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Improvement the Quality of Egyptian Kaolin for Industrial Applications

DA Refaei[1*], **MK Abdelrahman**[2], **IA Ibrahim**[2], **F Eldears**[1], **AT Kandil**[1]

[1]*Department of Science, Helwan Univesity, Egypt*

[2]*Central Metallurgical Research and Development Institute (CMRDI) Cairo, Egypt*

[*]**Corresponding author:** D A Refaei, Department of Science, Helwan Univesity, Egypt, Tel: +02 2 01022787512; E-mail: dinaElnagar@live.com

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Abstract

The present work aims to study a physical beneficiation of the Egyptian Kaolin from Kalabsha by using a wet high intensity magnetic filter. Since kaolin clay is an important for different industrial applications, but the presence of coloring materials such as iron and titanium, make it unusable for industrial applications as it affects the brightness and whiteness property.

Improvement the quality of kaolin was carried out using magnetic separation in a two scale, the first one is a laboratory scale and the second one is a semi pilot scale. Experimental work involved crushing, disintegration, hydrocycloning and magnetic separation.

Results showed that the whiteness of kaolin was improved through the application of wet high intensity magnetic separation technique, as in a laboratory scale, about 48% by weight of a non magnetic fraction of kaolin with 0.7% TiO_2 and 0.55% Fe_2O_3 was obtained. The TiO_2 % was decreased from 3.56 % to 0.7% with about 87% removal. This leads to increasing the whiteness of kaolin from 86% of the original kaolin to 91% in non-magnetic kaolin. While in a Semi pilot plant two products were obtained. The first is a non magnetic fraction which represents about 74% by weight with 0.56% titanium oxide and 0.49% iron oxide. The second is a middling fraction represents about 10% by weight with 0.76% titanium oxide and 0.49% iron oxide.

Finally a material balanced flow sheet is developed for upgrading of Egyptian kaolin to be used for different industrial applications.

Keywords: Egyptian kaolin; Magnetic separation; Titanium oxide; Ferrous oxide; Flow sheet

Introduction

Kaolin is a hydrated aluminum silicate ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$). It has a wide variety of industrial applications, due to its unique physical, physiochemical and chemical properties [1]. These include paper coating and filling, refractory, fiberglass and insulation, rubber, paint, ceramics, and chemicals.

Clays are processed by mechanical methods, such as crushing, grinding, and screening, however, because clays are used in such a wide range of applications, it is often necessary to use other mechanical and chemical processes, such as drying, calcining, bleaching, blunging, and extruding to prepare the material for use [2].

Kaolin samples originally exhibit white color with high clay brightness, but it mainly contains various amounts, of discoloring elements, such as anatase (TiO_2), mica and iron oxides (Fe_2O_3), which give low brightness and low quality. In addition, the anatase (titaniferrous) and mica can also contain iron contaminants [1]. The presence of such impurities is prohibitive to the production of optical fibers, glass, ceramics and refractory materials, so considerable efforts have been devoted to the problem of removing these contaminants by physical, chemical, or combination between them [3].

The primary step in kaolin processing is to separate the abrasive minerals like quartz and undesirable mineral such as mica. This is a simply process in case of a secondary deposit, but in contrast with the primary deposit as it is more difficult due to the presence of high proportion of the abrasive minerals that have survived the alteration process [4].

In order to improve the quality of kaolin clay for industry, the discoloring impurities must be removed from the samples by suitable techniques. However, these impurities are finer than the clay minerals, which, in turn, present difficulties in the separation processes. These separations generally include magnetic separation, froth flotation, selective flocculation, and size separation by hydro cyclone, and leaching [1].

For most industrial applications, kaolin should be processed to obtain refined clay so as to produce a remarkable product matches with the standard specifications. For example, kaolin used in paper and paint industries need to be of high brightness and low yellowness. Egyptian kaolin is not subjected to any beneficiation process and the Egyptian companies apply selective mining in some localities, followed by crushing and size reduction only. Such low quality kaolin can be used in refractory and pottery production but not in white ware and paper industries [5].

High gradient magnetic separation (HGMS) handles 75% of the world production of white porcelain and paper. A typical plant would have an HGMS with a filter diameter of about 2 m and capacity upto 20 t/hr [6].

Mostly kaolin used in the paper manufacturing industry where playing a dual role, as filler between the pulp fibers and as a surface coating for a white glossy finish. But natural kaolin has color as mined due to the iron containing micas, tourmaline, pyrite, anatase and rutile present in the material. To remove these impurities, kaolin can be magnetically cleaned with a continuous high gradient magnetic separator to produce highly white material suitable for paper or porcelain. A typical plant would have an HGMS with a filter diameter of about 2 m and capacity up to 20 t/hr [6].

Research and development to use superconducting magnets more effectively in kaolin refinement process, for example such process that was done in the united kingdom from the end of 1980s [7]. This involves the use of powerful magnets with field strengths ranging from 2 to 6 Tesla. The range from 2 to 6T is achieved by using liquid helium cooled superconducting coils which results in considerable savings in electric power. The kaolin slurry is pumped through a highly compressed fine stainless steel wool matrix, which when energized, separates the magnetic minerals and allows the non-magnetic kaolinite to pass through the matrix. The magnetic field is periodically switched off so that the accumulated magnetic particles can be rinsed with water, thus cleaning the steel wool matrix.

The magnetic minerals that are removed are dominantly hematite and yellowish iron enriched anatase along with some ilmenite, magnetite, and biotite. The magnetic separation process was described by Iannicelli (1976) who was one of the first to advocate the use of magnetic separation in order to brighten kaolin clays. The development of high intensity wet magnetic separation for use in the kaolin industry has resulted in a huge increase in kaolin reserves which can be used commercially.

It was also determined that high magnetic separators were effective for the nanosize- discoloring elements to produce high brightness clay. Therefore, other processes i.e... (Flotation and/ or selective flocculation) can be incorporated to increase the brightness of kaolin clay [8].

Eriez Magnetic Filters are high intensity electromagnetic matrix type separators, utilizing an oil cooled solenoid encased in steel combined with a flux converging matrix. An expansion tank may be located outside the body of the electromagnet to allow for oil volume change with temperature (Figure 1).

The magnetic field is produced through the energized coil generates a uniform magnetic field in the filter bore, comprising a ferro magnetic matrix sandwiched between re-entrant pole pieces. The matrix amplifies the background magnetic field and provides the high-gradient collection sites for magnetic particle capture.

As feed material flows through the matrix, the magnetic particles are captured and subsequently removed from the particle stream.

A typical amplified field produced by the matrix is approximately three times the background field, provided the matrix has not reached magnetic saturation. Saturation depends on the matrix material but approximately 18,000 gauss is typical of mild steel.

Kaolin plays a very significant role in the industrial aspects of life, it has been considered as an economic gateway for a lot of industrial applications and its usages is influenced by its functional properties. It used as functional filler, coatings, pigment and extender in several industrial application of which paper, plastic, rubber, PVC coating on wire and cables, and ceramics are also significant consumers [9].

The largest use of kaolin is in the paper industry (as filler and as a coating on the paper surface to enhance the printing) and the ceramics manufacture as additives [10]. For both industries, a great whiteness is required for the quality of the final products.

Egyptian kaolin is present in three main areas namely, Sinai, Red Sea coast, and Aswan Kalabsha. Sinai Manganese is the main producer of kaolin from the Nubia Succession of Sinai at Mussaba Salama, El-Tih, Farsh El-Ghozlan and other localities with total reserves of about 100 million tones of a grade ranging from 26% to 35% $Al_2 O_3$,while the GYMCO is the producer of kaolin from the Kalabsha region [5].

The main objective of this work is improvement of quality of Egyptian kaolin from kalabsh locality using wet high intensity magnetic filter to be used in different industrial applications.

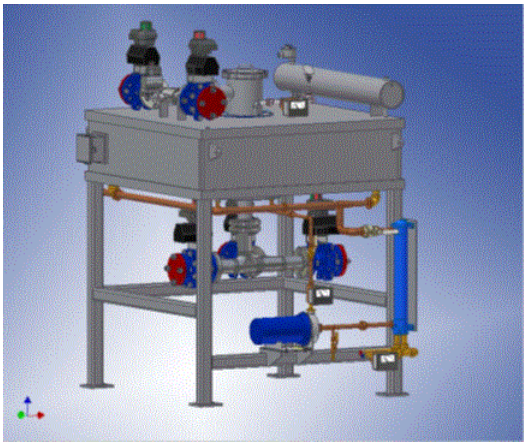

Figure 1: High Intensity magnetic filter separator.

Experimental

Material

A representative sample about two tons were delivered to CMRDI by komoshim Private Company in Egypt.

Crushing of kaolin: A representative sample was crushed in closed circuit using Denver jaw crusher. The crushed product was screened in screen size 6.63 mm, the oversize was returned to crusher. The crushed product was used as feed for attritor mill. A representative sample of crushed kaolin product was taken and ground for less than 75 micron for complete chemical analysis.

Grinding of kaolin using attritor mill: Grinding of kaolin less than 6.33 mm was carried out using laboratory "Union Process Atrirotor mill Model 1S. The grinding was carried out using 5 kilogram of kaolin with 5 kilogram alumina balls with size 10 mm, 1 kilogram alumina balls with 4 mm size and 3 liter water at different time. Figure 2 illustrates the attritor mill Union process Model 1 S.

After grinding process the kaolin was discharge and screened in 45 micron diameter sieve to be used as a feed for hydrocycloning of kaolin and magnetic separation techniques.

Figure 2: Attritor mill union process model 1S.

Hydrocyclone separation for Kaolin: Hydrocylone Mozely hydrocyclone one inch was used. The kaolin less than 45 micron produced from grinding was separated at 5 % by weigh at 30 psi to overflow and underflow fractions. The overflow and underflow fraction were dried and weighed to calculate the weight percentage of each. Complete chemical analysis was carried out for both overflow and underflow fractions.

The separated products by hydrocyclone were used as a feed for laboratory and semi-pilot plant magnetic separators.

Laboratory magnetic separation: Box mag wet high intensity magnetic separator was used for magnetic separation for both overflow and under flow of hydrocyclone separation. The magnetic intensity of equipment was 20000 gauss'. The kaolin feed to magnetic separator from down passing through stainless steel wool matrix, the non-magnetic fraction was separated which represent the kaolin concentrate. After the feeding of kaolin finished and separation of non-magnetic fraction, the equipment was stopped and washing the stainless wool to separate the magnetic fraction. The non-magnetic and magnetic fractions were dried and weighted to calculate the weight percentage of both. Complete chemical analysis was under taken for both magnetic and non-magnetic fraction.

Semi-pilot magnetic separation: Semi- pilot Magnetic separation was carried out using "Eriez high intensity magnetic filter. This experiment was carried out on the ground kaolin produced. The stirred kaolin was feed at solid liquid ratio about 20 % using feeding pump to the magnetic filter from down passing to canister containing stainless steel matrix. The magnetic filter was programmed to three cyclic automatically using valves in-order to separate non magnetic fraction followed by middling fraction, magnetic fraction and finally washing of magnetic filter cyclic. The three fractions were filtered using filter press and dried to calculate the weight percentage and chemical analysis. The non-magnetic and middling fraction was separated using hydrocyclone one inch at pulp density 5% and 30 psi to overflow and under flow fraction.

Results and Discussions

Chemical analysis of Kaolin

A complete chemical analysis is indicated in Table 1. It showed that the sample with silica and alumina content about 45.45%, and 36.35% respectively. The coloring materials such as iron and titanium represent about 0.64% and 3.04% respectively. Their presence of such impart color to kaolin. Consequently, a magnetic separation method has been applied to kaolin beneficiation in order to reduce these contaminants to be official used in industrial applications.

Elements	%
SiO_2	45.45
Al_2O_3	36.35
TiO_2	3.04
Fe_2O_3	0.64
MgO	0.01
CaO	0.17
Na_2O	0.04
K_2O	0.01
P_2O_5	0.09
SO_3	0.06
Cl	0.06
L.O.I	14.08

Table 1: Complete chemical analysis of Kaolin.

Crushing of Kaolin

The "Denver" jaw crusher was stetted up to crush kaolin. The crushing was carried out in closed circuit with screen size 6.63 mm. The crushed less than 6.63 mm was used as a feed to the attritor mill. Figure 3 illustrates the sizes distribution of crushed product. It has been shown that the d80 and d50 in case of attrition scrubber represent 2392 micron and 824 micron respectively.

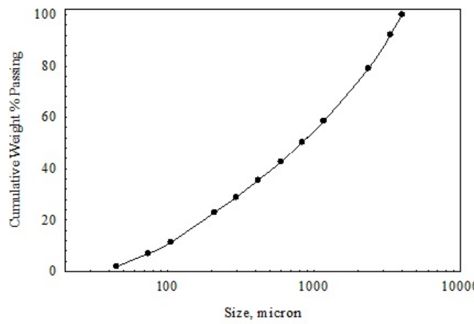

Figure 3: Primary and secondary crushing of Kaolin for Attritor mill.

Grinding of Kaolin using Attritor mill: The crushed kaolin to size less than 6.63 mm was used as a feed in attritor mill. Table 2 represents the result of grinding using 10 mm and 4 mm alumina balls at 1000 rpm. It showed that using two sizes of alumina balls increase the weight percentage of size less than 45 micron. It reached to 98% by weight compared with 93% by weight in case of using 10 mm alumina balls. Increasing the time of grinding to one and half hour increase the weight percentage of size less than 45 micron to 100% by weight. This could be used for hydrocycloning process of kaolin and magnetic separation using magnetic filter.

Time, min	Fraction, micron	Weight %
60	+75	
	+45	1.68
	-45	98.32
	Total	100
90	+75	
	+45	
	-45	100
	Total	100

Table 2: Attritor mill using 10 mm and 4 mm alumina balls at 1000 rpm.

Hydrocyclone separation of Kaolin less than 45 micron: The hydrocyclone separation was carried out for the kaolin product of attritor mill at one and half hour grinding time. Table 3 represents the results of separation using hydrocyclone one inch. It has been shown that the over flow fraction represents about 72% by weight of kaolin sample. It could be used for magnetic separation to produce high quality kaolin.

Fraction	Overall Weight %
Classification for attritor product at one and half hour	
O. F	72.07
U.F	27.93
Total	100

Table 3: Classification of attritor mill products at one and half hour grinding using hydrocyclone 1 inch.

Laboratory wet high intensity magnetic separation

Magnetic separation for one inch hydrocyclone overflow: Wet high intensity magnetic separation was carried out using Box mag magnetic separator for overflow product of hydrocyclone one inch. Table 4 shows the results of magnetic separation. It has been shown that the non-magnetic fraction was weighing about 64% by weight of kaolin with 0.56% TiO_2 and 0.55% Fe_2O_3. The removal percentage of titanium oxide was about 86%. Table 5 represents the optical properties of non-magnetic fraction. It has been noticed that the whiteness percentage was increased to about 91% compared with 86% of original kaolin. Table 6 shows the complete chemical analysis of separation process.

Fraction	Operational Wt. %	Overall Wt. %	TiO_2 %	% Removal	Fe_2O_3 %
Overflow product at 1000 r.pm, 10 mm and 4 mm balls for one and half hour					
Non-magnetic	89.39	64.42	0.56	85.94	0.55
Magnetic	10.61	7.65	16.12		1.25
Total	100	72.07	3.56		0.62

Table 4: Wet High Intensity Magnetic Separation for the overflow of hydrocyclone 1 inch using Box mag magnetic separator.

Fraction	Whiteness %	Brightness %	Iso-Brightness %	Redness %	Yellowness %
Original Kaolin					
	86.38	65.34	74.61	0.52	7.37
Optical measurement for non-magnetic of overflow product at one and half hour					
Overflow	89.08	71.72	79.36	0.65	5.82
Non-magnetic	90.8	75.11	82.45	0.46	5.46
Magnetic					

Table 5: Optical measurement for non-magnetic of the overflow of hydrocyclone 1 inch.

	Overflow	Non- Magnetic	Magnetic
Elements	%		
SiO_2	42.07	43.5	42.5
Al_2O_3	38.1	38.1	27.23
TiO_2	3.56	0.56	16.12
Fe_2O_3	0.62	0.55	1.25
MgO	0.14	0.14	0.14
CaO	0.22	0.3	0.45
Na_2O	0.04	0.04	0.04
K_2O	0.07	0.05	0.24
P_2O_5	0.11	0.11	0.11
SO_3	0.02	0.02	0.02
Cl	0.02	0.02	0.02
L.O.I	13.5	13.7	11.82

Table 6: Complete chemical analysis for Magnetic separation for overflow product of hydrocyclone one inch.

Magnetic separation using Eriez high intensity magnetic filter: Semi-pilot plant magnetic separation was carried out on the grinding product at one and half hour using attritor mill. Eriez high intensity

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magnetic filter was used at solid liquid ratio 20%. Table 7 illustriates the results of separation process. It has been shown that the non magnetic fraction represents about 74% by weight with 0.56% titanium oxide and 0.49% iron oxide. Hydrocyclone separation was carried out for non-magnetic fraction using hydrocyclone one inch at solid liquid ratio 5% and 20 psi. Table 8 depicted the results of hydrocyclone separation. It has been noticed that the over flow and under flow fraction represent about 38% and 36% respectively. Table 9 summarizes the complete chemical analysis of separation process. Figure 3 represents flowsheet design for beneficiation of kalabsh kaolin. A general flow sheet was designed to describe the beneficiation process (Figure 4).

Fraction	Weight %	TiO_2 %	% Removal	Fe_2O_3 %
+ 45 micron	2.65	1.84	98.4	0.39
Non-mag	73.69	0.56	86.43	0.49
Middling	10.2	0.76	97.45	0.49
Magnetic	13.46	15.5	31.37	1.18
Total	100	3.04		0.64

Table 7: Magnetic separation using filter with stainless steel materix at 25%.

Fraction	Operational Wt. %	Overall weight %
Over flow	51.05	37.62
under flow	48.95	36.07
Total	100	73.69

Table 8: Hydrocyclone 1 inch at 20 psi for non-mag at 5% solid liquid ratio.

	+ 45 micron	Non-Magnetic	Middling	Magnetic
Elements	**%**			
SiO_2	65.5	43.5	46.5	67.5
Al_2O_3	20.4	38.1	36.05	11.5
TiO_2	1.84	0.56	0.76	15.5
Fe_2O_3	0.39	0.49	0.49	1.18
MgO	0.08	0.08	0.08	0.41
CaO	0.22	0.3	0.3	0.4
Na_2O	0.05	0.05	0.05	0.08
K_2O	0.02	0.05	0.05	0.05
P_2O_5	0.11	0.11	0.11	0.12
SO_3	0.02	0.02	0.02	0.02
Cl	0.04	0.04	0.04	0.04
L.O.I	11.33	13.7	13.7	3.2

Table 9: Complete chemical analysis of separation.

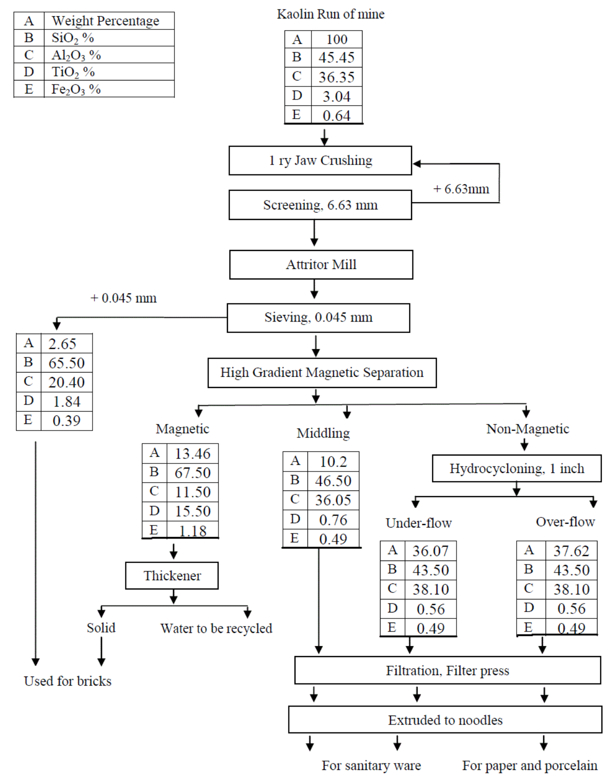

Figure 4: Wet beneficiation flowsheet for Klabsha Kaolin ore.

Conclusion

Kaolin in Egypt is localities in 3 main areas, namely Sinai, Red Sea coast,
and Aswan Kalabsha with a low grade ranging from 26% to 35% Al_2O_3 , accessory minerals, and varying degree of ferrugination and TiO_2 are observed in different localities.

Kaolins are exploited for a wide range of industrial applications, such as the production of paper (as a filler and/or a coating material), ceramics (to add strength, abrasion resistance, and rigidity), plastics (as a filler) and paints (as a filler and thickening agent) so, it has to be refined to meet commercial specifications out.

A laboratory Box- Mag wet high intensity magnetic separator is used for this purpose. It was resulted that the non-magnetic fraction was 46 % by weight of kaolin assaying 0.56% TiO_2 and 0.55% Fe_2O_3 with 89% removal of titanium oxide. This leads to increasing the whiteness of kaolin from 86% to 91% in non-magnetic kaolin.

In a semi- pilot plant, Eriez high intensity magnetic filter was used. It has been shown that the non magnetic fraction represents about 74% by weight with 0.56% titanium oxide and 0.49% iron oxide and middling fraction represents about 10% by weight with 0.76 %

titanium oxide and 0.49% iron oxide. A general flow sheet was designed to describe the beneficiation process (Figure 4).

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