

# Dry CFB-FGD By-Product Utilization - International Prospectives

**Yabing Jiang, Muh-Cheng M. Wu<sup>(1)</sup>, Qingfa Su, Maoyuan Lu and  
Chiqian Lin**

Lonjing Environment Technology Co. Ltd, Longking Square, No. 399, Linhou Road,  
Xiamen, Fujian, China, 361009

KEYWORDS, Dry CFB-FGD By-Product, Characterization and Utilization, International  
Prospectives.

## ABSTRACT

Circulating fluidized-bed flue gas desulfurization (CFB-FGD) process is an emerging dry FGD technology. In the United States (US), several CFB-FGD systems have installed recently in coal-fired power plants and industrial boilers after the process was successfully demonstrated in the AES Greenidge station with support of the US Department of Energy (DOE) in 2008. In China, the CFB-FGD technology has been widely applied to coal-fired power plants (up to 660 MW), sintering plants and other large industrial installation since 2004. There are many advantages of the CFB-FGD technology over other FGD systems. However, the utilization of CFB-FGD by-product has been developed slowly and could become the major barrier for further implementation of the technology. CFB-FGD by-product is a new type of by-product. Its compositions and properties are often site-specific and can be affected strongly by coal types, flue gas compositions, unit operating conditions and others factors.

In this paper, compositions and properties of CFB-FGD by-products from different sources in China and US will be compared and discussed. The recent development in by-product utilization, especially in China, will also be outlined and discussed. In addition, an international collaboration program between research and industrial organizations in US and China to advance CFB-FGD by-product utilization will be illustrated.

## INTRODUCTION

Dry FGD process was developed as an alternative to the wet FGD process. It generally has lower capital cost and energy consumption and has advantage in smaller scale power plants, which burn lower sulfur coals. Dry FGD process also has advantage in the region with limited water resources. CFB- FGD process is an emerging dry FGD technology. It has better calcium utilization and can apply to power plants burning relatively higher sulfur coal than other dry FGD processes. In addition to energy and water conservation and less land use, this process has capability of multi-pollutant

control<sup>(2)</sup>. In US, several CFB-FGD systems have installed recently in coal-fired power plants and industrial boilers after the process was successfully demonstrated in the AES Greenidge station with support of the US Department of Energy (DOE) under the Power Plant Improvement Initiative (PPII) program in 2008<sup>(2)</sup>. In China, the CFB-FGD technology has been widely applied to coal-fired power plants (up to 660 MW), iron and steel sintering plants and other large industrial installation since 2004. Due to the distinctiveness in the application background of dry FGD technology in US and China, there are differences in characteristics of dry FGD by-product generated. Compositions and properties of by-products are often site-specific and can be affected strongly by feedstock, flue gas compositions, unit operating conditions and others factors. In this paper, characteristics and the utilization of dry FGD by-products in US and Europe and in China will be evaluated and discussed

## DUSCUSSION

### Characteristics of Dry FGD By-Product

Most of dry FGD technology in US and Europe is spray dryer absorption (SDA), which lime slurry is injected into the spray dryer absorber for flue gas desulfurization. SDA has been applied to coal-fired power plants in US and Europe, since 1970's. In US, most of SDA is located prior to the particulate removal devise (i. e., baghouse) without ash pre-collection. Dry SDA by-products generally contain a substantial amount of fly ash components. In Europe, a particulate removal devise is located prior to SDA for ash pre-collection. Dry SDA by-product generally contains little fly ash components. SDA by-products generally have calcium sulfite hemi-hydrate ( $\text{CaSO}_3 \cdot 1/2\text{H}_2\text{O}$ ) as a major component<sup>(3,4)</sup>.

Dry CFB-FGD technology was initially applied to coal-fired power plants in 1990's. In CFB-FGD process, water and hydrated lime are injected separately in the fluidized-bed absorber to increase calcium utilization for flue gas desulfurization. In US, most of CFB-FGD units are operated without ash pre-collection. Dry CFB-FGD by-products generally contain a substantial amount of fly ash components. In China, the CFB-FGD technology has been widely applied to coal-fired power plants, iron and steel sintering plants and other large industrial installations since 2004. A particulate removal devise (baghouse or ESP) is often located prior to the CFB-FGD unit for ash pre-collection except in application as a polishing unit to a CFB boiler. The amount of fly ash components in CFB-FGD by-product is dependent on the efficiency of the particulate removal operation. Table 1 lists major elemental compositions and major and minor chemical components of three separate samples collected from CFB-FGD units at a pulverized coal-fired power plant, a iron and steel sintering plant and a CFB boiler in China and of two samples collected from CFB-FGD units at a pulverized coal-fired power plant and a CFB boiler in US, respectively, for comparison. As shown in Table 1, the elemental composition data reflect the trend that most of CFB-FGD by-products from coal-fired power plants in China has less amount of ash components than those in US and is similar to those in SDA by-product in Europe<sup>(3,4)</sup>. The by-product from

sintering plant may have the least fly ash components. Chemical composition data indicate that CFB-FGD by-products generated from coal-fired power plants and sintering plants in China have  $\text{CaSO}_3 \cdot 1/2\text{H}_2\text{O}$  as a major component as that containing in SDA by-products in US and Europe <sup>(5, 6)</sup>.

Physical properties of CFB-FGD by-products including particle size, specific gravity, bulk density, surface area and others are within the ranges of variation as those reported in SDA by-products <sup>(4,5,6)</sup>. CFB-FGD by-products generally have finer particle sizes, lower specific gravity and bulk density, higher surface areas with decreased amounts of fly ash components <sup>(5)</sup>.

Table 1 Major Elemental Compositions And Chemical Compositions of CFB-FGD By-products from Different Sources in China and US

Source of CFB-FGD By-Product	China			US	
	P. C. Power Plant	Sintering Plant	CFB Boiler(b)	P C Power Plant	CFB Boiler (c)
Moisture, % (as- rec.)	1.11	0.30	0.05	0.89	0.13
<u>Ultimate Analysis, wt% (dry)</u>					
Carbon	1.89	-----	1.06	12.89	4.16
Hydrogen	0.76	-----	0.12	-----	0.18
Nitrogen	0.10	-----	0.05	-----	0.08
Sulfur	13.63	13.14	8.71	9.89	4.35
Chlorine	-----	1.35	-----	0.34	-----
<u>Major Element (a), wt% dry</u>					
SiO <sub>2</sub>	5.94	0.67	15.15	12.94	38.90
Al <sub>2</sub> O <sub>3</sub>	2.22	0.34	9.40	6.66	13.31
TiO <sub>2</sub>	0.08	0.02	0.40	0.30	0.50
Fe <sub>2</sub> O <sub>3</sub>	0.57	0.34	1.73	4.51	5.91
CaO	46.44	48.06	44.87	31.82	17.61
MgO	1.66	1.70	1.69	0.60	2.62
Na <sub>2</sub> O	0.08	0.11	0.10	0.37	0.51
K <sub>2</sub> O	0.23	0.39	0.49	0.39	0.83
P <sub>2</sub> O <sub>5</sub>	0.06	0.02	0.05	0.08	0.41
SO <sub>3</sub>	34.09	32.86	21.78	24.73	7.53
SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub>	8.73	1.32	26.28	24.11	58.12
<b>Chemical Components (Major and Minor)</b>	CaSO <sub>3</sub> · 1/2H <sub>2</sub> O CaCO <sub>3</sub> (major) CaSO <sub>4</sub> · 2H <sub>2</sub> O Ca(OH) <sub>2</sub> , fly ash (minor)	CaSO <sub>3</sub> · 1/2H <sub>2</sub> O CaCO <sub>3</sub> (Major) CaSO <sub>4</sub> · 2H <sub>2</sub> O Ca(OH) <sub>2</sub> (Minor)	CaSO <sub>4</sub> , fly ash (major) CaSO <sub>3</sub> · 1/2H <sub>2</sub> O, Ca(OH) <sub>2</sub> (minor)	CaSO <sub>3</sub> · 1/2H <sub>2</sub> O CaCO <sub>3</sub> , fly ash (Major) CaSO <sub>4</sub> · 2H <sub>2</sub> O Ca(OH) <sub>2</sub> (Minor)	CaSO <sub>4</sub> , fly ash (major) CaSO <sub>3</sub> · 1/2H <sub>2</sub> O, Ca(OH) <sub>2</sub> (minor)

(a) Reported in oxide form

(b) Burning 70/30 pet coke/coal

(c) Burning low sulfur coal

## Utilization of Dry FGD By-Product

The utilization of dry FGD by-product is related to its chemical and physical properties. CFB-FGD and SDA by-products have similar chemical and physical properties. Both have high Ca and S contents with  $\text{CaSO}_3 \cdot 1/2\text{H}_2\text{O}$  as a major component and fine particle sizes<sup>(3, 4, 5, 6)</sup>. The following discussion will include major commercial utilization and high-potential R&D projects in the utilization of dry FGD and SDA by-product in US and Europe. The feasibility of applying these utilizations to CFB-FGD by-product is evaluated. In addition, the current status of the utilization of CFB-FGD by-product in China is discussed.

### Utilization of Dry FGD By-products in US and Europe

The utilization of dry FGD by-product is reported annually by the American Coal Ash Association (ACAA) in US and by the European Coal Combustion Product Association (ECOBA) in Europe. In the ACAA report, it is referred as dry FGD product, which is mostly SDA By-Product<sup>(3,4)</sup>. In the ECOBA report, it is referred directly as SDA product.

#### Mine applications

Dry FGD or SDA by-product has been used commercially as filling material for mine shaft and workings and other enclosed voids. Additionally, dry FGD by-product has been shown to be capable of neutralizing the spoil acidity and reestablishing vegetative cover to stabilize soils and reduce corrosion. According to ACAA coal combustion product production & use statistics, 30% of the utilized dry FGD by-product in US is used in mine reclamation in 2009. According to the ECOBA statistics, 20.4% of the utilized SDA by-product is used in reclamation and restoration in 2007. The feasibility for the utilization of CFB-FGD by-product in mine applications is high, due to similarity of chemical and physical properties.

#### Engineering and Structural Fills

Dry FGD or SDA by-product by-itself or mixed with additional fly ash have been used commercially in engineering and structural fills in US and Europe. According to the 2009 ACAA statistics, 46.7% of the utilized dry FGD by-product is used in structural fill and embankment and 3.7% are used in flowable fill in US. According to the 2007 ECOBA statistics, 20.5%, 11.1% and 13.5% of the utilized SDA are used in engineering fill, structural fill and general fill in Europe, respectively. The feasibility for the utilization of CFB-FGD by-product in engineering and structural fills is high, due to similarity of chemical and physical properties.

#### Agricultural Use

SDA by-product is used commercially as plant nutrient (a sulfur fertilizer) in Germany, Denmark and Austria, but not in US. The difference could be related to compositions of SDA by-product in Europe, which contains little fly ash components and, therefore, has less potentially toxic trace elements. The feasibility for the utilization of CFB-FGD by-product as plant nutrient is high, especially those with little fly ash components.

## Cement Replacement in Concrete

Certain SDA by-products can be used to partially replace cement in concrete product. According to the 2009 ACAA statistics, 4.5% of the utilized dry FGD by-product is used in concrete/concrete product/grout. Research has shown that concrete, in which cement was partially substituted by SDA by-product, showed strength and durability performance comparable to or superior to traditional concrete<sup>(3,4)</sup>. The technical feasibility for the utilization of CFB-FGD by-product as cement replacement in concrete is high, if the by-product with proper characteristics is used.

## Synthetic Aggregate

The technical feasibility of lightweight aggregate production from SDA by-product has been demonstrated commercially in US. It is feasible to produce lightweight aggregate from CFB-FGD by-product with a specific mix design, if economical conditions are favorable for commercial production.

## Utilization of CFB-FGD By-product in China

There is no official statistics of CFB-FGD by-product production and use available in China. The following discussion is based on published Chinese literatures and contacts with coal-fired power plants and iron and steel sintering plants in China

## Highway Construction

CFB-FGD by-products have been used commercially in base stabilization and as asphalt filler<sup>(7)</sup> in surface course for road and highway construction. Utilization in embankment construction has also been reported. The utilization is limited by seasonal and construction demands.

## Cement Additive

Limited amounts of CFB-FGD by-product have been reported for use as cement retarder to replace gypsum. The effectiveness for retardation appears related to cement compositions.

## Mine Applications

CFB-FGD by-product has been reported for use as filling material in mine, mostly in the northern and western regions in China. The utilization is limited by the potential impact on environments and by logistics issues.

## Agricultural Use

CFB-FGD by-product has been evaluated experimentally in large scales as plant nutrient and agent to treat salty soils. Test results indicate that concentrations of the leachable toxic trace elements are well below the allowable limits<sup>(8)</sup>. The status of commercial use is unknown.

### Cement Manufacture

Research and development work have been conducted to manufacture calcium sulfoaluminate (CSA) cement from CFB-FGD by-product<sup>(9)</sup>. CSA cement is produced by mixing CFB-FGD by-product, fly ash and limestone and calcining at 1300 –1350°C. The major components are calcium sulfoaluminate and dicalcium silicate. The development work has reached to the pilot-scale demonstration<sup>(10)</sup>.

### Production of Shaped Products

Autoclaved brick and aerated concrete block have been made experimentally from CFB-FGD by-product as a component. The brick product has high freeze and thaw resistance and meets the Chinese specifications. It has potential to replace conventional clay brick, which production is currently banned in China. Autoclaved brick product with CFB-FGD by-product as a component has been produced commercially with limited success and needs further development for commercialization.

### Dry Mixed Mortar

CFB-FGD by-product has been reported for use in manufacture of dry mixed mortar. Its application is related to the specific characteristics of the CFB-FGD by-product<sup>(11)</sup>.

### **International Collaboration**

An international collaboration program has been developed between Lonjing Environment Technology Co. Ltd in China and the Ohio State University School of Engineering and the University of Kentucky Center of Applied Energy Research (CAER) in US for the utilization of CFB-FGD by-products. The initial collaborative projects include sludge treatment, structural and flowable fills, mine applications, cement manufacture, characterization and durability evaluation of shaped products and others. The objective is to combine complimentary resources of research and industrial organizations in US and China to overcome barriers for the commercial utilization of CFB-FGD by-product.

### **Acknowledgement**

The authors would like to acknowledge the Ministry of Science and Technology of the People's Republic of China for its financial support of the International Science & Technology Cooperation Program (Project No. 2010DFB93990).

## REFERENCES

1. To whom for direct correspondence (E-mail address, muh-cheng,wu@lonjing.com)
2. Connell, Daniel P. I. "Greenidge Multi-Pollutant Control Project" DOE Final Report, Cooperative Agreement No. DE-FC26-06NT41426, April 2009.
3. Heebink, Loreal V. "A Review of Literature Related to the Use of Spray Dryer Absorber Material" EPRI Topical Report No.1014916, September 2007.
4. Heebink, Loreal V., Buckley, Tera D., Hassett, David J., Zacher, Erick J., Pflughoeft-Hassett, Debra F., and Dockter, Bruce A. "Current Status of Spray Dryer Absorber Material Characterization and Utilization" 2007 World of Coal Ash (WOCA), May 7-10, 2007, Lexington, Kentucky.
5. Guo, Bin, Bian, Jing-feng, Ren, Ai-ling, Liu, Ren-ping, Zhang, Zheng "Physical and Chemical Properties of Semi-Sintering Flue Gas Desulfurization Ash" Journal of Central South University (Science and Technology) in China, 2010,41(1), 387-392.
6. Ren, Xu Xi, Ma, Wang, Chun-Yuan, Wen-Long "Characteristics Study of Circulating Fluidized-Bed Flue Gas Desulfurization By-Product" Journal of Engineering for Thermal Energy and Power, 2010, 25 (2), 211-220.
7. Li, Cui-bin, Su, Da-gen, Zhang, Jing-feng "Research on Preparation of Bitumien Filler by Desulfurization Residue and Limestone Powder" Journal of Qingdao Technological University, 2010, 31(1) 54-57.
8. Lin, Jing and Shi, Lin "Study of the Efficacy and Safety of Dry and Semi-Dry Desulfurization Residues and its Calcined Product Use in Agriculture" Journal of Agro-Environmental Science, 2009, 28(1) 204-210.
9. Wang, Wen-Long, Cui, Lin, Ma, Chun-Yuan "Study on Properties and Comprehensive Utilization of Dry and Semi-Dry Desulfurization Residues" Power System Engineering, 2005, 21(5) 27-29.
10. Wang, Wenlong, Wang, Peng, Ma, Chunyuan and Luo, hongyang "Calculation for Mineral Phases in the Calcination of Desulfurization Residue to Produce Sulfoaluminate Cement" Industrial & Engineering Chemistry Research, 2010, 49 9504-9510.
11. Peng, Jinsheng, Hu, Mingyu, Ding, Chengping, Hu, Yuefang, Yu, Jianhua "Experimental Study on Desulfuization ash Characterization and Dry-Mixed Mortar" New Building Materials, 2010, 9, 19-21.