Vol. 20, No. 6 | 2009

CAER ENERGEIA

Economical Recovery of Fly Ash-Derived Magnetics AND EVALUATION FOR COAL CLEANING

JACK GROPPO and RICK HONAKER
University of Kentucky

Dense-medium separators (DMS) have become the predominate processes worldwide for cleaning coal coarser than 1 millimeter, accounting for as much as 65% of the processed coal in the U.S. In Kentucky, about 117 million tons of run-of-mine coals are cleaned in DMS units. This popularity is due to their superior ability to achieve high energy recovery values over a wide range of coal qualities. To create the dense-medium, fine magnetite is added to water to form a suspension having a medium density between the solid densities of coal and rock. As a result, the coal floats while the heavier mineral matter sinks through the medium. During the process, plant magnetite losses occur which are typically in the range of 1.0-1.5 lbs/ton of plant raw coal. As such, the coal industry in Kentucky alone utilizes approximately 130,000 tons of magnetite annually.

Until 2001, the magnetite used in the U.S. coal industry was supplied by the Pea Ridge Iron Ore Company located in the Missouri iron ore field. However, in August of that year, the operation closed due to the lack of economically recoverable reserves. As a result, magnetite suppliers to the coal industry were required to secure imported materials from Peru and Chile. Magnetite cost to the coal industry nearly doubled to approximately $100/ton. During the past two years, China's increased demand for magnetite resulted in a long term supply agreement with Peru and Chile, which has generated concerns by coal operators about the long term availability and cost of magnetite. Over the last six months, the delivered cost of magnetite for Kentucky operators has increased from $150 to $180/ton. A supply shortage in the future would have a significant impact on the ability to supply clean coal to Kentucky utilities.

Providing an alternative material to use as a dense medium in coal cleaning plants would calm fears of a potential future shortage and potentially reduce cost. Based on the need for 130,000 tons of magnetite annually, the increase in the annual cost of magnetite for Kentucky coal operators rose from $9.1 million to $21.5 million over the past five years. In terms of a single-unit operation, magnetite cost has increased $0.08/clean ton to $0.18/clean ton based on a 1998 coal preparation survey of operating costs.

One potential alternative source for magnetite is as a recovered product from coal combustion ash, an idea that is not new as evidenced by numerous US patents having been issued dating back as far as 1924. Despite the abundance of patents issued on this topic, only one has ever resulted in a commercial enterprise which operated in southwestern PA during the mid-1980's.

Figure 1. Magnetite recovery equipment.

(continued, page 2)

The primary reason that production of fly-ash derived magnetite has not been successful at the commercial scale is that there is simply insufficient recoverable material available to make recovery cost-effective; most fly ash substrates contain less than 2% magnetite. A more cost-effective approach would be to incorporate magnetite recovery with ash beneficiation being practiced for the recovery of additional products.

SITE DESCRIPTION

Bottom ash is currently processed at the Mill Creek power plant in Louisville, Kentucky by Charah, Inc., an ash management company based nearby. The process was jointly developed by Charah and CAER and has been in commercial operation since 2002, successfully marketing over 500,000 tons of graded fill sand produced from the bottom ash.

Bottom ash is sluiced from the boilers into a trench that flows into the ash pond. The trench is periodically excavated with a track hoe and the excavated material is stockpiled and allowed to drain. It is then transported to a feed hopper and conveyed into a processing plant where oversize (+3/8 inch) material is rejected. The -3/8 inch ash drops into a screw classifier, which dewaters the ash and conveys the finished fill sand onto a stockpile. The classifier overflow is a dilute slurry containing primarily -100 mesh (-150 µm) solids, which flow into a separate reject containment area that is periodically excavated. The stockpiled fines are currently utilized as kiln for cement manufacturing. This stockpiled fines reject is the substrate used for magnetite recovery.

MAGNETITE RECOVERY CIRCUIT

The recovery circuit used (Figure 1) consisted of a single bank of concentrating spirals fed by a slurry pump. Concentrated magnetite was collected from the inside race, which increased the magnetite grade of the feed from 12.1% to 68.0% magnetics. Further upgrading was accomplished with a continuous magnet. Using this approach, each ton of spiral feed produced 128 pounds of magnetite containing 59.6% Fe_2O_3. Petrographic analyses showed that the final product was comprised essentially of iron-rich spherical particles (Figure 2). Approximately 500 lbs of magnetite was recovered for dense medium cyclone testing.

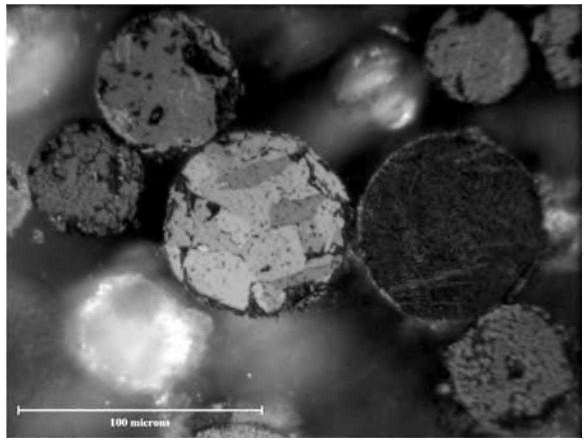

Figure 2. Spinel spheres in HGMS product.

DENSE MEDIUM CYCLONE TESTING

The coal sample used for the performance assessment of the medium was obtained from the dense medium cyclone process streams of an operating coal preparation plant that treats coal extracted from the Coalburg seam. This seam is prominent throughout the central Appalachia coalfields and is well known as being difficult-to-clean due to the relatively large amount of middling particles. The washability analysis is shown in **Table 1**.

PILOT-SCALE DENSE MEDIUM CYCLONE TESTING

The tests using the recovered magnetic product as a medium for cleaning coal were conducted using a 15-cm (6-inch) diameter Krebs dense medium cyclone with a 6.3 cm vortex and 4.5 cm apex diameter. The cyclone had a cone angle of 20° and was inclined at an angle of 10° from the horizontal. These parameters were kept constant throughout the study. The dense medium cyclone was operated in a closed loop using a feed bypass to control the inlet feed pressure to the cyclone.

MEDIUM STABILIZATION

One of the most important characteristics of a medium used for density-based separations is that the ultrafine particles used to develop the medium move nearly or completely with the fluid. In other words, the particles should not have a significant settling rate within the fluid. Medium stability is assessed by measuring the difference in the pulp

SPECIFIC GRAVITY	WEIGHT %	ASH %
1.3 float	27.87	2.88
1.30 x 1.40	11.63	9.03
1.40 x 1.50	5.78	18.41
1.50 x 1.60	5.60	28.90
1.60x 1.75	11.95	39.66
1.75 x 1.90	16.40	48.78
1.90 x 2.0	9.50	59.41
2.0 sink	11.27	79.07
Total	100.00	31.83

Table 1. Washability data of the Coalburg coal.

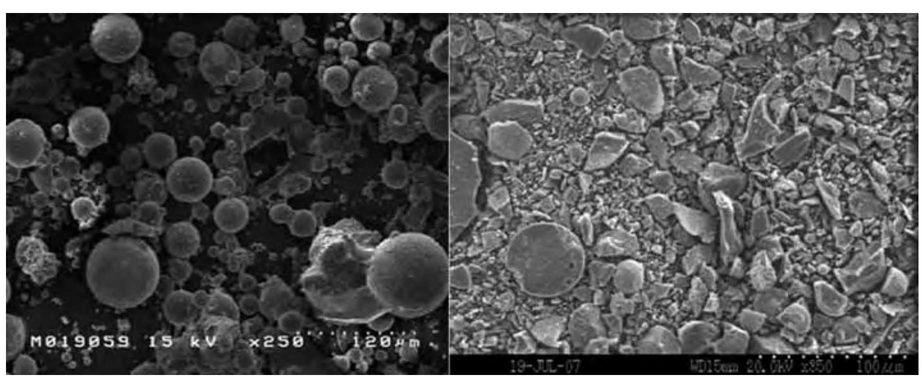

Figure 3. Scanning electron microscope images of raw (left) and ground (right) bottom ash-derived magnetrite. as a function of increased grinding time.

(continued, page 3)

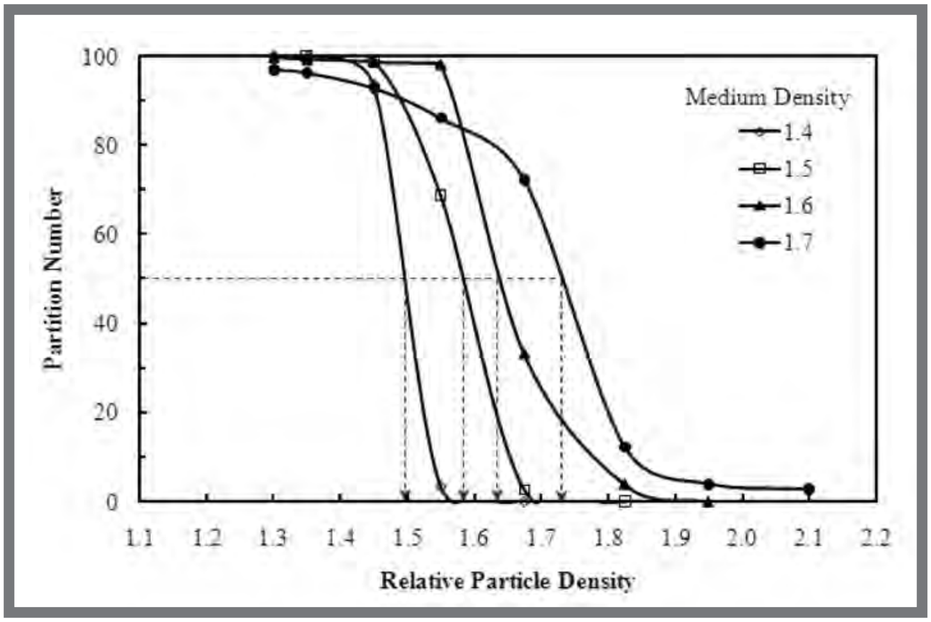

Figure 4. Partition curves generated over a range of medium density values using magnetic bottom ash.

VARIABLE	RELATIVE MEDIUM DENSITY			
	1.4	1.5	1.6	1.7
Feed Ash (%)	40.84	40.30	33.82	32.58
Product Ash (%)	6.11	8.82	11.7	15.43
Tailings Ash (%)	56.44	58.28	57.82	56.29
Yield (%)	31.00	36.36	52.04	58.03
Recovery (%)	49.19	55.53	69.43	72.79
Org. Efficiency (%)	96.81	98.92	95.49	89.94
ρ_{50}	1.495	1.583	1.640	1.733
Ep	0.023	0.044	0.051	0.063
$\rho_{50} - \rho_{medium}$	0.095	0.083	0.040	0.033

Table 2. Summary of separation performances achieved using the magnetic bottom ash at an inlet pressure of 34.5 kPa.

density of the overflow and underflow stream densities (i.e., $\rho_u - \rho_o$). The general criterion is that the pulp density difference should be less than 0.4 units. The bottom ash product was unstable when density differential values were over 0.8 density units. This is attributed to both the spherical shape and relatively large size.

To achieve a stable medium from the magnetic bottom ash, the material was ground in a ball mill, which effectively reduced the particle size from a d_{90} of 48µm to 22µm, while generating irregularly shaped particles (**Figure 3**). This provided a more stable suspension with relative density differences within the industrially-acceptable levels of around 0.4 density units or less. In fact, the magnetic bottom ash medium was found to be more stable than the medium formed using conventional Grade B magnetite.

DM CYCLONE PERFORMANCE

Dense medium cyclone tests were conducted to assess the separation efficiency achievable when using the magnetic bottom ash. Washability analyses were performed on samples collected from the clean coal, reject, and feed process streams. The data was used to develop the partition curves shown in **Figure 4** over a range in medium density values from 1.4RD to 1.7RD.

Separation efficiency is measured by the slope of the partition curve which is typically quantified by the probable error value (i.e., $Ep = [\rho_{25}-\rho_{75}]/2$). Bypass of low-density particles to the reject stream and vice versa are also a sign of inefficiency. A parameter that combines the efficiency associated with the probable error and bypass is the organic efficiency, which is the ratio of the actual energy recovery to the theoretical energy recovery at a given product ash content. A summary of the separation performances represented in **Figure 4** is shown in **Table 2**.

The separation efficiencies measured for the medium densities of 1.4RD and 1.5RD are excellent with organic efficiency values around 97% and probable error values of 0.04 or less. As of the case with conventional magnetite, the probable error increases with an increase in medium density, which represents a decline in efficiency due to medium viscosity impacts. The probable error values are comparable to those achieved when using conventional magnetite.

Dr. Groppo (groppo@caer.uky.edu) is a researcher in the CAER's Environmental and Coal Technologies group. Dr. Honaker (rick.honaker@uky.edu) is the Chairman of the UK Dept. of Mining Engineering.

Sponsored by the Governor's Office of Energy Policy (now DEDI, Energy and Environment Cabinet)

KENTUCKY COAL *and* MINING TRADE MISSION in South Africa

CAER Associate Director for Administration, Don Challman, joined the Kentucky Coal and Mining Trade Mission on a 10-day trip to South Africa. During the visit, the delegation met with representatives of the Chemical Engineering Department, University of Cape Town; US Department of Commerce (Johannesburg); the South Africa Department of Mineral and Energy and the South Africa Trade and Investment Department (Pretoria); and Council for Scientific and Industrial Research (Johannesburg).

Delegates also visited Sasol (South African Coal, Oil and Gas Corporation), which introduced the group to private sector coal operations on the African continent. Sasol is a South African company involved in mining, energy, chemicals and synfuels.

One of the highlights of the trade mission was a tour of the coal terminal at Richards Bay. Richards Bay Coal Terminal (RBCT) is one of the largest export coal terminals in the world. Opened in 1976 with an original capacity of 12 million tons per annum, it has grown into an advanced 24-hour operation with a design capacity of 76 million tons per annum. South Africa is the world's second-largest coal exporter after Australia. It is also the mining technology and services hub for mining operations for most African countries.

Richards Bay Coal Terminal

SASOL Works

Syfertein Mine

"No one UNDER THIRTY thinks..."

RODNEY ANDREWS
Director, CAER

In the current climate of economic uncertainty, unprecedented federal spending, worsening state budgets, and a near religious zeal for a "new green economy," perhaps the most striking comment I have heard is "I don't know anyone under thirty who thinks we'll be using coal in thirty years." This statement was made during the evening panel discussion at the Coal Forum hosted by the Center for Visualization and Virtual Environments at the University of Kentucky as part of its work to produce a documentary on the current and historical impact of coal on Kentucky. This was uttered by a popular author, an author who has written on the coal industry and claims to have developed this opinion by talking to a vast number of the up-and-comers on both coasts.

That statement, made very matter of factly, fascinated me. Perhaps more than anything, I thought it was the perfect example of what I've come to think of as the "green superiority" that seems to be directing our energy policy. At a time in our history when we are spending more than ever on energy development and infrastructure, we seem to have accepted, without any accompanying technical argument, that green is good and everything else is bad. Worse, this is being done in a climate in which any dissent about what is "green," or for that matter, what is logical and what is efficient, is trivialized as reactionary or simple bloody-minded obstinacy. More than once I have encountered the shocked silence for stating that a particular renewable energy option might not be best here in Kentucky, or that perhaps current spending could be most effective if used to improve the efficiency of our existing fossil systems. But, if it's not green, it obviously is not important, and anyone who disagrees is clearly out of touch with the new reality.

In deciding what to write about this year, I spent a lot of time contemplating the truth or untruth inherent in that statement. It bothered me, perhaps as a matter of perspective. After all, I tend to interact with energy technologists, engineers and scientist i.e., people who do math for a living. I should have offered to introduce the author to 40 or 50 people under thirty who would have given him a different opinion on the future of coal. They are:

- Students who are investing their time (and money) to prepare for careers in mining, electric power or fuel processing. They are very bright, very dedicated young people who are now concerned that their chosen careers are being taken away on what seems a national whim. These same students may be working on solar cars, or off grid high performance houses[1], but realize it will be coal that fuels their careers for the next couple of decades. Students who may be all for electric vehicles and developing better energy storage systems, but understand the electricity to power these greener vehicles has to come from somewhere.

- Researchers, in and out of graduate school, who work well beyond 9:00 am to 5:00 pm to push projects on carbon capture forward as quickly as possible, knowing "we only have a few years." They are enthusiastic, talented, dedicated to fixing the problems with coal, rather than writing it off with a glib "we'll just use solar."[2] These are smart, creative thinkers, who are combining ideas from fields like biotechnology, petroleum engineering and nanomaterials to address the real problem – how do we make coal work the way we want without breaking the bank.

- Under-thirty entrepreneurs who are finding innovative ways to use coal ash to create improved materials, new jobs, and a better environment. They are researching materials that are lighter, safer and consume less petroleum than existing choices, materials that may eventually be used to improve energy efficiency in low-income housing, or make vehicles lighter to save fuel, or make our buildings and transportation systems more resilient and secure.

- Designers and architects finishing their professional degrees who are working with coal by-products to make new, less-energy intensive products that have artistic form and real function. These students are looking for real and meaningful sustainability, not the band-aid version from television. The design students are turning this same creativity toward developing more efficient and affordable housing for those least able to bear higher energy prices.

Perhaps the most heartening thing I've begun to understand about these 'twenty-somethings' is that they do realize what is at stake, that the decisions we make as a nation today will be something they will have to live with well beyond the lifetimes of those

(continued, page 6)

UNIVERSITY OF KENTUCKY
Center for Applied Energy Research
2540 Research Park Drive
University of Kentucky
Lexington, Kentucky 40511-8479

Non-Profit Organization
U.S.Postage
PAID
Lexington, Kentucky
Permit No. 51

Energeia is published six times a year by the University of Kentucky's Center for Applied Energy Research (CAER). The publication features aspects of energy resource development and environmentally related topics. Subscriptions are free and may be requested as follows: Marybeth McAlister, Editor of Energeia, CAER, 2540 Research Park Drive, University of Kentucky, Lexington, KY 40511-8479, (859) 257-0224, FAX: (859) 257-0220, e-mail: mcalister@caer.uky.edu. Current and past issues of Energeia may be viewed on the CAER Web Page at www.caer.uky.edu.

No One Under Thirty Thinks... (cont.)

making the decisions. And they are beginning to speak up, basing arguments on common sense, system efficiency, and a fundamental understanding of how our electric power system works. I'm (nominally[3]) teaching the CME 599 Energy Systems class again this spring semester. This is a class that has been offered twice. Both times it has been offered has required the enrollment to be expanded from the 20 originally assigned to 34 last year and 36 this year. Students understand that their electricity does not simply come out of the wall, and want to understand more as they contemplate a carbon-constrained future.

The companion argument given by our coastal speaker about coal's future fate was one of climate change and global environmental impact: it's a moral imperative that we stop using such old fashioned fuels. I was asked by an 'under-thirty' if it wasn't also a moral imperative that the poorest members of our society have equal access to heat, light, healthy food, clean water, and education. Things we can provide with affordable and reliable electricity. My title was tongue in cheek, but I am encouraged that I know many people under thirty who DO think.

1 *UK competed in the U.S. Department of Energy's Solar Decathlon this year. The student team designed and built a state-of-the-art high performance house, coming in 9th out of 20 for our first time in the contest!*

2 *I do not hate solar, it's just the most obnoxious way I can think to make this point. Solar is, eventually, the answer – but not tomorrow, and not cheaply. More on my views on solar in a future editorial.*

3 *Real credit has to go to CAER researchers Jack Groppo and Jim Neathery who allow me, hyperkinetic travel schedule and all, to take credit for teaching this class while they cover about ¾ of the lectures.*