

Upgrading of Low Grade Egyptian Kaolin Ore Using Magnetic Separation

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ARTICLE INFO

Article history:

Received: 14 September 2019;

Received in revised form:

12 October 2019;

Accepted: 22 October 2019;

Keywords

Kaolin,

Titaniferrous Minerals,

Beneficiation, Magnetic

Separation,

Attrition Scrubbing,

Classification.

ABSTRACT

Kaolin is a clay mineral that has a wide application in the industry, depending on its purity. The quality of kaolin mined around the world is depleting especially with depth and rate of mining. Consequently, the usability of this mineral is threatened by the presence of some inherent impurities. Beneficiation enhances kaolin applications; hence, it becomes imperative to understudy comparative means of upgrading kaolin, for the process integration and optimization. The amenability of using magnetic separation for removing the iron oxide and titanium oxide impurities from the Egyptian Kaolin has been studied. Different variables affecting of magnetic separation process such as solid percent, magnetic field, matrix loading capacity, and retention time were studied. The results indicated that substantial decrease in iron oxide (from **1.69 %** to **0.75 %**) and TiO₂ (from **3.1 %** to **0.71 %**) contents as well as improving iso-brightness (from **63.76 %** to **75.21 %** and whiteness (from **79.85 %** to **86.72 %**) of the product could be achieved.

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1. Introduction

Kaolin ores are naturally occurring earthy materials predominantly containing the mineral Kaolinite. It is a hydrated aluminum silicate (Al₂O₃·2SiO₂·2H₂O) and has a wide variety of industrial applications, due to its unique physical, physiochemical and chemical properties [1-2]. 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, and extruding to prepare the material for use [3]. Unique mineralogy, morphology, chemical and physical specifications of kaolin makes its versatile raw material appropriate for many different applications [4-5].

Kaolin is used in many industrial applications such as sanitary ware, table ware, ceramic, paint and paper industries. Typical impurities present in kaolin ore are quartz, iron oxides, titaniferrous minerals, mica, feldspar, organic matter, etc. For most of the industrial applications, kaolin should be processed to obtain refined clay so as to match with standard specifications. For example, paper and paint industries need kaolin with very high brightness and low yellowness [6]. The iron removal processes can be categorized as physical, chemical, or a combination of both [7]. Physical approaches include intense magnetic separation which able to remove iron and titanium impurities, gravity separation, and hydro-cyclones [4].

The flotation process may be conceptualized in terms of a large number of sub-processes, most of which are still rather poorly understood. Because of the extremely complicated physicochemical mechanical conditions existing in the flotation process, the problems associated with the presence of fine particles are most pronounced in flotation. There is a general agreement that flotation decreases with a decrease of size in the fine particle range [8-11].

Conventional and superconducting magnetic separations are typically employed units with 1-2 Tesla and 2-5 Tesla magnetic fields, respectively. The prepared clay sample with a 15%-25% solid content is fed through a high gradient magnetic field created around the ferromagnetic stainless steel wool fiber. The magnetic separations are generally operated as a batch unit with 10-20 min cycles depending on the size of the units, feed rate, solid content, impurity content, applied led, machine capacity, etc., [8]. Sophisticated beneficiation flow sheets are well established, particularly in Georgia, USA and Cornwall, UK, to reach the required specification for good quality kaolin concentrates. However, the Egyptian kaolin is not subjected to any beneficiation process and the Egyptian companies apply selective mining followed by, in some localities, crushing and size reduction only. Such low quality kaolin is used mainly in refractory and pottery production because its quality does not satisfy the requirements for the white ware and paper industries, [9].

This paper aims to study the amenability of beneficiation of an Egyptian kaolin ore of El-Teih locality, Sinai, to be suitable for different industrial applications. Attrition scrubbing and classification followed by magnetic separation are applied to remove the associated impurities. Attrition scrubbing and classification are used to separate the coarse silica and feldspars. Wet high intensity magnetic separation was applied to remove colored contaminants such as iron oxide and titanium oxide.

2. Material and Methods

2.1. Materials

Representative kaolin sample from Sinai locality was used in this study

2.2. Methods

2.2.1. Identification of the Kaolin Sample

A Philips PW 1730 powder X-ray diffractometer with Fe filtered Co (K-alpha) run at 30 kV and 20 mA was used to

examine single kaolinite mineral. Infrared vibrational spectra were recorded on a Nicolet Magna 750 Fourier-transform spectrometer. For each sample, 28 scans were accumulated over the 4000-400 cm^{-1} spectral range employing the transmittance mode and a resolution of 4 cm^{-1} . The pressed KBr disc employed for this purpose was prepared using 0.4 mg of sample and 200 mg of KBr. Selected samples were observed on fractured surface under a JSM-6400 scanning electron microscope (SEM) to examine the morphology of single mineral. X-ray fluorescence (XRF) to determine the mineralogy and chemical composition. A Laser particle size analyzer "FRITSCH" model "AAAnalyste 22", was employed for size analysis of the pure mineral samples.

2.2.2. Wet High Intensity Magnetic Separation of Kaolin Sample

Wet high intensity magnetic separation of kaolin samples was conducted using "Boxmag Rapid" LHW magnetic separator. The separating box (canister) was packed with stainless steel wool (sp.gr. 7.13 gm/cm^3). The separating box was rectangular in shape, having the dimensions of 37 mm width X 82 mm length X 190 mm height with actual filling volume of 600 mm. The experiments were performed at the following pre-determined optimum conditions: matrix wire diameter 300 μm , 2.5 % loading capacity, retention time 150 seconds and magnetic field intensity 14.000 K gauss. The feed rate of slurry to the canister was controlled by a peristaltic pump.

2.2.3. Sample and Feed Preparation

Primary crushed kaolin lumps were further crushed in a "Denver" pilot jaw crusher to yield a product less than 25 mm. Attrition scrubbing of secondary crushed product was carried out using 50 liter rubber lined "Denver" attritoner. It consists of two chambers; each one has an impeller with two rows of plates of different inclination to keep the material under motion. These plates help also in moving the slurry up and down between them and shifting from one chamber to the other to increase the attritioning retention time. Batches of 25 kg secondary crushed samples are fed with the same volume of water to maintain 1:1 solid liquid ratio inside the attritoner. Autogenous and Semi- Autogenous attritioning by adding certain weight of gravels (5 kg of >2cm grain size) were conducted. The material was subjected to attritioning for a time periods, 30 min. The products were evaluated through sizing by screens and hydrocycloning for sub screen fractions. Size distribution of the hydrocyclone overflow products were measured using "FRITSCH" model "Analyste 22". The degree of whiteness was measured by DR LANGE Whiteness Tester, Germany [1, 12]. Settling behavior of the cyclone overflow product as well as at various medium pH values was measured. Dispersing reagents e.g. Na-hexametaphosphate (SHMP) and Na silicate (SS) were tried to increase the stability of the sample slurry.

3. Results and Discussions

3.1. Characterization of Kaolin Ore Sample

Complete chemical analysis of the kaolin sample was performed using XRF, the results of which are depicted in Table 1. The kaolin sample contains high amounts of Al_2O_3 (32.11%) and SiO_2 (46.06%). The sample has a relatively high content of TiO_2 (3.19 %). It has a lower percentage of Fe_2O_3 (1.69%) and loss of ignition, L.O.I. (13.8%) indicating the presence of calcite as one of the associated impurities. These results are in agreement with XRD analysis which confirms the presence of kaolinite associated with calcite, quartz and anatase, Fig. 1. SEM was used to reveal the morphology and

particle size of kaolinite crystals. SEM micro images indicated that kaolinite has a well-defined crystal structure revealed by its hexagonal plates with micro edges, Fig.2.

Table 1. Chemical analysis of Kaolin Sample

Oxide	Concentration %
MgO	0.195
Al_2O_3	32.117
SiO_2	46.064
SO_3	0.039
CaO	2.284
TiO_2	3.194
Fe_2O_3	1.697
P_2O_5	0.134
L.O.I	13.80

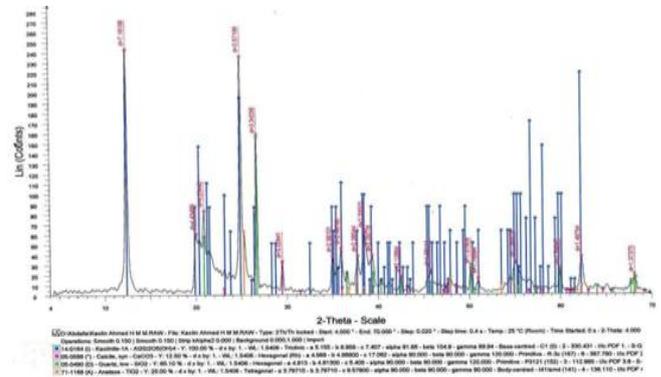


Figure 1. XRD Pattern for Kaolin Ore

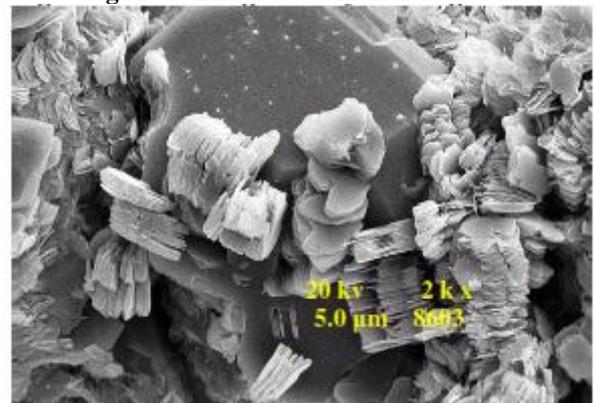


Figure 2. SEM Image of Kaolin

3.2. Beneficiation of Egyptian Kaolin

3.2.1. Preparation of Kaolin Pre-Concentrate (Attrition Scrubbing)

The primary crushed ore sample was subjected to attrition scrubbing, using a pilot scale blunger, at high solid liquid ratio for an hour, after which the scrubbed ore was delivered to a screen (0.074 mm) for its degritting. The oversize was dumped, as tail fraction, while the undersize fraction was further classified using a 3" hydrocyclone unit. Both overflow and underflow fractions of the hydrocyclone were collected, filtered and weighed. The hydrocyclone overflow was taken as a pre-concentrate for further upgrading tests. The size analysis of such pre-concentrate showed to have a very fine grain size distribution where about 75% by weight are below $\sim 2\mu\text{m}$

3.2.2. Wet High Intensity Magnetic Separation of Kaolin Suspension

In a trial to decrease the iron oxide contents of the kaolin pre-concentrate, the hydro cyclone overflow product was subjected to magnetic separation tests using "Boxmag Rapid" wet high intensity magnetic separator. The magnetic attractive force is a function of the volume and magnetic

susceptibility of the particle as well as the magnetic field intensity and gradient. The opposing force is the hydrodynamic drag force while the magnitude of the external applied magnetic field is an important factor; it is the matrix that provides the potential force separation [12-13]. Figure 3, illustrates the relationship between the magnetic field strength and the magnetic separation efficiency of the sample. Maximum separation at certain magnetic field could be attained. It could be concluded that by increasing the applied magnetic field, there is a remarkable increase in the upgrading degree of the product.

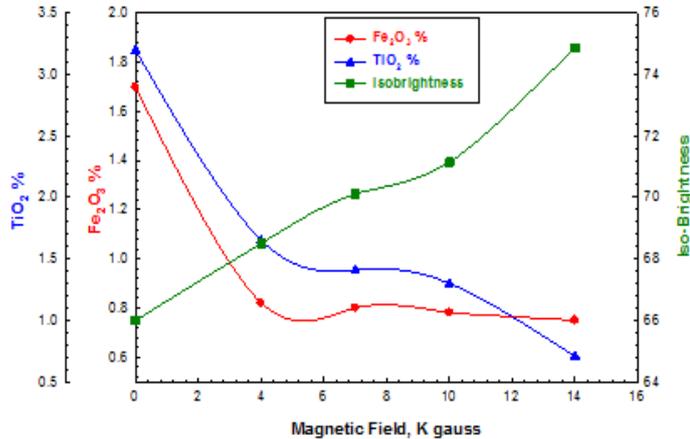


Figure 3. Product Grade as a Function of Magnetic Field Strength

Maximum removal of iron oxide reached 55.8% while TiO₂ removal reached 77.8% with a better degree of iso-brightness (75.21%) at a magnetic field intensity of 14 K Gauss. Optimum separation efficiency was observed at retention time equals 2 min. at material feeding rate of about 240 ml/min., Fig. 4. The concept of retention time involves the control of flow rate in a canister to balance the viscous drag of the medium on the suspended particles in slurry against the force of magnetic attraction induced in the matrix by the background field. Control of retention time is still the crux of the entire process, where it governs the product quality and the production rate [14-15]. The results showed also that at such conditions, it is possible to remove 55.8% of associated iron oxide and about 77.8% TiO₂ with a concentrate assaying 0.75% and 0.71% of Fe₂O₃ and TiO₂ respectively and the maximum iso-brightness was 75.21%.

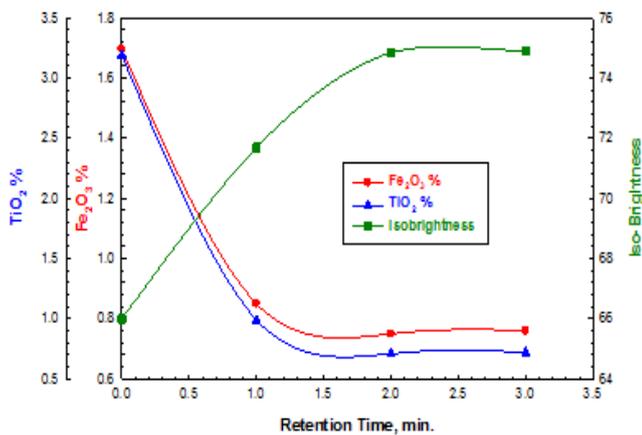


Figure 4. Product Grade as a Function of Retention Time

Figure 5 illustrates the relationship between the solid % and the magnetic separation efficiency. As shown from the Figure, the removal efficiency increases with increasing the solid percent starting from 2.5 till reaching the most efficient

separation at solid % 7.5% where the iron oxide removal reached 55.8% (0.75% Fe₂O₃) and TiO₂ removal reached 77.8% (0.71% TiO₂). After that the removal efficiency started to decrease gradually till solid % of 15 %.

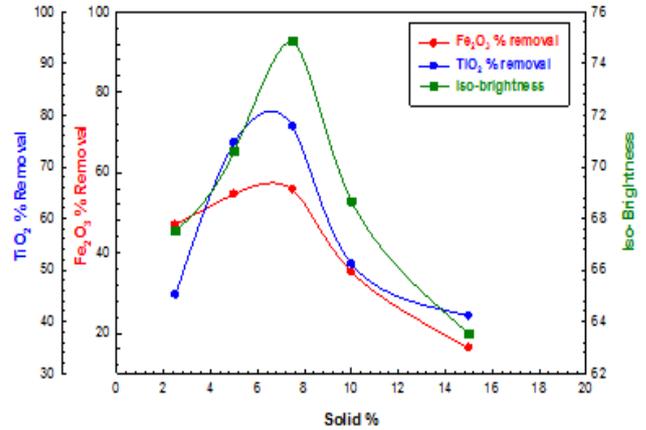


Figure 5. Product Grade as a Function of Solid Percent

Different beneficiation techniques were suggested such as attrition scrubbing, degrading and multiclassification using hydrocyclone. Using these techniques helped in removing coarse grit of silica and carbonates[16]. Successful separation of iron oxides to enhance the iso-brightness of the kaolin product could be achieved using magnetic separation. Applying such a combined beneficiation Flowsheet, Fig. 6, succeeded in producing a high grade kaolin concentrate (~75 wt.% below 2 μm) low in both iron oxides (0.75%) and TiO₂ (0.71%) with a significant improvement in its whiteness to 86.72 % and iso-brightness to 75.21 %.

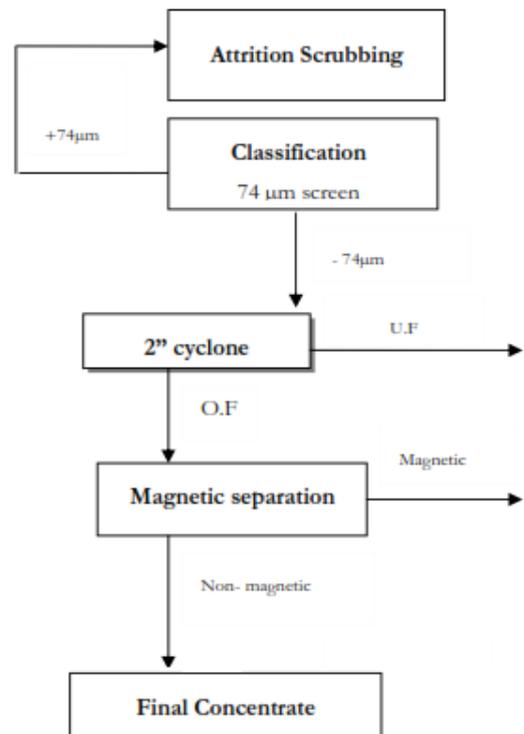


Figure 6. Tentative Flowsheet for Beneficiation of Kaolin Sample

4. Conclusions

The amenability of using magnetic separation for removing the iron oxide and titanium oxide impurities from the Egyptian Kaolin has been studied.

Successful separation of iron oxides to enhance the iso-brightness of the kaolin product could be achieved using magnetic separation.

Applying a combined beneficiation Flowsheet succeeded in producing a high grade kaolin concentrate (~75 wt.% below 2 µm).

The results indicated that substantial decrease in iron oxide (from **1.69%** to **0.75%**) and TiO₂ (from **3.1%** to **0.71 %**) contents.

Both of iso-brightness and whiteness values were improved (from **63.76%** to **75.21%** and whiteness (from **79.85%** to **86.72%**) respectively.

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