DESIGN AND OPERATION OF 300MW ULTRA-LOW EMISSION CFB BOILER BURNING LOW CALORIFIC VALUE COAL

Tong Boheng[1], Liu Chengliang[2], Zhang Xiaoyu[2], Lu Junfu[1], Yue Guangxi[1]

[1] *Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Thermal Engineering, Tsinghua University, Beijing 100084, China*

[2] *Shanxi Guofeng Coal and Electricity Co., Ltd., Shanxi Fenyang 032200, China*

Abstract –The paper introduce the basic pollution controlling system design and operation condition of Shanxi Guofeng 2×300MW subcritical CFB boiler burning low calorific value coal. This boiler use a low-nitrogen combustion technic combined with SNCR technology to control NO_x emission; a furnace desulphurization combined with semi-dry FGD technology to purify SO_X; a bag-filtering dust precipitator to reduce dust concentration. The results show that the boiler runs steadily and efficiently. The thermal efficiency at full load reaches 90.61%. As for exhaust gas, the concentration of SO_X, NO_X and inhalable particle concentration is 18.75mg/m^3, 40.30 mg/m^3, and 4.9 mg/m^3 respectively, both of which reaches the ultra-low emission standard. The results show that it is a realizable technical solution which contains low-nitrogen combustion with SNCR and furnace desulphurization with SDFGD.

Keywords: circulating fluidized bed boiler, low-calorific coal, ultra-low emission

INTRODUCTION

Thermal power generation has resulted in severe environmental problem such as atmospheric pollution. In order to maintain a healthy and sustainable development of energy industry, the pollution control of thermal power generation has been a priority project in China and all over the world. Chinese Ministry of Environmental Protection (2011) promulgate "Emission standard of air pollutants for thermal power plants"(GB13223-2011) in July, 2014. This standard restrict the dust, SO_X, NO_X concentration into 30 mg/m^3, 100 mg/m^3, 200 mg/m^3 respectively. In September 2014, NDRC (National Development and Reform Commission) and Bureau of Energy (2014) promulgated "Action plan for upgrading of coal energy saving and emission reduction (2014 - 2020)" and officially proposed the "ultra-low emission" concept for the first time. According to Wang S (2015), this standard is said to be the most stringent one which restrict the dust, SO_X, NO_X concentration into 10 mg/m^3, 35 mg/m^3, 50 mg/m^3 respectively. The ultra-low emission is the major development direction. Thus, making power plants meeting the ultra-low emission needs through technical design and reform is the key research target.

Yue G, Yang H, et al. (2010) wrote that circulating fluidized bed boiler (CFB boiler) features wider adaptability various kinds of coal and lower cost on pollution control. CFB boiler is one of the best commercialized clean coal combustion technologies. Particles fluidize and circulate in the boiler with low combustion temperature and limestone injection desulfurization inside, so inferior fuel and low calorific coal can be burned efficiently. However, inferior fuel itself has features of high ash, sulfur content and original pollution generation. Li J (2013) wrote that design and operate continuously a low calorific coal meanwhile maintaining ultra-low emission standard is a research emphasis now.

As the technology of circulating fluidized bed boiler developing, power plants burning low-calorific coal, especially coal gangue, have become more and more mature according to Shuang W (2014). Zhang Y (2014) reported that he biggest low-calorific coal utilizing power plant –Jilin Baishan coal gangue power plant adopt SNCR denitration technology, of which NO_X emission reaches 125 mg/m^3. Luo L (2015) reported that Shanxi Guojin 300MW power plant was put into use in 2015, and can burn 1.7 million tons inferior coal each year. However, neither of the power plants above meet the ultra-low emission standard.

Based on above problems, Tsinghua University and Dongfang Boiler Group CO., LTD research together for a reliable ultra-low technical route and work out Shanxi Guofeng 300MW subcritical CFB boiler burning low-calorific coal, integrating with energy-saving CFB technology (2010), low-nitrogen combustion, SNCR, inner desulphurization, semi-dry flue gas purification, bag dedusting and so on. This paper introduce the design and operation condition of pollutant removal system and the technological process, analysis the experiment statistics about the running condition. The results show that this boiler runs steadily and efficiently, and reaches the ultra-low emission standard.

MAIN FEATURES

Characteristics about the boiler

The primary parameters are shown in table 1. This boiler is a subcritical one. The property of the design and check coal is shown in table 2. This boiler burns high sulphur coal or coal gangue which features high ash, high volatiles and low carbon content. The ash content of the coal is more than 50%, and the carbon content is relatively low. It is worth noting that the Sulphur content is as much as 2.03%, which makes the original generation of SO_X is high.

Table 1 Design parameter of the boiler

Major parameters	Units	Value
Electrical load	MW	300
Flux of superheated steam	t/h	1085.3
Pressure of superheated steam	kJ/kg	17.5
Temperature of superheated steam	℃	541
Feed-water temperature at the economizer entrance	℃	280.6
Exhaust gas temperature（modified）	℃	117.28

Table 2 Property of the design coal and check coal

Project		Notation	Units	Design coal	Check coal
Elemental analysis	Carbon	C_{ar}	%	28.67	26.06
	Hydrogen	H_{ar}	%	2.9	2.63
	Oxygen	O_{ar}	%	3.51	3.64
	Nitrogen	N_{ar}	%	0.82	0.85
	Sulphur	$S_{t,ar}$	%	2.03	2.02
Proximate analysis	Ash	A_{ar}	%	50.64	52.99
	Moisture	$M_{t,ar}$	%	11.43	11.81
	Volatiles	V_{daf}	%	29.38	29.68
	Low heating value	$Q_{net,ar}$	kJ/kg	12248	11066

This is a subcritical natural circulating one-drum boiler adopting Γ-style structure design. The boiler consists of a furnace, three cooling cyclone separators and a tail shaft. There are six tube panels of medium temperature super heaters, six tube panels of high temperature super heaters, a water-cooling partition wall in the front wall of the furnace, and two water cooling wall in the back wall. There are eight coal-feed entrances uniformly distributed under the water-cooling partition wall. There are four slag outlets connected with four roller slag coolers at the bottom. There are two chimney flue in the tail, constructed with three low temperature reheaters and four low temperature super heaters. At the end of the flue, there are two economizers and a rotary air-preheater. The exit connect with a desulfurizing tower and fabric filters. The basic structure is shown in figure 1.

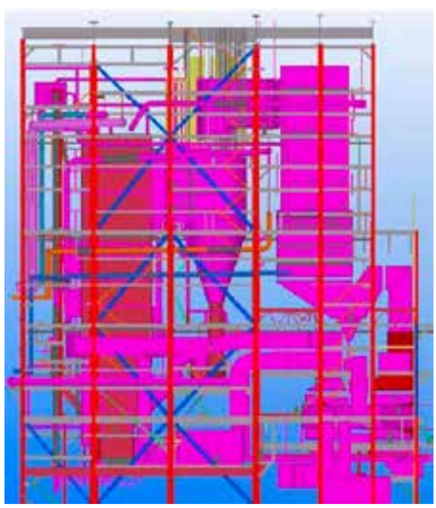

Fig 1. Front view of the 300MW subcritical CFB boiler

SO_2 controlling technology

The design fuel of the boiler is high Sulphur coal, so that the original generation of SO_2 is very high. According to the characteristics of the check coal (S_{ar}=2.06%), the original SO_2 generation without desulphurization device can be calculated as equation (1). Xun X, et al. (2014) reported this equation.

$$\omega_{so_2} = \frac{S_{ar} \times \dfrac{M_{SO_2}}{M_S}}{V_{gy}} \tag{1}$$

In the equation, S_{ar} represents the Sulphur content. M_S and M_{SO2} represent the formula weight of S and SO_2. V_{gy} represents the volume of dry flue gas each kilogram fuel creates, which have been calculated as 4.985 m^3/kg by the properties of the check coal. The original generation is 4132.39 mg/m^3[10]. If the emission reaches the ultra-low standard (35 mg/Nm^3), the total desulphurization efficiency has to be at least 99.1%.

Regular desulphurization efficiency inside the furnace of CFB is about 90%, which is unable to meet the ultra-low standard. Therefore, flue gas desulphurization (FGD) device should be equipped. In this boiler, an in-furnace desulphurization combined with FGD device is used, both of which efficiency are more than 90%.

In-furnace desulphurization is to add limestone into the boiler so that it will circulate as bed material. The coal particle and the limestone stay and mix adequately in dense-phase zone. Limestone calcine and decompose into CaO and CO_2. Flue gas carry unburned coal and CaO particles into the lean-phase zone where SO_2 carry on sufficient gas-solid reaction on the surface of the particles and is absorbed. The efficiency is more than 90%.

Desulfurizer inside the furnace is limestone. The calcium sulfur ratio Ca/S is usually more than 1. The higher ratio is, the higher desulphurization efficiency is. However, too much limestone leads to low bed temperature and less thermal efficiency. Li X (2007) wrote that the Ca/S is chosen to be 2 after analysis[11]. The details are shown in table 3.

Table 3 Desulphurization performance by limestone particle injection into the furnace

Project	Units	Design coal	Check coal
Sulphur content	%	2.03	2.02
Coal feed quantity	t/h	257.23	197.78
In-furnace desulphurization efficiency	%	90	89.49
Calcium sulfur ratio		2	1.66
SO_2 original generation	mg/m^3	4132.3	4041.4
Furnace outlet SO_2 concentration （6% O_2）	mg/m^3	441.4	424.6
Limestone quantity	t/h	26.55	16.7

Flue gas desulphurization (FGD) in this boiler adopt semi-dry desulfurization (SDFGD) technology. This system includes gas flue, absorption tower, fabric filter, absorbent supply system, recirculating system, ash discharge system and so on. The schematic diagram is shown in figure 2.

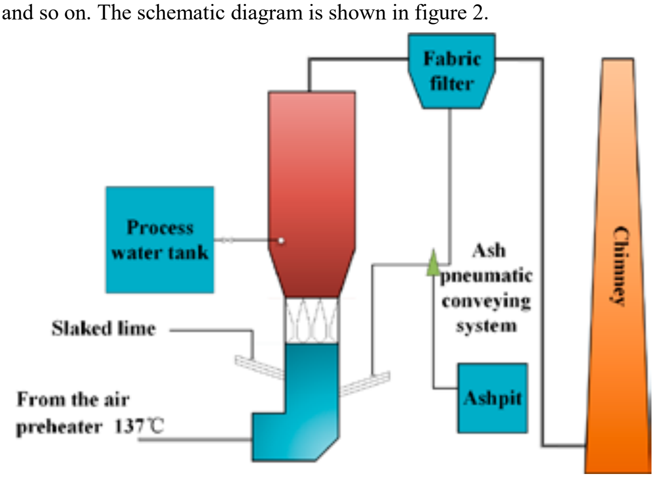

Fig. 2 System diagram of circulating fluidized bed flue gas desulphurization

137℃ flue gas from the air preheater enter the bottom of absorption tower. At the entrance, flue gas, desulfurization ash and slaked lime slurry mix sufficiently and then make preliminary reaction. Then the mixture accelerate by a Venturi tube. After nebulized by a nozzle, the temperature reduce to about 75℃ (20℃ more than gas dew point). In the circulating fluidized bed of the absorption tower, particles and gas mix drastically where SO2 and Ca(OH)2 react sufficiently. After the reaction, flue gas together with circulated desulfurized ash enter the fabric filter and separate into gas and solid phases. The seized circulated ash return to absorption tower. Redundant ash is carried to a ash pit by ash pneumatic system.

In the absorption tower, slaked slime and other particles form into floccule. In the tower, floccule arise and descend repeatedly so that the sliding velocity can be ten times more than one particle's. On the other hand, the density of the bed is high, and the Ca/S is more than 50, where SO2 is absorbed sufficiently. The designed flue gas velocity is between 4 and 6 m/s. the residence time is about 6 seconds.

NO_X controlling technology

Guofeng 300MW CFB boiler adopts low-nitrogen combustion combined with SNCR technology.

The low-nitrogen technology is based on state specific design theory. The invalid bed material quantity is reduced, thus primary air flow rate is reduced. Consequently, secondary air flow rate increase, and reducing atmosphere in dense-phase is strengthened, according to Li J (2016). The NOX generation amount is reduced .

In this boiler, primary air enter into the furnace from the air inlet chamber. Secondary air contributes on the front and back wall in three layers. The secondary air can help supply adequate air, control equivalence ratio and optimize the redox atmosphere. Therefore, the NOX generation in this boiler is lower than normal CFB boiler.

Thanks to the low-nitrogen technology, a SNCR device can meet the final needs of 50mg/Nm3. According to the experiment statistics, the efficiency of SNCR can be at least 67%.

The SNCR device adopt urea solution. There are three spray gun on the top and three at the bottom in the entrance of separator. Dilute urea solution react with the flue gas and denox. The system diagram is show in figure 3.

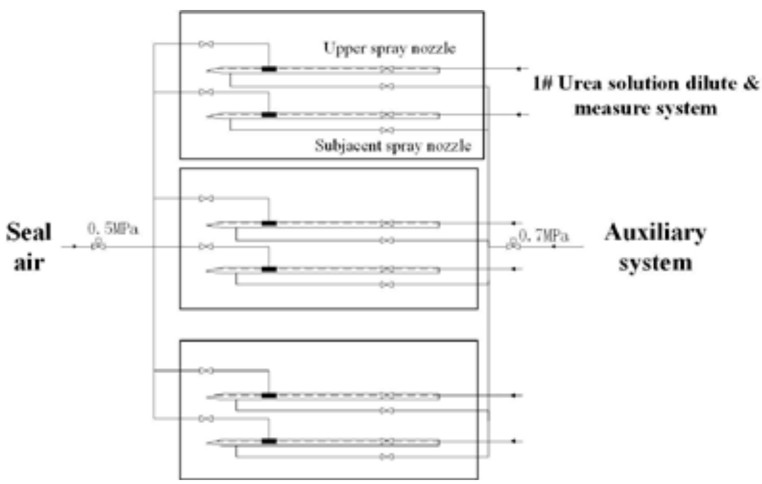

Fig. 3 System diagram of SNCR by urea solution

Dust controlling technology

Based on the semi-dry gas fuel desulphurization technology, fabric filters are used to control dust concentration. According to the experiment, the ash concentration is below 10mg/Nm3.

OPERATION RESULTS AND ANALYSIS

Since the project start up, this boiler has been running stability and efficiently. The thermal efficiency on full load is 90.61%. When the electrical load varies from 200 to 300MW, the emission of SO2, NOX and dust remain stable, and meet the ultra-low emission standard. Here are the experimental statistics of the operation results.

Operation results of desulphurization and dust removal system

The operation results of in-furnace desulphurization is shown in figure 4 with limestone injection amount fixing. In the figure, the desulphurization efficiency means the ratio between the concentration in the absorption tower inlet and the original generation of SO2. It is shown that as the electrical load increase, the furnace outlet SO2 concentration decreases and the in-furnace efficiency increases. This can be explained by the bed temperature. After the limestone enters the furnace, it will first decompose into quick lime and carbon dioxide. When the temperature increases within certain limits (850~900℃), the pyrolysis reaction rate increases. Therefore, there are more and larger pore spaces on the surface so that the reaction is more sufficient. The desulphurization efficiency increases. It is also shown that the efficiency is as high as 98%, which largely reduce the burdens of semi-dry desulphurization. There are even some operations that the slaked slime slurry simplify into water. The residential desulfurized fly ash can meet the needs. But despite of the high efficiency, the SO_2 concentration is still about 100~300 mg/Nm^3. The flue gas desulphurization device is essential. Because of the semi-dry FGD, the calcium sulfur ratio in furnace is slightly under 2.

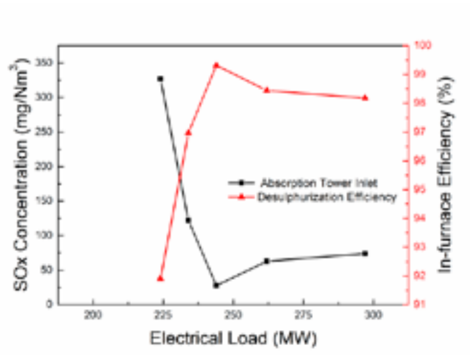

Fig. 4 Desulphurization efficiency by limestone particle injection into the furnace at different load

The flue gas desulphurization results between designed and operation parameters on full load are shown in table 4. The SO_2 emission concentration is 28.65 mg/m^3 and meets the ultra-low emission standard.

Table 4 Comparison of circulating fluidized bed flue gas desulphurization between design and operation

Project	Units	Design	Operation
Inlet flue gas flow rate（measured）	m^3/h	1907854	1419085
Excess air ratio		1.3	1.29
Inlet SO_2 concentration（6% O_2）	mg/m^3	441.1	424.6
Inlet flue gas temperature	℃	137	109.95
Desulphurization efficiency	%	90	93.3
Outlet SO_2 concentration（6% O_2）	mg/m^3	44.1	28.65
Outlet dust concentration	mg/m^3	≤10	1.25
Outlet flue gas temperature	℃	75	77.02

Figure 5 shows the SO_2 emission concentration on various electrical load when semi-dry desulphurization devices are put into operation. The SO_2 concentration statistics are from the exit of absorption tower. As the figure shows, the SO_2 concentration is below 20 mg/Nm^3 at various electrical load, which all meet the ultra-low emission standard.

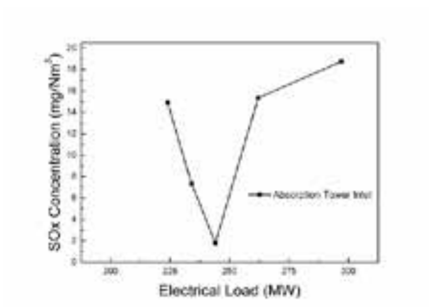

Fig. 5 SO_2 emission at different load

Operation results of denitration system

The operation parameters of NO_X control are shown in table 5. The NO_X generation concentration is measured when SNCR device is turned off. It is shown that at the full electrical load, NO_X emission concentration is 40.3 mg/m^3 which meets the ultra-low emission standard. The efficiency is 83.6%.

Table 5 Operation parameter of NO_x control

Project	Units	Operation
Flue gas flow rate	m^3/h	1419085
NO_x generation concentration	mg/m^3	246.95
NO_x emission concentration（measured）	mg/m^3	42.25
NO_x emission concentration（6% O_2）	mg/m^3	40.3
Denitration efficiency	%	83.6

The NO_X emission concentration under several electrical load is shown in figure 6. In this figure, the SNCR urea injection amount of every operating point maintain stable. It can be shown that the highest emission concentration is about 43 mg/Nm^3, and is below the ultra-low emission standard. As the electrical load increases, the NOX generation concentration increases. According to Li J (2013), the combustion temperature of CFB boiler is around 850~950℃, where NO_X is primarily fuel-NO_X. As the thermal load increases, the bed temperature increases. Therefore, the coke concentration in dense phase decreases, and thus the NO decomposition reaction on the coke surface gets harder to take place. Also the reducing atmosphere is weaken because of the CO concentration decreases. Hence the NO decomposition rate is lower. NOX concentration increases consequently.

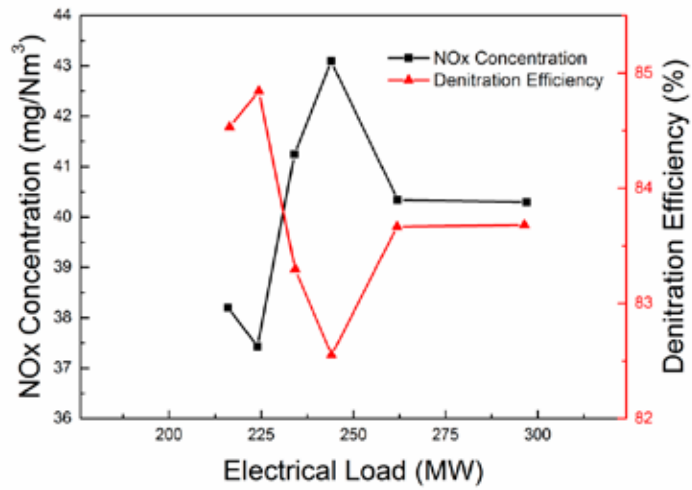

Fig. 6 NO_x emission at different load

CONCLUSION

Shanxi Guofeng 300MW power plant burning low-calorific coal adopt energy saving circulated fluidized bed design. In-furnace desulphurization, flue gas desulphurization, low nitrogen combustion, SNCR, fabric filter technologies are used and ultra-low emission standard is reached. At the full load, the thermal efficiency is about 90.61%. The SO_2 emission concentration is 18.75mg/Nm^3. The NO_X emission concentration is 40.30 mg/Nm^3. The dust concentration is about 4.9mg/Nm^3. The in-furnace desulphurization efficiency is more than 98%, which largely reduce the burdens of semi-dry flue gas desulphurization. The FGD efficiency is more than 90%. The SNCR denox efficiency is more than 82%. At different load (210~300MW), the pollution emission maintain stable, and meet the ultra-low emission standard. The Guofeng power plant show that it is a quite feasible technical route that CFB boiler adopt low-nitrogen combustion, SNCR, in-furnace desulphurization, semi-dry FGD and fabric filter technologies.

NOTATION

S_{ar}	Sulphur content, %	M_{SO2}	formula weight of SO_2, mol
M_S	formula weight of S, mol	V_{gy}	volume of dry flue gas, m^3/kg

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