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Recent development of high gradient superconducting magnetic separator for kaolin in china

Zhu Zian[a, b, c], Wang Meifen[*, a, b], Ning Feipeng [a, b], Yang Huan[a], Li Peiyong[c], Zhang Yiting[c], Wang Zhaolian[c], Zhang Guoqing[a, b], Hou Zhilong[a, b], Liu Zhongxiu[a], and Dai Zhong[a, b]

[a] *Institute of High Energy Physics and*
[b] *University of Chinese Academy of Sciences*
[c] *Weifang Xinli Superconducting Technology Co.,Ltd.*

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Abstract

A series of high gradient superconducting magnetic separator (HGMS) for kaolin has been developed. It is used for processing kaolin to increase the brightness or whiteness whether it is for paper or ceramic applications. The HGMS system mainly consists of a solenoid magnet with a zero boil-off helium cryostat, a double reciprocating canisters system, and a PLC (Process Logic Controller) fully automatic control system based on SCADA (Supervisory Control and Data Acquisition) system. We have successfully developed CGC-5.5/300 and CGC-5.0/500 HGMS systems in the recent years, and now three sets of them are on-site operation in different customers. This paper will present recent progress of the HGMS system, the results of some experiments on processing kaolin clay used HGMS, and the on-site operation.

Keywords : high gradient magnetic separation (HGMS), zero boil-off, on-site operation

1. INTRODUCTION

Magnetic separation has been increasingly used for purification of liquid, such as heavy-metal ion removal from laboratory waste water, purification of kaolin clay in the paper-coating industry, waste recycling in the steel industry, and recycling of glass grinding sludge in cathode-ray tube polishing factories [1]. The first fully developed high gradient magnetic separation system process being implemented just thirty years ago to assist the kaolin clay industry in the cleaning and brightening of china clay. A higher magnetic field caused higher separation efficiency [2]. Compare with the other conventional HGMS, it is well known that the basic characteristics of superconducting magnet is to produce strong magnetic field about 2~10T over large working volume without an excessive expenditure of power, that is only about 1/10 to the conventional HGMS. The higher magnetic fields can be applied to separate-more weakly paramagnetic and micro-sized particles, or to operate at high fluid velocity with 10 times throughput to the conventional HGMS. In China, lot of low quality kaolin clay are needed to be processed with high brightening to used in ceramic and paper industry, and so a High Gradient Superconducting Magnetic Separation magnet (HGMS) for kaolin has been developed. Now there are two models, one is CGC-5.5/300 with a 5.5 T central field, a 300 mm room temperature bore, and run in zero boil-off regimes which will process kaolin slurry at typically 0.6~2.5cm/s resulting in a production rate of approximately 80~120 tons per day; the other is CGC-5.0/500 with a 5.0 T central field, a 500 mm room temperature bore, and run in zero boil-off regimes which will process kaolin in a production rate of approximately 15 tons per hour. Two sets of CGC-5.5/300 and one set of CGC-5.0/500 have been on-site operation in different concentrating mills. This paper will show the whole HGMS system, some experiments results on processing kaolin clay used HGMS, and the on-site operation.

* Corresponding author: wangmf@ihep.ac.cn

2. THE HGMS SYSTEM

The whole HGMS system consists of a 5.5/5.0T superconducting magnet with a 300/500mm room temperature bore cooled by a cryocooler, a double canisters system made of fine magnetic metal fibers of about 20μm in diameter with demagnetization circuit and liquid circulation pump for the solvent containing the kaolin slurry, and a PLC fully automatic control system [3]. Two magnetic filters in the room temperature bore of the superconducting magnet will reciprocate in and out of the magnetic field.

Some main parameters of the HGMS system are shown in TABLE 1.

Figure 1 shows the photo of whole HGMS system. In the picture, we can see the superconducting magnet with octagonal iron shield (orange part) and the reciprocating canister (silver part). On top of the magnet, there is a service tower, which houses a pair of current leads, a cold head, a pressure relief valve, and a burst disk.

The superconducting magnet uses a single solenoid configuration to obtain the central magnetic field 5.5/5.0T. After adding octagonal iron shield, for CGC-5.5/300, the leakage magnetic field is limited to 50 G in radial and axial

TABLE 1
MAIN PARAMETERS OF THE HGMS SYSTEM.

Parameter	CGC-5.5/300	CGC-5.0/500
Central field (T)	5.5	5.0
Room temperature bore (mm)	300	500
Operation current (A)	148	150
Charging time (h)	1	1
Length (C)*Width (B)* Height (A)	8*2.5*2.5	13.3*3*3.38
Liquid Helium(liter)	45	400
The net weight of system(ton)	15	35
Capacity (ton/d)	80~120	360

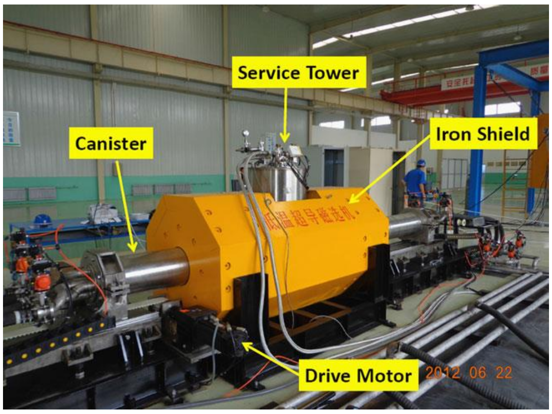

Fig. 1. the HGMS system.

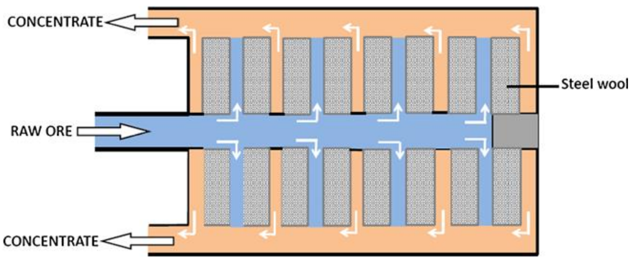

Fig. 2. Slurry flow through the pad sections of multiaxial canister train.

distances of 0.8 m and 1.08 m, respectively. We can get more detailed parameters of the magnet from paper [3, 4].

The HGMS system is designed with a small amount of stored liquid helium by inserting a 4.2 K cryocooler to recondense liquid helium boil-off during static operation. By reducing the size of the LHe vessel and eliminating one thermal shield, we got a more compact design as compared to traditional superconducting magnet systems. The zero boil-off cryostat can minimize liquid helium costs has the ability to tolerate power faults without superconducting magnet quenches [5, 6].

The double canisters system in the magnetic separator is used to process kaolin clay. Two magnetic filters in the room temperature bore of the superconducting magnet will reciprocate in and out of the magnetic field. When one magnetic filter is separating particles, another one is being cleaned. The reciprocation time between one canister section and the next is short, the process efficiency is maximized. There is a magnetically balanced dummy canister section between two canister sections. Figure 2 depicts the slurry flowing through the pad sections of the multiaxial canister train within the CGC-5.5/300 HGMS. The canister is filled with stainless steel wool about 20μm in diameter. The slurry flows through the steel wool.

The control system of HGMS is a very important part. It is designed for reliability and ease of operation. The start-up and shutdown are fully automatic, requiring only push button operation. An industrial PLC (Process Logic Controller) and a SCADA (Supervisory Control and Data Acquisition) system are designed to control and monitor the complete operation of the filters and allow for the complete integration with the process plant. Figure 3 is a schematic diagram of the control panel. There are only a few buttons to operate. It is very easy to understand and operate for users. Figure 4 shows the real-time monitor. From it, we can get the status of the canister position, fluid flows, and the levels of all tanks.

We have developed CGC-5.5/300 and CGC-5.0/500 HGMS systems. All parameters reach the designed objects. Every part works very well. There are some obvious advantages: the HGMS has a very high magnetic field 5.5/5.0T; the consumption of liquid helium of the cryostat is very low; the system consumes very low power, less than 11 kW for CGC-5.5/300 and 15 kW for CGC-5.0/500; it is a fully automatic operation and the weight of the whole system is very low, so it is very easy to transport and install.

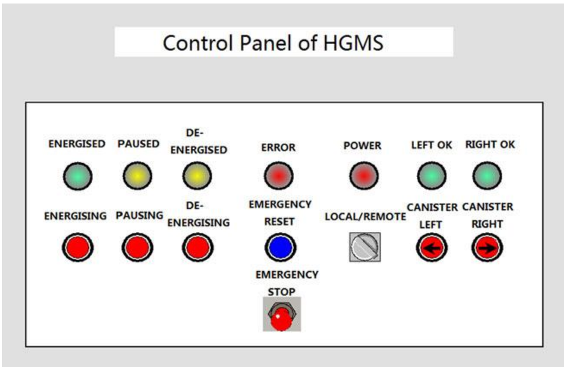

Fig. 3. Control panel of HGMS

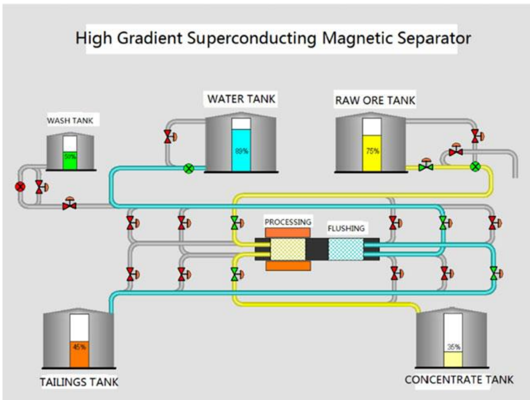

Fig. 4. Real-time HGMS monitor.

3. KAOLIN EXPERIMENTS

We have done some experiments of kaolin using the CGC-5.5/300 HGMS system to study the main variables that influence the color removal process. The key factors in achieving excellent results include: dispersion, percent solids, water hardness, and flow rate. The product quality was evaluated in terms of its brightness.

Two kaolin clay samples from Guangxi province in China are treated in the CGC-5.5/300 HGMS system. The results showed that the brightness value of concentrate is higher than that of the raw ore, with the canister packed to 5 percent density, the percent solid 20%, and the flow rate 1 cm/s. Two different stainless steel matrix types, 50 µm fine fibers, and 20 µm fine fibers were used.

Table 2 summarizes the results of HGMS tests. Figure 5 is the photo of the sample 1# after processing.

Figure 6 is the other kaolin sample from Jiangxi province in China. After processing the iron content decreases from 0.9 % to 0.3 %; the brightness is also increased significantly [7].

Table 3 summarizes the other experiment results of CGC-5.5/300 HGMS tests for different ores.

TABLE 2
THE FEED CHARACTERISTICS OF THE GUANGXI KAOLIN CLAY.

Sample		**Fe_2O_3**	**Whiteness** (nosintering)	**Sintering whiteness** (1180℃)
1#	Raw ore	0.76	70.0	77.1
	Concentrate	0.42	72.4	86.8
	Tailings	1.41	58.9	48.8
2#	Raw ore	1.47	78.3	53.0
	Concentrate	0.77	80.6	78.0
	Tailings	2.12	69.4	26.7

Fig. 5. The photo of Sample 1#.

Fig. 6. The photo of Sample 2#.

TABLE 3
EXPERIMENTS RESULTS OF DIFFERENT ORE.

Ore sample	**Species**	**Fe (%)**	
		Raw ore	**Products**
Fujian	Kaolin	1.212	0.812
Zhangzhou 1	Kaolin	1.177	0.839
Ganzhou 1	Kaolin	0.912	0.325
Chengde 1	Illite	1.078	0.558
Chengde 2	Illite	1.187	0.708
Ganzhou 2	Kaolin	0.882	0.657
Hunan	Kaolin	0.967	0.663

From the experiment results, the HGMS system shows very high separation efficiency and can achieve low cost owing to its large production rate compared with conventional systems. This superconducting equipment can obtain higher magnetic field 5.5/5.0 T. The CGC-5.5/300 HGMS system can process kaolin slurry at typically 0.6-2.5 cm/s, resulting in a production rate of approximately 80-120 tons per day (dry basis).

4. ON-SITE OPERATION

At present, we have successfully developed CGC-5.5/300 and CGC-5.0/500 HGMS systems, and two set of CGC-5.5/300 and one set of CGC-5.0/500 HGMS systems have been on-site operation in different concentrating mills. For these HGMS systems, all parameters reach its designed objects and every part works very well.

The first set of CGC-5.5/300 HGMS system was settled at Quanzhou city, Fujian Province since October 2013. Figure 7 shows the site photo in Quanzhou. After processing, the iron oxide weight fraction decreases to 0.07 %, and the users requirement is less than 0.3%.

Fig. 7. The first CGC-5.5/300 HGMS system at Quanzhou City, Fujian Prov.

TABLE 4
THE PROCESS RESULTS OF NEPHELINE SYENITE ORE IN XISHUANGBANNA CITY.

Nepheline syenite	**Fe%**	**Ti%**	**Al%**	
Raw ore	8.25	/	/	black
Product 0#, (0.5T)	6.54	0.69	18.81	Concentration,15%
Product 1#, (2.5T)	1.23	0.01	21.28	Flow velocity, 1.5cm/s Filling rate,6%
Product 1#, (5.5T)	0.37	0.01	19.99	dispersant,3‰

TABLE 5
THE PROCESS RESULTS OF KAOLIN ORE IN XISHUANGBANNA CITY

Kaolin	**Fe%**	**Ti%**	**Al%**	
Raw ore	0.73	0.04	37.77	yellow
Product	0.49	0.01	37.88	Concentration,15% Flow velocity, 1.5cm/s Filling rate,6% dispersant,3‰

Fig. 8. Another CGC-5.5/300 HGMS is settled at Xishuangbanna City, Yunnan Prov. Sep. 2014.

Fig. 9. The first CGC-5.0/500 HGMS system at Huaiji City, Guangdong Prov.

Another CGC-5.5/300 HGMS system was settled at Xishuangbanna city, Yunnan Province in September 2014, just as be shown in Figure 8. Table 4 gives the process results of nepheline syenite ore under different background magnetic field and Table 5 gives the process results of kaolin ore.

After the HGMS system process, the iron content decreases from 8.25 % to 0.37 % for nepheline syenite ore following the special conditions; and for kaolin, the value is from 0.73% to 0.49%, it is also an obvious effect.

Figure 9 shows the site photo of the first set of CGC-5.0/500 HGMS system in Huaiji city, Guangdong Province. Now the shakedown test is going on. For its large working bore, it will process kaolin in a production rate of approximately 15 tones per hour.

5. CONCLUSION

We have successfully developed CGC-5.5/300 and CGC-5.0/500 HGMS systems in the recent years, and three sets of them are on-site operation in different customers. The HGMS system mainly consists of a solenoid magnet with a zero boil-off helium cryostat, a double reciprocating canisters system, and a PLC (Process Logic Controller) fully automatic control system based on SCADA (Supervisory Control and Data Acquisition) system.

According to the results of kaolin process experiments and the on-site operation, this HGMS system has obvious advantages compared with other conventional HGMS from the point of its energy saving, low operating cost, higher product quality and higher throughputs. And more experiments will be performed to extend the application of the superconducting HGMS system.

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