Advanced Multi-Product Coal Utilization By-Product Processing Plant

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ABSTRACT

The objective of the project is to build a multi-product ash beneficiation plant at Kentucky Utilities 2,200-MW Ghent Generating Station, located in Carroll County, Kentucky. This part of the study includes the examination of the feedstocks for the beneficiation plant. The ash, as produced by the plant, and that stored in the lower pond were examined.

Filter media candidates were evaluated for dewatering the ultrafine ash (UFA) product. Media candidates were selected based on manufacturer recommendations and evaluated using standard batch filtration techniques. A final media was selected; 901F, a multifilament polypropylene. While this media would provide adequate solids capture and cake moisture, the use of flocculants would be necessary to enable adequate filter throughput. Several flocculant chemistries were also evaluated and it was determined that polyethylene oxide (PEO) at a dosage of 5 ppm (slurry basis) would be the most suitable in terms of both settling rate and clarity.

PEO was evaluated on a continuous vacuum filter using 901F media. The optimum cycle time was found to be 1.25 minutes which provided a 305% moisture cake, 85% solids capture with a throughput of 115 lbs dry solids per hour and a dry cake rate of 25 lb/ft2/hr. Increasing cycle time not did not reduce cake moisture or increase throughput.

A mobile demonstration unit has been designed and constructed for field demonstration. The continuous test unit will be operated at the Ghent site and will evaluate three processing configurations while producing sufficient products to facilitate thorough product testing. The test unit incorporates all of the unit processes that will be used in the commercial design and is self sufficient with respect to water, electricity and processing capabilities.

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INTRODUCTION

This project will complete the final design and construction of an ash beneficiation plant that will produce a variety of high quality products including pozzolan, mineral filler, fill sand, and carbon. All of the products from the plant are expected to have value and be marketable. The ash beneficiation process uses a combination of hydraulic classification, spiral concentration and separation, and froth flotation. The advanced coal ash beneficiation processing plant will be built at Kentucky Utility's 2,200 MW Ghent Power Plant in Carrollton, Kentucky. The technology was developed at the University of Kentucky Center for Applied Energy Research (CAER) and is being commercialized by CEMEX Inc. with support from LG&E Energy, Inc., the UK CAER, and the U.S.DoE.

This technical report includes research that was conducted during the first quarter of 2005. The focus of the research was on dewatering of the ash products to enable use as cement additives. The primary objective of this effort was to select the appropriate filter media and flocculant chemistry for effective dewatering.

Additional efforts were focused on the design, fabrication and construction of a mobile processing facility that will be installed and operated at the Ghent sits to evaluate three different processing flowsheets. The objectives of this effort will be to determine the final flowsheet design while producing sufficient processed products to enable large-scale testing in mortar and concrete.

EXECUTIVE SUMMARY

The project area is located in Carroll County, Kentucky, approximately one mile northeast of Ghent, Kentucky. The lower ash pond is situated immediately adjacent to U.S. Highway 42 on the southwest corner of the Ghent power plant site. Disposal of ash into the 120-acre pond began when the Ghent power plant became operational in 1973 and continued over a period of 20 years until the upper ash pond became operational in 1993. The Ghent power plant has four separate generating units. Units 1 and 2 burn a high sulfur coal and an Appalachian low sulfur compliance coal. Units 3 and 4 have multi-fuel burners and are fueled by a mixture of low sulfur subbituminous and bituminous coal. The coals burned within these units were subjected to major and trace elemental analyses, mercury analysis, and loss-on-ignition (LOI) tests.

Approximately 2 tons of pond ash was retrieved from the Ghent site and processed at CAER in Lexington, KY. The purpose of this testing was to use continuous pilot-scale equipment to produce product streams that would be similar in characteristics and quality to what would be produced in commercial operation. This was necessary to evaluate the thickening and dewatering characteristics of the product slurries.

Filter media evaluations were conducted on the ultrafine ash (UFA) product which is recovered as a dilute (3-5% solids) slurry. A total of 5 filter media candidates were selected based on manufacturer recommendations and evaluated using standard batch filtration techniques. A final media was selected based on these results; 901F, a multifilament polypropylene. It was apparent that while this media would provide adequate solids capture and cake moisture, the use of flocculants would be necessary to enable adequate filter throughput. Several flocculant chemistries were evaluated and it was determined that polyethylene oxide (PEO) at a dosage of 5 ppm (slurry basis) would be the most suitable in terms of both settling rate and clarity. PEO has also been used extensively as a viscosity modifier in concrete, so compatibility with concrete chemistry will not be an issue.

PEO was evaluated on a continuous vacuum filter using 901F media. The optimum cycle time was found to be 1.25 minutes which provided a 305% moisture cake, 85% solids capture with a throughput of 115 lbs dry solids per hour and a dry cake rate of 25 lb/ft2/hr. Increasing cycle time not did not reduce cake moisture or increase throughput.

A mobile demonstration unit has been designed and constructed for field demonstration. The continuous test unit will be operated at the Ghent site and will evaluate three processing configurations while producing sufficient products to facilitate thorough product testing. The test unit incorporates all of the unit processes that will be used in the commercial design and is self sufficient with respect to water, electricity and processing capabilities.

EXPERIMENTAL

Evaluation of Filter Media

A series of tests were conducted with a variety of filter media samples in order to assess the feasibility of using vacuum filtration with conventional media to recover the ultrafine ash (UFA) product. This testing was conducted in response to discussions and recommendations with technical representatives from several filter manufacturing companies. The filtration media samples evaluated were a variety of monofilament, multifilament and combination polypropylene fabrics.

The evaluation was conducted using 6 inch diameter media samples mounted on a stainless steel batch filtration apparatus using 4 mesh stainless steel screen as media support. A 0.5 liter suspension of UFA was poured into a vessel clamped above the media and vacuum was applied through a vacuum flask mounted on an electronic balance. Filtrate weight and time were recorded for 2 minutes. After filtration was completed, the formed cake was removed and cake moisture was determined by drying the cake at 65°C. Solids recovery was also determined by filtering the solids in the filtrate with a Millipore filter (0.5 µm) and drying at the same temperature.

A total of 5 media candidates were evaluated. One multifilament candidate, 853F was eliminated since the entire sample passed through media and no solids recovery occurred. Results from the other candidates are summarized in Figure 1. All of the media candidates tested provided essentially the same cake moisture after a cycle time of 2 minutes (i.e. 28.5 to 29% moisture). The fastest filtration results during cake formation were obtained with 901F multifilament with M929 monofilament providing the slowest. In terms of solids capture, M929, 901F and 950A recovered 97to 99.5% of the feed solids in the cake while 950B provided 90.9% solids capture.

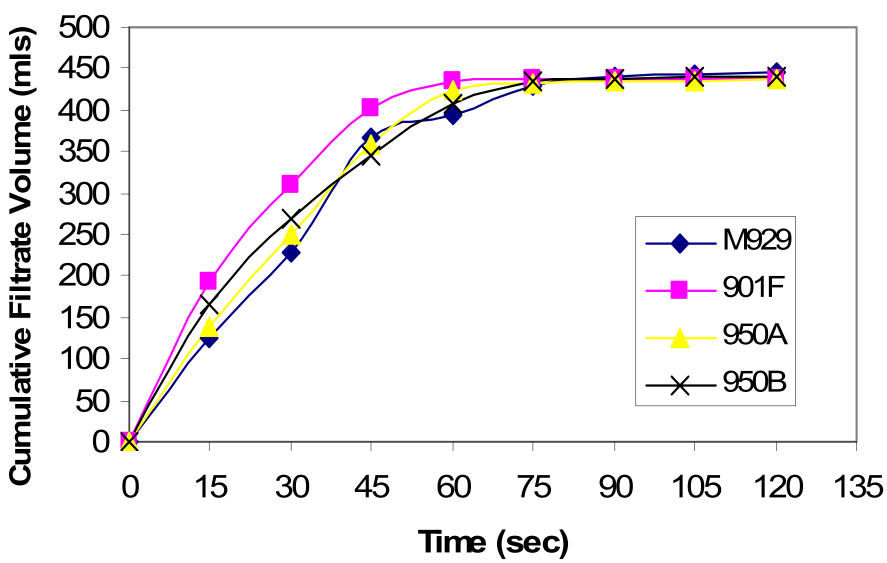

Figure 1. Filtrate Volume vs. Time for Different Media on UFA.

The differences in filtration performance are more clearly illustrated in Figure 2, where the incremental filtration rate is plotted as a function of time. During the initial cake formation stage, media 901F was clearly superior to the other candidates.

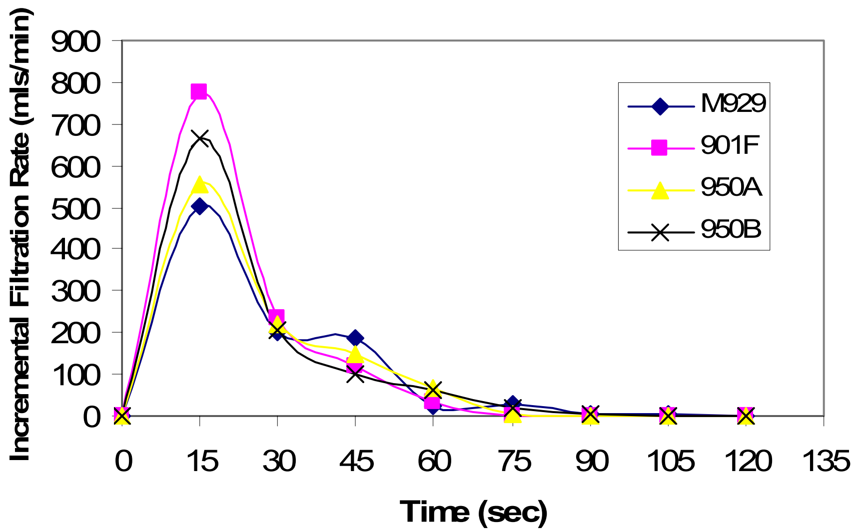

Figure 2. Incremental Filtrate Rate vs. Time for Different Media on UFA.

These results were obtained by limiting the filtration cycle to 2 minutes. What is evident from these results is that minimal additional filtrate was recovered after 90 seconds. Another series of tests were conducted to determine if a longer cycle time provide additional moisture reduction after cake formation. Using the same feed and test conditions, the cycle time was lengthened and the results are shown in Figure 3. No additional moisture reduction was evident by prolonging the cake drying stage of the filtration cycle. Based on the results obtained from batch filtration testing, it was determined that the most suitable filter media for this substrate, in terms of filtration rate, solids capture and cake moisture was 901F multifilament fabric.

Although the fabrics evaluated provided good results for filtering such fine particulates, it was apparent that the filtration rate was inadequate for an industrial process. Cake thickness was too small (<2 mm) to ensure cake removal. In order to continuously dewater a significant amount of UFA with a reasonably sized filter, it would be necessary to use flocculating agents.

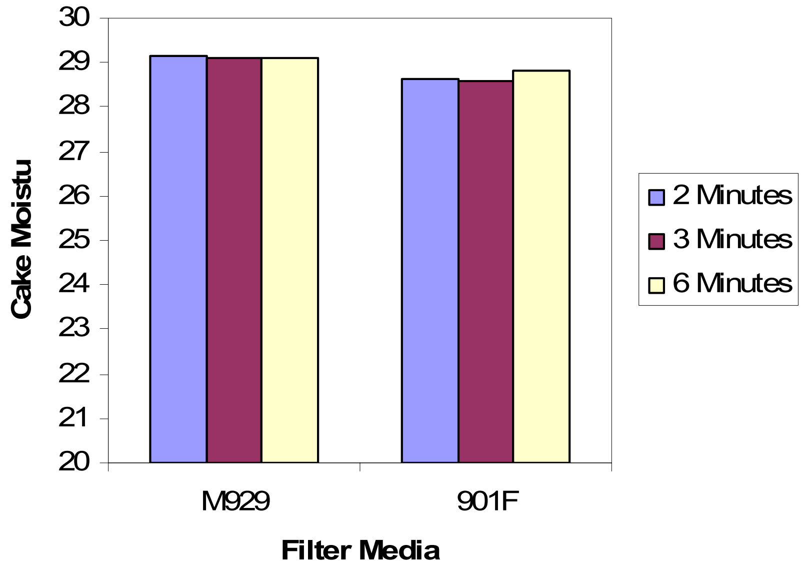

Figure 3. Effect of Cycle Time on Cake Moisture for 2 Media Candidates.

Evaluation of Flocculants

To improve filter throughput, the use of flocculants was evaluated. A variety of flocculants (anionic, nonionic and cationic) and molecular weights (4 to 16 million) were screened using standard jar tests to determine the appropriate chemistry that would provide effective floc formation. After the initial screening, it was determined that two different chemistries would be appropriate; polyethylene oxide (PEO) and polyacrylamide (PAM). A molecular weight series of PEO products was obtained from Dow Chemical and a similar series of PAM products was obtained from Cytec, Inc. Settling tests were conducted and it was determined that the lower molecular weight products (i.e., 4 million MW) provided the most desirable floc structure. Higher molecular weight flocculants, while providing faster setting rates, provided large, fluffy flocs which would entrain moisture in the floc structure during filtration. In addition, the fast settling rate provided poor clarity.

Settling tests were conducted in 1 liter glass cylinders. A feed slurry was prepared containing 5 % solids (w/w) UFA, to which the appropriate dosage of flocculant was added as a 0.1% solution. The suspension was mechanically mixed with a low shear mixer and settling rate was recorded. The results obtained with PEO are shown in Figure 4. At a dosage of 1 ppm PEO, the settling rate of the flocculated UFA was 4.5 inches/minute for the first 2 minutes, and decreased to 3 inches/minute after 5 minutes. Essentially the same results were obtained with a dosage of 5 ppm. A more desirable initial settling rate of 6 inches/minute was obtained with a dosage of 2.5 ppm PEO while increasingthe dosage to 10 ppm was not advantageous at all. For effective thickener operation, an initial settling rate of 4 to 12 inches/minute is desirable. This settling rate provides adequate solids settling and compaction while maintaining overflow clarity.

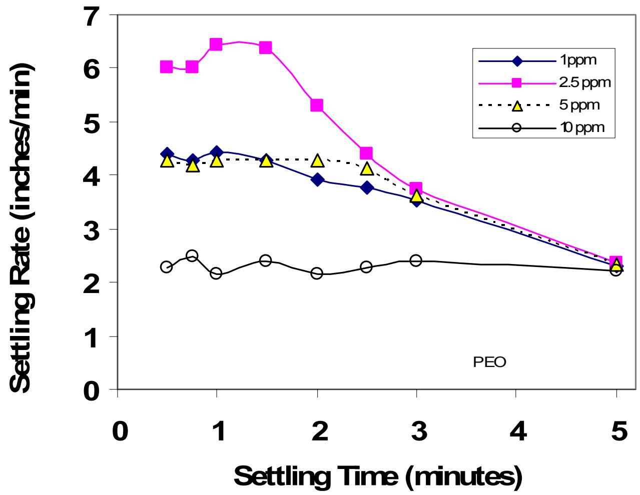

Figure 4. Effect of PEO Dosage on Settling Rate of UFA.

A comparison of settling rates obtained with PEO and PAM are shown in Figure 5. The initial settling rate obtained with 5 ppm PAM was very high (22 inches/minute). While this may seem beneficial, it is in practice much too fast to maintain consistent thickener operation in terms of both solids compaction and overflow clarity. Based upon these results, it was determined that t he most appropriate flocculant treatment for UFA would be 5 ppm PEO.

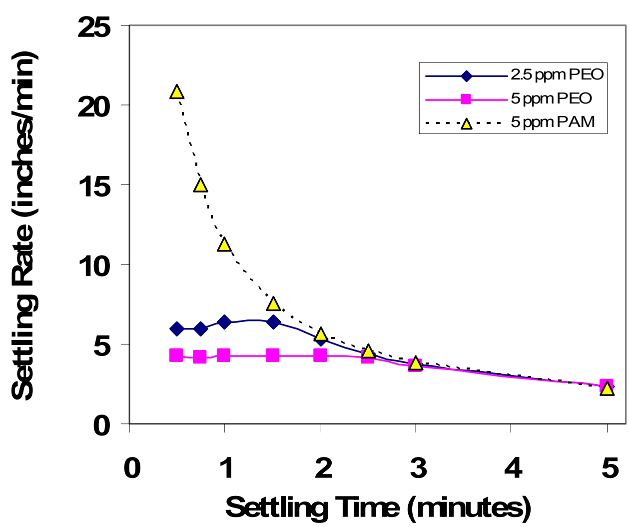

Figure 5. Effect of PEO and PAM Dosage on Settling Rate of UFA.

In order to assess the filtration characteristics of flocculated UFA a series of batch filtration tests was conducted. A quantity of UFA slurry was produced using laboratory pilot-scale equipment. The slurry was produce from the Ghent pond ash under conditions that would be anticipated during commercial operation. The slurry (5% solids w/w) was flocculated with 5 ppm PEO and the settled solids (25% solids w/w) were recovered for filtering using F901 media. Varying amounts of the slurry were filtered to provide varying cake thicknesses and the results are shown in Figure 6. At a cake thickness of 4.3 mm, cake formation occurred at 30 seconds and the resulting cake moisture after 2.5 minutes was 32.1% moisture. Increasing the cake thickness to 5.8 mm increased the cake formation time to 45 seconds and provided a cake with 31.0% moisture. Further increasing the cake thickness to 7.3 mm increased cake formation to 53 seconds and cake moisture was 31.8%. For comparison, when no flocculant was used, cake formation occurred at 90 seconds (1 mm cake thickness) and the final cake moisture was 29.0%.

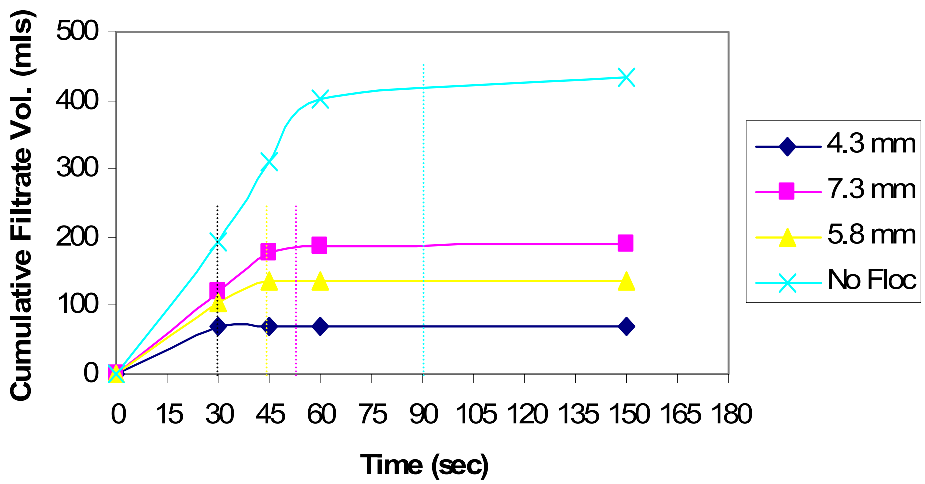

Figure 6. Effect of Cake Thickness on Filtration of 30% Solids Flocculated UFA.

Evaluation of Continuous Filtration

Upon completion of the batch filtration evaluation, a series of tests were conducted to evaluate continuous filter performance. These tests were conducted using an Eimco vacuum drum filter (12" wide x 18" diameter drum) with 901F media. The drum filter is segmented at 6" intervals along the drum face and the media was installed using manufacturer recommended polypropylene cords in the segments along the drum face. The media was secured along the edge of the drum using steel wire pulled taught. Although this is not the most desirable method of securing the media along the edge, it is a limitation of using this particular filter. Vacuum leaks were sealed with vacuum grease to minimize solids loss around the edges where the media contacted the drum.

A drum of flocculated (5 ppm PEO) UFA (25% solids w/w) was agitated with a stirrer and pumped into the vacuum filter tub. Vacuum was applied to the filter and drum rotation speed was determined. The slurry feed rate was adjusted to maintain a constant tub level and the filter was allowed to operate under fixed conditions for 15 minutes. Timed samples of the discharged filter cake and filtrate were simultaneously taken. The cake was weighed and dried while the filtrate volume was recorded and the solids in the filtrate were recovered by batch filtration to determine solids recovery. The procedure was repeated for different cycle times and the results are shown in Figure 7. Maximum throughput (115 lb/hr) and dry cake rate (25 lb/ft2/hr) were achieved at a cycle time of 1.25 minutes. Under these conditions the cake moisture was 30.5% with 85% solids capture. Increasing cycle time not did not reduce cake moisture but did reduce the dry cake rate and throughput. The longer cake formation time during the longer cycle time did not provide addition cake deposition, suggesting that the cake resistance is quite high. At shorter cake formation time (i.e. shorter cycle time), dry cake rate and throughput also were diminished with a modest reduction in moisture. These results indicate that there is an optimum cake thickness and it is achieved at a cycle time of 1.25 minutes with this filter. These conditions will be used during the field demonstration. It may be feasible to increase throughput with this filter by increasing the filter feed solids. Insufficient sample was available to evaluate this approach in the laboratory and it will be evaluated during the field demonstration phase.

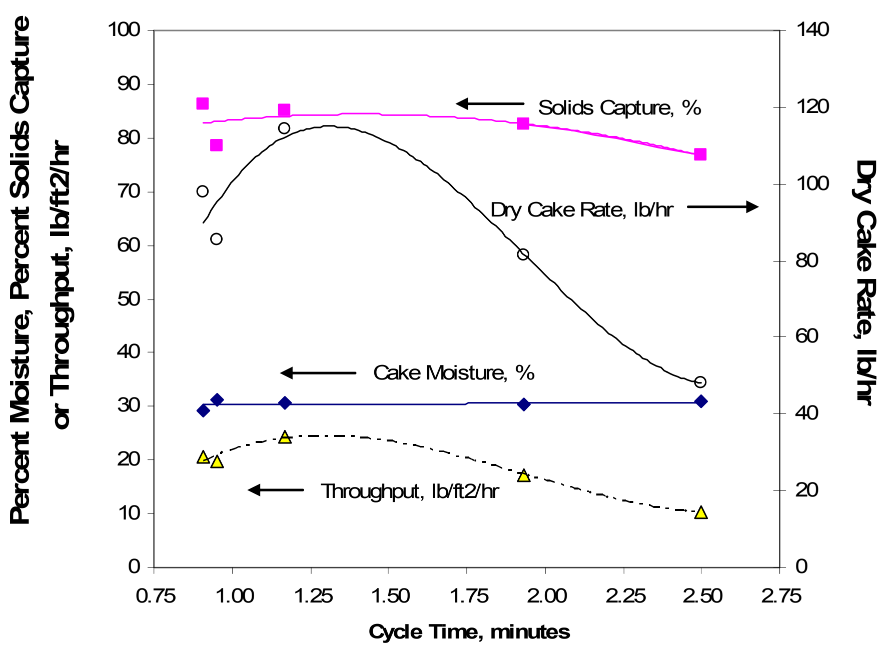

Figure 7. Results of Continuous Filtration Testing on Flocculated UFA.

Evaluation of UFA Slurry

Once the UFA product is recovered as a cake via filtration, there are two options for preparing the cake for use in concrete. One option is to dry the material using thermal drying. Another option is to produce slurry that would be pumpable. This option, while adding to the transportation cost, would be more cost effective since the cost of drying would be eliminated. An additional benefit would be derived from eliminating the need for handling such fine-sized dry material. To investigate the feasibility of using such an approach, a series of simple lab experiments were conducted.

The filter cake obtained from continuous vacuum filtration was agitated for 30 seconds in a high shear mixer and a pourable slurry was produced. The viscosity of the slurry was not measured since the appropriate viscometer was not available. Nevertheless, the slurry was quite fluid and pumpable. The slurry was poured into glass cylinders and monitored for several days to determine if settling occurred. After 24 hours of settling, the top half and bottom half of the suspension were withdrawn and separately filtered to determine the % solids. He results are shown in Figure 8. Under ideal conditions, the initial and final solids concentration of the top and bottom half of the slurry would be the same if no settling occurred. At an initial solids concentration of 42.5%, the top half of the suspension contained 30.9% solids while the bottom half contained 62.8% solids, clearly illustrating that significant settling had occurred. However, as the initial solids were increased to 70% solids, after 24 hours, the top and bottom half contained 66.4 and 74.0% solids, respectively. Minimal settling occurred without the use of any slurry stabilizers. These results suggest that it may be feasible to produce a stable slurry at high solids concentration and the higher the initial solids concentration, the less segregation will occur. This approach will be investigated in more detail in the future once larger quantities of UFA are available. The emphasis will be on producing high initial solids concentration and monitoring changes in viscosity and yield stress over time.

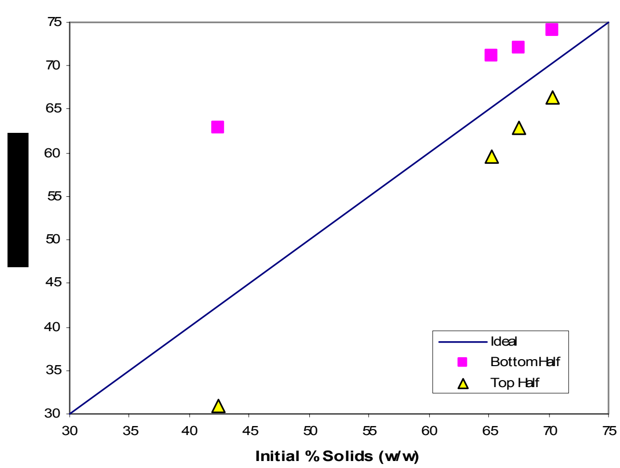

Figure 8. Results of Preliminary Slurry Stabilization Evaluation.

FIELD DEMONSTRATION TESTING

Extensive effort was expended during this reporting period on preparations for field demonstration of the ash beneficiation technology. The field demonstration will take place at the Ghent site and will include the evaluation of 3 processing strategies. The first will include primary classification and froth flotation to produce coarse carbon fuel, fine carbon fuel and pozzolan. The second will include primary classification, froth flotation and secondary classification to produce coarse carbon fuel, fine carbon fuel, pozzolan and UFA. The third will include primary and secondary classification to produce coarse carbon fuel, pozzolan and UFA. The third configuration eliminates froth flotation and the associated costs of equipment, power and reagents.

A primary additional objective of the field demonstration testing is to generate sufficient products to conduct larger scale concrete testing. It is anticipated that approximately 10 tons of pozzolan will be produced along with 2 tons of UFA.

In order to conduct the field testing, a mobile pilot plant has been designed and constructed. Because the field testing will occur at a remote location, it will be necessary that the entire operation be self-sufficient including provisions for water, electricity and all equipment. A flowsheet of the field unit is shown in Figure 9.

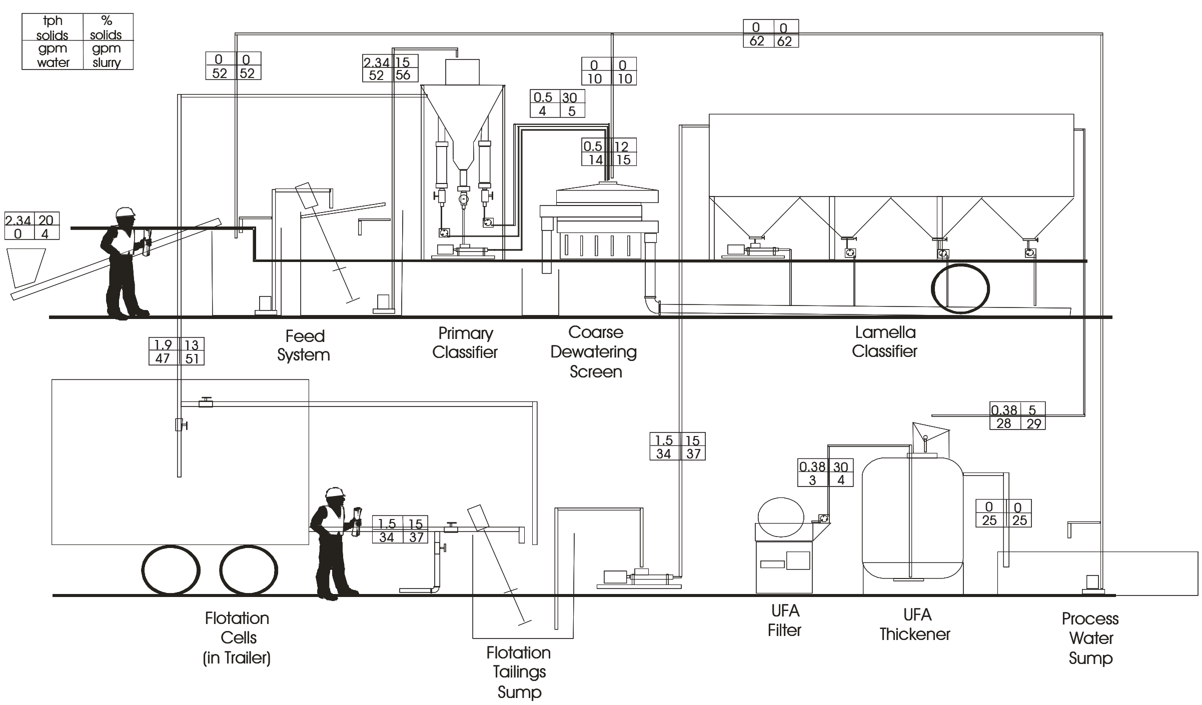

Figure 9. Flowsheet of Mobile Field Demonstration Unit.

All of the equipment is mounted on two separate trailers; a 48 ft. long flatbed trailed and a 53 ft long enclosed box trailer. The flowsheet shows major equipment and design flow rates. The design feed rate will be 2.3 tph dry solids which will be fed by conveyor into a primary feed tank (500 gal) and diluted to 15% solids and pumped to a secondary feed tank (500 gal) before pumping into the primary classifier. A photograph of the feed system is shown in Figure 10.

Figure 10. Conveyor and Feed Mix Tanks.

The primary classifier (Figure 11) will reject +100 mesh solids, primarily coarse carbon fuel with some coarse ash, which will be dewatered on a dewatering screen. The overflow from the primary classifier will be -100 mesh ash which will be fed into a bank of froth flotation cells to remove fine carbon fuel. The flotation tailings will be dewatered to produce pozzolan. A portion of the flotation tailings will be pumped into a lamella classifier to recover UFA or -5 μm ash.

The lamella classifier (Figure 12) will be fed through a feed manifold at one end and the UFA slurry will be overflow the opposite end. Coarse ash will be rejected from the classifier as it settles on inclined lamella plates and slides into collection hoppers under the plates for removal by pumps. The lamella classifier has four separate collection hoppers; the first will remove the coarsest ash and each of the subsequent hoppers will reject progressively finer ash. The UFA product will be collected in a sump (100 gal), flocculated and pumped into a thickener (1500 gal) shown in Figure 13. The thickener tank has a sloped base (45^o) to facilitate removal of the settled solids. The clarified overflow will be diverted to the process water reservoir for recirculation.

Figure 11. Primary Classifier.

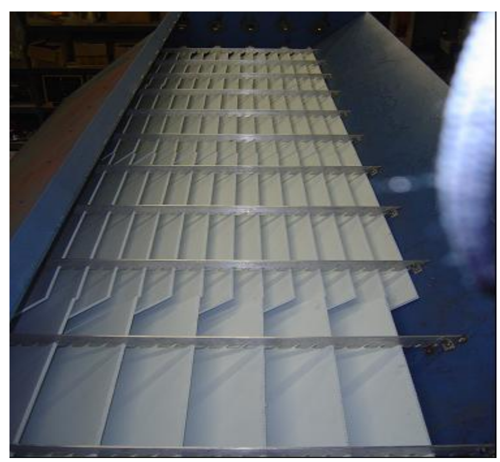

Figure 12. Lamella Classifier (left) with Plates Installed (right).

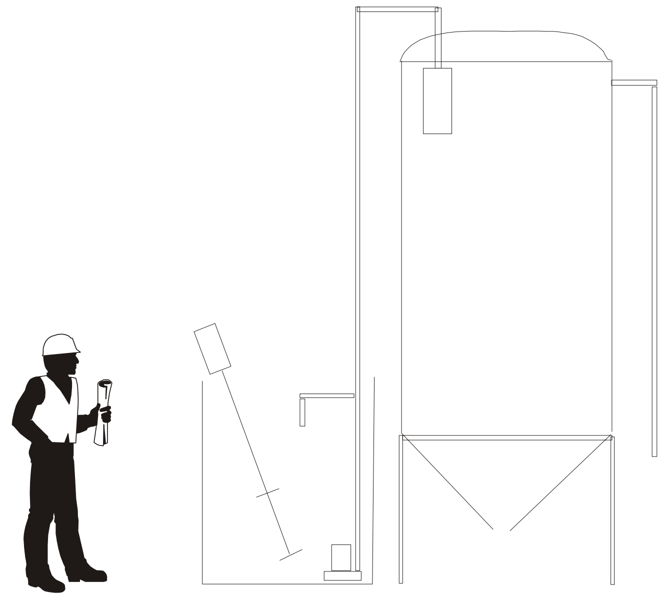

Figure 13. UFA Collection Sump and Thickener.

Settled solids will be pumped from the thickener and fed into a vacuum filter (Figure 14) for dewatering. The vacuum filter will recover a UFA product with 30% moisture, which will be stored in drums for evaluation in mortar and concrete.

Figure 14. Vacuum Drum Filter.

The layout of the process equipment is shown in Figure 15. Also shown is the primary flow streams that will be evaluated. The first circuit will use primary classification and flotation to produce coarse carbon fuel, fine carbon fuel and pozzolan. The second will add lamella classification to produce coarse carbon fuel, fine carbon fuel, pozzolan and UFA. The pozzolan will be recovered in this configuration from the last collection hopper of the lamella classifier. The third configuration that will be evaluated will be to bypass flotation and feed the lamella classifier with the primary classifier overflow. This configuration will produce coarse carbon fuel, fine carbon fuel, pozzolan and UFA. The fine carbon will be recovered from the first collection hopper of the lamella classifier while the pozzolan will again be recovered from the last collection hopper. The primary advantage of this configuration is that flotation equipment and chemical requirements will be avoided.

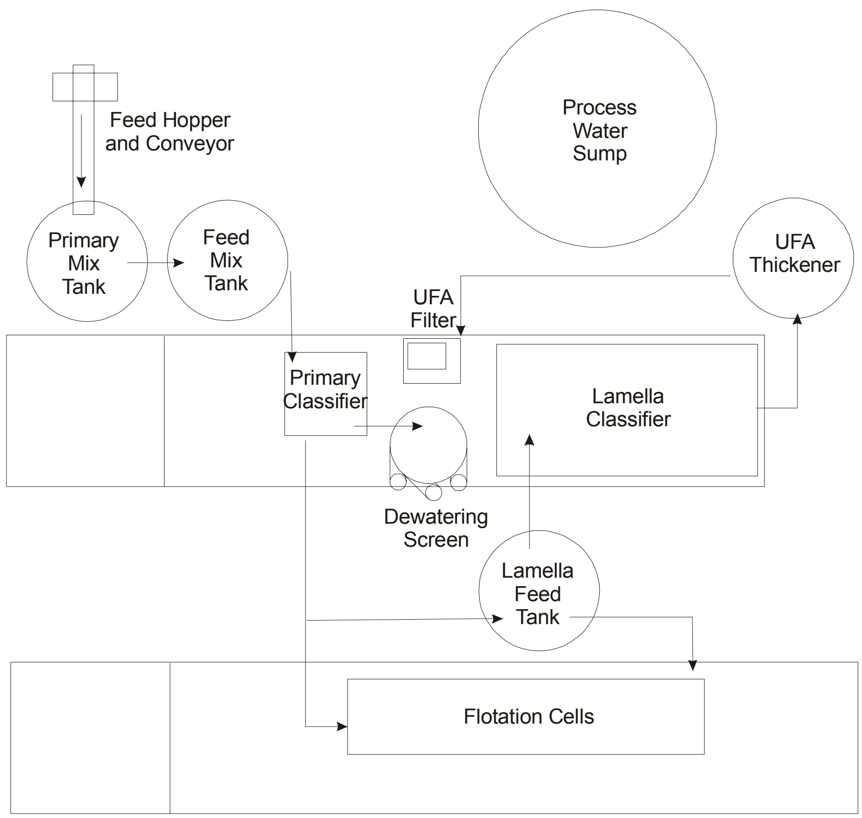

Figure 15. Equipment Layout and Process Flow Streams.

The field demonstration testing will be conducted at the Ghent site. Candidate locations for the testing is shown in Figure 16. After consultation with LG&E representatives, site A was selected. In order to use this site, upgrading to the access road was necessary to maneuver the trailers to the test site. Upgrading has been completed and trailers will be moved in mid June, 2005.

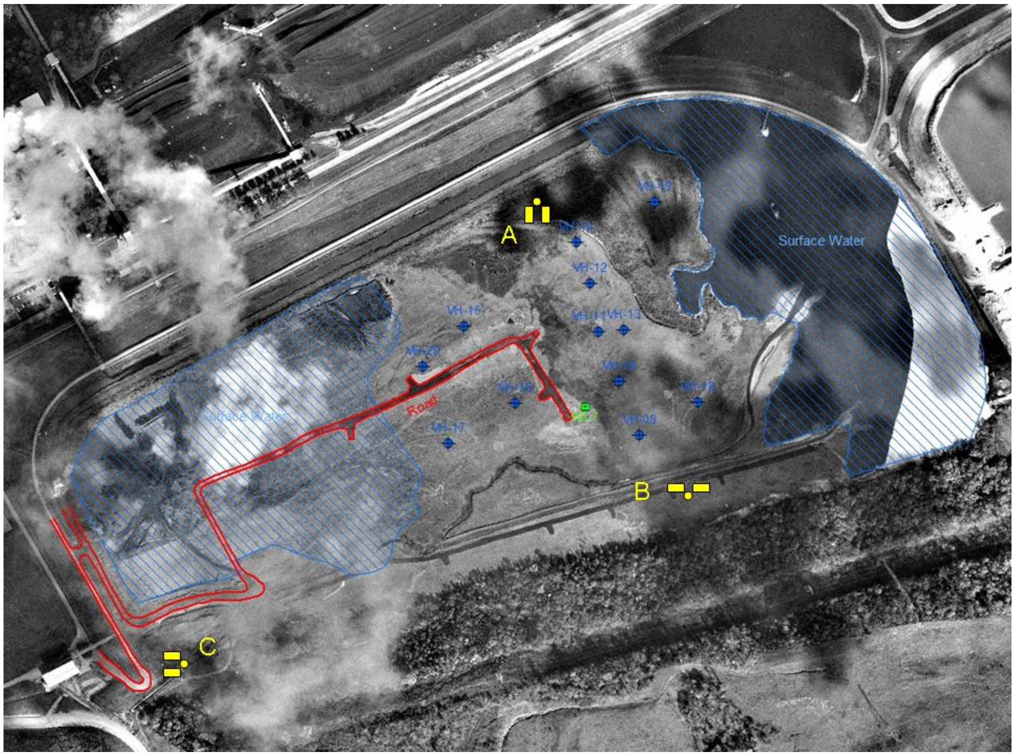

Figure 16. Aerial Photo of Ghent Pond with Candidate Test Locations.

The site layout is shown in Figure 17. Water will be supplied from the rim ditch with a remote gas powered pump and stored in a 2000 gallon water reservoir. Drain lines will be installed to divert reject and clean-out streams away from the trailers during testing. Electrical service will be provided by a diesel generator capable of providing 440V, 208V and 110V service, all of which will be required to operate the equipment in the processing plant.

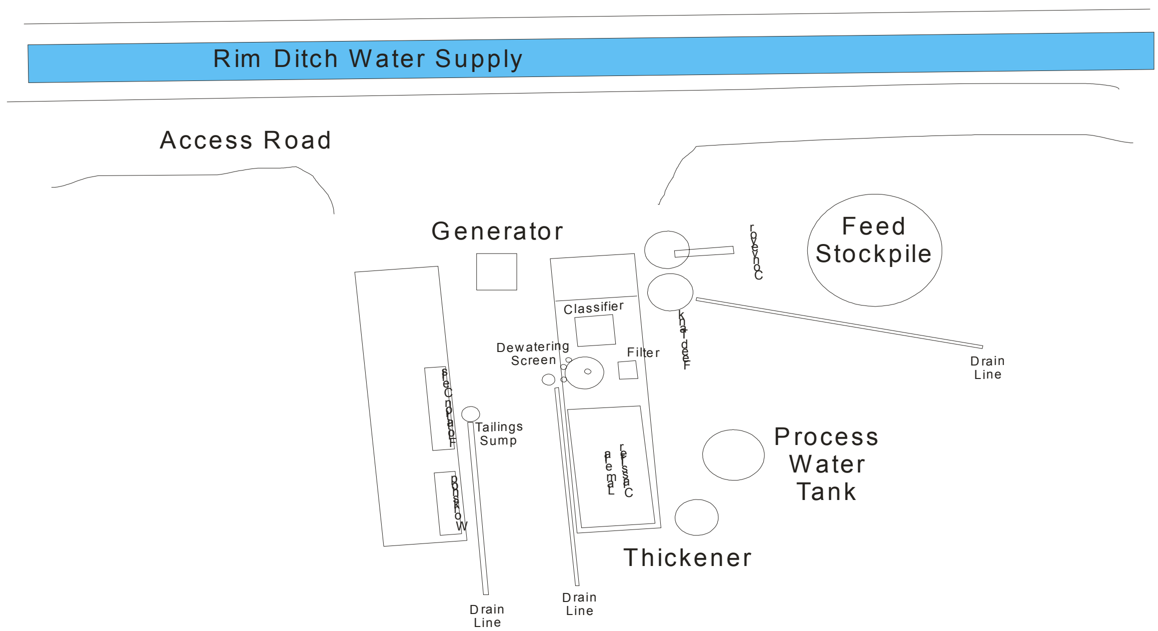

Figure 17. Demonstration Site Layout.

CONCLUSIONS

One of the major processing considerations has been addressed in this reporting period; thickening and dewatering UFA. Laboratory evaluations clearly illustrated the necessity of using flocculants to increase filter throughput. The proper flocculant has been selected and will be used at a minimum dosage of 5 ppm on a slurry basis. It is important to note that PEO has been used in numerous concrete applications as a viscosity reducer and will not present any adverse effects to cement chemistry, particularly when used at such a minimal dosage. Vacuum filtration (1.25 minute cycle time) with the proper filter medium should provide a product with sufficient moisture reduction to enable direct use in concrete (30% moisture). If warranted, the dewatered slurry product can be sheared to produce a slurry which will greatly reduce processing costs by eliminating the need for thermal drying. This option will be further evaluated once a sufficient amount of UFA is available.

The mobile demonstration plant is in the final stages of construction. The entire plant will be constructed at CAER, disassembles, packed and transported to Ghent in Mid June 2005. Upon delivery, the plant will be reassembled and testing will begin. Access to the test site has been upgraded to facilitate transport of the trailers.