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Analysis of electrostatic precipitation characteristics of coal fired in Vietnam and engineering application

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Abstract

The electrostatic precipitation (ESP) characteristics of 16 kinds of Vietnamese coal smoke and dust are counted and compared with 51 kinds of China coal. It finds that the Na_2O content of Vietnamese coal ash is significantly low and resulting in poor ESP performance. A comparison is made between the emission indicators of coal-fired flue gas and dust at home and abroad, and it find that the Vietnamese standard requirements are relatively low. The selection and design of the ESPs for the *Yongxin* project in Vietnam are carried out. After the project is put into operation, the performance of the project is tested and compared. The results shows that the core components of the ESP, which were produced in China, could achieve an export dust concentration of 30.2 mg m^{-3} and a dust removal efficiency of 99.93%, far superior to the owner's requirement of 98 mg m^{-3} and Vietnam 200 mg m^{-3} Emission standards when burning low-quality Vietnamese coal, which have the advantages of compact structure, low cost, and great potential for international market promotion.

Keywords: Coal power plan, electrostatic precipitator (ESP), foreign applications, outlet dust concentration, Vietnamese coal.

1. Introduction

Electrostatic precipitators have a history of over 400 years of application in the world. In early 1600, Gilbert [1] discovered that dust in flue gas can be separated by charging. China has experienced rapid development for more than 50 years since the introduction of electrostatic precipitator technology with the assistance of the United Nations. Currently, China's electrostatic precipitator level is among the world's leading countries, with the technology level reaching international level. The number of electrostatic precipitators produced and used ranks first in the world, especially in recent years, with the comprehensive implementation of China's "ultra-low emissions" policy, the world's largest coal-fired clean power generation has been created.

In August 2021, the State Administration for Market Regulation and the National Standardization Administration officially released the national standard GB/T 40514 Electrostatic Precipitator [2], which improved the electrostatic precipitator standard from the national standard level and maintained the international status and image of China's electrostatic precipitator technology and products. In March 2022, the Opinions on Jointly Building the "the Belt and Road" Green Development jointly issued by the Ministry of Ecology and Environment and other departments requires that overseas projects be promoted in a coordinated manner, and under the "the Belt and Road" initiative and policy, overseas business will become a new growth point of the environmental protection industry.

Electrostatic precipitators have an absolute advantage in Germany and Japan because developed countries have better coal quality, stable coal sources, high calorific value, low ash content, and commonly use coal washing technology. The advantages of using electrostatic precipitators are obvious. Most coal-fired power plants in developing countries such as India and Vietnam also use electrostatic precipitators. Indian coal has disadvantages such as high fly ash content, high specific resistance, and low calorific value, making it difficult for electrostatic precipitators to capture dust from Indian coal. However, in recent years, new 600MW units have still chosen electrostatic precipitators with multiple electric fields and large dust collection areas. Over 90% of Indian coal-fired power plants use electrostatic precipitators. The European HVAC Association Alliance has stated that "dry electrostatic precipitators can ensure emissions below 10 mg m^{-3} and can reach below 5 mg m^{-3} if needed". From the above analysis, it can be seen that many unique advantages of electrostatic precipitators are recognized by various countries.

In order to improve the dust removal performance of electrostatic precipitators on coal-fired flue gas, fully understand the differences in coal types and electrostatic precipitator characteristics in different regions, it is urgent to analyze the influence of coal composition and ash composition on electrostatic precipitators. Coal composition and ash composition data were collected from different regions of the world to provide data support and analysis for improving the adaptability of electrostatic precipitators to different coal types worldwide, especially for improving the selection accuracy.

2. Analysis of ESP dust removal characteristics of Vietnamese coal and ash

The main affecting factors of ESP performance mainly include external conditions [3], ESP technology status, and operating conditions, as shown in Fig. 1. The coal and fly ash components under external conditions have the greatest impact on the dust removal performance of ESP [4, 5].

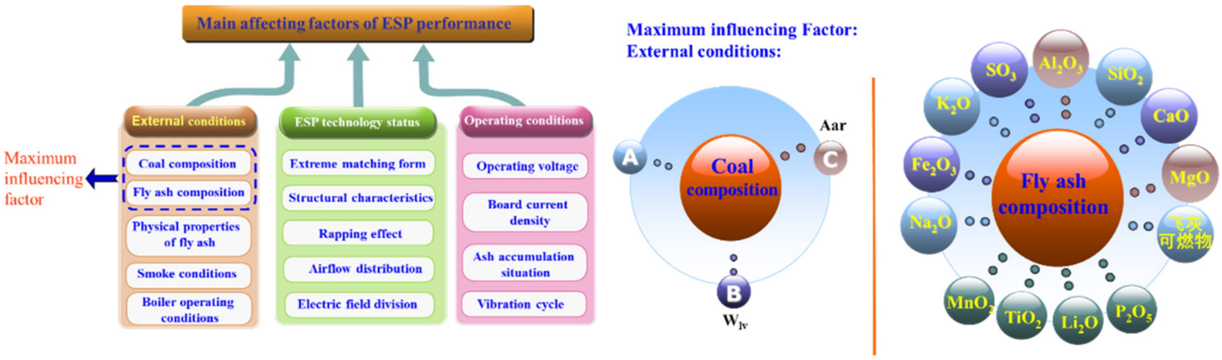


Fig. 1. Conditions of pilot test.

Sar and Na_2O in coal components and Al_2O_3 and SiO_2 in ash components have a significant impact on ESP performance. Sar and Na_2O are beneficial for dust removal, while Al_2O_3 and SiO_2 are not. The 16 commonly used coal-fired coal types in Vietnam were collected, tested and analyzed, and the coal and ash components that have the greatest impact on ESP are shown in Table 1. Statistical analysis was conducted on the coal and ash components of 51 types of coal in China. The distribution of the main components of coal and ash in China that affect the dust removal performance of ESP is shown in Table 2.

In the table, Sar means sulfur activity ratio, refers to the proportional relationship between sulfur element and ash content in coal. Aar means ash as received basis, refers to the ash content of coal in the received state. W_{lv} means coal's received moisture content.

By comparing and analyzing data, the coal composition and ash content of 51 coal types in China and 16 coal types in Vietnam were classified. The distribution range of coal composition and ash content of Chinese coal types is shown in Table 1. From the data, it can be seen that the Na_2O content in Chinese coal ash generally ranges from 0.3% to 3.72%, while only the Na_2O content in the ash corresponding to Laibin coal, Pingdingshan bituminous coal, and Zhungeer coal is below 0.3%. The Na_2O content in Vietnamese coal ash is generally below 0.5%, which is significantly lower than that in Chinese coal ash.

Bickelhaupt from the Southern Institute of Research in the United States found that the content of Li_2O and Na_2O has a significant impact on the dust specific resistance. K_2O and Na_2O are beneficial for dust removal, but K ions transform into glass phase and need to act through Fe_2O_3. Therefore, the effect of K_2O is smaller than that of Na_2O. Studies have shown that its contribution to electrostatic dust removal is about 20% of that of Na_2O

Table 1. Main components of coal and fly ash in Vietnam's major coal-fired coal types; Unit: %.

Item	Main coal components			Main fly ash components							
	Aar	Sar	W_{lv}	SiO_2	Al_2O_3	Na_2O	Fe_2O_3	CaO	MgO	TiO_2	K_2O
Vietnamese coal type A	38.8	0.82	8.9	59.15	25.68	0.38	7.5	0.7	1.27	0.8	3.52
Vietnamese coal type B	30.9	0.62	8.2	60.15	24.20	0.30	6.70	0.73	0.73	0.90	4.30
Vietnamese coal type C	36.0	0.25	16.0	23.00	13.00	0.25	17.75	31.00	6.50	0.60	0.50
Vietnamese coal type D	35.2	6.16	12.0	45.17	27.60	0.50	19.26	1.12	1.40	0.39	2.32
Vietnamese coal type E	27.7	0.85	9.4	54.97	26.96	0.46	11.09	0.81	0.88	0.52	3.7
Vietnamese coal type F	8.98	0.53	25.0	37.4	23.2	0.3	17.0	8.0	3.2	1.28	0.7
Vietnamese coal type G	10.9	0.76	28.0	58.10	23.50	0.19	9.97	2.80	0.30	0.78	0.76
Vietnamese coal type H	41.3	0.83	8.0	59.15	25.68	0.38	7.5	0.7	1.27	0.8	3.52
Vietnamese coal type I	40.0	0.19	15.0	23.00	13.00	0.25	17.75	31.00	6.50	0.60	0.50
Vietnamese coal type J	9.5	0.42	9.5	55.90	32.50	1.00	3.20	2.80	1.70	1.80	0.50
Vietnamese coal type K	27.7	0.85	9.40	54.97	26.96	0.46	11.09	0.81	0.88	0.52	3.70
Vietnamese coal type L	90.0	0.23	15.0	58.75	27.23	0.26	6.58	0.71	0.59	0.66	4.00
Vietnamese coal type M	50.2	0.18	12.3	60.83	26.47	0.84	5.51	0.50	0.84	0.61	4.15
Vietnamese coal type N	28.7	0.65	12.4	23.00	13.00	0.25	17.75	31.00	6.50	0.60	0.50
Vietnamese coal type O	26.0	0.53	12.0	55.90	32.50	1.00	3.20	2.80	1.70	1.80	0.50
Vietnamese coal type P	45.0	0.70	8.55	58.12	27.86	0.30	6.00	1.30	1.06	0.52	3.44

The comparison of coal composition between China and Vietnam is shown in Figs. 2 and 3. Na_2O increases the volume conductivity of fly ash, reduces the volume specific resistance, increases the concentration of conductive ions, thereby reducing the dust specific resistance and improving the electrostatic dust removal performance. When the sulfur content in coal is very low, if the Na_2O content is above 2%, high electrostatic dust removal efficiency can still be guaranteed.

The relationship between Na_2O content and ω_k was tested for typical coal types at different S_{ar} contents, as shown in Fig. 4. ω_k represents the approaching speed of the ESP, ω_k refers to the speed at which dust particles migrate towards the dust collection plate under the action of electric field force. This speed is one of the important indicators for evaluating the performance of electrostatic precipitators, as it directly affects the dust removal efficiency of the precipitator. The faster the approach speed, the faster the dust particles are collected, and the better the dust removal effect.

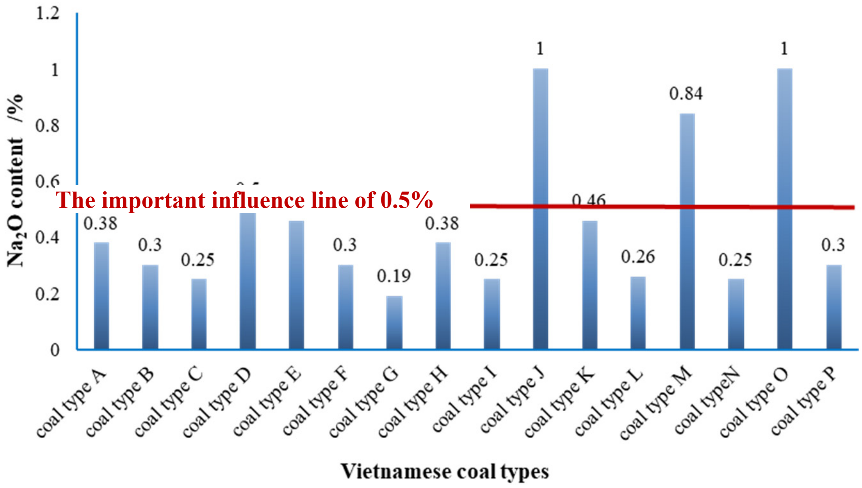


Fig. 2. Distribution of Na_2O content in flue gas ash from Vietnamese coal types.

Table 2. The main components of coal and fly ash in China's major coal-fired coal types; Unit: %.

ON.	Coal type	Main coal composition		Main fly ash composition							
		Aar	Sar	Na_2O	Fe_2O_3	K_2O	SO_3	MgO	Al_2O_3	SiO_2	CaO
1	Junlian anthracite coal	32.25	2.80	1.40	12.18	1.40	4.57	1.54	18.33	51.77	7.69
2	Songzao Mine Poor Coal	25.35	3.47	0.76	16.51	0.85	2.38	0.63	24.36	44.61	5.22
3	Shenfu Dongsheng Coal	11.00	0.41	1.23	13.85	0.72	9.30	1.28	13.99	36.71	22.92
4	Shenhua coal	8.50	0.45	1.23	11.36	0.73	9.30	1.28	13.99	36.71	24.69
5	Shenmu bituminous coal	6.40	0.39	1.50	7.00	0.70	11.00	1.20	13.00	35.00	26.00
6	Lignite from Shengli Coalfield	20.22	1.00	2.53	7.74	1.59	4.50	2.13	20.16	52.86	4.89
7	Shaanxi Huangling Coal	18.61	0.98	0.44	5.08	1.33	6.28	1.67	17.12	53.64	6.63
8	Shaanxi bituminous coal	28.83	0.90	0.91	5.72	0.78	4.68	0.91	26.66	51.70	4.17
9	Longxi Mine bituminous coal	23.80	0.78	0.72	11.53	1.43	2.26	1.66	21.83	50.64	10.76
10	Hunchun lignite	32.18	0.24	1.62	5.26	1.46	2.20	1.83	23.73	58.70	2.22
11	Pingzhuang lignite	20.41	0.89	1.19	7.99	3.00	0.38	1.34	21.99	60.14	3.36
12	Jinbei Coal	19.77	0.63	0.78	23.46	1.55	1.28	1.27	15.73	50.41	3.93
13	Nayong anthracite coal	21.38	2.90	3.63	7.85	1.39	1.10	1.96	25.19	54.40	2.88
14	Shuicheng bituminous coal	30.86	2.15	1.32	10.41	0.81	0.54	0.92	28.75	50.25	3.56
15	Iron ore coal	30.58	0.39	1.78	7.53	2.43	0.74	1.62	19.87	59.91	1.58
16	Yongcheng coal type	21.59	0.42	0.68	3.56	2.43	2.12	1.04	9.76	54.87	4.48
17	Jiangxi Fengcheng Coal	30.00	1.62	1.10	7.09	1.29	0.02	0.46	32.12	54.90	0.64
18	Okubrak coal	13.63	0.62	2.29	8.65	4.98	1.67	2.41	19.06	54.08	5.24
19	Coal in Datong area	22.44	1.11	0.53	8.95	1.15	1.28	1.30	31.76	50.50	2.89
20	Ulanmulun coal	13.07	0.58	0.82	6.11	1.20	6.69	1.18	14.99	45.01	18.21
21	Anthracite coal	16.18	1.11	0.62	11.38	0.89	3.65	0.79	26.00	50.77	3.12
22	Shanxi Pingshuo 2 # Coal	18.30	1.00	0.71	4.14	0.80	1.32	0.44	42.16	42.76	3.50
23	Live chicken and rabbit coal	7.04	0.50	0.43	20.66	0.70	16.20	1.08	12.66	26.31	18.09
24	Binchang bituminous coal	18.88	0.73	0.30	5.42	0.87	4.15	1.59	22.46	49.59	11.66
25	Shanxi Pingshuo Coal	21.47	1.13	0.68	2.63	0.43	2.20	0.33	40.02	47.96	4.15
26	Baorixile coal	7.22	0.24	0.52	12.04	0.74	5.42	2.31	18.80	42.86	12.65
27	Jinzhushan smokeless coal	32.87	0.80	1.00	4.18	1.86	1.86	1.35	32.00	53.97	2.72
28	Shuicheng lean coal	23.78	0.43	0.42	7.81	0.81	0.73	0.67	27.06	55.98	4.23
29	Diandong bituminous coal	32.45	0.85	0.57	8.97	0.16	0.75	1.04	22.43	58.94	3.25
30	Shanxi anthracite coal	20.84	0.39	0.52	3.97	1.34	2.95	1.03	30.39	52.05	4.55
31	Longyan anthracite coal	30.00	0.98	0.14	7.79	2.27	5.31	2.88	28.61	40.86	9.27
33	Jixi bituminous coal	34.15	0.22	0.90	3.35	2.08	0.18	0.96	22.34	64.38	0.48
33	Xinji bituminous coal	26.33	0.63	0.62	4.76	0.95	1.76	0.61	32.61	53.64	1.08
34	Huainan coal	26.65	0.35	0.70	3.20	1.00	1.20	1.20	33.00	54.00	2.00
35	Pingshuo Antaibao Coal	21.30	0.87	0.49	3.60	0.67	1.67	0.81	33.50	52.31	4.65
36	Shenhua Zhuluoji Coal	7.55	0.47	0.37	15.00	0.70	11.00	1.20	13.00	30.00	28.00
37	Shanxi lean coal	20.00	0.37	0.62	4.55	0.85	0.62	1.23	31.15	52.88	5.67
38	Hegang Coal Mine	34.93	0.19	0.70	4.53	2.46	0.70	0.79	20.79	66.71	1.56
39	Shanxi Fenxi Coal	26.86	0.55	0.61	2.82	1.48	0.45	0.70	30.90	59.65	1.36
40	Huolinhe lignite	19.01	0.34	0.69	2.82	1.11	1.7	0.94	22.6	64.25	4.01
41	Huaibei bituminous coal	29.80	0.70	0.28	4.50	1.78	1.59	1.16	32.81	55.18	2.40
42	Datong Tashan Coal	11.76	0.45	0.34	5.17	0.85	2.29	0.44	35.47	48.69	3.21
43	Tongxin Coal	24.52	0.80	0.17	5.76	0.34	1.19	0.41	38.97	47.24	2.13
44	Yitai 4 # coal	16.77	0.63	0.20	6.36	0.78	1.51	0.62	34.70	49.90	2.27
45	Yanzhou coal	21.39	0.55	0.32	3.99	1.54	2.08	1.44	27.45	55.93	4.17
46	Zhaozhuang Mine Poor Coal	20.97	0.33	0.43	2.64	0.85	1.45	1.40	30.55	57.03	3.53
47	Zhengzhou Poor Coal	28.11	0.17	0.40	4.93	1.40	1.06	0.94	29.00	54.24	6.04
48	Laibin Guomei	39.25	0.31	0.10	11.86	0.78	1.50	0.97	25.31	51.13	3.01
49	Pingdingshan bituminous coal	37.80	0.44	0.13	4.05	0.30	0.41	0.40	27.93	64.57	0.60
50	Jungar coal	21.36	0.62	0.02	2.56	0.22	0.49	0.47	46.50	42.75	4.18
51	Xinjiang Zhundong Coal	3.3	0.44	6.43	5.89	0.27	16.50	9.13	7.90	23.48	28.96

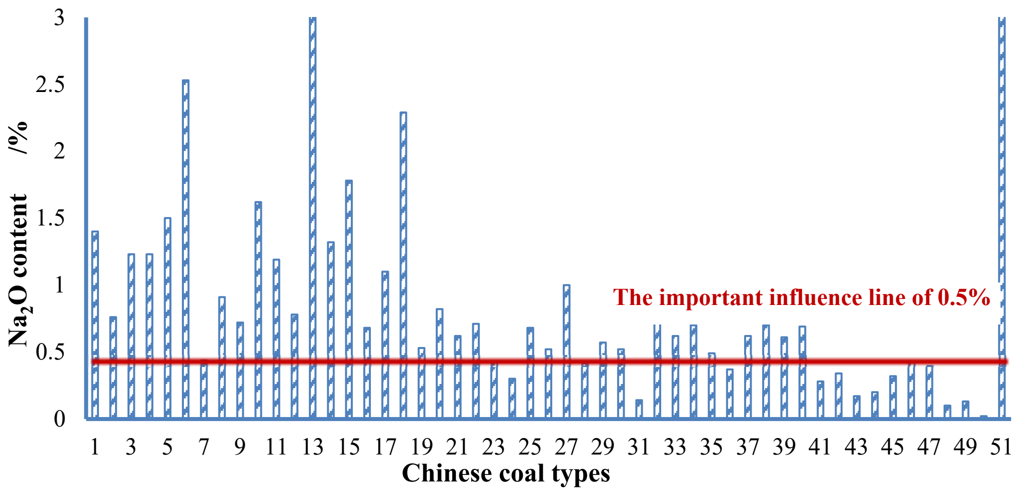


Fig. 3. Distribution of Na_2O content in flue gas ash of Chinese coal types.

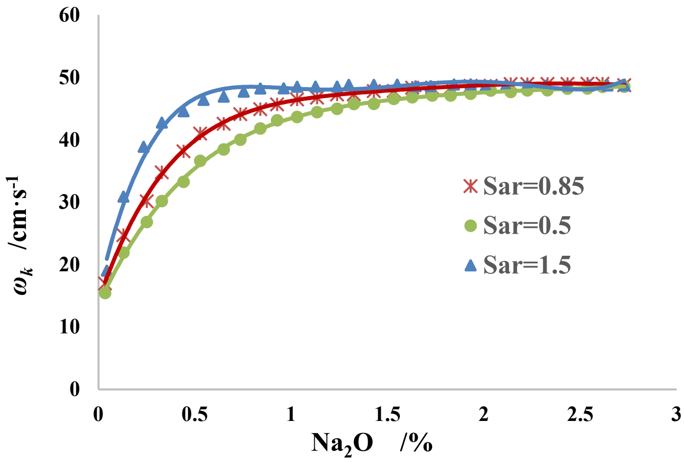


Fig. 4. Relationship curve between ω k and Na_2O content.

From the data, it can be concluded that:

a. The higher the Na_2O content, the better the electrostatic dust removal performance.

b. The effect of Na_2O on electrostatic dust removal performance is related to the content of S_{ar} in coal.

c. When the Na_2O content in fly ash is less than 0.5%, the value of ω_k is relatively small, within the range of 0-0.5%, an increase in Na_2O content can significantly enhance the electrostatic dust removal performance, with a significant impact within this range. d. After the Na_2O content exceeds 1%, the value of ω k is relatively high, but the increase in Na_2O content has almost no effect on the change of ω_k. That is, when the Na_2O content is greater than 1%, the increase in its content cannot significantly enhance the dust removal performance.

From the above analysis, it can be seen that the Na_2O content in Vietnamese coal ash is generally below 0.5%. Within this range, the Na_2O content has a great impact on the electrostatic dust removal performance, which is significantly lower than that of Chinese coal.

3. Comparison of dust emissions in major countries and regions

The concentration limit form adopted in China's GB 13223-2011 Emission Standards for Air Pollutants from Thermal Power Plants [6, 7] shows that China has complex coal types, variable loads and operating conditions, and there is still room for improvement compared to the collaborative dust removal efficiency between pollution control equipment in developed countries such as Japan [8−11].

The 2005 version of the United States requires coal-fired power plant boilers to reach 0.015 lb/MBtu or 0.14lb/MWh (approximately 20 mg m^{-3}), with electrostatic precipitators accounting for about 80%. The

European Union has implemented the "Directive on Emission Limits for Air Pollutants from Large Combustion Enterprises" (2001/80/EC) to limit smoke and dust emissions, requiring boilers with a capacity of 50-100MW or above that use solid fuel to operate at 50 mg m^{-3} and boilers with a capacity of 3100 MW or above that use solid fuel to operate at 30 mg m^{-3} The EU's electrostatic precipitators account for about 85%, and the average export dust concentration limit of electrostatic precipitators in Western Europe is less than 10 mg m^{-3} Almost all coal-fired power plants in Japan use electrostatic precipitators, which require large coal-fired power plants to emit smoke and dust below 100 mg m^{-3}, with a special emission standard of 50 mg m^{-3}. Local governments can establish stricter local standards through laws and regulations. Most local governments set dust emission standards below 20 mg m^{-3}, and the actual operating electrostatic precipitators have reached lower values.

The National Technical Specification for Waste Gas from Thermal Power Industry in Vietnam (QCVN22-2009) stipulates that the total particulate matter emission limit when burning coal is 200 mg m^{-3} [12]. From the analysis of coal combustion characteristics in the previous text, it can be seen that Vietnamese coal generally has poor dust removal performance.

4. Application of *Yongxin* electrostatic precipitator in Vietnam

4.1 Design of ESP

When selecting ESP, the main consideration is the influence of coal and ash components. In 1964, Sweden's S Matts used the concept of apparent driving speed ω_k, which is difficult to calculate in the Matts formula. Therefore, based on the Matts formula, the national standard GB/T40514 Electrostatic Precipitator proposes a simple selection design method for selecting the specific dust collection area of electrostatic precipitators through the analysis of the difficulty of coal types. This selection method fully considers the influence of coal and ash components on the electrostatic precipitator efficiency, simplifying the influence of power supply and pole pairing on the dust removal efficiency. The selection and design of the *Yongxin* project in Vietnam was carried out through the national standard "Electric Dust Collector". The coal and ash components provided by the boiler manufacturer for the project were Na_2O with a content of 0.3%, S_{ar} is 0.55%, Al_2O_3 is 22.3%, S_iO_2 is 48.1%. The evaluation results cannot be obtained using the method in Appendix D of Table GB/T 40514 (as shown in Table 3), mainly due to the low Na_2O content of Vietnamese coal.

On the basis of comprehensive consideration of the influence of coal and ash components on dust removal performance and practical engineering application experience, the specific dust collection area is adopted as 91.09 m^2 (m^3 s^{-1}). The main technical parameters are shown in Table 4, and the structural diagram is shown in Fig. 3.

Table 3. Evaluation of the difficulty of ESP in coal type.

Difficulty or ease of use	The conditions met by the weight percentage content of coal and fly ash components /%				
	NO.	Na_2O	S_{ar}	$Al_2O_3+SiO_2$	Al_2O_3
Ease	1	≥ 0.4	≥ 1	≤ 90	≤40
	2	≥ 1	≥ 0.4		
	3	≥ 0.3	≥ 1	≤ 80	
	4	≥ 0.4	≥ 0.4		
	5	≥ 1	≥ 0.3		
Commonly	1	0.1−0.4	≥ 1	85−90	
	2	≥ 1	≤ 0.45		
	3	0.4−0.8	0.45−0.9	80−90	
	4	0.3−1.7	0.1−0.3		
Difficulty	1	≤ 0.4	≤ 1	≥ 90	/
	2		≤ 0.6	≥ 80	
	3	≤ 0.2	≤ 1.4	≥ 75	

Note: When all horizontal elements of the serial number meet the conditions, the corresponding difficulty can be determined.

Table 4. Main technical parameters of *Yongxin* ESP in Vietnam.

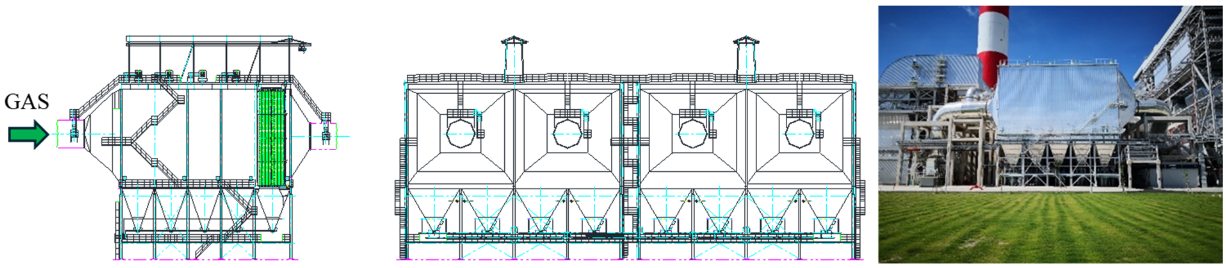
Item	Technical parameter
Effective cross-sectional area,	508.4 m^2
Number of chamber and electric fields	2/5
Number of channels	2 × 2 × 41
Specific dust collection area,	91.09 $m^2/(m^3\ s^{-1})$
Total dust collection area,	91512 m^2
Effective length of electric field	4 × 3.5 + 4 m 4 × 16.4 m 15.5 m
Gas velocity	0.99 m s^{-1}

Vietnam *Yongxin* Coal fired Power Plant Phase I 2 × 620 MW Electrostatic Precipitator Project is a project witnessed and signed by leaders of China and Vietnam, a key project to implement the "the Belt and Road" policy, and Vietnam's first supercritical W-shaped flame boiler power plant burning local anthracite. This project is equipped with two dual chamber five electric field electrostatic precipitators for each furnace. It was put into operation in May 2018, and after collaborative dust removal by downstream environmental protection equipment, the flue gas emissions reached ultra-low emission standards.

4.2 Testing and result analysis of ESP

According to the testing methods of EPA method 5 and GB/T 16157 standards [13−20], the joint venture of the owner and testing unit conducted performance tests on the electrostatic precipitator of the 620 MW unit of furnace 1. The results showed that the dust removal efficiency of the electrostatic precipitator was 99.93%, the smoke concentration at the outlet of the electrostatic precipitator was 30.2 mg m^{-3}, the pressure drop of the main body was 66 Pa, the air leakage rate of the main body was 1.03%, and the power consumption was 281.8 kW, which was far superior to the design requirements of the owner for 98 mg m^{-3}, and the Vietnamese emission standard for 200 mg m^{-3}, and both reached the performance guarantee value.

The layout and actual scene of the electrostatic precipitator supporting the No.1 boiler of Vietnam's *Yongxin* coal-fired power plant are shown in Fig. 5.



(a) Elevations (b) Right view (c) Right view

Fig. 5. Leaders of China and Vietnam witness the signing of the Vietnam *Yongxin* electrostatic precipitator project.

5. Conclusion

The following conclusions are derived from these test results in this work.

a. Based on the statistical analysis of the electrostatic dust removal characteristics of 16 types of Vietnamese coal flue gas dust and comparison with 51 types of domestic coal, it was found that the Na_2O content in Vietnamese coal ash was significantly too low, leading to poor electrostatic dust removal performance.

b. In the case of using inferior coal from Vietnam, the core components of the domestically produced electrostatic precipitator in China can achieve an export dust concentration of 30.2 mg m^{-3} and a dust removal efficiency of 99.93%, which is far superior to the design requirements of the owner's 98 mg m^{-3} and the emission standards of Vietnam's 200 mg m^{-3}.

c. The mainstream technology for smoke and dust control at home and abroad is still electrostatic precipitators, but the characteristics of coal types, emission standards, and overall pollutant control routes vary in different countries. In order to expand the adaptability and technological advantages of electrostatic precipitator products in China, it is of great significance to study the application of electrostatic precipitator technology at home and abroad.

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