIGN PRINCIPLES OF BIOMASS CFB BOILERS

Generally, compared with coal, biomass has more oxygen, more chlorine and potassium, less carbon, aluminum, iron, titanium and sulfur, and sometimes more calcium. Some special elements in biomass should deserve special attention because the existence of them will be the reason for designing different type boilers from those for coal. The most important element in biomass is potassium, which may form a low melting point ash during combustion in a CFB boiler. The low melting point ash constituents can induce the formation of agglomerates in a CFB boiler, in addition to deposition and corrosion. Accumulation of the agglomerates composed of sand and ash particles bound by fused and glassy materials may lead to defluidization and unscheduled shutdown of a plant (1, 2). The other important element is chlorine with regard to its behavior for related problems in different combustors. Chlorine found in high quantities in certain kinds of biomass, such as straw, may affect a boiler's operation since it can cause serious corrosion. The high chlorine and alkali content of some biomass fuels can lead to severe damage of combustion units. The greatest concern is high temperature corrosion of the superheater by chlorine on the tube surface. Therefore, agglomeration, deposition and corrosion should all be concerned in the biomass CFB boilers design. To biomass CFB boilers, the IET's design has the features as the follow:

- Relatively low temperatures at the combustion chambers, the cyclones and the loop seals, approximately 780 ^{o}C to 880 ^{o}C, which will be different to different kinds of biomass;
- To adopt the final stage superheater panels at the tops of the combustion chambers in order to reduce corrosion. There is no deposition on these tubes due to the movement of bed material particles;
- Kaolin or other minerals are used as bed material or added to the bed to avoid agglomeration of bed material;
- Relatively low gas velocities in the back passes to reduce deposition.

The bulk density of the most biomass fuels, especially agricultural origin, is much lower than that of coals (3). Many disadvantages of biomass fuels, for example, relatively low heating values per unit volume, difficulty of feeding control, requirement of huge storage vessels and expensive transportation, are due to the very low bulk densities The energy density resulting from the bulk density and the net calorific values influences the process control of the fuel supply system. Densification is a good process to overcome these disadvantages. However, it is expensive and some project owners would not like to accept the extra cost to the fuel pretreatment. Nevertheless, herbaceous biomass should be densified before being fed into a biomass CFB boiler. For woody biomass, suitable pretreatment for sizing is necessary to meet the CFB facilities requirements.

Biomass fuels show higher combustion reactivity due to their high volatile content and highly reactive char, but have much lower carbon and high oxygen contents which are responsible for their lower heating values. The moisture content of biomass can vary in a wide range from 10% to 60% in different seasons in a year. High moisture contents would cause ignition and agglomeration issues and reduce the combustion temperature, which in turn hinder the combustion of the reaction products and consequently affects the quality of combustion. Therefore, larger dimensions are required to guarantee the normal operation of the boiler for biomass fuel with high moisture content which generates more flue gas.

Most biomass fuels have low inherent ash contents. However, some materials are produced from the process because soil is incorporated into the fuel. Although dirt increases the ash content, it is still difficult to form good bed material circulation without adding external bed material during the operation of a CFB boiler. Therefore, adding kaolin or other minerals during operation is necessary for a biomass CFB boiler, which also can control the agglomeration of bed material at the same time.

12 MW_e BIOMASS CFB BOILER

Design Specification of the 12 MW_e Biomass CFB Boiler

Biomass fuels for the boiler are mainly sawdust, wood chips and bamboo. The ultimate and proximate analyses of the fuel for the boiler design are listed in Table 1, the biomass boiler arrangement is shown in Figure 1, the main design parameters are given in Table 2.

Table 1 Composition of biomass

	For the 12 MW_e Boiler			For the 25 MW_e Boiler	
	sawdust	bamboo	wood	corn stalk	cotton stalk
Proximate analysis					
Moisture (wt% as received)	48.57	30.4	42.1	9.0	10.5
Ash (wt% as dry)	3.67	4.02	0.74	22.28	11.79
Fixed carbon (wt% as dry)	17.85	—	—	15.60	18.74
Volatile (wt% as dry)	78.48	53.36	47.55	62.12	69.47
Ultimate analysis (wt% as dry)					
C	49.41	48.19	51.19	38.47	44.03
H	5.76	5.01	6.10	4.70	5.23
N	0.63	0.66	0.16	1.11	0.94
O	40.43	42.03	41.73	33.27	37.88
S	0.08	0.05	0.02	0.16	0.14
Cl	0.07	—	—	0.515	0.226
Heating value (MJ/kg, as received)					
LHV	9.48	11.70	10.03	14.10	16.43

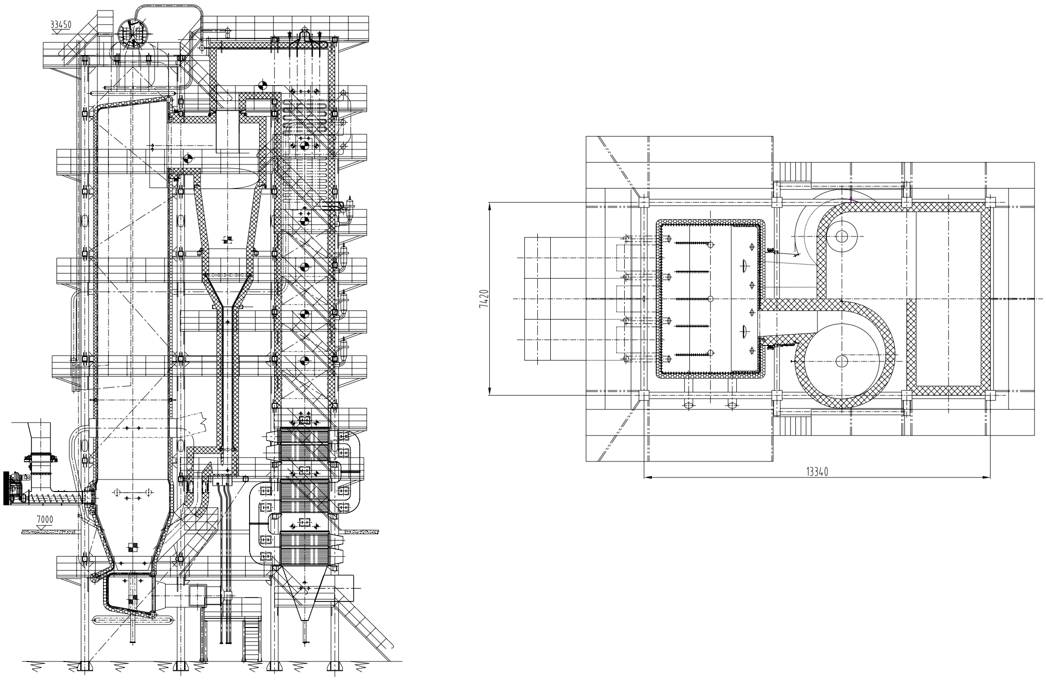

Figure 1 The 12 MW_e biomass CFB boiler arrangement

In Figure 1, there are three sets of horizontal double screw feeders conveying the biomass to the bottom of the furnace. Two adiabatic cyclone separators with a diameter of 3.0 m with water-cooled diplegs are placed between the rear wall of the furnace and the back pass. Two non-mechanical loop seals are located below the two separators. There are two water wall panels and three final-stage superheater panels close to the front wall in the furnace. In the back pass, a middle-stage superheater, a primary superheater, an economizer and an air preheater are arranged along the flow direction of flue gas. Only one stage of spray desuperheater is arranged at the outlet of the middle-stage superheater in the superheater system.

Operation Results

The boiler is at Changguang electricity generation plant in Changxing county of Zhejiang province, China. Commercial operation of the biomass CFB boiler started in March 2010. After a successful 72-hours trial run, the plant was handed over to the owner. The performance test of the boiler was conducted in August 2010.

The design of the biomass CFB boiler was confirmed during commissioning and subsequent commercial operation. The main commercial operating results of the biomass CFB boiler are shown in Table 2. All gas emission values are far below the guaranteed limits.

Table 2 Main design values and operating results of the 12 MW_e biomass CFB boiler

Item	Unit	Design Values	Operating results
Nominal steam capacity	t/h	75	75.18
Steam temperature	^oC	485	481.3
Steam pressure	MPa	5.3	5.3
Feed water temperature	^oC	150	149
Flue gas exit temperature	^oC	138	142
Preheated air temperature	^oC	180	180
Guaranteed boiler efficiency	%	89.37	90.75
Furnace temperature	^oC	810	800
Outlet of furnace temperature	^oC	—	730
NO_x emission (O_2=6%)	mg/Nm^3	200	66
SO_2 emission (O_2=6%)	mg/Nm^3	200	4

Unburnt carbon contents of recirculation ash, fly ash and bottom ash were 0.49%, 3.47% and 1.35%, respectively. The size distributions of recirculation ash and fly ash are shown in Figure 2 and Figure 3. The size of the recirculation ash is widely distributed from 10 μm to 450 μm with a 50% cut size of 135 μm, and the size of the fly ash ranges from 0.5 μm to 120 μm with a 50% cut size of 40 μm.

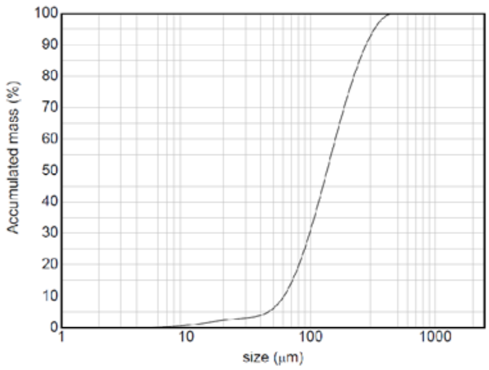

Figure 2 Size distribution of recirculation ash

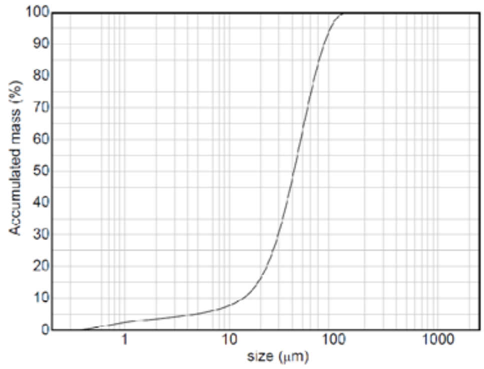

Figure 3 Size distribution of fly ash

However, the moisture content of the biomass fuel often reached 40%~45% in summer. The high moisture content and the non-uniformity feeding of biomass fuel affected the boiler load greatly. In addition, some problems occurred in the biomass fuel feeding system, which resulted in the break age of the fuel supply. The fuel feeding system has now been improved.

25 MW_e BIOMASS CFB BOILER

Design Specification of the 25 MW_e Biomass CFB Boiler

The Main design parameters of the 25 MW_e (130 t/h) boiler are given in Table 3. The biomass fuel for this project were mainly corn stalk and cotton stalk pellets, the ultimate and proximate analyses for boiler design are listed in Table 1, the boiler arrangement is shown in Figure 4.

Table 3 Main design parameters of the 25 MW CFB Biomass Boiler

Item	Unit	Value
Nominal steam capacity	t/h	130
Steam temperature	^oC	540
Steam pressure	MPa	9.81
Feed water temperature	^oC	215
Flue gas exit temperature	^oC	150
Preheated air temperature	^oC	220
Guaranteed boiler efficiency	%	89
Average furnace temperature	^oC	818
NO_x emission limit	mg/Nm^3	200
SO_2 emission limit	mg/Nm^3	200

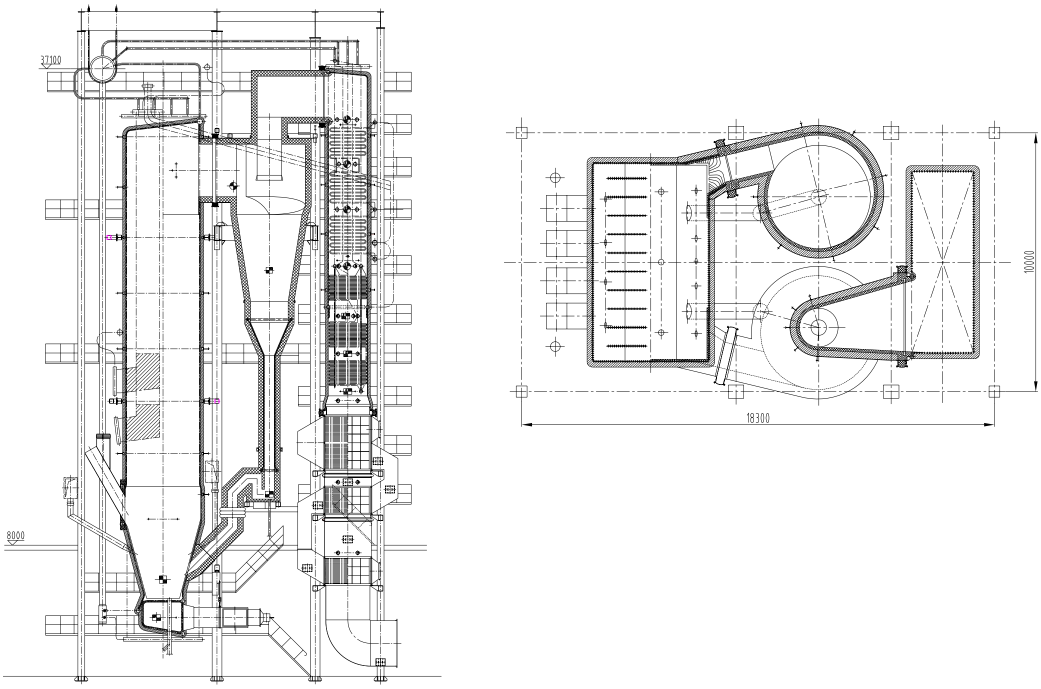

Figure 4 The 25 MW_e biomass CFB boiler arrangement

In Figure 4, there are four sets of horizontal double screw feeders conveying the biomass pellets to the bottom of the furnace. Two adiabatic cyclone separators with a diameter of 4.0 m with water-cooled diplegs are placed between the rear wall of the furnace and the back pass. Two non-mechanical loop seals are located below the two separators. There are four water wall panels, three final-stage superheater panels and three middle-stage superheater panels close to the front wall in the furnace. In the back pass, a primary superheater, an economizer and an air preheater are arranged along the flow direction of flue gas. Two stages of spray desuperheater are arranged at the outlet of the primary and middle-stage superheater separately in the superheater system.

Operation Results

The 25 MW_e demonstration biomass plant is located in Guantao county of Hebei province, China. Commissioning of the plant started in October 2010. In January 2011, the plant met all guaranteed targets in the performance test.

CONCLUSIONS

The 100% of IET CFB biomass boiler technology is capable of combusting a broad range of different biomass fuels, including wood biomass and other agriculture biomass. Furthermore, the technology ensures high steam parameters and enables biomass fired power plants to obtain high efficiencies with emissions far below the limits. So far, the 25 MW_e demonstration power plant has been the biggest 100% biomass fired CFB power plant in China, which is an important milestone.

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