Industrial-scale purification of kaolin using a conduction-cooled superconducting high-gradient magnetic separator

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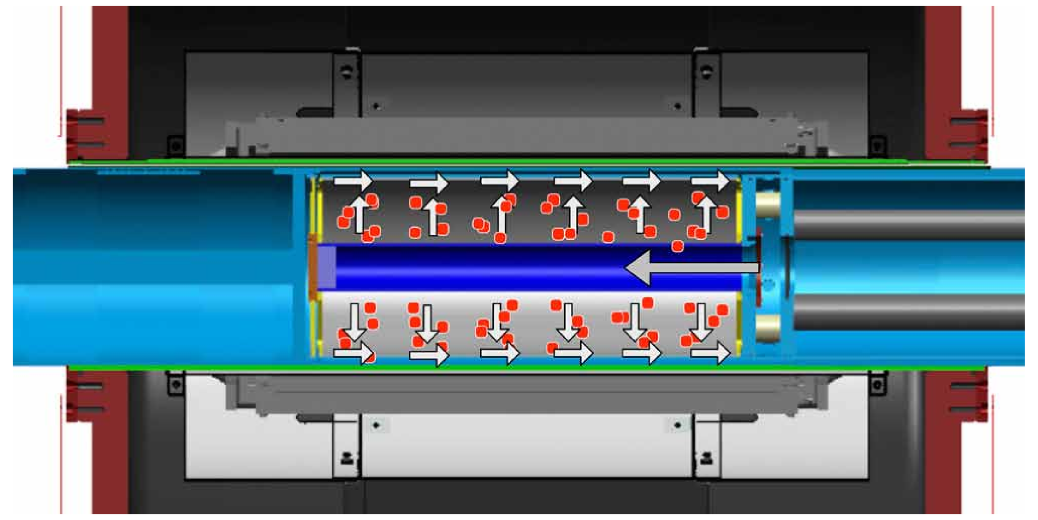
ABSTRACT

Increasing the brightness of kaolin at an industrial scale is commercially important for a variety of industries such as ceramics, paint, cosmetics, paper, and more. Quantum Design, Inc. has developed a high throughput conduction-cooled superconducting high-gradient magnetic separator (SHGMS) which operates at 5 Tesla with a 10% uniformity over 406 mm. This long uniformity range, along with its 203 mm diameter bore and high magnetic field, result in a single system capable of processing 10-15x10^6 kg of clay per year. The magnet temperature is maintained using an Energy Smart 1.5W Gifford-McMahon refrigerator, which dramatically reduces operating costs compared to a liquid helium cooled magnet ($40 to cool down at $0.10/kWhr). The small footprint of this magnetic separator combined with the inexpensive operating costs allow for a modular design so that multiple systems can be used in combination to fit the needs of each kaolin mining facility. Tests carried out to process kaolin from three different mines show a reduction in Fe_2O_3 by over 60%. For example, the as-received specifications for one sample contained 0.85wt% Fe_2O_3 and a fired brightness of 88%. After purifying using the SHGMS, the Fe_2O_3 content was reduced by 65% to 0.29wt%, and the fired brightness increased to 92.5%, resulting in a three-fold increase in the value of the clay.

THE QUANTUM DESIGN MAGNETIC SEPARATOR

Magnetic separation is a well-established industrial method used extensively in mineral processing that allows materials with different magnetic properties to be separated by the use of inhomogeneous magnetic fields. It is achieved using a combination of a magnetic field and a field gradient which generates a force on magnetizable particles. This is usually achieved by the use of a finely divided filter matrix magnetized by an external field source.

The Quantum Design SHGMS is a new type of reciprocating canister magnetic separation system which incorporates a superconducting magnet that is cooled directly by conduction using a single 1.5W Gifford-McMahon cycle cryocooler with a compressor utilizing 'Smart Energy' technology. It requires 42 hours to cool down from ambient temperature and costs around $40 in electricity (based on $0.10 per kW-h).



The SHGMS has a room-temperature horizontal bore of 8" (203mm) with an effective processing space length of 16" (406mm). Over this cylindrical volume the superconducting magnet produces an average of 5 T flux density with variation of less than +/- 10%.

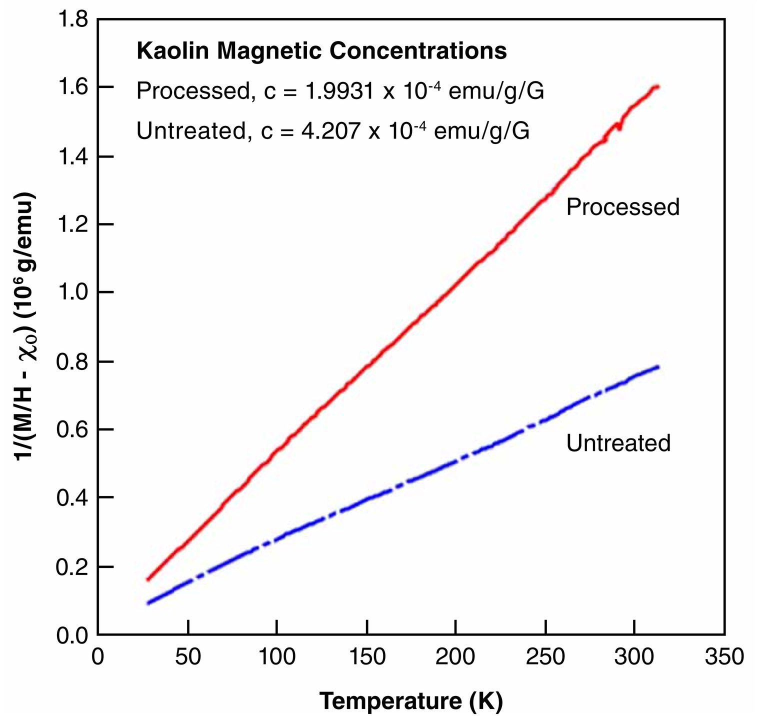
The system uses two independent processing canisters which are switched using a servo drive which allows for rapid canister exchange. The canisters have an innovative design which maximizes processing volume, and is able to process between 10,000 and 15,000 tonnes of clay per year depending on the properties of the clay and the desired level of improvement.

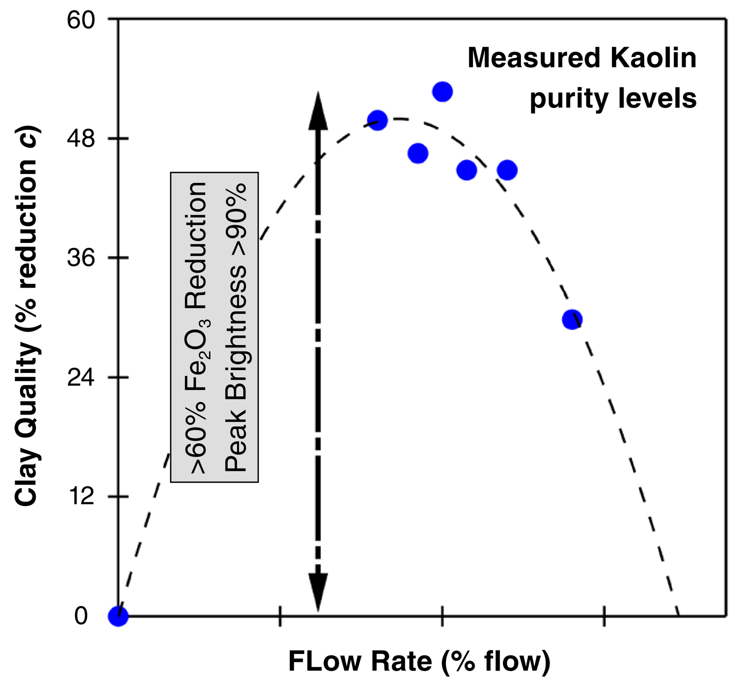
Clay testing has been carried out using the system. In each case the output from the canister was collected and analyzed for fired brightness and chemical composition. Of particular interest was the reduction in Fe_2O_3 content from the unprocessed clay. The clay was dried in an oven and the magnetic properties were investigated using a Quantum Design MPMS 3. The results were compared with the raw clay samples. The magnetic moment for each sample was measured at 500 Gauss for 27K < T < 315K. The results were analyzed using a modified Curie-Weiss behavior, $M/H = c/(T-\theta) + \chi_0$, where c is the Curie constant, θ is an effective temperature related to magnetic interactions, and χ_0 is a temperature independent term. The Curie constant is proportional to the concentration of magnetic impurities through the relation, $c = 1/k_B N\mu^2$, where k_B is Boltzman constant, N is the concentration of magnetic moments, and μ is the value of the magnetic moment.

A plot of $1/(M/H - \chi_0)$ vs. T reveals a straight line whose slope is inversely proportional to the magnetic concentrations in the sample. The plots show the results of a kaolin sample after being processed. The increase in the slope represents a 53% reduction in the magnetic impurities, primarily Fe_2O_3 by treatment in the machine.

One of the key tuning parameters for optimizing the process is to vary the flow speed at which the clay moves through the magnet. At the optimum flow speed, the system captures and retains the desired fraction of the raw clay that compromises its brightness, as shown in the plot. Under these parameters this particular clay was improved to 0.29% Fe_2O_3 content (a 65% reduction) and was improved to a fired brightness of 92.5% (~4.5 points increase). On current market prices the clay would be improved in value by greater than a factor of 3.

Results for a typical, secondary deposit type of kaolin are shown below. The untreated clay is on the right and has a clear brown color to it.





CONCLUSIONS

Quantum Design has demonstrated that a commercially viable, compact and effective high gradient magnetic separation system can be constructed without the need for liquid cryogens.

The analysis of processed and unprocessed clays using a Quantum Design MPMS 3 combined with measurements of the fired brightness and Fe_2O_3 content has confirmed that such a magnetic measurement can provide a rapid method of optimizing and verifying the parameters for processing a particular clay.

The first system has been successfully installed at the Jing Ding Kaolin Company facility in Zhangzhou, China.

- 5T Superconducting Magnet
- Cryogen Free
- PLC Controlled
- Modular Design