Basic characteristics and comprehensive utilization of FGD gypsum

Zhang Yichao, Wang Ying, Zhou Jinghai, Liu Jiaxi*, Li Tong

School of civil engineering, Shenyang Jianzhu University, Shenyang 110168, Liaoning
liujiaxi_1982@163.com

Abstract. Firstly the basic characteristics of Flue-gas-desulfurization gypsum (FGD gypsum) is described in this paper. Then the research status of FGD gypsum is introduced, especially the comprehensive utilization of FGD gypsum. Finally, some suggestions are put forward to solve the problems existing in the application of FGD gypsum, which provides a reference for further research and development.

1. Definition and generation of FGD gypsum
Flue-gas-desulfurization gypsum (FGD gypsum) is an industrial by-product gypsum obtained by desulfurizing and purifying the flue gas generated after combustion of sulfur-containing fuel (coal, oil, etc.). Its composition is mainly calcium sulfate dihydrate (CaSO₄·2H₂O) [1-2]. Limestone-gypsum flue-gas-desulfurization has developed for decades, which is the first choice of flue-gas-desulfurization for large and medium-sized units of thermal power plants in China. In this method, limestone is used as desulfurizer, and limestone is injected into the absorption tower, which is fully mixed with the flue gas, so that SO₂ in the flue gas reacts with CaCO₃ in the limestone and strong oxidation air to generate calcium sulfate dihydrate. Flue-gas-desulfurization process is shown in Fig. 1.

Fig. 1 Flue-gas-desulfurization process

2. Basic characteristics of FGD gypsum
The physical and chemical characteristics of FGD gypsum and natural gypsum have the same law, and there is no significant difference in hydration kinetics, setting characteristics and physical properties of the calcined gypsum powder. However, as an industrial by-product gypsum, it has some characteristics of recycled gypsum, which is different from natural gypsum in some aspects, such as original state, mechanical properties and chemical compositions, especially in impurity compositions, resulting in differences in mechanical properties, rheological properties and other macro characteristics of calcined...
gypsum powder [3]. FGD gypsum can completely replace natural gypsum for building materials and ceramic molds. Generally, according to the different types of coal burned and the dust removal effect of flue gas, the color of FGD gypsum is different in appearance. The common color is grayish yellow or grayish white, mainly due to a high content of unburned carbon in the flue gas and a small amount of CaCO₃ particles. The formation process of FGD gypsum is completely different from that of natural gypsum. Natural gypsum is formed in a slow and long geological history, in which impurities are basically distributed on the crystal surface. However, the soluble salts and inert substances of FGD gypsum are distributed inside and on the surface of the crystal.

The same points of FGD gypsum and natural gypsum:
1. The hydration kinetics is consistent with the condensation characteristics.
2. The main mineral phases, five forms after transformation and seven varieties have the same physical and chemical properties.
3. Neither of them is radioactive and does not harm health.

Differences between FGD gypsum and natural gypsum:
1. The original physical state is different: the natural gypsum is a lump bonded together, while the FGD gypsum exists as a single crystal particle.
2. Particle size and gradation: the particle size of FGD gypsum is relatively narrow, with high fineness and particles mainly concentrated in the range of 30-60μm. The gradation is far worse than that of natural gypsum.
3. High water content, water content generally around 10% or higher, poor liquidity, only suitable for belt conveyer.
4. The difference of impurity composition results in the difference of dehydration characteristics, grindability and mechanical and rheological properties of calcined gypsum powder.

3. Application status of FGD gypsum at home and abroad

3.1. Research status in China
The utilization methods of FGD gypsum in China can be simply divided into two categories [4-6]. One is direct utilization of FGD gypsum, mainly used as cement retarder and soil improver in saline alkali land. The other is the application after calcining FGD gypsum into building gypsum, which can be used for gypsum products such as gypsum board, gypsum block, plastering gypsum, etc. FGD gypsum is the waste produced in the process of flue gas desulfurization of coal-fired power plants. Each ton of SO₂ can produce 2.7 ton by-product FGD gypsum. With the rapid development of coal-fired power plants, the amount of FGD gypsum will be more and more, and it will become the second largest solid waste after fly ash. At present, domestic FGD gypsum is mainly stockpiled, which not only occupies a lot of land resources, but also easily causes secondary pollution. If the active and effective measures are not taken for comprehensive utilization, it will cause serious consequences.

The production of cement retarder with FGD gypsum has a very broad prospect, but there are some problems in the transportation and measurement, because FGD gypsum contains more than 10% attached water. Due to the need to improve the existing equipment of cement, the use of FGD gypsum as cement retarder has not been widely used. Plastering gypsum is a green building material in line with the national industrial policy and the requirements of building energy saving, and it is the replacement product of traditional cement mortar. Now, plastering gypsum has been widely used in northern China. According to the prediction of gypsum industry association of China, the amount of plastering gypsum is increasing by more than 20% every year. It is a potential indoor plastering product with huge market potential. Moreover, the production of gypsum board with FGD gypsum has developed rapidly in China, especially in the power plants in Jiangsu province and Zhejiang province. In addition, gypsum block has good processability, light weight and high strength, which is suitable for flexible partition wall. However, gypsum block products are restricted by market and economy, with low output value, high energy consumption, small transportation radius.
3.2. Research status at abroad

The research of FGD gypsum in foreign countries began in the late 1970s and early 1980s. Japan, the United States, the European Union and other countries and regions attach great importance to the comprehensive utilization of FGD gypsum. Now, a relatively complete research, development and application system has been formed [7,8]. Almost all FGD gypsum is used in building materials industry in foreign countries.

Japan is one of the first countries in the world to control sulfur dioxide emissions from thermal power plants with large-scale application of flue gas desulfurization devices, among which the limestone-gypsum desulfurization units account for more than 75% of the total installed capacity. Due to the limitations of resources, land area, population and environment, Japan attaches great importance to the utilization of FGD gypsum resources, and has accumulated rich experience in the comprehensive utilization of FGD gypsum. FGD gypsum products in Japan mainly include gypsum wallboard, building cement, process cement, adhesive, gypsum ceiling, etc. In addition, they attach great importance to the introduction and promotion of foreign advanced technology in environmental protection and energy conservation, and support the scientific and technological research and development of domestic recycling industry through tax preference, providing a large number of subsidies and commission fees, low interest financing and other measures, and encourage technological innovation. Japan has passed legislation to restrict the exploitation of natural gypsum and encourage the comprehensive utilization of FGD gypsum, that is, to plan the utilization of FGD gypsum while making economic planning. In addition, the law also stipulates that buildings with gypsum as the main raw material must use a certain proportion of FGD gypsum, refuse to landfill and prohibit the exploitation of natural gypsum.

FGD gypsum has been widely used as raw material of gypsum industry in Europe. Around the end of 1970s, the output of desulfurization by-products in Europe has exceeded $1 \times 10^6$ t. Germany is the country with the most developed application of FGD gypsum, and also the country with the largest output and utilization in Europe. At present, Germany’s FGD gypsum can basically realize the resource utilization. Since the regulations of large-scale combustion equipment came into effect in 1983, German industry has invested a lot of money in FGD equipment of thermal power plants in a short time. About 87% of the coal power stations in Germany are equipped with desulfurization devices, and about 80% produce FGD gypsum. The above pressure forces the power plant to dispose of ash regardless of economic benefits. In order to standardize the use of FGD gypsum in gypsum industry, European Union of coal combustion products, European gypsum industry association and Power Technology Association jointly formulated the quality standards of FGD gypsum for gypsum industry to ensure the quality of gypsum products. According to German industrial standard 1164 (din1164), the cement industry has the following requirements for FGD gypsum: loss on ignition <5%; undissolved residue <3.0%; MgO <5%; additive <5%; chloride <0.1%. The free magnesium oxide in FGD gypsum is not expected to appear, because it will change into magnesium hydroxide [$\text{Mg(OH)}_2$] after mixing with water, which will lead to a sharp increase in volume and magnesium oxide expansion effect.

The United States is rich in natural gypsum resources. The qualitative analysis and utilization of FGD gypsum have experienced a transformation process from abandonment to utilization. In the early years, the limestone gypsum FGD process installed in the United States mostly used natural oxidation method, and the by-product was calcium sulfate, which had unstable performance and little comprehensive utilization value. Basically, all of them were abandoned for treatment. Later, it began to pay attention to the utilization of FGD gypsum resources. More and more FGD gypsum was used in wall building materials industry, and the utilization of FGD gypsum also replaced some of the natural gypsum resources. However, due to the distance between most power plants and gypsum companies (hundreds of miles), as well as the rich and cheap natural gypsum resources in the United States, the growth of FGD gypsum application is relatively slow. In general, FGD gypsum in the United States does not have competitive advantages over natural gypsum. The main reasons are as follows: (1) FGD gypsum cannot compete with natural gypsum in terms of transportation distance; (2) The purity of
FGD gypsum cannot be kept constant, especially the specific content of chlorine and fly ash cannot meet the production requirements of wallboard; (3) The local supply of natural gypsum has grown for the local wallboard accepted by the manufacturer. (4) In addition to economic reasons, the vast land area of the United States provides site guarantee for the disposal of FGD gypsum by abandonment.

4. Summary
Based on the problems existing in the application and development of FGD gypsum, this paper puts forward the following suggestions:

4.1. Advocate the concept of resource recycling.
Since the 1970s, the United States, Britain, Germany, France, Japan and other countries have begun to vigorously advocate the concept of resource recycling and advocate the development of industrial waste from passive storage to comprehensive utilization due to the shortage of waste placement sites and high treatment costs. For example, the resource protection and recovery act of the United States and the circular economy and waste management act of Germany.

4.2. Formulate laws and regulations on the prevention, control and management of solid waste and on the restriction of exploitation of resources.
In the western developed countries, the policies of prevention and control of solid waste pollution and utilization of solid waste are mostly reflected through legislative means. Many countries have formulated solid waste management regulations and environmental standards. Japan, Germany and other countries have issued relevant laws and regulations to restrict the exploitation of natural gypsum.

4.3. Improve the enthusiasm of power enterprises and users of FGD gypsum.
Through relevant policies, it is clear that the most important responsibility of enterprise producers for the comprehensive utilization of resources is to improve the enthusiasm of enterprise producers. Due to the restrictions on the construction of ash yard of new power plants in Germany, power plants must find the market for fly ash and FGD gypsum. The Japanese government gives the FGD gypsum preferential policies of tax reduction and tax refund for equipment investment, and deducts the tax equivalent to 7% of the equipment investment from the income tax or corporate tax.

4.4. Set up a scientific research institution of fly ash / FGD gypsum, and constantly look for ways of utilization.
The purpose of setting up scientific research institutions is to better study the properties, characteristics and environmental hazards of fly ash and FGD gypsum, and to study the disposal, recovery and utilization technology of fly ash and FGD gypsum. It is precisely because of the high investment in science and technology that the utilization way of FGD gypsum can be expanded, the added value of utilization can be increased, and the land occupation and secondary pollution can be reduced. In addition, advanced technology promotes the development of related industries and brings considerable economic benefits.

References
[1] LU Lanping, et al. Research status and analysis on comprehensive utilization of desulfurization gypsum[J]. FLY ASH comprehensive utilization, 2019.
[2] China power encyclopedia editorial board[M]. Beijing: China electric power press, 2014.
[3] China federation of electric power enterprises. Annual development report of China's electric power industry[M]. Beijing: China market press, 2016.
[4] Li Dongxu. Comprehensive utilization of industrial by-product gypsum resources and related technologies[M]. Beijing: China construction industry press, 2013.
[5] Zhao Yi, Wang Zhuokun, et al. Environmental protection technology of electric power industry[M]. Beijing: China electric power press, 2007.
[6] Chu Yiping. Technical feasibility of comprehensive utilization of FGD gypsum[J]. Environmental science and technology, 2008, 3(6): 86118.

[7] Mao Shubiao. comprehensive utilization analysis of FGD gypsum[D]. Hangzhou: Zhejiang University, 2005.

[8] Song Jiekun, et al. Comparison of policies and regulations on comprehensive utilization of energy at home and abroad [J]. Industrial technology and economy, 2007, 26(12).