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HYDROACOUSTIC CAVITATION FOR RECLAIMING ANTHRACITE FINES FROM WASTE SILT SLURRY

A Thesis in

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by

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ABSTRACT

Hydroacoustic cavitation treatment, coupled with cyclone and spiral separation, were tested to reclaim anthracite fines from a silt-coal slurry. This waste slurry had been received from an anthracite producer, and it contained approximately 36% combustible material (i.e. fuel). Control experiments that did not include hydroacoustic treatment were also conducted. When hydroacoustic treatment was included, this process reclaimed 68.8% of all the fuel (i.e. non-ash volatiles: carbon, hydrogen, and oxygen) as a sellable product. The hydroacoustic cavitation process apparently dislodged the coal from silt particles so that they could be better separated through the cyclone and spiral. When hydroacoustic cavitation treatment was not included (control test), the cyclone and spiral reclaimed only 14.3% of all the fuel.

The spiral included seven splitter box divisions (i.e. exit ports) -- three inner ports combined as refuse, two middlings ports, and two outer clean coal ports. When hydroacoustic treatment was included, the two clean coal ports plus one middlings port yielded coal that averaged less than 8.5% ash in the -16+100 U.S. mesh size range. In comparison, for the control experiments (no hydroacoustic cavitation treatment), only the clean coal ports (1 and 2) yielded coal that averaged less than 8.5% ash for the same size fraction. In another set of tests, ozone and hydrogen peroxide were coupled with hydroacoustic cavitation treatment that preceded cyclone, spiral, and simulated sieve bend separation. In this case, two clean coal ports plus one middlings port produced coal with 8.5% ash. The total recovery of this material was 72.4% or an increase of 3.6% of the available fuel that was reclaimed without ozone and hydrogen peroxide addition.

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Chapter 1

Introduction

Overview of Anthracite and Silt Ponds in Pennsylvania

Anthracite has the highest carbon content of all coal types (Stefanenko, 1983). The reserves of anthracite in the United States are primarily located in northeastern Pennsylvania (Averitt and Berryhill, 1969). Pennsylvania is the fourth largest coal-producing state in the United States, and the only state that mines anthracite (U.S EIA, 2012). In a typical anthracite preparation plant, coal is classified into five to ten different size ranges—down to several millimeters in size (Laskowski, 2001). Any coal fines that are smaller than this size are conventionally disposed along with fine silts, because the mix of coal fines with silt offer little value as a very low-grade product. This silt-coal fines stream results from the coal washing technologies that are used in a conventional coal processing plant. Millions of tons of these silts remain in ponds in Pennsylvania; and it is difficult for coal-mining companies to obtain permits for new silt ponds. Moreover, the silts that remain in the bygone ponds do not compact well, and this renders them unstable for constructing roads and buildings on them.

This project combines novel technologies with conventional processes to reclaim high-grade anthracite fines from a combined slurry of inorganic silts and coal. These reclaimed coal fines could be fashioned into bindered anthracite bricks, which could partially replace coke in the foundry industry and other similar industries (Huang et al., 2010). This approach tackles an environmental problem that arises from silt ponds and provides the opportunity of reclaiming otherwise wasted coal fines as a valuable product.

Processing System Design

The novel processing system consists of a hydroacoustic cavitation (HAC) unit, a hydrocyclone, and a spiral. The coal-silt slurry first flows through the novel HAC unit where the intense energy of hydroacoustics and cavitation liberate the coal fines from the silts and clays. Then the slurry is routed to a conventional hydrocyclone where silt gets separated to the overflow stream. The underflow stream, which is rich in coal, is processed through a conventional spiral to further separate the clean coal fines from the silts and clays.

The ultrasonic-cavitation system used herein was developed by Furness-Newburge (Versailles, KY). This novel technology has been used successfully to reclaim silica sand, active clay and sea coal from spent green sand at Neenah Foundry, WI and at other foundries (Fox et al., 2009, 2009a, 2008). When this novel process is applied to coal, cavitation creates nanobubbles that collapse under the intense pressure incurred by hydroacoustics, thus releasing blasting energy that tears the silts and clays away from the anthracite fines. Wang et al. (2005) showed that when processing foundry baghouse dust from green sand operations, 5 minutes of ultrasonics treatment of slurry dislodged 3 times more clay than merely stirring without ultrasonics. In addition, advanced oxidation technology involved adding ozone and hydrogen peroxide to the waste slurry, so as to generate hydroxyl radicals (OH^-) that were effective at shearing organic residues and clays away from fine sand grains in foundry green sand systems (Fox et al., 2008). Some of the tests herein coupled ozone and hydrogen peroxide with the HAC process.

Separation Principles of the Cyclone and Spiral

Hydrocyclones (or cyclones) have been conventionally used to classify particles based on differences in particle size (Wills, 2011). Feed slurry enters the cyclone tangentially at the inlet along the perimeter of the cyclone. Fine particles such as the silts and clays are carried inward by the fluid and leave upward through the vortex finder with the bulk of the fluid. Coarse particles such as the coal are driven outward by the centrifugal force and travel spirally downward and exit through the apex (Kelly, 1982; Bain and Morgan, 1983).

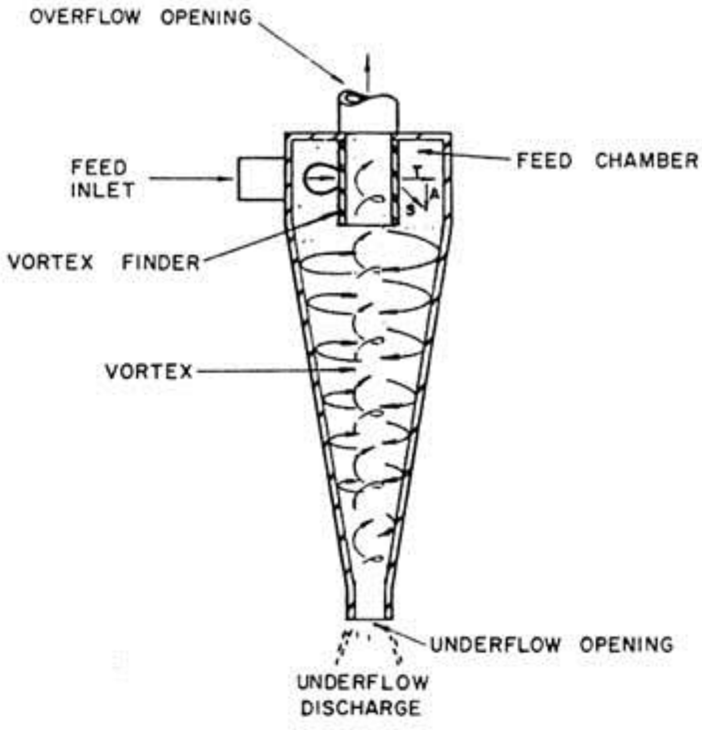

Figure 1. A Schematic of Hydrocyclone

Source: Drilling and Excavation Technologies for the Future (1994)

A spiral concentrator consists of multiple turns of a curved trough, which separates particles primarily by density (Atasoy and Spottiswood, 1995). As slurry enters from the top and flows down the trough, the action of the flowing film in combination with centrifugal force causes coal particles to travel to the outer periphery of the trough, while silts and clays remain in the inner periphery (Kelly, 1982). Several exit ports are located at varying distances from the centerline of the trough to transport slurry to different product streams (Figure 2).

Generally, a larger spiral flow rate is desirable when processing coarse denser material, whereas lower flow rates are better suited for fine and less-dense material (Benusa and Klima, 2009). Extreme conditions, such as too high or too low flow rates will lead to very poor separation. Though a single-stage spiral can achieve an acceptable separation, compound spirals have been developed to minimize the misplacement of silt and clay to the clean coal stream by reprocessing the product stream in the same unit (Benusa and Klima, 2009). Multiple-start spirals also offer higher capacities within a given space; and they are commonly used in full-scale coal cleaning plants to process coal in the size range of approximately 0.15 mm to 1 mm (Hornsby et al., 1985).

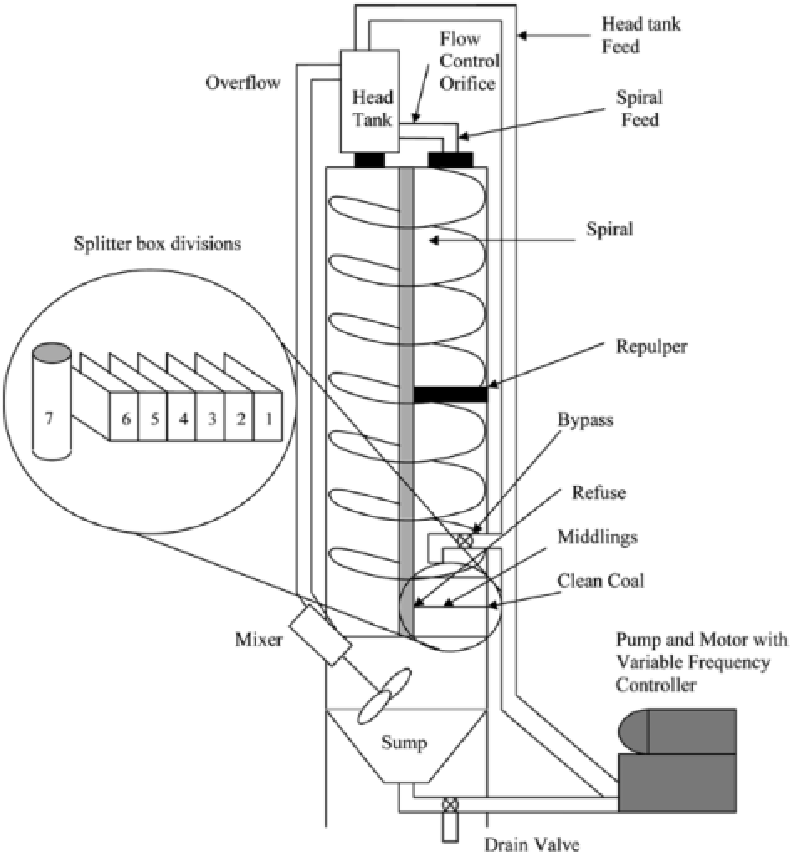

Figure 2. A Schematic of spiral concentrator circuit
(source: Benusa and Klima, 2009)

For ease of description, splitter box divisions 1 and 2 were combined to represent "clean coal", 3 and 4 as "Middling" and 5- 7 as "Refuse" (See Figure 2). Conventionally, it is expected that a high grade of coal will be yielded from the clean coal streams (i.e. exterior streams), a slightly lower grade of coal from the middling stream, and most of the high-ash material from the refuse streams (i.e. interior streams) (Honaker et al., 2007). However, when HAC preceded cyclone separation preceding spiral separation, the ash content of the middling streams was reduced to less than 8.5% ash for some streams.

Chapter 2
Materials and Methods

Materials: A number of 55-gallon drums of coal-silt slurries were obtained from the thickener underflow stream at the Jeddo Coal processing plant (Hazelton, PA) on December 18, 2012 and June 15, 2013. The collection process entailed filling a drum with slurry, letting it settle, decanting off the liquid, and filling it with slurry again, through several cycles of decanting and filling. After concentration, the drums contained approximately 26-29% solids by weight.

Processing Procedures

Methods: System parameters were adjusted independently and in a manner that allowed the source of changes in output to be identified. Each parameter was tested using a separate batch of material, which was then compared to a control test using the same material. Parameters such as hydrocyclone vortex finder and apex diameters, inlet pressure, spiral feed tank outlet diameter, and sonication amplitude and frequency were each appraised as independent variables during preliminary testing to determine the flow and separation conditions for detailed testing. The addition of oxidizing agents was also examined. Spiral samples (clean coal, middlings, and refuse) were collected simultaneously. The duration of sample collection from the spiral discharge ports was approximately three seconds. Size fractions were examined separately after spiral separation and tested for ash content.

The HAC system included a 6-inch diameter by 4-feet long acoustics chamber, centrifugal pump, and 50-gallon mix tank. This system was coupled to a Krebs 4-inch diameter hydrocyclone and to a Multotec seven-turn, two-stage spiral concentrator as shown in Figure 1. The HAC system also included a system to add hydrogen peroxide and/or ozone to the circuit. The ozone was generated from pure oxygen via an ozone generator provided by Furness-Newburge. The discharge from the acoustics chamber flowed to the cyclone. The cyclone flow rate was maintained at approximately 40 gal/min, which corresponded to an inlet pressure of about 15 psi (unless otherwise stated). The cyclone underflow slurry was used as spiral feed.

The spiral was initially fed through orifices of 35 mm, 32 mm, 28 mm, or 23 mm, which gave spiral flow rates of 31.5, 27.4, 19.8, and 12.1 gal/min, respectively. Based on these preliminary tests (not shown), the 32 mm orifice was found to perform the best and was used for subsequent testing. Spiral splitter box ports 1 and 2 were combined to represent “clean coal”, 3 and 4 represented “middlings” and 5- 7 represented “refuse” (Figure 2). Conventionally, it is expected that a high grade of coal will be yielded from the clean coal streams, a slightly lower grade of coal from the middling stream, and most of the high-ash material will remain in the refuse streams (i.e. interior streams) (Honaker et al., 2007).

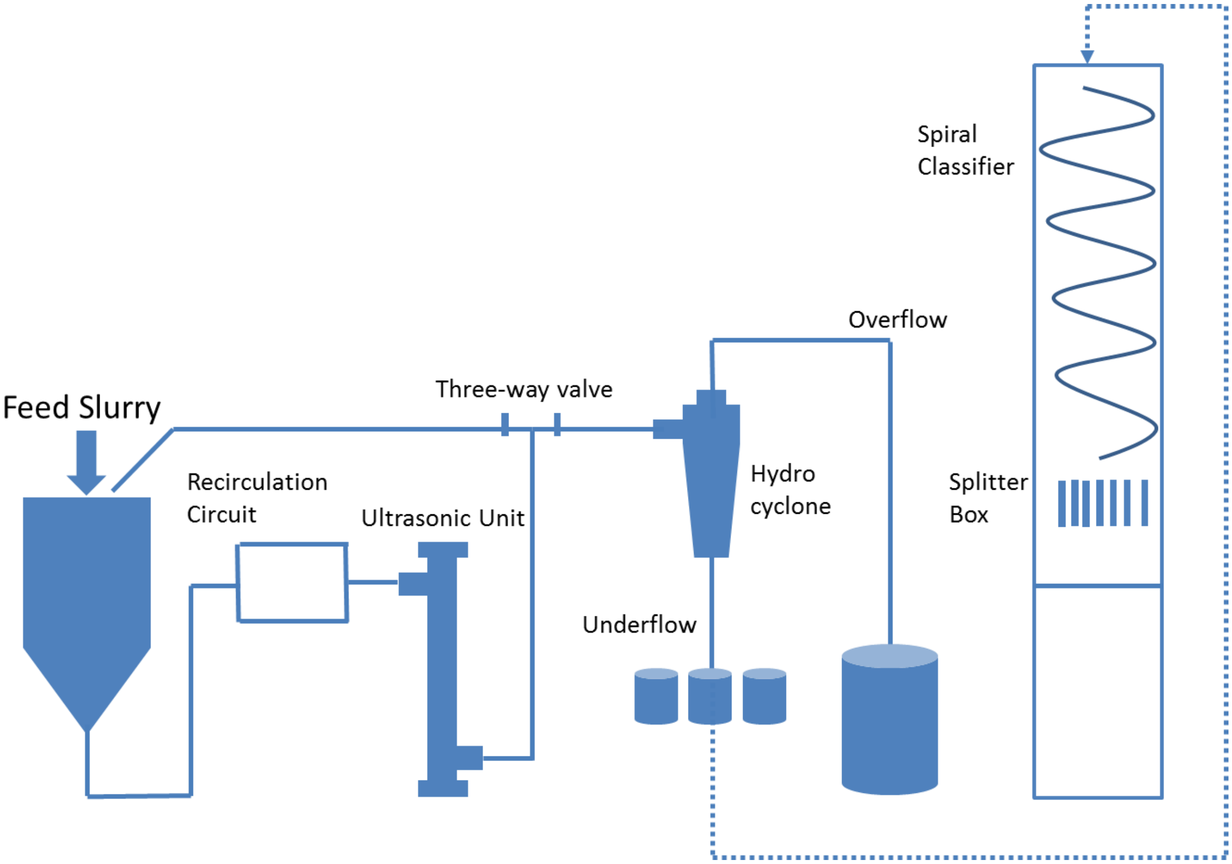

Figure 3: A Schematic of the separation system

Cyclone separation followed treatment that was comprised of either: (a) hydroacoustics following cavitation (HAC), (b) HAC coupled with H_2O_2 and ozone (HAC-H_2O_2-O_3) or (c) control where the cavitation chamber was bypassed, and the ultrasonics was turned off. Under each of these scenarios, approximately 50 gallons of anthracite silt slurry at 10% solids by weight was prepared in the mix tank. This slurry was pumped around a recirculation loop for about two minutes to ensure that the slurry was homogeneous. For the control experiments, flow bypassed the cavitation chamber, and the ultrasonics generator was turned off. After circulation, the slurry was routed to the hydrocyclone.

The ultrasonics vibrator in the acoustics chamber was operated at 50% of its maximum frequency for HAC runs. The slurry also flowed through a cavitation chamber during the HAC runs. For several runs, the hydroacoustics and cavitation were augmented by two strong oxidants, hydrogen peroxide (H_2O_2) and ozone. These were added to the feed slurry for HAC-plus- Advanced Oxidation runs. Concentration of H_2O_2 in the feed tank was kept at 500 ppm and ozone was at near saturation levels, per protocols similar to those described by Milan-Segovia et al. (2007). They found that when H_2O_2 was combined with ozone, the two together accumulated twice as much OH^- radicals than when H_2O_2 was used alone.

The cyclone's underflow slurry (rich in coal) was collected in four 5-gallon buckets for subsequent spiral processing, whereas the overflow (high in silts and clays) was discarded as waste. In order to collect four 5-gallon buckets of underflow slurry, the HAC system was operated through two batches of operation. Thus the results before the spiral effectively represent the average of two batches. The four buckets of cyclone underflow slurry, along with water, were transferred to the spiral sump together to make about 40 gallons of slurry at approximately 26% solids by weight. The slurry in the spiral sump was pumped to the spiral head tank, which then discharged onto the spiral for particle separation. For each test, samples were taken from (a) the underflow and overflow of the cyclone, and (b) the exit ports of the spiral for the purpose of size distribution and ash analyses.

Sieve and Ash Analyses Protocols

The wet weights of the slurry samples were recorded. The slurries were dried in aluminum pans at 110° C in a convection oven, and the dry weights were recorded. The dried samples were wet screened using a 140 U.S. mesh (105 μm) sieve, as the -140 mesh material was predominantly high-ash material. The sieving process simulated the particle size separation that could be anticipated to occur through a sieve bend (or other screening process) in full-scale operations. The +140 mesh material was dried, and size distribution data were obtained by sieving the sample at 1200, 420, 150, and 105 μm (16, 40, 100, and 140 U.S. mesh) on a Ro-Tap sieve shaker for 20 minutes to give +16, -16+40, -40+100, -100+140, and -140 mesh size fractions.

In order to determine the ash content, one gram of dry sample was taken from each size fraction. These samples were placed into ceramic crucibles, and the crucibles were placed into an air-charged furnace at 700° C for 12 hours. The ash content of each sample was calculated based on the weight of material that remained after this combustion. Triplicate ash analyses were conducted for each condition, and the % ash values generally varied by less than 5% of one another.

In several cyclone runs (as noted in the Appendix), a low inlet pressure of 5 psi was noted. This low pressure occurred due to the clogging of the pump impeller by larger grit particles that were present in the silt slurry. For these (chronologically earlier) runs, the results of these low-pressure runs were included (in the Appendix). In subsequent runs, this issue was resolved by sieving all as-received material on a 4 mesh (4760 μm) screen to remove any oversize material.

Chapter 3

Results and Discussion

The system operations were compared for three treatments that preceded the cyclone, namely: (a) hydroacoustics cavitation (HAC), (b) HAC with ozone plus hydrogen peroxide, and (c) control, where the cavitation chamber was bypassed, and the ultrasonics remained off. For each of the batch operations, the cyclone inlet pressure was 15 psi. Then the cyclone underflow (that was rich in coal fines) was processed through the spiral at 27.4 gal/min.

Ash content at various sampling points for HAC, HAC-H_2O_2-O_3, or the control

Table 3 Ash content, solids yields, and fuel yields from various points in the coal-fines processing systems for : (a) Conventional operations of cyclone and spiral (i.e. control), (b) HAC preceding cyclone and spiral separation, and (c) HAC with hydrogen peroxide and ozone treatment preceding cyclone and spiral separation

Sample Point		HAC	HAC-H_2O_2-O_3	Control
As - Received	Total, Ash%	63.6	67.1	63.6
Cyclone	Underflow, Ash % (= spiral feed)	33.7	38.5	33.3
	Overflow, Ash % (not wet-screened)	70.1	70.0	69.9
Spiral	% of all as-received solids yielded as product coal (with <8.5% ash)	22.1	22.2	4.7
	% of all as-received solids yielded as product fuel (i.e. non-ash volatiles)	20.5	20.3	4.1
	% of all fuel-content in slurry that was reclaimed as fuel*	**68.8**	**72.4**	**14.3**
	Splitter box ports from which clean coal could be gleaned	**1, 2, 3**	**1, 2, 3**	**1, 2**
	% ash for product coal from these ports	**7.3**	**8.5**	**8.2**

*The fuel content is taken to be proportional to the non-ash volatiles, measured as the lost mass when dry solids are burned, and this includes the carbon, hydrogen, and oxygen mass (see Appendix for sample calculation).

** Following the spiral, the % ash was monitored following sample drying and wet-screening, which simulated sieve-bend operation.

***The bolded values in Table 1 were computed from Tables 2, 3a and 3b.

As shown in Table 1, the as-received slurry that was used as feed to the HAC-cyclone circuit had an ash content ranging from 63 to 67%. After wet screening, the ash content of the +140 mesh material ranged from 26 to 29%. After the as-received slurry was processed and passed through the cyclone, the cyclone underflow had an ash content of 33-38.5% (i.e., before removing the -140 mesh material), whereas the ash content of the overflow material was 70%. These ash levels were about the same regardless of which of the three treatments was employed.

The big difference was observed following the spiral processing. With HAC alone or HAC-H_2O_2-O_3, much of the clean coal found its way to spiral ports 1 and 2, whereas for the control test, considerably less of the coal proceeded to ports 1 and 2. Moreover, with either HAC or HAC-O_3-H_2O_2 treatment, even middlings port 3 contained relatively low-ash -16+100 mesh coal (less than 8.6%). The net effect was that 22% of all the as-received solids were collected as clean coal through ports 1, 2 and 3 when HAC or HAC-O_3-H_2O_2 was used, whereas only 4.7% of the solids were collected as clean coal when the Control treatment was employed. Or yet more notably, when HAC or HAC-O_3-H_2O_2 was used, this novel process reclaimed 69-72% of the fuel content (<8.5% ash) that had been present in the as-received coal-silt slurry. This value was much greater than that obtained for the control test in which only 14.3% of the fuel content was reclaimed out of ports 1 and 2. And port 3 did not yield a low-ash product (port 3 was at 14.4% ash as shown in Table 2). These ash values corresponded to the spiral products after wet sieving to remove the -140 mesh material to simulate sieve bend or similar size separation. These results demonstrate that HAC or HAC-H_2O_2-O_3 treatment made a significant improvement in the anthracite and clay separation, yielding five times more clean coal than did the control experiment.

Ash content of clean coal and middlings from spiral for HAC, HAC-H_2O_2-O_3, or the control

Table 2 Ash values from various spiral ports when using HAC, HAC-H_2O_2-O_3, or the control

	Ash, %		
Port No.	Control	HAC	HAC-H_2O_2-O_3
Clean coal 1	7.3	6.1	7.6
Clean coal 2	8.8		7.3
Middlings 3	14.4	8.4	12.5
1,2,3 combined	12.4	7.2	8.5

*Percentages for all size fractions -16+100 mesh. Percentages computed as normalized composite of all size fraction samples (see Appendix). Table 2 data was derived as a composite from measurements of solid yield and % ash (Tables 3a and 3b).

As is shown in Table 2, following HAC, spiral ports 1 and 2 yielded a product with 6.05% ash, while port 3 yielded an 8.4% ash product. Following HAC-H_2O_2-$O_{3,}$ ports 1 and 2 yielded 7.3-7.6% ash material, while port 3 yielded 12.5% ash material. For the control test, ports 1 and 2 yielded 7.3% and 8.8% ash products, respectively; and port 3 yielded 14.4% ash material. This anthracite mine produces clean coal products with approximately 8.5% ash. Therefore, an ash content of 8.5% was the targeted value in this analysis.

Ash content of clean coal, middlings and refuse from spiral for HAC, HAC-H_2O_2-O_3, or the control

Table 3 Percent ash from various sieve size fractions (US Mesh), when using HAC, HAC-H_2O_2-0_3, or the control

HAC	Ash Values (%) for Various Size Fractions (mesh)				
Ports	+16	-16+40	-40+100	-100	
1, 2	9.0	6.1	6.0	32.0	
3	22.0	9.0	6.9	15.0	
4	15.1	12.1	13.0	16.2	
5, 6, 7	73.0	52.5	43.4	71.7	
HAC- H_2O_2 O_3					
	+16	-16+40	-40+100	-100+140	-140
1	30.0	7.0	7.8	16.4	24.1
2	24.8	5.3	7.4	12.3	18.9
3*	42.7	12.3	12.5	32.3	41.6
5, 6, 7	60.7	47.4	57.5	24.5	54.7
Control					
	+16	-16+40	-40+100	-100+140	-140
1	28.6	8.93	7.0	11.1	26.3
2	35.6	10.9	8.0	16.3	29.1
3*	45.4	18.8	12.0	28.7	49.0
5, 6, 7	63.4	62.6	55.0	57.4	57.0

*Port 4 yielded no mass

Table 2 is a computed composite from Tables 3 and 4. Per Table 3, it is noted that amongst the size fractions, the -16+40 mesh and -40+100 mesh fractions offered the lowest ash, whereas the +16 and -100 mesh sizes hosted higher % ash material. For the +16 sizes, the “ash” was often comprised of individual sand grains. For the -100 mesh, the “ash” was often silts. Notably, for the HAC and HAC-H_2O_2-O_3 treatments, the third (middlings) port yielded a product that was relatively low in ash, specifically in the -16+40 and -40+100 mesh ranges. This meant that clean coal could be drawn from this third port when including this treatment. However, for the Control condition, the % ash from port 3 was higher than was suitable. Killmeyer (2001) suggested that a spiral normally is only effective for processing -16+100 mesh anthracite, which is consistent with the findings in this study (Table 3).

Mass of clean coal, middlings and refuse at various size intervals from spiral for HAC, HAC-H_2O_2-O_3, or the control

Table 4 Solid mass in grams from various sieve size fractions when using HAC, HAC-H_2O_2-O_3, or the control

HAC	Product Weights (g) for Various Size Fractions (Mesh)						Clean coal proportion of solids, %	Fuel yield, %
Ports	+16	-16+40	-40+100	-100		Sum	53.1	68.8
1, 2	10.6	131.2	23.3	8.5		173.6		
3	3.1	116.6	47.6	3.2		170.5		
4	0.9	21	11.5	0.5		33.9		
5, 6, 7	6.8	134.7	93.4	35		269.9		
HAC- H_2O_2 O_3								
Ports	+16	-16+40	-40+100	-100+140	-140	Sum	70.4	72.4
1	4.8	10.4	33.3	13.3	2.9	64.7		
2	0.3	0.4	12.5	10.2	4.4	28.8		
3*	0.68	19.16	32.64	6.92	1.64	61.04		
5, 6, 7	0.35	52.4	9.75	0	2.55	65.05		
Control								
Ports	+16	-16+40	-40+100	-100+140	-140	Sum	24.5	14.3
1	1	1.5	8.5	6.2	10	27.2		
2	1.6	1.4	3.9	1.6	0.6	9.1		
3*	0.2	12.8	24.1	4.8	2.6	44.5		
5, 6, 7	0.3	15.2	40.2	7.7	3.9	67.3		

*Port 4 yielded no mass

Per Table 4, ports 1, 2, and 3 received a far higher proportion of total solids (53% and 70%) when HAC or HAC-H_2O_2-O_3 were employed, than did ports 1 and 2 under the control conditions (25%). Moreover, quite notably, when HAC or HAC-H_2O_2-O_3 was employed, about half of all the spiral discharge was -16+100 mesh coal that exited ports 1, 2, and 3. This was in stark contrast to the behavior under the control condition where only 11% of all spiral discharge was -16+100 mesh coal that exited ports 1 and 2. This result highlights the favorable effect that hydroacoustics achieved: HAC dislodged the higher density silts from the low density coal grains in such a manner that the coal grains could more readily proceed to the spirals outer periphery. In contrast, without HAC, the coal grains remained locked with the higher density silts, which hindered this material from migrating to the outer periphery of the spiral with the lower density clean coal.

Chapter 4

Conclusion

HAC has significantly enhanced the separation of anthracite fines and clay, producing a stream of high carbon content anthracite. Coupling ozone and hydrogen peroxide with HAC also proved to have a positive effect in addition to the HAC favorable effect. When HAC was followed by cyclone and spiral separation, two thirds of all the coal could be reclaimed that would otherwise be thrown away as silt-coal slurry to impoundments in conventional operations. This compared to only about 15% of the coal that could be reclaimed from such a slurry if HAC was not included with the conventional cyclone and spiral processes.

Chapter 5

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Appendix A

Experimental Procedure

Pre-processing

Take samples from barrels to obtain solids concentration and % ash

Separate barrel into 9 buckets of equal mass.

Processing

1. Fill HAC circuit preparation tank with known volume water
2. Start pump in recirculate mode
3. Set 3-way valve for recirculation
4. Add known volume of solids from separated buckets; continue recirculation until slurry is homogeneous
5. Place bucket underneath the cyclone to collect underflow, and barrel to collect overflow
6. Open 3-way valve for full pressure at gauge (15psi)
7. Take 2 underflow and 1 overflow samples from each
8. Take buckets that have collected underflow and estimate % solids
9. Repeat previous steps until adequate underflow solids are obtained
10. Ensure that the spiral -3-way valve is set to recirculate. Fill spiral sump with water and start the large pump, and set the speed at 18 Hertz
11. Transfer underflow buckets to sump to obtain 26% solids in the sump
12. Set large pump speed to 22 Hertz and immediately turn 3-way valve to direct the slurry to the spiral

13. Obtain 3 samples, 1 from ports 1 and 2, 1 from ports 3 and 4, and 1 from ports 5,6,7
14. Set the 3-way valve to recirculation mode, and reduce the pump speed to 18 Hertz
15. Change spiral orifice diameter
16. Repeat steps 12-15 until all spiral orifices are tested

*measure all fluid masses and container masses before use and after collection.

Appendix B

Sample Calculation of Fuel Recovery

Sample Calculation of Fuel Yield for HAC condition

Clean coal proportion of solids:

$$\frac{\text{mass of coal in ports } 1-3}{\text{mass of solids in all ports}} = \frac{173.6 + 170.5}{173.6 + 170.5 + 33.9 + 269.9} = 53.1\%$$

Percent of -16+100 mesh size coal in ports 1-3:

$$\frac{\text{mass of} - 16 + 100 \text{ coal in ports } 1-3}{\text{mass of coal in ports } 1-3} = \frac{131.2 + 23.3 + 116.6 + 47.6}{173.6 + 170.5} = 92.6\%$$

Overall ash content in ports 1-3:

$$\frac{(\%ash\,ports\ 1-2) * (mass\ of\ ports\ 1-2) + (\%ash\,ports\ 3) * (mass\ of\ ports\ 3)}{mass\ of\ coal\ in\,ports\ 1-3}$$

$$= \frac{6.1\% * 173.6 + 8.40\% * 170.5}{173.6 + 170.5} = 7.2\%$$

Fuel yield:

$$\frac{(\text{Clean coal proportion of solids}) * (\text{Percent of} - 16 + 100 \text{ size coal in ports } 1-3) * (1 - (\text{Overall ash content in ports } 1-3}{(1 - (percent\ of\ ash\ solids\ in\ the\ as - received\ slurry))}$$

$$= \frac{53.1\% * 92.6\% * (1 - 7.2\%)}{(1 - 33.7\%)} = \mathbf{68.8}\%$$

Appendix C

Low-Pressure Cyclone Performance

The results indicated in Tables 1-4 were conducted using a cyclone pressure of 15 psi. Chronologically, those tests were preceded by another series of tests that were conducted at a cyclone inlet pressure of 5 psi pressure. The lower pressure occurred when large coal grains (greater than approximately 4 mesh) clogged the pump impeller blades. This issue was solved in subsequent testing by pre-screening all the coal-silt slurry on 4 mesh screen. Nonetheless, when only 5 psi pressure was employed, the same favorable trends were observed as shown in Table A. When HAC treatment was coupled with flow through the spiral (32 mm orifice), the % ash from ports 1 and 2 was 8.9%. Also, 32.8% of all the fuel that had been present in the as-received coal-silt slurry could be reclaimed as clean product. In contrast, with the Control run, ports 1 and 2 yielded coal with 11.6 % ash; and only 17.1% of all the fuel that had been present in the as-received coal-silt slurry could be reclaimed (Table 5).

Table 5 Ash content, fuel yields from various points in the coal-fines processing systems for : (a) Conventional operations of cyclone and spiral (i.e. Control), (b) HAC preceding cyclone and spiral separation

Sample Point		HAC	Control (Bypass HAC)
As - Received	Slurry, Ash%	65.5	63.6
Cyclone	Underflow, Ash % (=spiral feed)	35.6	33.3
	Overflow, Ash % (not wet-screened)	70.2	69.9
	% of all fuel-content in slurry that was reclaimed as fuel*	**32.8**	**17.1**
	Splitter box ports from which clean coal could be gleaned	1, 2	1, 2
	% ash for product coal from these ports	**8.9**	**11.6**