Final Report

Development of an Ultra-fine Coal Dewatering Technology and an Integrated Flotation-Dewatering System for Coal Preparation Plants

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Content

1 Executive Summary

The projected was supported by the United States Department of Energy, under award No DE-FG26-05NT42498, which contributes to 80% of the project's cost. The rest 20% cost of the project was covered by Luscar Ltd. (Edmonton, Alberta Canada) as in-kind cost share.

The project proposal was approved for only the phase I period. The goal for this Phase I project was to develop an industrial model that can perform continuous and efficient dewatering of fine coal slurries of the previous flotation process to fine coal cake of ~15% water content from 50~70%. The feasibility of this model should be demonstrated experimentally using a lab scale setup. The Phase I project was originally for one year, from May 2005 to May 2006. With DOE approval, the project was extended to Dec. 2006 without additional cost from DOE to accomplish the work.

The total project cost for the Phase I period was $99,984, in which $79,984 was awarded from DOE (DE-FG26-05NT42498), and Luscar provided $20,000 as in-kind cost share. Mineral Technologies International provided some key testing equipment, and led the setup and testing of the Yang's floatation column. DeVall Bros. Inc manufactured the initial screw, a key component for the dewatering system. WVU researchers and researcher from Mineral Technologies International undertook most of workload. Engineers from Luscar McLanahan reviewed and provided feedback comments on reports.

West Virginia University led this project (Morgantown, WV). The participants were, Luscar Ltd. (Edmonton, Alberta Canada), McLanahan Corp. (Hollidaysburg, PA), DeVall Bros. Inc. (Morgantown, WV), and Mineral Technologies International, Inc. (Morgantown, WV). The principle investigator was Dr. Wu Zhang, Department of Chemical Engineering, West Virginia University. Researchers were Dr. David Yang, Mineral Technologies International, Inc., Mr. Jim Williams from DeVall Bros, and Mr. Jim Hall, Department of Chemical Engineering, West Virginia University. Consortium/teaming members include Dr. Amar Amarnath and Dr. Iftikhar Huq, from Luscar Ltd., and Mr. Scott C. O'Brien of McLanahan Corp.

1.1 How the research adds to the understanding of the area investigated

Water has been used in mining for a number of purposes such as a carrier, washing liquid, dust-catching media, fire-retardation media, temperature-control media, and solvent. When coal is cleaned in wet-processing circuits, waste streams containing water, fine coal, and noncombustible particles (ash-forming minerals) are produced. In many coal preparation plants, the fine waste stream is fed into a series of selection processes where fine coal particles are recovered from the mixture to form diluted coal fine slurries. A dewatering process is then needed to reduce the water content to about 15%-20% so that the product is marketable. However, in the dewatering process currently used in coal preparation plants, coal fines smaller than 45 micrometers are lost, and in many other plants, coal fines up to 100 micrometers are also wasted. These not-recovered coal fines are mixed with water and mineral particles of the similar particle size range and discharged to impoundment. The wasted water from coal preparation plants containing unrecoverable coal fine and mineral particles are called tailings. With time the amount of wastewater accumulates occupying vast land space while it appears as threat to the environment.

This project developed a special extruder and demonstrated its application in solid – liquid separation of coal slurry, tailings containing coal fines mostly less than 50 micron. The extruder is special because all of its auger surface and the internal barrier surface are covered with the membranes allowing water to drain and solid particles retained. It is believed that there are four mechanisms working together in the dewatering process. They are hydrophilic diffusion flow, pressure flow, agitation and air purging. Hydrophilic diffusion flow is effective with hydrophilic membrane. Pressure flow is due to the difference of hydraulic pressure between the two sides of the membrane. Agitation is provided by the rotation of the auger. Purging is achieved with the air blow from the near bottom of the extruder, which is in vertical direction.

1.2 Technical effectiveness and economic feasibility of the methods

The technology developed from this project is effective in recovering from coal slurries coal fines with the size between 5 micron to50 micron with a hydrophobic membrane and 0.1 micron to 50 micron with a hydrophilic membrane. The water content of the feed stream was 90% and that of the recovered coal fine (cake) is reduced to about 10%wt for both particle size ranges. The apparatus so far built is capable of processing 1lb/min. coal slurry with solid concentration of about 10%wt.
The technology developed should have the future not only to deal with slurry freshly from plants but also those from impoundments. Further more, the dewatering technology developed from this project should not be limited to waste coal slurry treatments. In principle, the technology should be applicable to any applications in which separation of solid from its liquid suspension. The application may extend to medical, and food and chemical industries *etc.* Coal fines with smaller particle sizes on the other hand might be of greater value. Being of greater surface area, they could be better candidate as power plant fuel than those of coarse particles. Coal fines of a particle size between 5 to 45 micrometers are not available in the U.S. and international markets yet, because they are wasted in the current dewatering processes.

It was also found from this work that, coal fine suspensions of the particle size smaller than 1 micron (*i.e.* nano particle) could form stable suspension with water without the use of surfactant. This finding could open applications of nano coal fine slurry as ink or others.

The most import impact from the results of this project would be the confidence we have to establish industrial scale facility for the recovery of coal fines currently wasted. It is reasonable to estimate that the amount of coal fines lost in the current process (i.e., those of particle size smaller than 50micorn takes about 1% of the total coal mined. As of year 2000, the annual total energy produced in US is 15,987,811 billion Btu by coal, 633,609 billion Btu by petroleum, and 2,681,659 billion Btu by gas [1]. This means that, energy contained in coal fines lost in waste stream accounts for about 25% and 5.95% of that produced by petroleum and gas in year 2000 respectively. This is indeed a huge energy benefit.

2 Comparison of the actual accomplishments with the goals and objectives of the project.

The ultimate goal of this project was to establish an efficient and low-cost equipment and process for use in existing or future coal preparation plants, with which coal fines (typically any coal less than 1/16" or 1.6 mm) between 5 to 45 micrometers or greater can be recovered and dewatered, and used alone or in combination with the pulverized coal as power plant fuel.

The project proposal was approved for only the phase I period. The goal for this Phase I project was to develop an industrial model that can perform continuous and efficient dewatering of fine coal slurries of the previous flotation process to fine coal cake of ~15% water content from 50~70%. The feasibility of this model should be demonstrated experimentally using a lab scale setup. The Phase I project was originally for one year, from May 2005 to May 2006. With DOE approval, the project was extended to Dec. 2006 without additional funding from DOE. The major objective of this non-cost extension period is to accomplish the remaining work and also to improve the alignment of the auger, with the hope to improve its life time.

Comparing the set objectives with what has been accomplished, it is clear that we have accomplished following major objectives:

- A lab scale dewatering model has been design, constructed, tested and modified;
- The model can take coal slurries either from Yang's floatation Column or directly from mixer where coal fine is mixed with water.

Not only coal fines between the targeted range of 5 to 45 micron was recovered with the model, coal fines of a wider range (0.1 – 50 micron) can also be recovered when the model is equipped with a hydrophilic membrane.

Due to limited time and resource, the goal set for the non-cost period was not reached.

3 Proroject tasks and accomplishments

The project activities mostly followed as planned. All the planned tasks (Table 1) have been performed.

Table 1. Planned Milestones

Planned Milestones	Scheduled Completion	Actual Completed
Task 1. Design and construction of the dewatering extruder	Oct., 05	100%
Task 2. Integration of the dewatering and flotation processes	Nov., 05	100%
Task 3. Test of the research concept	Feb., 06	100%
Task 4. Preliminary study on the enhancement of the life time of the dewatering extruder	April, 06	100%

Task 5*. 2nd Auger model development	Sept, 06	100%
Task 6. Data Analysis and report	Dec. 06	

*Non-cost extension period.

3.1 Task 1. Design and construction of the dewatering extruder

The apparatus built is based on the original hypotheses (sketched as Figure a1 Appendix). The key activity of the task 1, and also of the entire project, is to design and construct the auger. The auger should provide effective drainage channels from all over its surface. The first design was developed through the collaboration between WVU and DeVall Bros. The first sample was made of Nylon with reduced size. A full size sample was made of the same materials at RCBI (Advanced Manufacturing Technologies), Huntington, WV. This sample auger however turned out to be not strong enough.

A new augur was made of perforated stainless steel tubing as its shaft. Both ends of the shaft were fit into a stainless steel rod with grooves(Appendix). DeVall Bros then made the framework to house the extruder. The extruder was mounted vertical, and seat on trust bearing housed in a metal fixture made in DeVall Bros. The auger is driven by a variable speed motor, through chain and sprocket mounted onto the upper end of the auger shaft.

The fixture was modified at WVU, with reduced weight and convenient connections for frequent mounting and dismounting of the apparatus.

3.2 Task 2. Integration of the dewatering and flotation processes

The task was accomplished between WVU and MTI researches and engineers. In addition to the Yang’s floatation column, MTI also provided pumps, valves, and connection parts to help complete the integration of Yang’s floatation column with the WVU dewatering separator. MTI also provided recipe and materials for the recipe material. The integration and test run was completed on time.

3.3 Task 3. Test of the research concept

This task was accomplished mainly by WVU researchers. The following results were obtained:

a) Dewatering can be achieved with the conceptual model, the solid recovered contains less than 15% water in weight percentages. A picture of recovered coal cake was shown as figure 1.

b) With the 5micron membrane, any solid particles greater than 5 micron are effectively recovered (table 2 and figures 2-a, 2-b and 2-c.

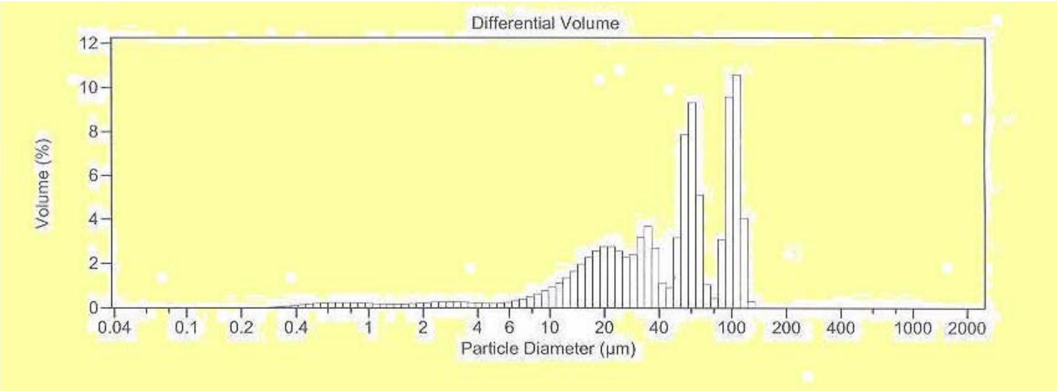
c) With the 0.1 membrane, the size of solid particles remained in the filtrate became undetectable (Table 3).

d) The processing rate of the apparatus can reach 50lb/hour.

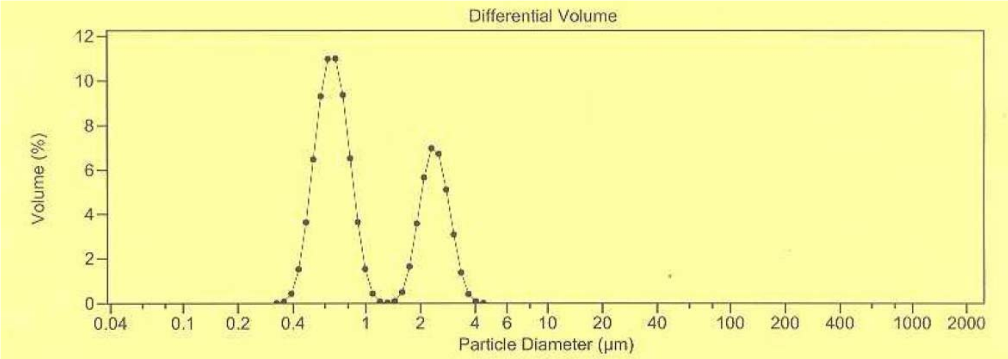
Figure 1. Dewatered coal fine from solid outlet

Table 2. Summary of Testing Results for 5-micron hydrophobic membrane at a feed rate of 1 lb/min.

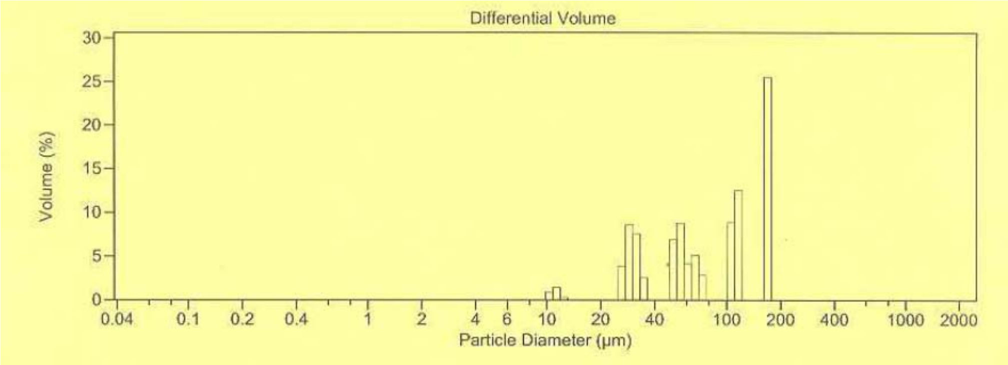
	Solid Content, %	Size range, micron	Appearance
Feed stream	~9	0.3~120(Fig3. –a)	Black slurry
Solid Outlet	>88	10~180(Fig3. –b)	Cake/powder
Liquid outlet	<0.1	0.3~5 (Fig3 –c).	Black-yellowish Suspension



a) Particle size distribution of the feed stream



b) Particle size distribution of filtrate from 5-mircon membrane.



c) Particle size distribution of the cake retained from 5-micron filtration.

Figure 2. Particle Distribution Curves of coal fines

Table 3. Summary of Testing Results from 0.1-micron hydrophilic membrane at a feed rate of 1 lb/min.

	Solid Content, %	Size range, micron	Appearance
Feed stream	~9	0.3~120	Black slurry
Solid Outlet	>90	0.3~120	Cake/powder
Liquid Outlet	Undetectable	Undetectable	Light yellowish liquid

3.4 Task 4. Preliminary study on the enhancement of the life time of the dewatering extruder

This task was conducted through the collaboration mainly between WVU and MTI researches. A close loop system version of the integrated Yang's floatation column and the WVU dewatering column was built. In this setup, coal fine cakes and filtrate were all sent back to mixer, where they were remixed and pumped back to the separation system as feed stream. The flow diagram and the close-up look of the testing system is presented in Appendix.

Preliminary life time evaluation of the apparatus was performed with the close-loop setup. In the beginning of each run, there was a period of time during which the coal fines were accumulated in the separating column. Then the gradually, the output of coal fine start balancing the amount of solid from the feed stream, and the system reached a steady state. We found there were two problems. One is that manual adjustment of the flow rate of the feed stream is needed maintain the steady state. The other is that rotation of the auger appeared not stable, which hinder the establishment of the steady state. The unstable rotation of the auger turned out to be the combination of the misalignment of the accumulation of coal fines in the separating column that exerts an additional load on the rotating auger.

We realized that the auger was not strictly straight at all. Due to the stress of the double flight formed by stainless steel sheet on the central shaft made of perforated tube that is of low stiffness, the auger has a very noticeable bending curvature. The membrane protection material at the high back of the bending curvature of the auger was seriously worn after each continuously run. It was also realized that there was big room to improve the alignment of the bearing housings to screw auger. It was believed that the high resistance due to auger misalignment played a major role in unstable separating process in the continuous run.

3.5 Task 5 2nd Auger model development

The original goal of the task 5 was to make a new auger to eliminate the alignment problem. The goal was unfortunately not accomplished due to the shortage of financial resource and limited time. However, we analyzed the problem of the existing auger with the auger manufacturer, Falcon Industries. The conclusions are as follows, 1) the overall shape of the existing model is still valid, 2) the central shaft needed to be made stronger; and 3) the bending problem of the existing model can easily be eliminated if the auger were made in a larger dimension. In other words, based on the opinion of the manufacture, a scaled-up apparatus would be more easily made, which is good news.

3.6 Task 6 Data Analysis and Final Report

All the consortium team members participated this activity. In particular, Dr. Yang of MTI, Dr. Amarnath and Dr. Huq of Lusca provided valuable insight. The Final report was also reviewed by the Chair of the Department of Chemical Engineering and the Associate Director of the WVU Technology Transfer Office of WVU Sponsored Program Offices. The Final Report was completed by March 1st, 2007.

4 New products developed and technology transfer activities

4.1 Publications (list journal name, volume, issue), conference papers, or other public releases of results. If not provided previously, attach or send copies of any public releases to the DOE Project Officer identified in Block 11 of the Notice of Financial Assistance Award

Presentation will be made on the Coal Prep Exhibition and Conference, May 1-3 2007, Lexington, KY USA. http://coalaggprepshow.com/conference/index.html

Publication will be made in Journal of the Coal Preparation Society.

4.2 Web site or other Internet sites that reflect the results of this project

DOE published significant details of the technology in May 2006 on one of their websites: http://www.eere.energy.gov/industry/mining/pdfs/coaldewatering.pdf

We will be putting the final report on the www.netl.doe.gov site and the www.eere.energy.gov/industry/mining/index.html.

4.3 Networks or collaborations fostered

Collaboration with following enterprises has been established:
Luscar Ltd. (Edmonton, Alberta Canada), McLanahan Corp. (Hollidaysburg, PA), DeVall Bros. Inc. (Morgantown, WV), Mineral Technologies International, Inc. (Morgantown, WV), and Falcon Industries, Inc.

4.4 Technologies/Techniques

A 50lb/min laboratory model of dewatering column has been built. Technology information of design, construction, and operation of the dewatering column has been documented.

4.4 Inventions/Patent Applications, licensing agreements

Proprietary disclosure is in preparation with WVU patent office. WVU is going to file a provisional patent application.

4.5 Other products, such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment.

The other product includes following items:

4.1 Final report
4.2 Power Point Slide
4.3 Photo gallery of the project
4.4 Notebook
4.5 Database

5. Acknowledgements

The project was benefited from the great collaboration and support of all the participants. In particular, David Yang, MTI, collaborated in the integration of dewatering column with his floatation column. Amar Amarnath, and Iftikhar Huq, Luscar provided insight in needs of core preparation plants. Scott C. O'Brien, McLanahan Corporation, reviewed the reports. Jim Williams, Devall Brothers, manufactured and installed the framework of the dewatering column. Thanks are also to supports from WVU, i.e., to Jim Hall, for fabricating parts for the modification of the dewatering column and technique supports in various aspects; to Elliot Kennel and Olufemi Olajide for sample; Dady Dadyburjor, for reviewing and modifying reports, and Vince Alvarez, and Linda Rogers, for managing the Financial reports. Finally, we would like to thank Morgan Mike Mosser, DOE, for managing this project.