THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

JOHN AND WILLIE LEONE FAMILY DEPARTMENT OF ENERGY AND MINERAL ENGINEERING

HYDROACOUSTICS RECLAIMING OF ANTHRACITE FINES IN WASTE COAL SLURRY FROM COAL MINES

SHANG LIU
SPRING 2013

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Environmental Systems Engineering
with honors in Environmental Systems Engineering

Reviewed and approved* by the following:

Mark S. Klima
Interim Department Head
Associate Professor of Mineral Processing and Geo-Environmental Engineering
Thesis Supervisor, Honors Advisor

M. Thaddeus Ityokumbul
Undergraduate Program Officer of Environmental Systems Engineering
Associate Professor of Mineral Processing and Geo-Environmental Engineering
Thesis Reader

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

The performance of a hydroacoustics unit, a hydrocyclone and a spiral concentrator processing fine anthracite was evaluated. Samples from the spiral discharge were collected at 3 different diameters of the inlet (23mm, 32mm, and 35mm). It was examined that lowest ash content of approximately 6.5% was achieved with hydroacoustic treatment and with an spiral inlet size of 32mm. Highest yield with acceptable ash content (7.5%) occurred with hydroacoustics and an inlet size of 35mm. Future work involves a comprehensive experiment design and the application of laboratory results at Jeddo Coal, an anthracite mining company in Pennsylvania.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I am grateful to the generous funding from the National Science Foundation that made all this work possible. I would also like to thank Dr. Mark Klima and Dr. Fred Cannon for their leadership and helpful advice. Finally, I want to thank Tom Geeza and Branden Barry who have helped me substantially in running experiment tests.

Chapter 1

Introduction

Pennsylvania was the fourth largest coal-producing state in the United States in 2011, and the only state that mines anthracite (U.S EIA, 2012). The production of anthracite unavoidably generates fines that are typically less than several millimeters in size. These anthracite fines have often been wasted in silt ponds because of its little value as a very low grade of coal. The instability of silt ponds also makes it difficult to build roads and buildings on them. Millions of tons of silt ponds remain in PA, making it difficult for coal-mining companies to obtain permits for new silt ponds.

This project uses a novel combination of technologies to reclaim high-grade anthracite fines, which can then be made into anthracite bricks for the foundry industry. This approach tackles environmental problem that arises from silt pond and turns the wasted coal into a marketable product.

Chapter 2

Pipe Circuits, Equipment and Procedure

The processing system consists of a hydroacoustic-cavitation unit, a 4-inch diameter hydrocyclone, and a 7-turn spiral concentrator (10 feet tall by 3 feet diameter).

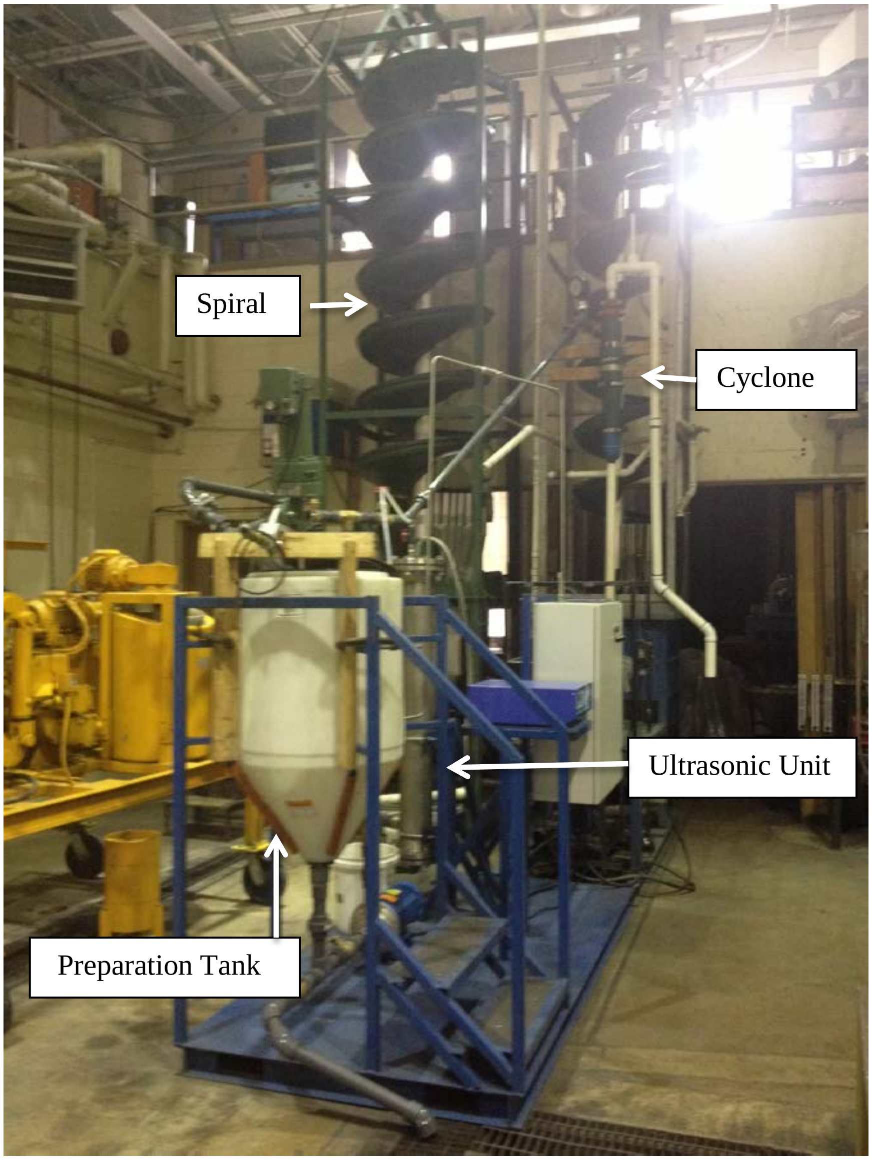

Figure 1: Test Circuit

Ten 55-gallon barrels of silt slurries were obtained from the thickener underflow stream in Jeddo Coal. The collection process entailed filling a barrel with slurry, letting it settle, decanting off the liquid, and filling it with slurry again.

A coal slurry of 10% solids by weight was prepared in the white tank prior to hydroacoustic treatment. Two sets of runs were undertaken in such a way that hydroacoutsitc cavitation was turned on and off to investigate its effects on the separation of anthracite and silt particles. The processed slurry from both sets of runs was collected from the cyclone underflow and sent to the spiral sump for further processing. The concentration of solids in the spiral sump was kept at approximately 26% and the volume of total slurry was 70 gallons. A number of samples were taken from the underflow and overflow of the cyclone and the exit ports of the spiral for the purpose of size distribution and ash analyses.

Wet and dry weights of the samples were recorded. The dry coal samples were later wet screened through a 100 mesh sieve as it was believed that the -100 mesh material was predominantly ash. The +100 material was dried, and size distribution data were obtained by sieving the sample at sieves 8, 16, 40 and 100 mesh in a Ro-Tap shaker. This gave us size fractioned samples of +8, 8x16, 16x40, 40x100, and -100 mesh.

One gram of coal was taken from each of the +8, 8x16, 16x40, 40x100 and -100 mesh samples were placed into crucibles. The burning of the one-gram samples was done at a temperature of 700 degree Celsius for 12 hours in a furnace. Ash content of each sample was based on the weight of the solids remaining after combustion.

Chapter 3

Separation Principle of the Equipment

Hydrocylones are commonly used to classify particles in mineral processing plants. A cutaway drawing of a typical hydrocyclone is shown in Figure 2. Feed slurry enters the cyclone through the inlet to a cylindrical chamber under pressure. The difference in size of the solid particles results in two opposite directions of flow. Fine particles flow upward and leave through the vortex finder, whereas coarse particles travel spirally downward and exit through the apex (Kelly, 1982).

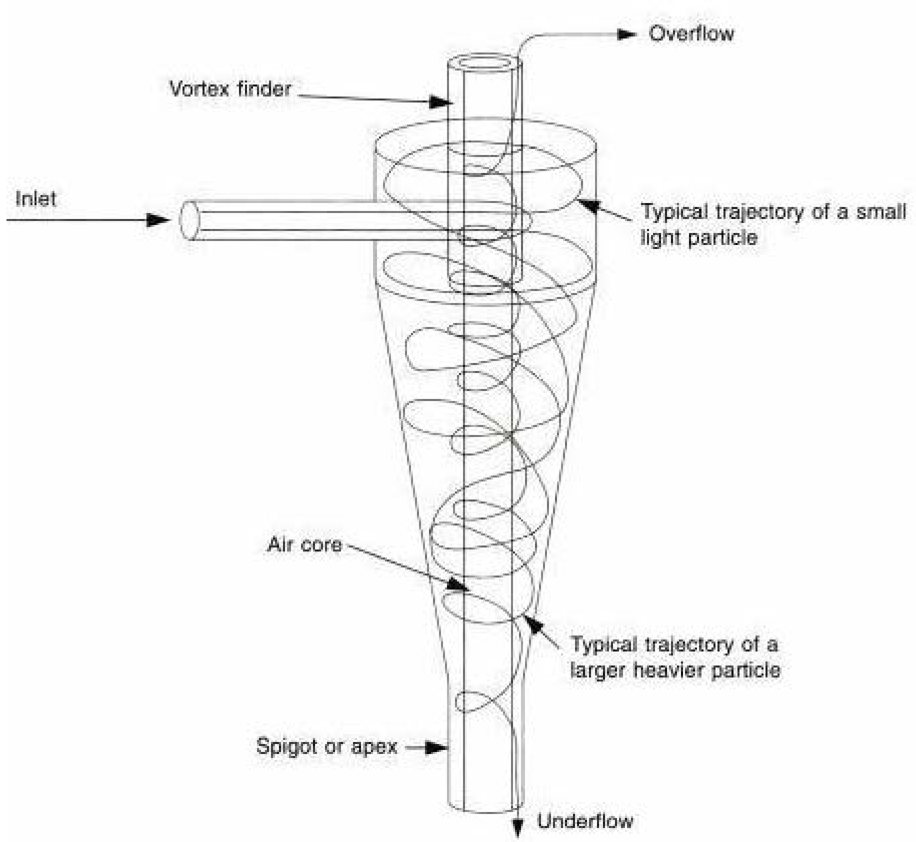

Figure 2: A Diagram of Hydrocyclone **Source: Lenntech.co**

The ultrasonic unit separates particles by developing cavities or air bubbles in the slurry. Implosion occurs at a high pressure induced by the ultrasonic unit and pulls the loosely attached silt particles apart from anthracite fines, making it easier to have better separation of silt and coal in the cyclone and spiral (Farmer et al, 2000). Green sand, which is used in the foundry industry, can be separated from clay with the use of advanced oxidation and ultrasonic cavitation (Fox et al, 2009).

A spiral concentrator typically consists of multiple turns of a curved trough and separates solid particles primarily by density (Figure 3). As slurry enters from the top and flows down the trough, low-density particles travel to the outer periphery of the trough while high-density solids remain in the inner periphery. Several exit ports are located at varying distances from the centerline of the trough to transport slurry to different product streams (Kelly, 1982).

Generally, a higher flow rate is desired for coarse denser material, whereas a lower flow rates suits fine and less denser material (Benusa and Klima, 2009). Extreme conditions, such as too high or low flow rate 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 spiral circuits are often used in plant operations.

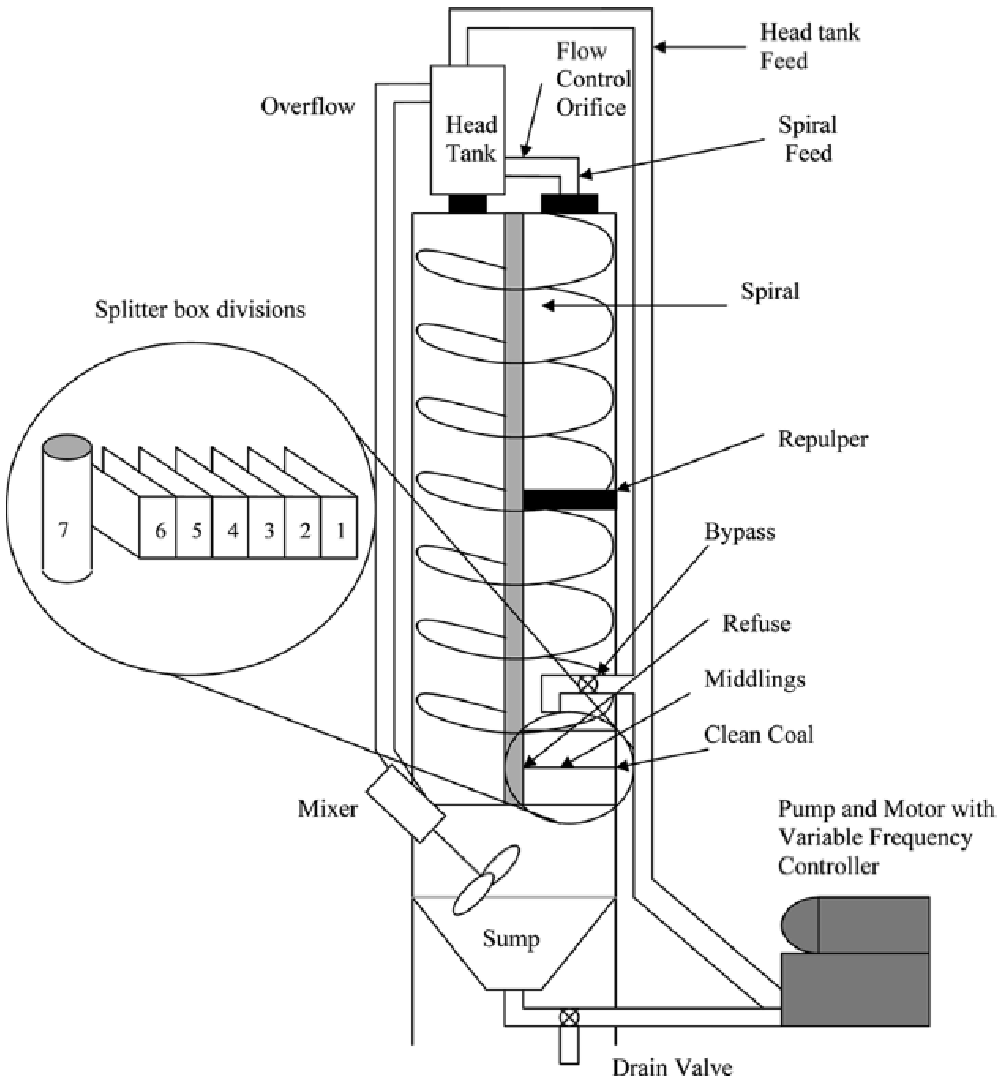

Figure 3: Spiral Concentrator Source: Benusa and Klima, 2009

For ease of description, splitter box divisions 1 and 2 are combined to represent "clean coal", 3 and 4 as "Middling" and 5- 7 as "Refuse" (See Figure 3). It is expected that a high grade of coal will yield to the clean coal stream, a lower grade of coal to the middlings stream, and most of the ash to the refuse stream.

Chapter 4

Results

Table 1 gives the size distributions of the clean coal samples for the different spiral products with and without hydroacoustic treatment. It reveals that, with the hydroacoustics treatment, the weight of clean coal is much greater than that without hydroacoustics. The 16x40 mesh appeared to be the dominant size, followed by 40x100 mesh material.

Table 3: Size Distribution of Clean Coal Samples

23 mm	+8	8x16	16x40	40x100	-100
wt. g	0.3	3	8.4	7.4	6.1
% wt.	**1.2**	**11.9**	**33.3**	**29.4**	**24.2**
H23 mm	+8	8x16	16x40	40x100	-100
wt. g	0	10.9	87.9	33.7	23.3
% wt.	**0.0**	**7.0**	**56.4**	**21.6**	**15.0**
32 mm	+8	8x16	16x40	40x100	-100
wt.g	0.8	11.3	75.6	31.3	47
% wt.	**0.5**	**6.8**	**45.5**	**18.9**	**28.3**
H32 mm	+8	8x16	16x40	40x100	-100
wt. g	0.6	11.9	100.6	52	62.3
% wt.	**0.3**	**5.2**	**44.2**	**22.9**	**27.4**
35 mm	+8	8x16	16x40	40x100	-100
wt. g	0.2	5.6	53.5	30.9	30.9
% wt.	**0.2**	**4.6**	**44.2**	**25.5**	**25.5**
H35 mm	+8	8x16	16x40	40x100	-100
wt. g	0.7	20.7	237.6	107.1	68.7
% wt.	**0.2**	**4.8**	**54.6**	**24.6**	**15.8**

*The letter “H” designates hydroacoustic.

Table 4: Summary of Ash Content Results

	Clean Coal				Middlings				Refuse
Inlet Size	+16M	16x40M	40x100M	-100M	+16M	16x40M	40x100M	-100M	
23	8.00	12.00	7.07	31.68	21.78	9.90	8.82	35.29	51.00
H23	9.00	7.84	8.00	35.64	29.29	9.00	9.09	23.76	38.24
32	12.62	7.07	8.00	44.00	56.44	12.00	9.90	45.54	53.92
H32	9.90	6.06	7.00	47.47	51.00	12.00	11.00	52.48	59.00
35	11.76	6.86	6.93	40.40	70.00	11.00	10.00	51.49	56.86
H35	12.87	5.94	7.84	45.45	67.00	13.00	11.00	51.49	51.00

The feed ash content for the +100 mesh material was examined to be in the range of 17%-31% (Appendix A). After processing through the ultrasonic unit, the cyclone and the spiral, ash percentage for the +100 mesh material in clean coal was mostly less than 10%. The middlings stream could also be reprocessed through another stage of spiral to further separate ash from coal to achieve a higher overall yield of clean coal from the wasted silt slurry.

Chapter 5

Conclusion and Future work

It can be seen that the most recoverable anthracite fines in the silt slurry are in the size range of 16x100 mesh, which has a combined ash content of around 7% after processing through our designed cleaning circuits. Killmeyer (2001) suggested that a spiral normally only processes the size fraction of 16x100 mesh anthracite particles, which is consistent with the results of this investigation.

The ultimate goal of this project is to apply the bench-scale laboratory results to full – scale operations. Bench-scale laboratory trials proved that satisfactory reclamation of fine anthracite could be achieved. A more comprehensive design of experiment for thorough understanding of this processing system is currently being developed. Once bench-scale research is adequately conducted, efforts of adding a cleaning circuit in Jeddo Coal would be made to realize the goal of the project.

Appendix A

Feed Size Distribution and Ash

Feed Sample	+16M	16x40M	40x100M	-100M
Crucible wt. g	26.52	22.98	23.85	23.59
Sample wt. g	1.04	0.99	0.99	1.02
Remaining wt. g	26.81	23.15	24.16	24.15
Ash, g	0.29	0.17	0.31	0.56
% Ash	**27.88**	**17.17**	**31.31**	**54.90**

Appendix B

Clean Coal Ash Analyses and Size Distribution

Table B1: Ash Analyses of Clean Coal Samples at Different Spiral Inlet Sizes with or without Hydroacoustics

23 mm	8x16M	16x40M	40x100M	-100M
Crucible wt. g	26.52	47.78	134.67	24.74
Sample wt. g	1.00	1.00	0.99	1.01
Remaining wt. g	26.60	47.90	134.74	25.06
Ash, g	0.08	0.12	0.07	0.32
% Ash	**8.00**	**12.00**	**7.07**	**31.68**

H23 mm	8x16M	16x40M	40x100M	-100M
Crucible wt. g	23.85	24.74	22.98	23.59
Sample wt. g	1.00	1.02	1.00	1.01
Remaining wt. g	23.94	24.82	23.06	23.95
Ash, g	0.09	0.08	0.08	0.36
% Ash	**9.00**	**7.84**	**8.00**	**35.64**

32 mm	8x16M	16x40M	40x100M	-100M
Crucible wt. g	27.32	25.83	25.31	24.82
Sample wt. g	1.03	0.99	1.00	1.00
Remaining wt. g	27.45	25.90	25.39	25.26
Ash, g	0.13	0.07	0.08	0.44
% Ash	**12.62**	**7.07**	**8.00**	**44.00**

H32 mm	8x16M	16x40M	40x100M	-100M
Crucible wt. g	26.68	20.92	24.78	22.26
Sample wt. g	1.01	0.99	1.00	0.99
Remaining wt. g	26.78	20.98	24.85	22.73
Ash, g	0.10	0.06	0.07	0.47
% Ash	**9.90**	**6.06**	**7.00**	**47.47**

35 mm	8x16M	16x40M	40x100M	-100M
Crucible wt. g	27.32	25.83	25.31	24.82
Sample wt. g	1.02	1.02	1.01	0.99
Remaining wt. g	27.44	25.90	25.38	25.22
Ash, g	0.12	0.07	0.07	0.40
% Ash	**11.76**	**6.86**	**6.93**	**40.40**

H35 mm	8x16M	16x40M	40x100M	-100M
Crucible wt. g	26.68	20.92	24.78	22.26
Sample wt. g	1.01	1.01	1.02	0.99
Remaining wt. g	26.81	20.98	24.86	22.71
Ash, g	0.13	0.06	0.08	0.45
% Ash	**12.87**	**5.94**	**7.84**	**45.45**

Inlet size, mm	23	H23	32	H32	35	H35
% Ash (+100 mesh)	**9.03**	**8.28**	**9.27**	**7.67**	**8.52**	**8.88**

Table B2:Size Distribution of Clean Coal Samples at Different Spiral Inlet Sizes with or without Hydroacoustics

23 mm	+8M	8x16M	16x40M	40x100M	-100M
wt. g	0.3	3	8.4	7.4	6.1
% wt.	**1.2**	**11.9**	**33.3**	**29.4**	**24.2**

H23 mm	+8M	8x16M	16x40M	40x100M	-100M
wt. g	0	10.9	87.9	33.7	23.3
% wt.	**0.0**	**7.0**	**56.4**	**21.6**	**15.0**

32 mm	+8M	8x16M	16x40M	40x100M	-100M
wt.g	0.8	11.3	75.6	31.3	47
% wt.	**0.5**	**6.8**	**45.5**	**18.9**	**28.3**

H32 mm	+8M	8x16M	16x40M	40x100M	-100M
wt. g	0.6	11.9	100.6	52	62.3
% wt.	**0.3**	**5.2**	**44.2**	**22.9**	**27.4**

35 mm	+8M	8x16M	16x40M	40x100M	-100M
wt. g	0.2	5.6	53.5	30.9	30.9
% wt.	**0.2**	**4.6**	**44.2**	**25.5**	**25.5**

H35 mm	+8M	8x16M	16x40M	40x100M	-100M
wt. g	0.7	20.7	237.6	107.1	68.7
% wt.	**0.2**	**4.8**	**54.6**	**24.6**	**15.8**

Appendix C

Middlings and Refuse Ash Analyses and Size Distribution

Table C1:Ash Analyses of Middlings Samples at Different Spiral Inlet Sizes with or without Hydroacoustics

23 mm	+16M	16x40M	40x100M	-100M
Crucible wt. g	23.85	22.98	22.27	22.76
Sample wt. g	1.01	1.01	1.02	1.02
Remaining wt. g	24.07	23.08	22.36	23.12
Ash, g	0.22	0.10	0.09	0.36
% Ash	**21.78**	**9.90**	**8.82**	**35.29**

H23 mm	+16M	16x40M	40x100M	-100M
Crucible wt. g	24.82	25.31	23.59	25.84
Sample wt. g	0.99	1.00	0.99	1.01
Remaining wt. g	25.11	25.40	23.68	26.08
Ash, g	0.29	0.09	0.09	0.24
% Ash	**29.29**	**9.00**	**9.09**	**23.76**

32 mm	+16M	16x40M	40x100M	-100M
Crucible wt. g	27.32	20.92	26.68	24.74
Sample wt. g	1.01	1.00	1.01	1.01
Remaining wt. g	27.89	21.04	26.78	25.20
Ash, g	0.57	0.12	0.10	0.46
% Ash	**56.44**	**12.00**	**9.90**	**45.54**

H32 mm	+16M	16x40M	40x100M	-100M
Crucible wt. g	26.52	24.78	47.78	134.67
Sample wt. g	1.00	1.00	1.00	1.01
Remaining wt. g	27.03	24.90	47.89	135.20
Ash, g	0.51	0.12	0.11	0.53
% Ash	**51.00**	**12.00**	**11.00**	**52.48**

35 mm	+16M	16x40M	40x100M	-100M
Crucible wt. g	22.37	22.26	22.35	22.68
Sample wt. g	1.00	1.00	1.00	1.01
Remaining wt. g	23.07	22.37	22.45	23.20
Ash, g	0.70	0.11	0.10	0.52
% Ash	**70.00**	**11.00**	**10.00**	**51.49**

H35 mm	+16M	16x40M	40x100M	-100M
Crucible wt. g	22.53	22.59	22.28	24.44
Sample wt. g	1.00	1.00	1.00	1.01
Remaining wt. g	23.20	22.72	22.39	24.96
Ash, g	0.67	0.13	0.11	0.52
% Ash	**67.00**	**13.00**	**11.00**	**51.49**

Table C2:Size Distribution of Middlings Samples at Different Spiral Inlet Sizes with or without Hydroacoustics

23 mm	+16	16x40	40x100	-100
wt. g	2.0	52.3	16.8	1.4
% wt.	**2.8**	**72.1**	**23.2**	**1.9**

H23 mm	+16	16x40	40x100	-100
wt. g	2.0	66.6	34.4	4.0
% wt.	**1.9**	**62.2**	**32.1**	**3.7**

32 mm	+16	16x40	40x100	-100
wt.g	2.8	151.8	61.0	17.0

% wt.	**1.2**	**65.3**	**26.2**	**7.3**

H32 mm	+16M	16x40M	40x100M	-100M
wt. g	2.0	98.0	90.2	27.6
% wt.	**0.9**	**45.0**	**41.4**	**12.7**

35 mm	+16M	16x40M	40x100M	-100M
wt. g	1.4	92.7	52.9	13.8
% wt.	**0.9**	**57.6**	**32.9**	**8.6**

H35 mm	+16M	16x40M	40x100M	-100M
wt. g	1.6	74.2	81.8	21.0
% wt.	**0.9**	**41.5**	**45.8**	**11.8**

Table C3: Ash Analysis of Refuse Samples at Different Spiral Inlet Sizes with or without Hydroacoustics

	H23	**23**	**H32**	**32**	**H35**	**35**
Crucible wt. g	22.78	20.51	22.91	22.54	23.68	23.64
Sample wt. g	1.00	1.02	1.02	1.00	1.02	1.00
Remaining wt. g	23.29	20.90	23.46	23.13	24.26	24.15
Ash, g	0.51	0.39	0.55	0.59	0.58	0.51
% Ash	**51.00**	**38.24**	**53.92**	**59.00**	**56.86**	**51.00**

Appendix D

Complete 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 preparation tank with known volume water
2. Start pump in recirculate mode
3. 3 way valve set for recirculation
4. Add known volume of solids from separated buckets, recirculation until fluid 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 sample from each.
8. Take buckets that have collected underflow and estimate % solids
9. Repeat previous steps until adequate underflow solids are obtained
10. Fill spiral sump with water and start large pump at 18 hertz
11. Transfer underflow buckets to sump to obtain 26% solids in the sump
12. Turn 3 way valve to turn of recirculation and set large pump at around 22 Hertz to send the slurry to the spiral
13. Obtain 3 samples, 1 from tubes 1 and 2, 1 from tubes 3 and 4, and 1 from tubes 5,6,7
14. Turn pump back to 18hz and set to recirculation mode
15. Change inlet size
16. Repeat steps 12-15 until all inlet sizes are tested

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

REFERENCES

Benusa M., Klima M., 2009. An Evaluation of a Two-Stage Spiral Processing Fine Anthracite Refuse, International Journal of Coal Preparation and Utilization. 29, 49-67.

Farmer, A.D.; Collings, A.F., Jameson, G.J.; "Effect of ultrasound on surface cleaning of silica particles," *International Journal of Mineral Processing*, v 60, n 2, Sep, 2000, p 101-113.

Fox, J.T., F.S. Cannon, R.C. Voigt, J.C. Furness, F. Headington, D. Coan, S. Lewallen (2009) Waste Green Sand to Core Sand Reclamation, Demonstration via Casting Study, with Simultaneous Clay Recovery and AO Benefits. American Foundry Society Transactions. Vol 116.

Kelly, Errol G., and David J. Spottiswood. *Introduction to Mineral Processing*. New York: Wiley, 1982. Print.

Killmeyer, R. P. et al. Fine Anthracite Coal Washing Using Spirals, U.S. Department of Energy, May 2001. Web. Accessed March 24, 2013 <http://www.osti.gov/bridge/servlets/purl/781457k8MVFD/webviewable/781457.pdf>

U.S. EIA, State Profile and Energy Estimated, *U.S Energy Information Administration*, Accessed March 27. 2013 < http://www.eia.gov/state/?sid=PA>

ACADEMIC VITA

Shang Liu

sql5199@psu.edu

Education

B.S. Environmental Systems Engineering, 2013

Pennsylvania State University, University Park, PA

Honors and Awards

EME General Scholarship; Matthew J. Wilson Honors Scholarship	2012 – Present
John & Elizabeth Holmes Scholarship; Chevron ENVSE Scholarship	2010 –2012
EME Photo Contest Honorable Mention	2009 –2011

Association Memberships/Activities

Honor Society of Phi Kappa Phi 2012 – Present

Research Experience

NSF REU, Pennsylvania State University, Advisor: Dr. Fred Cannon, Summer 2012 – Present

Research Interests

I have very broad interests in wastewater treatment technology and coal processing.

Professional Presentations

"GIS and World Travel", Presented at the Middle States AAG Conference, Sept 2012

"Design of a Water Quality Map of the United States", Presented at the USGS Headquarters in Reston, VA, Nov 2012