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ADVANCED DEWATERING SYSTEMS DEVELOPMENT

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DISCLAIMER

ABSTRACT

A new fine coal dewatering technology has been developed and tested in the present work. The work was funded by the Solid Fuels and Feedstocks Grand Challenge PRDA. The objective of this program was to "develop innovative technical approaches to ensure a continued supply of environmentally sound solid fuels for existing and future combustion systems with minimal incremental fuel cost." Specifically, this solicitation is aimed at developing technologies that can (i) improve the efficiency or economics of the recovery of carbon when beneficiating fine coal from both current production and existing coal slurry impoundments and (ii) assist in the greater utilization of coal fines by improving the handling characteristics of fine coal *via* dewatering and/or reconstitution. The results of the test work conducted during Phase I of the current project demonstrated that the new dewatering technologies can substantially reduce the moisture from fine coal, while the test work conducted during Phase II successfully demonstrated the commercial viability of this technology. It is believed that availability of such efficient and affordable dewatering technology is essential to meeting the DOE's objectives.

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INTRODUCTION

1.1 BACKGROUND

More than 1.1 billion tons of coal is shipped annually in the United States. About 350-400 million tons of this shipped product is prepared for market using wet processing operations at coal preparation plants. For material larger than 1 mm, dense medium processes are used to efficiently clean run-of-mine coals, while screens and centrifugal dryers are used to efficiently dewater the clean coal products. Particles in the size class between 1 and 0.15 mm are typically cleaned using water-based density concentrators including spirals, water-only cyclones, teeter bed separators or multi-stage combinations of these units. The only commercially viable process for treating particles finer than 0.15 mm is froth flotation. The minus 1 mm particles, which are more difficult to dewater due to a higher specific surface area, typically require the use of energy intensive devices such as screenbowl centrifuges or filters to remove the unwanted surface moisture. In many cases, coal producers are forced to discard fines without treatment because of unacceptably high moisture contents and processing costs. The topsize of the material discarded may vary from 0.15 to 0.44 microns (i.e., 100 to 325 mesh), depending on the value of the coal and demands imposed by the sales contract. As a result, is it estimated that 70-90 million tons of fine coal are discarded annually into refuse impoundments in the U.S. As of 2001, approximately 500-800 million tons of coal had been discarded in 713 active waste impoundments. In the United States, the majority of the coal waste impoundments are found in the eastern states of West Virginia, Pennsylvania, Kentucky and Virginia. This situation represents a loss of valuable natural resources, loss of profit for coal producers, and the creation of a potential environmental problem.

A large part of the problem in upgrading fine coal is the high cost of dewatering. Figure 1

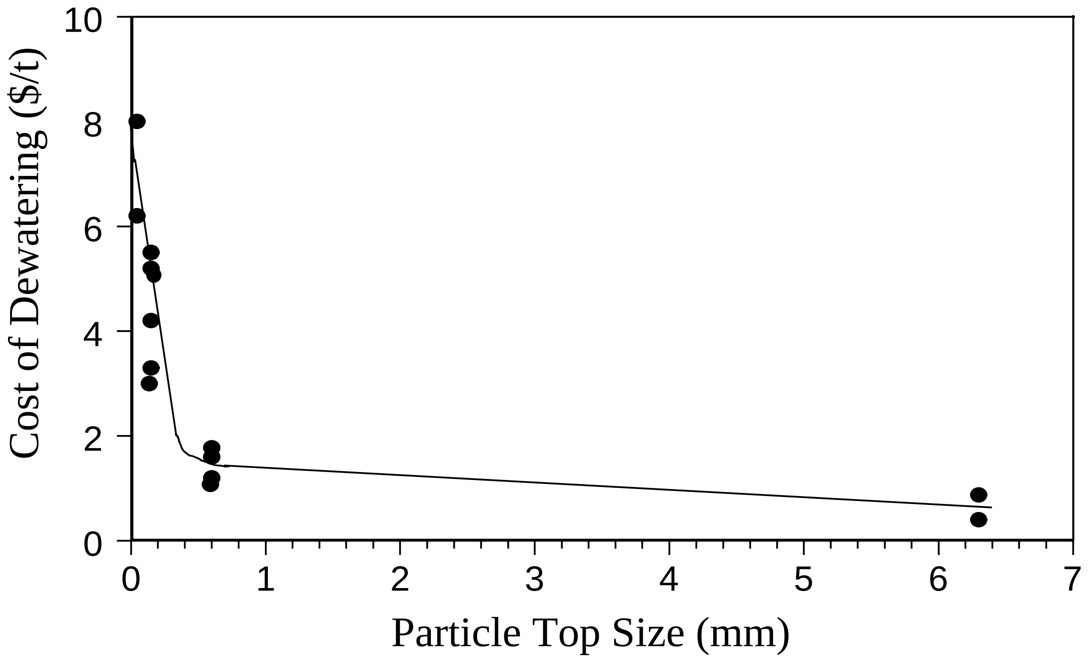

Figure 1. Effect of particle size on the cost of dewatering coal (Hucko, 1981).

shows the costs of dewatering as a function of particle size. As shown, the cost increases sharply below 0.5 mm. The cost data include those for thermal drying, which is the only practicable method of drying fine coal to below 10% moisture by weight. However, thermal drying is capital-intensive and costly. For this reason, thermal dryers are built large to take advantage of the economy of scale. It is difficult, on the other hand, to justify large capital expenditures to process a relatively small fraction of the product stream in a coal preparation plant. This is particularly the case with pond fines recovery projects, whose life spans are typically in the range of 2 to 5 years. Furthermore, it is difficult to obtain permits to install thermal dryers in many states. An alternative would be to use mechanical dewatering techniques, which are not only incapable of achieving substantial moisture reductions, but also costly when finer coal is dewatered. The availability of efficient processes that can remove moisture from fine coal will greatly benefit coal companies by improving profitability and reducing environmental risks.

1.2 PROJECT OBJECTIVES

An important objective of the Solid Fuels and Feedstocks Grand Challenge PRDA was to "*develop innovative technical approaches to ensure a continued supply of environmentally sound solid fuels for existing and future combustion systems with minimal incremental fuel cost*." Specifically, this solicitation sought to develop technologies that can (i) improve the efficiency or economics of the recovery of carbon when beneficiating fine coal from both current production and existing coal slurry impoundments and (ii) assist in the greater utilization of coal fines by improving the handling characteristics of fine coal *via* dewatering and/or reconstitution. The objective of the current project was to develop advanced fine coal dewatering processes that can greatly assist in the greater utilization of coal fines. To meet this objective, a suite of dewatering aids were developed and tested.

In Phase I, the dewatering aids were tested using bench-scale equipment. The scope of the bench-scale tests were:

i) Testing of a suite of dewatering aids on various bituminous coal fines using laboratory-scale batch dewatering devices, which included Buchner funnel filters and an air pressure filter,

ii) Testing selected dewatering aids on a variety of coal fines using pilot-scale (or bench-scale in DOE's definition) mechanical dewatering devices, which included a vacuum disc filter, a horizontal belt filter, two drum filters, and a screen bowl centrifuge,

iii) Conducting continuous tests on selected vacuum filters and screen bowl centrifuges in a mini-plant set-up, in which coal samples are floated and subsequently dewatered with and without using selected novel dewatering aids for an extended period of time,

iv) Making technical and economic evaluations on the basis of the test result obtained in the present work,

v) Developing conceptual Proof-of-Concept (POC) plant designs that will allow testing some of the advanced dewatering technologies in large scale at industrial sites.

In Phase II, the conceptual POC designs will be further refined after testing selected novel dewatering aids using a specially designed mobile test circuit. The most promising POC circuits were then installed and tested at an industrial site.

DEWATERING THEORY

2.1 RATE EQUATION

Mechanical dewatering is described as a process concerned with the flow of water through the porous media created by a bed of particles. Darcy (1856) was the first to derive the rate equation for the process as follows:

$$\frac{dV}{dt} = K\frac{A}{\eta}\frac{\Delta P}{L}, \qquad [1]$$

in which V is the volume of fluid, t the time, ΔP the pressure drop across the bed, L the bed (cake) thickness, A the cross-sectional area of the cake, η the viscosity of water, and K is the rate constant known as permeability. Eq. [1] suggests that the rate of dewatering is proportional to the pressure gradient and the cross-sectional area, and is inversely proportional to the viscosity.

The process of filtration is often related to the flow of liquid through a bundle of capillary tubes. In this case, one can use the Poiseulle's equation (1846):

$$\frac{dV}{dt} = \frac{\pi r^4}{8\eta}\frac{\Delta P}{L} \qquad [2]$$

where r is the radius of the capillary.

By combining Eqs. [1] and [2], Kozney (1927) obtain the following relationship:

$$\frac{dV}{dt} = \frac{A\varepsilon^3}{kS^2(1-\varepsilon)^2}\frac{\Delta P}{L} \qquad [3]$$

where ε is the cake porosity, which is defined as the volume fraction of the void space in the filter cake, S the specific surface area of the particles per unit volume, and k is a constant which is referred to as Kozney constant. Theoretically, k should be 2 for an ideal filter cake that is a porous medium made of capillary tubes of radius r. In experiment, k is found to be approximately 5 for filter cakes made of simple monodisperse solids (Carman, 1937). For many industrial filter cakes formed in the presence of flocculants, *k* is often greater than 5 and can be as large as several thousands (Gray, 1958).

From Eqs. [1] and [3], one can obtain the following relationship:

$$K = \frac{\varepsilon^3}{kS^2(1-\varepsilon)^2} = 1/\alpha \qquad [4]$$

where α is referred to as specific cake resistance. Eq. [4] suggests that cake permeability decreases with decreasing ε and *S*, both of which decrease with decreasing particle size. Thus, the rate equation derived based on Darcy's law (Eq. [1]) provides an explanation for the difficulty in dewatering fine coal.

Eq. [1] suggests that the flow of filtrate versus time should be linear. However, practically all filtration experiments show parabolic behavior. Figure 2 shows the results of typical batch filtration experiments. Initially, cake moisture decreases rapidly and then tapers off as drying time increases. The situation gets worse with increasing cake thickness. The main reason for the discrepancy is that the rate equation based on Darcy's law disregards distribution of pore sizes, *i.e.*, there exists a range of pore sizes (and also shapes) in a porous bed (Gray, 1958). According to the Laplace equation (the implications of which will be discussed in the following section), the water in larger pores will be more easily removed than the water in smaller pores. Thus, the larger pores should determine the initial dewatering rate, while the finer pores determine the water retention (final cake moisture).

2.2 LAPLACE EQUATION

In order to remove the water from a capillary of radius *r*, it is necessary that the applied

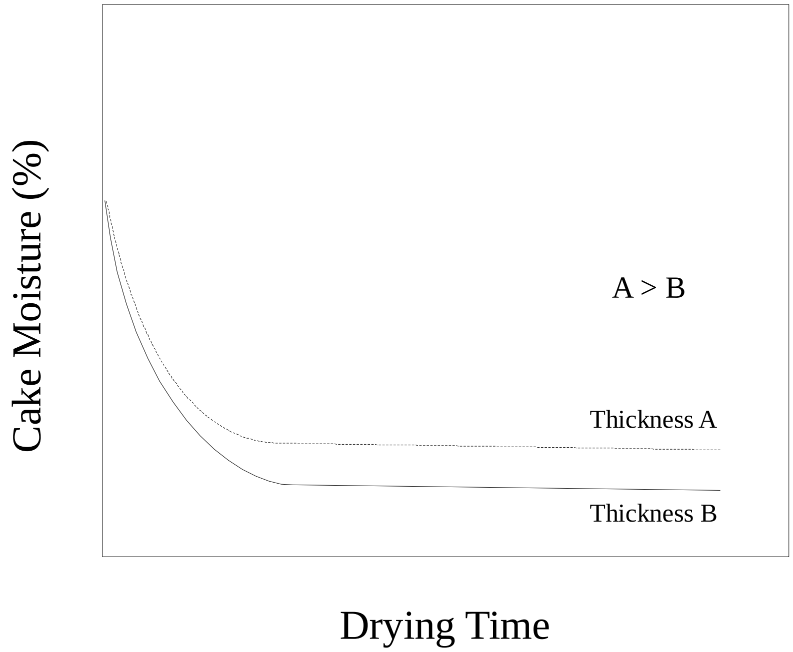

Figure 2. Effect of drying time on cake moisture for a typical filtration test.

pressure be larger than the capillary pressure, *p*:

$$p = \frac{2\gamma_{23}\cos\theta}{r} \quad , \qquad [5]$$

which is known as Laplace equation. Here, γ_{23} is the surface tension, and θ the water contact angle. One can see that *p* decreases with decreasing γ_{23}, increasing θ, and increasing *r*.

Various chemicals (dewatering aids) are added to coal slurry to control these parameters so that *p* can be reduced. One group of reagents that are most widely used is surfactants. The main purpose of using these reagents is to reduce γ_{23}. Consider a case of filtering fine coal slurry at a vacuum pressure of 22-inches Hg (0.735 atm or 0.745×10^5 Pa). Assume that θ=45^o for the coal, which is typical of many high-volatile bituminous coals mined in the U.S, and that no dewatering aids are used, i.e., γ_{23}=72 mN/m. Substituting these numbers into Eq. [5] and solving it for *r*, one obtains *r*=1.4 μm. The water in the capillaries of smaller radius will have pressures higher than the vacuum pressure and, therefore, cannot be removed. When γ_{23} is reduced to 40 mN/m by surfactant addition, however, the critical capillary radius at which water can be reduced by vacuum suction is reduced to 0.76 μm.

Thus, it is possible to reduce the final cake moisture using surfactants. However, the amount of surfactants needed to obtain γ_{23}=40 mN/m is excessive. When sodium dodecylsulfate (SDS) and dodecylammonium hydrochloride (DAH) are dissolved in distilled water, for example, approximately 6×10^{-3} M of these reagents are needed, as shown in Figure 3.

Recently, Singh (1997) compared the performance of SDS and DAH as dewatering aids

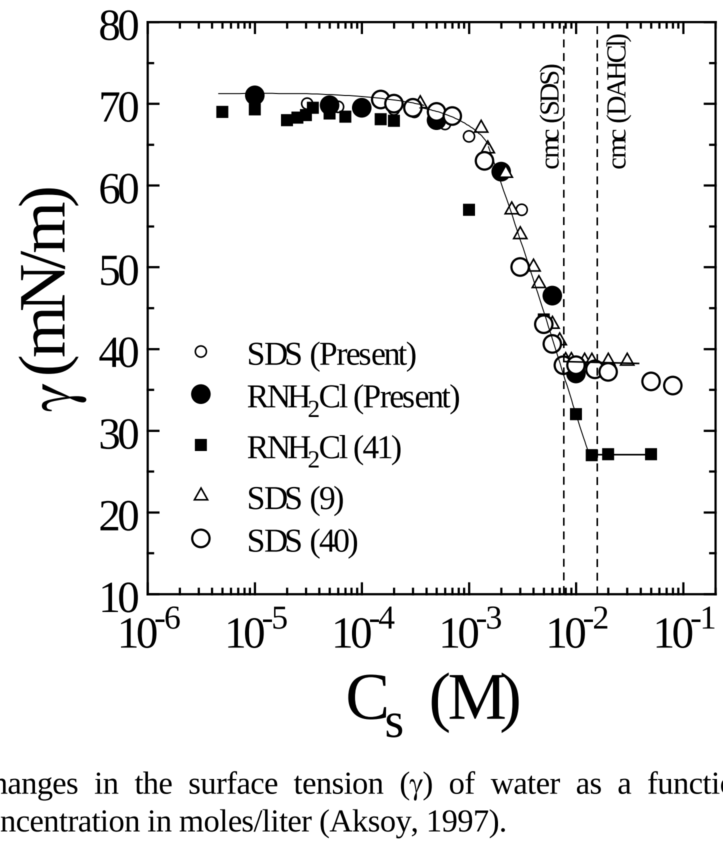

Figure 3. Changes in the surface tension (γ) of water as a function of surfactant concentration in moles/liter (Aksoy, 1997).

for fine coal. He showed that the former is more effective than the latter for the following reason. Coal particles are negatively charged in water; therefore, DAH^+ ions adsorb on the surface, resulting in a decrease in the surfactant concentration in solution and, hence, higher surface tension. The anionic surfactant, SDS, on the other hand, does not adsorb on coal and, therefore, can reduce the surface tension more effectively. Sulfosuccinate is one of the most widely used dewatering aids for coal, probably for the same reason.

It should be noted here that sulfosuccinate is also used as a wetting agent for coal in mining operation. The reason is that surfactants with high hydrophile-lipophile balance (HLB) numbers such as sulfosuccinate, SDS and DAH decreases the water contact angle of coal and increases its wettability. Figure 4a shows indeed that SDS addition decreases the contact angles of surfaces with different hydrophobicities (Aksoy, 1997). The decrease in contact angle can be attributed to the inverse orientation' of the surfactant molecules on the surface. In this mode of orientation, the non-polar hydrocarbon tails touch the hydrophobic surfaces, while the polar heads point toward the aqueous phase, thereby rendering the surface hydrophilic. Figure 4b shows a similar set of contact angle measurements conducted using DAH. With very hydrophobic surfaces, the trend is the same as with SDS in that the surfactant addition decreases contact angle. With weakly hydrophobic surfaces, however, the DAH addition increases the contact angle at low concentrations. Once the contact angle reaches 85-90^o at 10^{-5} M, however, it begins to decrease again with further addition of the cationic surfactant.

Thus, the use of high HLB surfactants can reduce the final cake moisture by virtue of lower γ. However, it can also decrease θ, which is detrimental. Virtually all of the dewatering aids used in industry today are high-HLB surfactants. In this regard, it is not surprising that many dewatering aids actually increase the cake moisture.

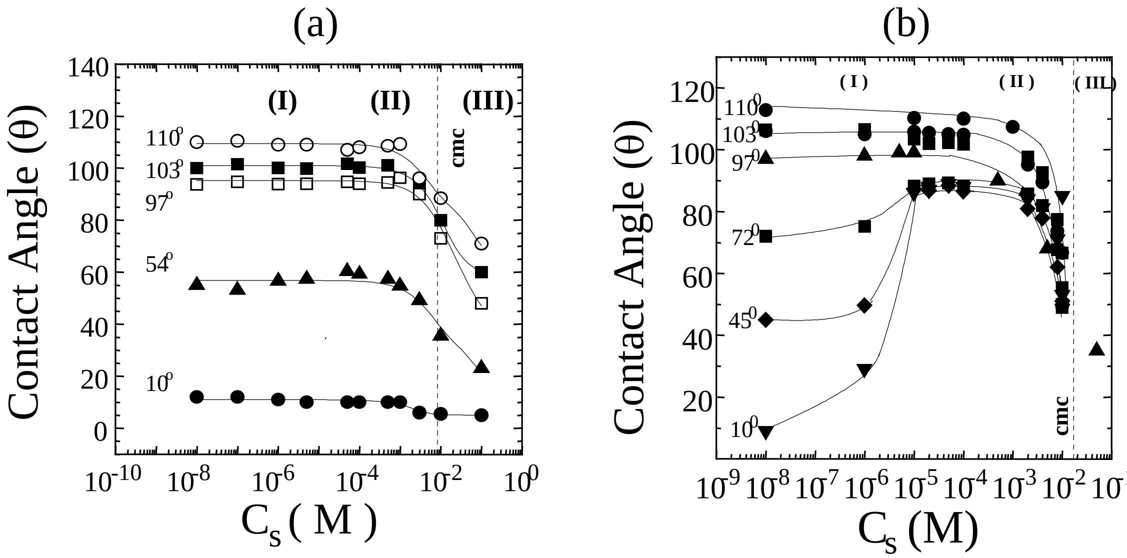

Figure 4. Contact angle on surfaces of various hydrophobicities as a function of the concentration of (a) an anionic surfactant (sodium dodecylsulfate) and (b) a cationic surfactant (dodecylaminium hydrochloride).

Various flocculants are used as dewatering aids. Some are organic, e.g., polyacrylamide, while others are inorganic, e.g., alum. The role of these reagents is to increase the effective size of the particles in the filter cake, so that the pore radius *r* can be increased. This will greatly reduce the capillary pressure *p* and, hence, increase the filtration rate. However, most of the flocculants cause θ to decrease and at the same time create micro-pores within large flocs, both of which contributing to increased final cake moisture. The work done with most coals actually showed that flocculants increase the moisture of filter cake.

TECHNICAL APPROACH

3.1 GENERAL APPROACH

The difficulty in removing water from the surface of fine particles may be attributed to the fact that water molecules are held strongly to the surface *via* hydrogen bonding. One can break the bonds and remove the water by subjecting the wet particles to intense heat, high-pressure filters, or high-G centrifuges. However, the use of such brute forces entails high energy costs, maintenance problems, and environmental concerns. A better solution would be to destabilize the surface water by appropriate surface chemical treatment, so that it can be more readily removed by the weaker forces imparted by vacuum, low-pressure filters, or low-G centrifuges.

The state of the water adhering to a surface may be best represented by the hydrophobicity (water-hating property). The stronger the hydrophobicity, the weaker the bonds between the water and the surface would become. Therefore, the key to finding appropriate chemical means to destabilize surface water is to increase the hydrophobicity of the particles to be dewatered. A more traditional measure of surface hydrophobicity is water contact angle. In the sessile drop technique, a water droplet is placed on a flat surface of the solid of interest, and the angle at the three-phase contact is measured through the water phase. In general, contact angle increases with increasing hydrophobicity of the surface.

As discussed in the foregoing section, the high-HLB surfactants that are used in industry can reduce the surface tension of water but tend to render the surface hydrophilic due to inverse orientation. Therefore, the approach taken in the present work was to use low-HLB surfactants. By virtue of its low polarity of the polar head, a low-HLB surfactant may adsorb on the surface of hydrophobic coal with its polar head in contact with the surface and its hydrocarbon tail directed toward the aqueous phase. The polar group of the low-HLB surfactant may adsorb preferentially on the polar sites of the surface *via* acid-base interactions, thereby masking the hydrophilic parts of the surface. The net results of adsorbing a low HLB surfactant on the surface of a coal would be a substantial increase in hydrophobicity, and thereby facilitate the process of dewatering. A detailed description of specific types of reagents used in the present work for fine coal dewatering is provided in Appendix I.

In addition to increasing contact angle, the use of low HLB surfactants results in surface tension lowering and increase in capillary radius. The increase in contact angle brought about by the adsorption of low HLB surfactants should increase the size of the particles to be dewatered by hydrophobic coagulation, which in turn should increase the radii of the capillaries in the filter cake. Thus, the methods of using low-HLB surfactants should meet all three of the requirements for improved dewatering, i.e., surface tension lowering, contact angle increase, and capillary radius enlargement.

The Laplace equation suggests that capillary pressure becomes negative when contact angle exceeds 90^o. Many of the low-HLB surfactants used in the present work can indeed increase the contact angle above this value. However, a closer examination of the Laplace equation (Eq. [5]) reveals that a relatively modest increase in contact angle above the levels that are usually attained during the process of mining and flotation can bring about a substantial decrease in capillary pressure and, hence, a reduction in cake moisture. For example, an incremental increase in contact angle from 60 to 85^o should decrease the capillary pressure by 5.7 times. In comparison, an increase in contact angle from 0 to 60^o results in a decrease in capillary pressure by only one half. Thus, a method of increasing contact angle incrementally should serve as an efficient means of improving dewatering. Many eastern U.S. coals have their contact angles in the range of 45-60^o. The low-HLB surfactants used in the present investigation are designed to adsorb on moderately hydrophobic surfaces and further increase their water contact angles close to or above 90^o. They do not adsorb on hydrophilic surfaces. When a coal sample loses its hydrophobicity due to superficial oxidation, it is, therefore, necessary to pulverize the sample to regenerate fresh unoxidized surfaces.

Another chemical approach taken in the present work was to increase the capillary radius by coagulating the particles to be dewatered. In the present work, divalent and trivalent cations were used as coagulants. These ions adsorb on the coal surfaces that are usually negatively charged and, thereby, reduce the repulsive forces between particles and allow them to coagulate. Effective utilization of inorganic electrolyte should reduce the amount of the low HLB surfactants required for achieving a given cake moisture.

According to the Laplace equation, it is necessary to reduce the surface tension of water to decrease the capillary pressure. Various high-HLB surfactants are used to reduce the surface tension. Typically, these reagents are added to feed streams. However, much of the reagents are wasted in that bulk of the water is removed readily with or without the surfactants. What is difficult to remove is the water in fine capillaries, and its removal requires a long drying time. An approach taken in the present work was, therefore, to spray a relatively small amount of surface tension lowering reagent(s) at the beginning of a drying cycle time. Also, reagents used for this purpose are typically less expensive than high HLB surfactants.

Since low-HLB surfactants can increase the rate of dewatering substantially, the kinetics can improve by more than an order of magnitude. An increase in dewatering rate invariably results in a substantial increase in cake thickness when using vacuum disc filters, which are the most widely used filters in the coal industry. An increase in cake thickness should increase throughput. However, a thicker cake requires a longer drying cycle time to achieve a desired cake moisture. Thus, if one wishes to increase the drying cycle time, then he should run the filter at a lower rotation speed, which will further increase the cake thickness and exacerbate the problem.

In the present work, the difficulty described above was addressed by implementing two different modifications. One was to shorten the pick-up time by modification of the vacuum valve, and the other was to install a dual vacuum system. It was found that the latter was a better solution. In this method, a specially designed control valve was installed so that vacuum pressures for the pick-up (cake formation) and drying cycles could be controlled separately. These modifications were made in cooperation with Peterson Filter Company, who supplied the 24-inch diameter pilot-scale disc filter.

Another method of handling fast dewatering materials would be to use horizontal belt filters (HBF). Since it is a top-feeding device, cake thickness can be controlled by control of feed rate. Also, drying cycle times can be controlled by control of belt speeds. Therefore, HBF is an ideal dewatering device to be used in conjunction with the low-HLB surfactants. For this reason, a pilot-scale HBF has been designed and constructed in the present work.

In essence, the role of the novel dewatering aids tested in the present work is to destabilize the water molecules adhering on the surface of coal. The increase in contact angle and all of the benefits of using them for dewatering is its consequence. Thus, one may consider that surface water is ‘liberated’ by the adsorption of the low-HLB surfactants. However, the process of transporting the liberated water through a filter cake is a slow process. In the present work, methods of increasing the rate of the transport process were developed. These include application of ultrasonic and mechanical vibration of the filter cake.

3.2 PROJECT TASKS

3.2.1 Phase I – Concept Development

Task 1 – Phase I Planning and Reporting

To assist in the coordination of project activities, a detailed Project Management Plan was prepared and submitted to DOE's Contracting Officer's Representative (COR). The work plan included a description of all project activities and detailed the assignment of project responsibilities for each participant. All technical progress reports required by DOE per the Reporting Requirements Checklist were also prepared and submitted to DOE in a timely fashion by the project investigators. The Office of Sponsored Programs (OSP) at Virginia Tech prepared and certified all of the financial and property reports for the project.

Task 2 - Sample Acquisition

This task involved the selection, acquisition and shipping of coal samples (both solid and slurry) from industrial sites to the testing facilities at Virginia Tech. Although the investigators at Virginia Tech coordinated this activity, the industrial participants were largely responsible for most of the work related to the on-site sampling campaigns. For each sample, pertinent information was documented including geographic location, mine site name, sample description and gross sample weight. A limited number of standard analyses (e.g., particle size analysis, density partition analysis, flotation release analysis, etc.) were performed on selected samples to provide baseline data related to a particular sample.

Table 1 provides an overview of selected samples used in the bench-scale dewatering tests. In general, four different types of coal samples were used. The first was feed streams to industrial dewatering equipment such as vacuum disc filters and screen-bowl centrifuges. The

Table 1. Selected coal samples evaluated in the laboratory dewatering test program.

Company	Mine Name	Geographic Location	Coal Seam	Sample Description	Sample Weight
Massey Coal Services	Goals Coal Co.Inc	Sundial W V	Rum Creek	Froth Product, Screen Bowl Feed (-28#)	2x5 gal pails
Massey Coal Services	Goals Coal Co.Inc	Sundial W V	Rum Creek	DMC Product	2x5 gal pails
Massey Coal Services	Marfork Coal Co.Inc	Whitesville, W V	Eagleton	Svedaula Pressure Filter Feed (-325 #)	1x5gal pail
Massey Coal Services	Elk Run Coal Co.Inc	Whitesville, W V	Coalburg	Flotation Feed	1x5gal pail
Red River Coal	Red River Mine	Norton,VA	Dorchester	DMC Product	2x55gal drums
Red River Coal	Red River Mine	Norton,VA	Taggart	DMC Product	2x55gal drums
Red River Coal	Red River Mine	Norton,VA	Dorchester	WOC Product (-100 #)	6 x 55 gal drums
Red River Coal	Red River Mine	Norton,VA	Dorchester	WOC Product (-60 #)	8 x 55gal drums
Pittston	Moss 3	Dante,VA	Upper Banner	DMC Product (-2 inch)	2 x 55 gal drums
Pittston	Middle Fork Reclamation	Dante,VA	Mixed Refuse	Column Product (-28 #)	2x5 gal pails
Pittston	Meadow River	VA	Swell, Pocahontas	Sized Coal	2x5 gal pails
Coastal	Toms Creek	VA	Jawbone, Kelly	Column Product (-100 #)	2x5 gal pails
Consol	Bailey	Graysville,PA	Pittsburgh	DMC Product (-2 inch)	2 x 55gal drums
Consol	Bailey	Graysville,PA	Pittsburgh	DMC Product (-2 inch)	2 x 55gal drums
Consol	Bailey	Graysville,PA	Pittsburgh	Filter Feed (-28 #)	4 x 55gal drums
Elkview Coal Ltd	Elkview Mine	Sparwood, BC	No. 10	DMC Product	
Elkview Coal Ltd	Elkview Mine	Sparwood, BC	No. 10	WOC & Flotation Product (-28 #)	2 x 55 gal drums

samples were usually received in 55-gallon drums. When they arrived in the Plantation Road Pilot Plant facility, they were transferred to a holding tank and agitated by means of a mixer for homogenization. Representative samples were taken and used for dewatering tests. For laboratory-scale batch dewatering tests, the samples were received in 5-gallon buckets. They were homogenized by agitating the slurry by means of a dynamic mixer. While they were being agitated, a volume of the slurry was scooped out of the 5-gallon bucket in a dipper of known volume and used for dewatering tests.

It was found that the performance of the novel dewatering aids tested in the present work deteriorates with time. In general, the performance becomes seriously deteriorated in two weeks since the time a sample was taken from an operating preparation plant. This was attributed to the superficial oxidation of the surface of the coal particles. To overcome this problem, some of the samples were wet ground in a ball mill for just a few minutes to regenerate a fresh unoxidized surface. In most cases, grinding for a short period restored the performance of the novel dewatering aids. When a coal sample was ball mill ground, the pulverized coal was subjected to a flotation using a Denver D-12 laboratory flotation machine. This was done to ensure that the sample to be used for dewatering tests would have the same chemistry as the normal flotation products. The flotation was carried out using kerosene as collector and MIBC as frother. Thus, the coal samples pulverized for a short period and floated represent the second type of samples used in the present work.

The third type of coal samples were cyclone overflows from an operating coal preparation plants that have been floated to remove the ash-forming minerals. Again, the flotation step was necessary to ensure that the samples used for dewatering tests are similar to those produced in industry. Finally, the fourth type of coal sample used in the present work was obtained as dense-medium cyclone (DMC) products. Because of their large particle size, these products could be stored for an extended period with minimal oxidation. They were pulverized in a hammer mill as needed, and then subsequently wet ground in a ball mill to produce fine coal samples with fresh unoxidized surface. In most cases, the ball mill product was subjected to flotation using kerosene and MIBC to ensure that the surface chemistry of the fine coal samples thus prepared were the same as that produced by flotation in an operating plant.

Task 3 – Bench-Scale Tests

This task involved the laboratory testing and evaluation of a variety of innovative reagents developed at Virginia Tech for fine coal dewatering. The work was required in order to (i) identify the best possible reagents and combinations thereof for different coal samples and (ii) identify the conditions under which a given dewatering aid can give the best performance. The tests were carried out using bench-scale dewatering equipment, which included laboratory vacuum and pressure filters. Reagents examined in these tests included both natural and synthetic reagents. Several proprietary reagents were also developed and evaluated as part of this effort. In addition, the use of byproduct solvents and reagent blends were also tested to reduce the cost and improve the efficiency of dewatering fine-size coal.

Figure 5 shows the apparatus used for the Buchner funnel filtration tests. Most of the tests were conducted using 2.5-inch diameter funnels with medium porosity glass frit. Buchner funnel tests have advantages over the standard filter leaf tests in that cake thickness is determined by the amount of a coal sample used in each experiment. A Buchner funnel was mounted on a vacuum flask, which in turn was connected to a larger vacuum flask to stabilize the vacuum pressure. A known volume of slurry was poured into the funnel before opening the valve between the two flasks to subject the slurry to a vacuum pressure. To prepare the slurry for testing, the desired amount of a dewatering aid (or a mixtures thereof) was added to the slurry by means of a Microliter syringe. The mixture was then conditioned using a mechanical shaker for a given period time to allow for the reagent to adsorb on the surface of the coal particles to be dewatered. Filtration was commenced when a vacuum was applied to the slurry. The time for the bulk of the

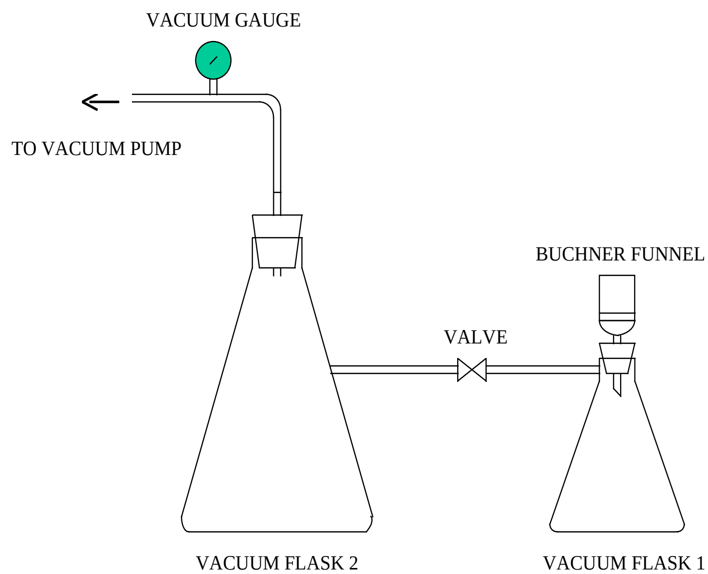

Figure 5. Experimental setup for the Buchner vacuum filtration tests.

water to pass through the filtering medium is referred to as cake formation time. After the cake formation, the vacuum pressure was kept on for a desired period of time to remove the residual water trapped in the capillaries formed between the particles in the cake. After this period, which is referred to as drying cycle time, part of the filter cake was removed, weighed, and dried for overnight in a convention oven. The coal sample was weighed again after the drying, and the moisture content was calculated from the difference between the dry and wet weights. In each experiment, the cake thickness, vacuum pressure, and cake formation time were recorded. The cake thickness was determined by the volume and diameter of the Buchner filter. Some of the tests were also conducted using Buchner funnels with coarse fabric filters (which were provided by EIMCO). It was found that there were not much difference between the funnels with glass frit or fabric medium in terms of final cake moisture or dewatering rate, as the resistance from the medium were small as compared to the resistance from filter cake.

Figure 6. Photograph of the 3.5-inch diameter pressure filter.

Several of the laboratory tests were also conducted using a pressure filter that was specifically designed and constructed for use in the present work. The unit was made of a Plexiglas cylinder with dimensions of 2.5 inches in diameter and 8 inches in height. As shown in Figure 6, the bottom of the pressure filter was made of perforated Plexiglas frit, on which a fabric filter medium was placed. The top of the filter was covered with a Plexiglas lid. Compressed air was injected to the top portion of the pressure filter, so that the slurry introduced to the chamber was subjected to a desired pressure. The pressure was varied in the range of 100 to 400 kPa.

Task 4 - Pilot-Scale Testing

The most promising dewatering aids identified in the bench-scale test work were further evaluated using a mini-plant processing circuit. As shown in Figure 7, the mini-plant included three different types of continuous pilot-scale dewatering units, i.e., drum filter, horizontal belt filter and disc filter. The drum filter used in the present work incorporated three novel features, i.e., mechanical vibration, reagent sprayer and steam addition. All of these filtration tests were carried out in conjunction with the bench-scale tests (Task 3) to identify reagent types, reagent dosages and carrier solvents that were most effective for moisture removal. The filtration equipment used in the project work program consisted of pilot-scale units that were purchased commercially or fabricated in-house. The various pilot-scale filtration equipment used in the mini-plant tests included (i) a 6-inch diameter Westec vacuum drum filter, (ii) a 10-inch diameter Sepor vacuum drum filter, (iii) a 24-nch diameter Peterson vacuum disc filter, and (iv) a 6-inch x

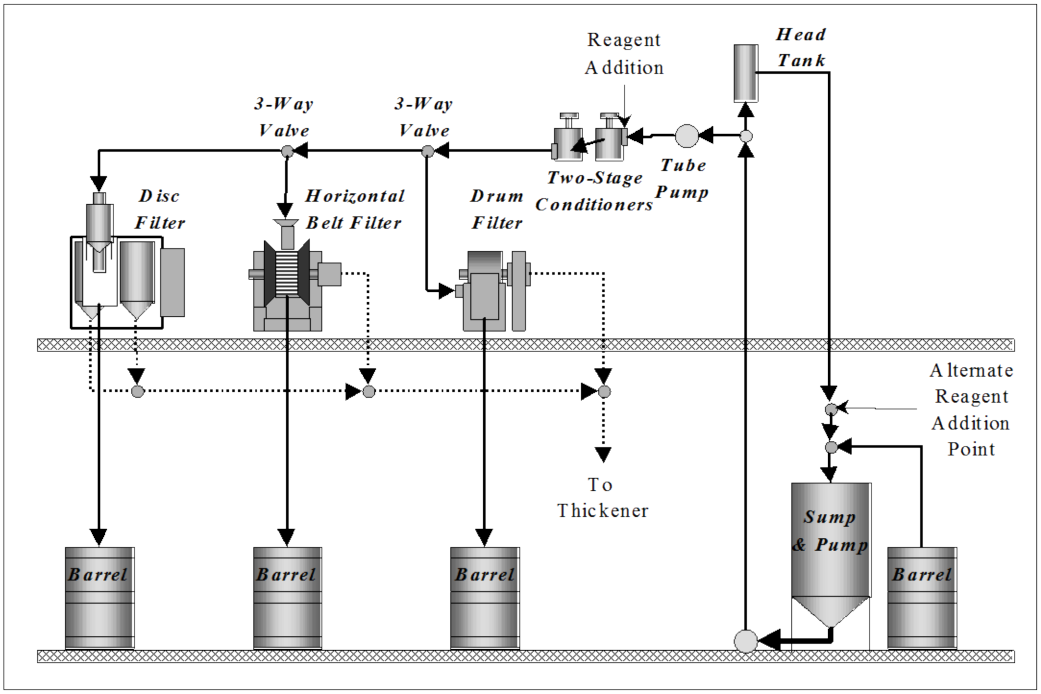

Figure 7. Schematic of the test circuit used in the evaluation of the various filtration technologies.

6-ft homemade horizontal belt filter (HBF).

Initially, a 7-inch diameter Westec drum filter was used for dewatering tests. The equipment had been purchased prior to this project; therefore, it was necessary to refurbish the equipment by sending it to Westec in Salt Lake Utah. However, the equipment continued to have problems in two aspects. First, waster was entrained with the compressed air during the air blow cycle. Second, the rake mixer was not strong enough to suspend coarse particles. As a result of the inadequate mixing, the filter cake formed on the drum surface was uneven. It was, therefore, decided to purchase a new 10-inch diameter drum filter from Sepor, which is shown in Figure 8. The filter has 1 ft^2 filter area and overall dimensions of 50 x 48 x 44 inches.

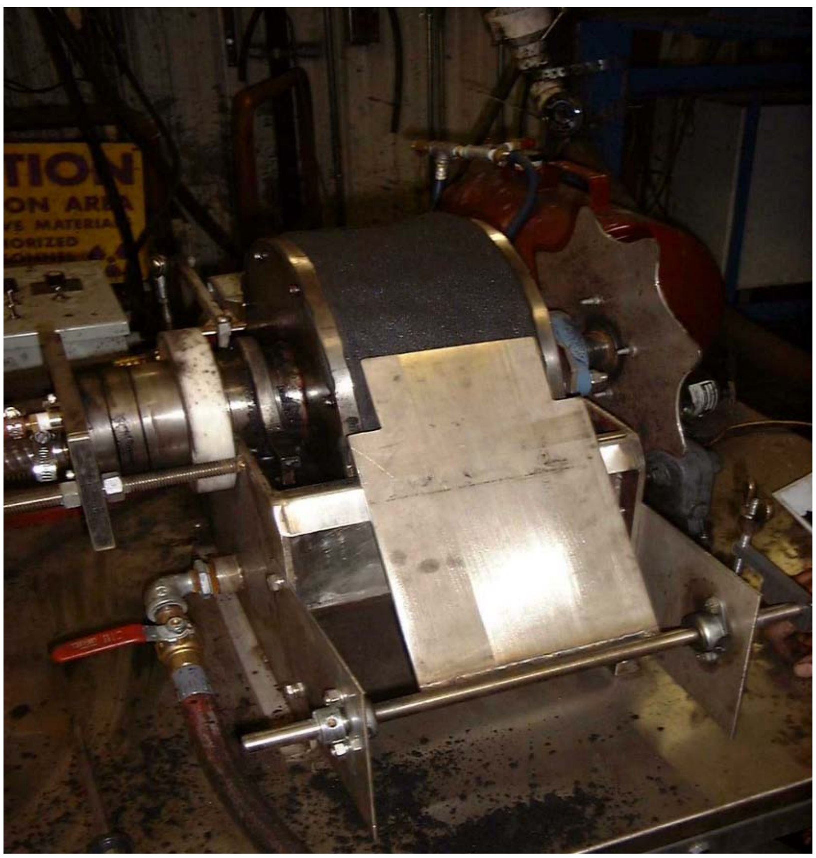

Figure 8. Photograph of the Sepor drum filter.

Figure 9. Photograph of the Peterson disc filter.

The pilot-scale disc filter was purchased from Peterson Filter Company, Salt Lake City, Utah (see Figure 9). The disc vacuum filter consisted of a disc mounted on a horizontal shaft. The disk had interchangeable elements that could be changed for fitting and removing filter cloths. The disc rotates through a partitioned tank into which the feed suspension was fed. The tank was also equipped with two agitators to keep particles in suspension and to provide even cake formation. Vacuum was applied through the core of the shaft and into the various filter sectors. The submerged sector of the disc collects the cake and then removes it by blow-back air cake discharge system utilized in conjunction with a scraper just before re-entering to the tank.

The pilot-scale disc filter was designed with a 2 ft diameter disc with 10 removable sectors. This configuration provided 0.2 - 2.0 ft^2 of adjustable filter area by varying number of filter sectors used. The filter was also supplied with a “Syncro-Blast” air cake discharge system for efficient cake removal. The supplied vacuum pump provided up to 29 inches Hg vacuum pressure at 2.5 cfm of air flow. The disc speed was variable and capable of providing 0.5 - 12 minutes per revolution.

Although the as-built vacuum filter worked well, it should be noted that the use of the dewatering aids tested in the present work can increase the rate of dewatering by orders of magnitude. In many cases, the increased thickness tended to increase the product moisture content. Attempts to produce a thinner cake by increasing the disc speed was unable to overcome this problem since it also shortened the drying cycle time. Therefore, to overcome this problem, the filter was equipped with a dual vacuum system that split the vacuum manifold into two separate lines (see Figure 10). One line was directed to the submerged sectors, while the other

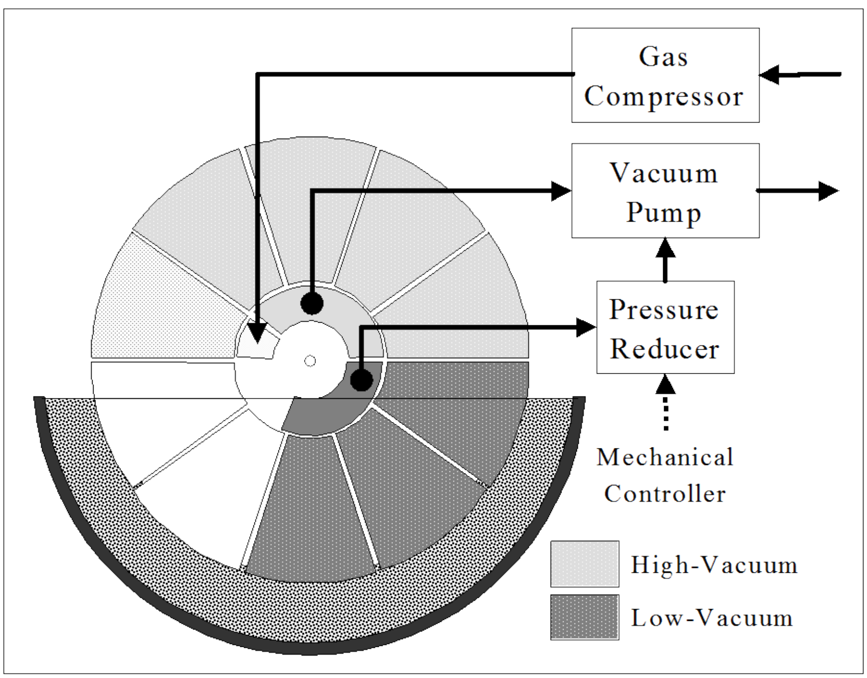

Figure 10. Operating principle of the dual vacuum system.

was directed to the sectors open to the atmosphere. The line directed to the submerged section was equipped with a pressure reducer to lower the vacuum pressure applied to the submerged section. This made it possible to reduce the pressure and cake thickness while maintaining a high vacuum during the drying cycle.

A homemade horizontal belt filter (HBF) was also used in this project (see Figure 11). HBFs are gaining popularity in the Australian coal industry. This equipment is designed to feed coal slurry on top of a moving vacuum belt. The thickness of a filter cake is determined by the rate at which the coal slurry is fed on to the belt, and the drying time is controlled by the belt speed. The fact that the cake thickness and drying time can be controlled independently is a distinct advantage of HBF over disc filters. An additional advantage of HBF is that it does not have the problem of picking up coarse particles, as it is a top-feeding device.

EnviroClear initially designed, constructed and delivered a pilot-scale HBF for use in this project. The unit, which provided an effective vacuum area of 2 ft^2, had overall dimensions of 4-

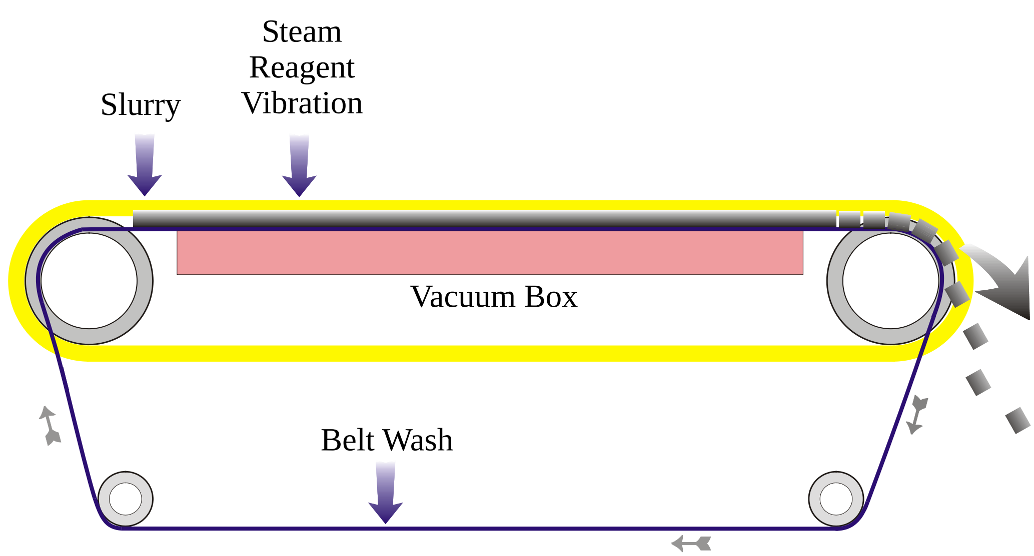

Figure 11. Schematic representation of a horizontal belt filter (HBF) with provisions for applying steam injection, reagent spray and mechanical vibration.

inch width and 6-ft length. During the commissioning of the equipment, it became obvious that the unit was under designed and suffered from poor workmanship. There was insufficient sealing between the vacuum chamber and the belt, and the vacuum pump was under sized. As a result, the unit could not hold a vacuum pressure of more than 5-inch Hg. EnviroClear made two visits and made several modifications; however, the supplier was unable to commission the HBF to specification, which stipulated a minimum of 15-inches Hg vacuum pressure. The company insisted that all of the problems can be overcome in time, but the PIs decided that no further delays could be tolerated. Therefore, the unit was returned at no cost to Virginia Tech.

A different type of HBF was obtained from Pannevis, Holland, on a trial basis. The unit operated with a moveable vacuum cartridge with a quick return mechanism (indexing system). Since the vacuum chamber moved along with filter cloth, reasonable vacuum pressures of up to 15-inch Hg were obtained. However, the quick return mechanism caused the filter cake to crack severely with an attendant loss of vacuum. Several methods of minimizing and sealing the cracks were tested but to no avail. It became clear that this unit could not meet the requirements of the test program, and it was returned. It was then decided to design and build a pilot scale filter at Virginia Tech. The filter was designed and built by VT staff. A photograph of the unit is shown in Figure 12. Considerable attention was given to the design of rubber belt and effective water seals between the vacuum chamber and belt. In addition, a robust vacuum system was provided to compensate possible leaks. The 6 ft long filter provided 1.5 ft^2 (4 inch x 6 ft) of filter area. The filter cloth was 8-1/4 inch wide and 19 ft long polyester cloth with 22 μm openings.

Task 5 – Sample Analysis

Several routine sample analyses were required to complete this project. Two primary

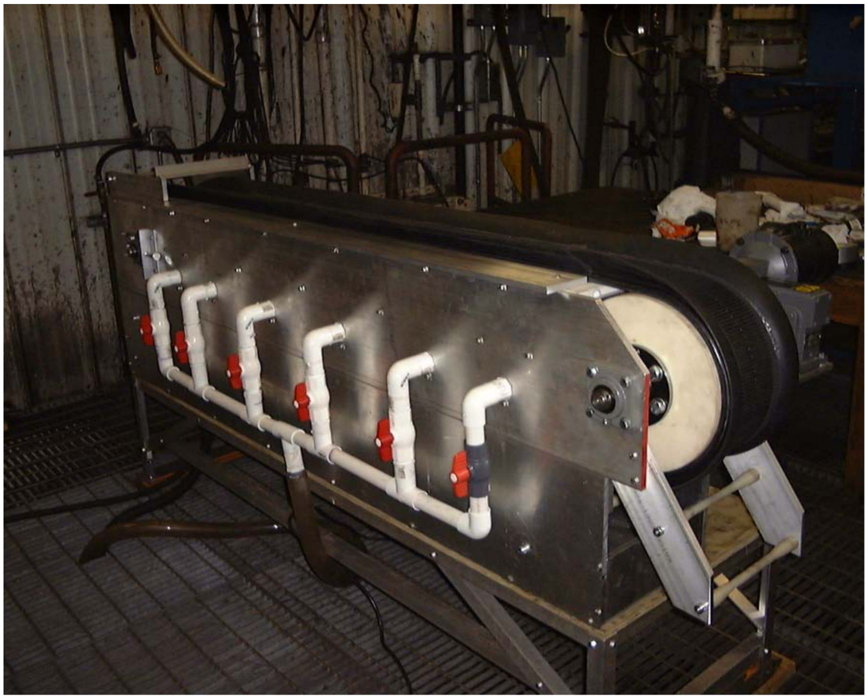

Figure 12. Photograph of the horizontal belt filter (HBF)constructed at Virginia Tech.

types of analyses were conducted, i.e., moisture analysis (for dewatered products) and proximate analysis (for dry samples). The thermal method was used to determine the moisture content of most of the products generated during the course of this work. In this approach, moisture content was calculated from the percentage loss in weight of coal sample when heated to a temperature above the boiling point of water. In the present work, the total moisture was determined by drying representative samples of the dewatered products to constant weight at 105^{o}C. An original sample mass of no less than 100 gms was generally employed in these analyses. Details related to this procedure have been described in the technical literature (ASTM D3173 - Test Method for Moisture in the Analysis Sample of Coal and Coke; ASTM D3302 - Test Method for Total Moisture in Coal; ISO 33-1-1975 - Determination of Moisture in the Analysis Sample).

The proximate analysis (ASTM D3172 - Practice for Proximate Analysis of Coal and

Coke) was performed to determine the distribution of products present in each sample after heating under a set of standard conditions. This method of coal analysis typically includes the determination of moisture content, volatile matter content, ash content and fixed carbon content (by difference). The ash content of the samples was generally of greatest interest in this project. Ash is defined as the noncombustible residue derived from the mineral matter during complete incineration of coal. Ash content was determined in the present work form the percentage weight remaining of 1 gram of slowly heated coal after complete combustion (indicated by constant weight) in a well-ventilated muffle furnace at 750oC. Details associated with this procedure are described elsewhere (ASTM D3174 - Test Method for Ash in the Analysis Sample of Coal and Coke from Coal).

Samples collected during the bench-scale and pilot-plant tests were obtained using standard sampling techniques. During these tests, the flow rates of solids and slurries were directly measured by collecting timed samples under steady state conditions. The mass and liquid flow rate of any product that was not directly measured was calculated from sample assays using the two-product formula.

Task 6 – Process Evaluation

The raw test data obtained from the sample analyses was compiled and evaluated to determine the individual and combined capabilities of the various dewatering technologies tested in the preceding tasks. Data from all ancillary operations (e.g., pumps, screens, classifiers, etc.) will also be examined to ensure that technical problems do not arise during the circuit development and system integration. Criteria used in evaluating the various dewatering technologies will include final moisture content, dewatering rate, and effluent clarity (as deemed appropriate). Information obtained from these analyses will be used to establish the overall potential of the proposed dewatering strategies.

A preliminary economic feasibility study was also conducted to evaluate the overall commercialization potential of the dewatering technology. Items addressed in the study included (i) a summary of total capital costs for the full-scale commercial installation of the proposed technologies and any required ancillary operations, (ii) a listing of expected operation and maintenance costs including electrical power, reagents, and other consumables, and (iii) a preliminary cost-benefit analysis that specifies the expected pay-back period of the capital investments.

Task 7 - Conceptual POC Design

This task involved the conceptual design of the dewatering equipment successfully developed in Phase I. Elements of work completed in this effort included (i) development of scale-up criteria that may be used in projecting the appropriate equipment sizes needed in the POC test program, (ii) preparation of scale drawings of equipment designs that are conceptually capable of meeting the project goals for dewatering in terms of moisture removal and throughput capacity, (iii) preparation of a list of a required standard parts and specialty components required to successfully fabricate, construct and manufacture the proposed dewatering technologies, and (iv) preparation of a list of anticipated operational requirements for each unit operation (i.e., power requirements, air/water requirements, reagent dosages, operating limitations, etc.).

Conceptual flow diagrams were also developed for the POC circuits that incorporate the technologies developed in Phase I. Work elements carried out under this task included (i) identification of the most appropriate circuit configurations, processing strategies and unit operations for each POC test site, (ii) preliminary calculations of mass and liquid flow rates based on data obtained from the bench-scale test work, (iii) preparation of a preliminary listing of required ancillary equipment including equipment type, unit size, throughput capacity, power requirements, air/water requirements, and operating limitations, and (iv) construction of a process flowsheet that summarizes the general arrangement of the unit operations, connecting streams, and projected material balances as well as flow rates, solids contents, mean particle sizes, assays, etc., for all streams.

Task 8 - Phase I Close-Out

After completing Tasks 1-7, a Draft Final Report was prepared according to the contract reporting requirements. The report included a summary of all major experimental data, engineering analyses, computations, test results, major findings, technical deficiencies and recommendations for further work. In addition, the draft report provided an overall evaluation of the project successes and failures with respect to the specific project goals.

3.2.2 Phase II – Concept Demonstration

Task 9 – Planning and Management

Prior to initiation of the Phase II work, a Project Management Plan was prepared and submitted to the DOE's Contracting Officer's Representative (COR). The plan consisted of a work breakdown structure, detailed project schedule, and a narrative description of the test plan, experimental procedures, analytical methods used in the project. The plan also included documentation required for NEPA approval of the Phase II work.

Task 10 – Reagent Procurement/Blending

This task involved the procurement, manufacture and blending of dewatering reagents required to complete the Phase II testing. A list of candidate reagents was supplied by Mineral and Coal Technologies based on criteria such as cost and availability. The general characteristics of the reagents are provided in Table 2. The reagents were typically purchased in bulk quantities and blended in various combinations. The optimum blend for a specific site was formulated in advance using data collected from batch filtration tests.

Table 2. Listing of candidate dewatering reagents.

Code	Description
U	Good Performance, Moderate Supply Cost
W	Best Overall Reagent, Highest Supply Cost
A	Effectiveness is Coal Specific, Low Supply Cost
R	Lowest Supply Cost, Influenced by Clay Content and Oxidation
G	Low-Cost Natural Product, Influenced by Clay Content and Oxidation
E	Synthetic Polymer Product, Influenced by Clay Content and Oxidation

Task 11 – Field Testing

In this task, bench-scale and mini-plant dewatering tests were continued as necessary to provide critical performance data and scale-up information for the design, construction, operation and evaluation of the POC plant. The work included additional follow-up testing of coal samples and reagents used in Phase I as well as new coal samples and reagents identified as promising candidates during the course of completing the Phase II work. In most cases, these follow-up tests were conducted as a function of reagent type and dosage for each coal feed. These tests were essential to identify and resolve any unexpected problems that may occur during the POC testing of the novel dewatering aids.

The laboratory scale dewatering tests were conducted using both a 2.5 inch diameter Buchner funnel and 2.5 inch diameter pressure filter. The Buchner funnel was used in the bulk of the tests and was fitted with various sizes of filter cloth depending on the samples treated (see Figure 13). The Buchner funnel was mounted on a vacuum flask, which in turn was connected to a larger vacuum flask to protect the pump itself and stabilize the vacuum pressure. Before initiating the filtration, first, a known volume of coal slurry was transferred to container, to which a known amount of a dewatering aid (or a mixtures thereof) was added by means of a microliter syringe. The coal slurry then subjected to mixing with a three-blade propeller type conditioner for a given time to ensure that proper chemical dispersion and adsorption were achieved. After conditioning, the slurry sample was poured into the funnel before opening the vacuum valve. Filtration started when a vacuum was applied to the slurry. After the cake formation, the vacuum pressure was kept on for a desired length of time to remove the remaining water trapped in the capillaries. This period is called the dry cycle time. The amount of volume added to the Buchner funnel was determined the cake thickness. After the pump was stopped a

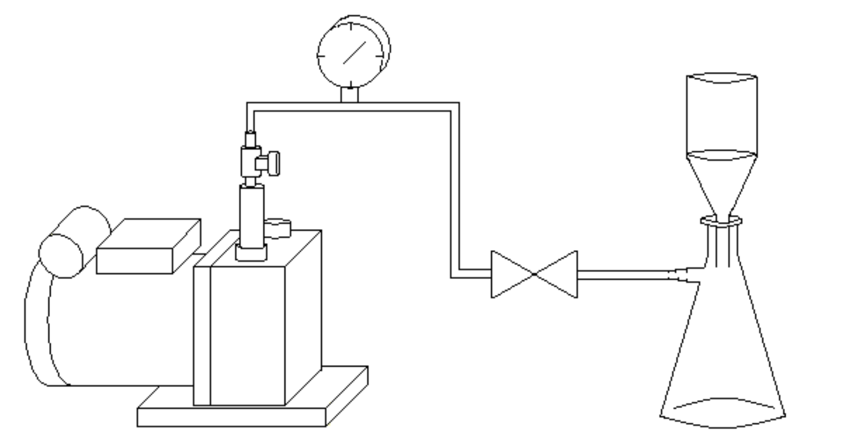

Figure 13. Experimental setup for laboratory vacuum filtration tests.

representative sample was removed from the cake and dried for a give time. The filter cake was weighed before and after drying; and moisture content was determined from the dry-wet weight differences. In each experiment, the cake thickness, set up and actual vacuum pressure and cake formation time were recorded.

A limited number of tests were also conducted using a stainless steel pressure filter with dimensions of 2.5 inches in diameter and 8 inches in height. Both the top and the bottom of the filter are covered with stainless steel lids. The filter cloth is placed on the bottom lid where filter cake is formed which is also the discharge spot. Compressed air is introduced from the upper side of the chamber and adjusted to a desired level.

Task 12 – Mobile Unit Testing

Prior to initiating the final engineering and construction of the POC circuits, additional field data was collected at various field locations that were candidate sites for installing the proposed POC circuitry. To accommodate this effort, a mobile test unit was designed and constructed. A conceptual drawing of the mobile unit is provided in Figure 14. The unit included three primary unit operations, i.e., advanced flotation column, multi-stage conditioning tanks and enhanced disc filter, as well as all ancillary components required for continuous operation. Each processing unit, such as the column cell, was fabricated so that it can be disassembled, stored on the trailer, and easily relocated to a new industrial site. Only a limited amount of on-site work will be required to make the circuit operational once hook-ups for feed slurry, electrical power and clarified water were provided.

It is important to note that the test data collected in Phase I indicated that the advanced flotation cell, novel dewatering reagents, conditioning tanks, and enhanced filtration system were

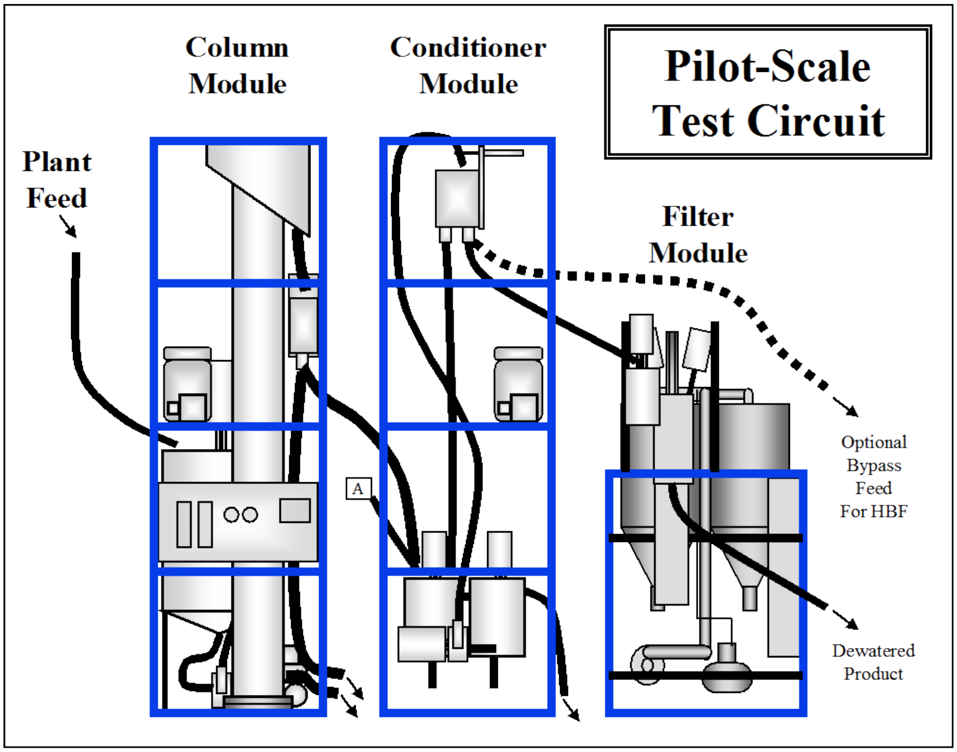

Figure 14. Schematic of the pilot-scale test modules.

all required to maximize the removal of moisture. The advanced flotation cell (column) was required to reject ultrafine hydrophilic clay that adversely impacts the effectiveness of some of the proposed dewatering chemicals. Proper conditioning of the dewatering reagents with the coal slurry was also important since the dewatering reagents are not water-soluble. Data collected in Phase I indicate that conditioning times in excess of 4-5 minutes may be required for some reagents and coal types. The enhanced disc filter, which incorporates the dual vacuum system developed in Phase I, was also required to prevent the formation of excessively thick cakes (>1 inch) when dewatering reagents are added. The disc filter was configured so that it may be interchanged with the horizontal belt filter or drum filter tested in Phase I if so that longer drying times may be evaluated. The mobile circuit was also been designed with sufficient flexibility so that a continuous pressure filter supplied by Svedula can also be evaluated as part of the Phase II effort. This capability was included since batch tests conducted in Phase I suggested that pressure filters outperform vacuum-type machines in the removal of moisture.

The mobile test unit was operated at each of the proposed test sites in order to evaluate the potential of the proposed dewatering technologies under actual field conditions. The test work will included full-circuit tests (which include advanced flotation) at several industrial sites as discussed later within this report. In each test, sized feed slurry from the existing preparation and/or pond reclaim facilities were directed into the circuit feed sump by means of flexible piping. The slurry will then be fed at a constant rate into a 12-inch diameter column by means of a peristaltic pump. The clean coal froth flowed by gravity into a multi-stage conditioner, while the column reject slurry flowed by gravity to a refuse sump. After adding appropriate dewatering reagents, the conditioned slurry was pumped at a constant rate into the filter test rig. The filter cake was discharged onto the ground and intermittently transferred to the clean coal storage pile, while the filter effluent was pumped to the reject sump. In addition, any excess feed to the column feed sump or conditioner tanks was allowed to overflow to the reject sump. All streams entering the reject sump were pumped to the existing plant thickener for disposal.

The pilot scale filtration equipment used in tests consisted of two types of filter units, i.e., a 24-inch diameter Peterson vacuum disc filter and a 12-inch wide x 7 ft long Westech Horizontal Belt Filter. The mobile test unit also incorporated a pilot-scale flotation column and filter feed conditioner module. The schematic diagram of the Column Module, shown in Figure 15, consists of a 30-cm diameter by 3-m tall flotation column. The column was equipped with the Microcel sparging system that circulates a portion of the slurry from the bottom of the column through an in-line static mixer. During testing, up to 100 liters per minute of air was

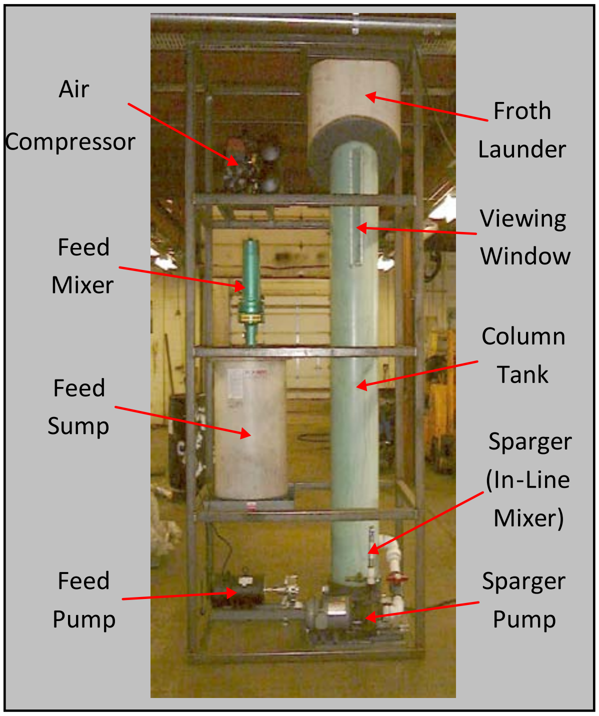

Figure 15. Photograph of the modular column flotation test unit.

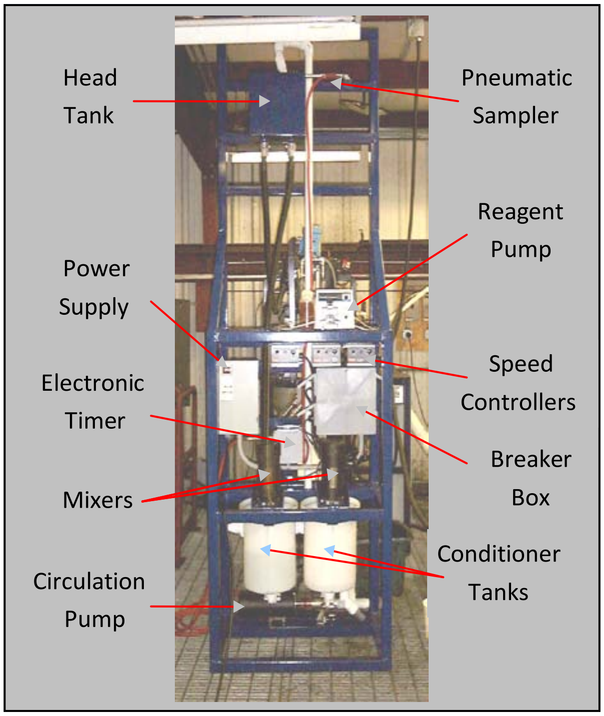

Figure 16. Photograph of the modular conditioner test unit.

supplied to the static mixer by a rotary air compressor. Coal slurry was fed to the column from an agitated tank using a variable-speed centrifugal pump. Pulp level in the column was maintained by adjusting the tailings flow rate using a pneumatic control valve. The valve actuated based on readings from a pressure transducer mounted in the side of the column. Wash water was added to the froth to minimize the entrainment of fine mineral matter. Chemical metering (reagent) pumps were used to add the desired dosages of frother and/or collector to the feed slurry.

A schematic diagram of the Conditioner Module is shown in Figure 16. The module incorporated two 20-liter conditioning tanks operated in series to provide up to 10 minutes of conditioning time. The conditioning tanks were equipped with single-impeller mixers that could be varied in speed from 0 to 2500 rpm using electronic controllers. To ensure that coarser particles did not settle when low feed rates were used, the slurry in the conditioning tanks was continuously circulated through a head tank using a centrifugal pump. The head tank was equipped with an automated sampling system that consisted of an electronic timer and a pneumatic sample cutter. During operation, the sampling system was used to divert a defined portion of circulated slurry to the Filter Module (or any other downstream operations). A chemical metering (reagent) pump was used to add the proper dosage of dewatering aid to the feed slurry as it entered the conditioning tanks. To obtain a consistent feed rate, a small peristaltic pump was installed at the plant to pump feed slurry from the plant's filter feed box to the conditioning module.

The Horizontal Belt Filter (see Figure 17) was rented from the WesTech Corporation.

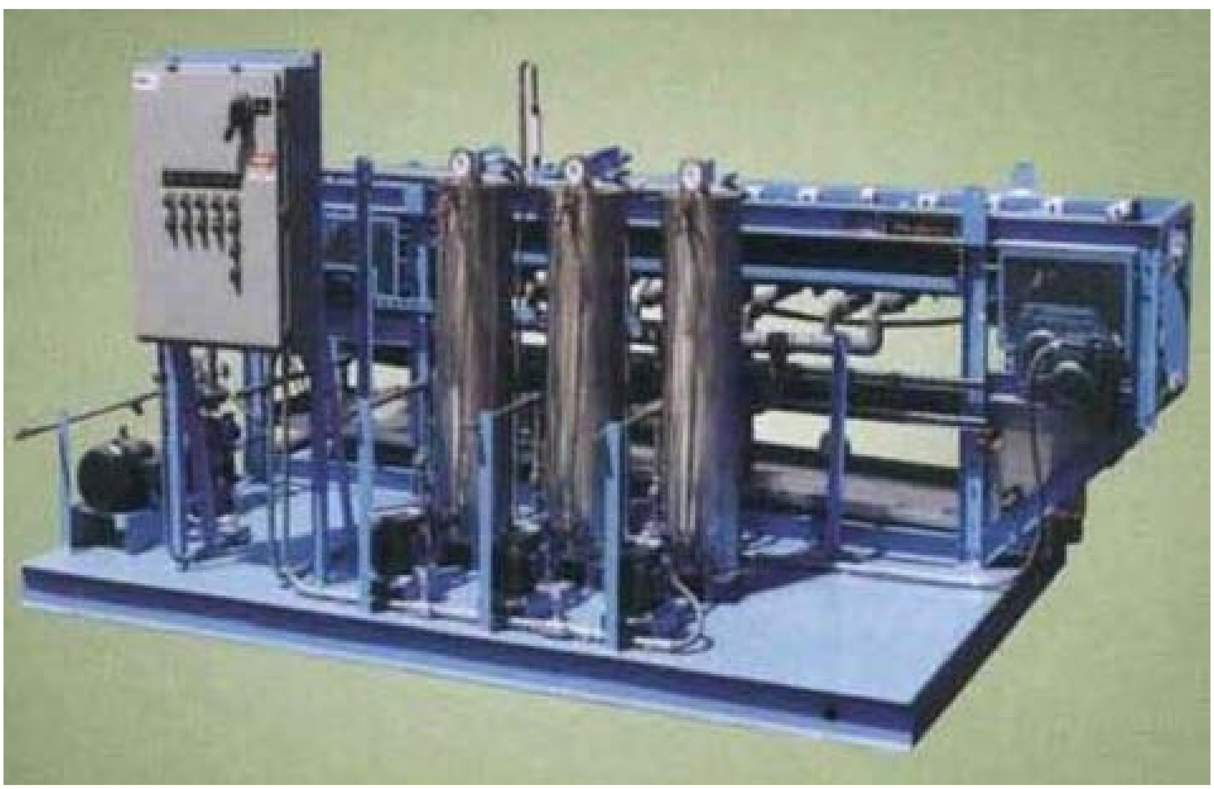

Figure 17. Photograph of the horizontal belt filter.

The unit has a continuously moving grooved rubber belt that supports and transports the filter cloth. Vacuum is applied through holes drilled in the center of each groove of the belt located directly over the vacuum box running the length of the filter. The vacuum also holds the cloth on the rubber belt and helps it move forward at the same speed. The test unit was 1 ft wide and 7 ft long, which provided 5.9 ft^2 of total filter area. The speed of the belt was controlled using a variable speed motor. The vacuum was supplied using a 5 HP motor. The filtrate was diverted to three 1 ft diameter by 4 ft tall vacuum receivers.

Task 13 – POC Design/Construction

Upon completing the field tests with the mobile unit, the conceptual flowsheets for the POC circuits was evaluated and updated. Detailed flowsheets were then be prepared for the POC test site. The detailed flowsheets included mass and flow balances, equipment specifications, size distributions, and reagent balances. Included in this work was the preparation of detailed listings of required unit operations such as equipment type, unit size, throughput capacity, reagent/chemical requirements, power requirements, air/water requirements, operating limitations, vendor cut-sheets, etc. In addition, detailed plant layout diagrams were prepared that specified the spatial arrangement of all primary operations, ancillary processing units, all connecting streams, location of electrical wiring, arrangement of piping and plumbing, and other pertinent electrical/mechanical requirements.

Bid packages were prepared for soliciting bids for major purchases of equipment, materials, fabricated components, and services necessary to complete the installation of the proposed POC circuitry. Upon receipt, the bid packages were reviewed and appropriate vendors selected based on cost, availability and suitability. The procurement and fabrication of all essential components of the proposed circuitry began immediately upon the completion of the bidding effort for each POC site. This work included (i) fabrication of all required components associated with the various POC circuits, (ii) shipping of POC modules, ancillary equipment and construction materials to the POC site (iii) inspection of all purchased POC modules, ancillary equipment and materials to ensure that they are of suitable workmanship, and are structurally, mechanically and/or electrically operational, and (iv) preparation of operation, maintenance and safety manuals for each unit operation.

After completing the bidding process, work was initiated to install all of the unit operations, piping, electrical wiring, instrumentation, etc. designated in the POC flowsheet. At the completion of the on-site construction, a system safety analysis was performed to identify potential hazards prior to module/circuit operation.

Task 14 – POC Testing

At the completion of Task 13 (POC Design/Construction), preliminary shakedown tests were conducted to resolve operational problems that may arise during start-up of the POC circuit. Initial test runs were performed to ensure that pumping capacities, pipe sizes, electrical supplies, control systems, instrumentation, etc., are adequate. After completing start-up activities, exploratory tests were conducted to validate the design capacities of the various unit operations used in the POC circuits. Data obtained from the preliminary POC tests were also used to identity key operating parameters that should be investigated. Detailed testing of the POC circuits was then conducted using parametric experiments. After completing these detailed tests, a long-duration test run was performed under optimized conditions. This test run was used to demonstrate the continuous steady-state performance of the proposed POC circuitry.

Task 15 – POC Circuit Evaluation

Appropriate analyses were conducted on each of the samples collected during the proposed Phase II test program. ASTM procedures and standards were employed for all samples as appropriate to the testing objectives. Unless otherwise specified, these analyses generally consisted of the determination of moisture, volatile matter, ash, fixed carbon and total sulfur. Mass and/or liquid flow rates were directly measured using timed samples or magnetic or mechanical flow meters. The mass and liquid flow rate of any product that cannot be directly measured was calculated from sample assays using the two-product formula.

The data obtained from the sample analyses was used to complete a technical evaluation of the POC plant. In this work, the raw test data was compiled, analyzed, and reviewed. Items in the evaluation included (i) a summary of all major experimental data, engineering analyses, computations and test results, (ii) a synopsis of the individual and combined capabilities of the various unit operations in terms of product quality, and throughput capacity, and (iii) a review of the scale-up procedures and the reliability estimation of the procedures. Once the technical evaluation was completed, the cost-benefit analyses conducted based on the data obtained from the POC-scale test work.

Task 16 – Final Report Preparation

After completing all project tasks, a Draft Final Report was prepared to provide a complete summary of all project activities carried out under Phase II. After review by DOE, the draft Phase II report was revised and submitted to DOE for final approval as the Final Project Report.

RESULTS AND DISCUSSION

4.1 BENCH-SCALE TESTING

4.1.1 Overview

A variety of laboratory dewatering tests were conducted using different coal samples to identify the best possible reagents and combinations thereof for different coal samples and to establish the conditions under which a given dewatering aid can give the best performance. Three different groups of reagents were used including (i) low HLB surfactants, (ii) natural products and (iii) modified natural products. In this section, some of the selected test results are summarized and discussed.

4.1.2 Low HLB Surfactants

a) Effect of Reagent Type

The first group of reagents used in the present work was nonionic surfactants with HLB numbers of less than 15. Most of these reagents are insoluble in water; therefore, they were used as solutions in appropriate solvents. The exact chemical compositions for these reagents are only listed in Appendix I for confidentially reasons. Table 3 shows the results obtained with Reagent

Table 3. Effect of using Reagent HLB-1 with various solvents for the vacuum filtration of a Pittsburgh coal (0.5 mm x 0) sample.

Reagent Dosage (lb/ton)	Cake Moisture (%)				
	Diesel	Kerosene	Fuel Oil	Gasoline	Butanol
0	25.7	25.7	25.7	25.7	25.7
1	15.1	15.0	16.6	16.3	17.2
3	13.8	13.7	14.8	14.5	15.8
5	12.5	13.4	14.2	14.2	15.3

HLB-1 whose HLB number is 12. The tests were conducted using a 2.5-inch diameter Buchner funnel at 25-inch Hg vacuum pressure with 2 minute drying cycle time and 0.45-inch cake thickness. The tests were conducted on a Pittsburgh coal sample. It was a DMS product, which was pulverized to -0.5 mm and then floated in a Denver laboratory flotation cell using 1 lb/ton kerosene and 75 g/ton of MIBC. Diesel oil and kerosene gave the best results. In general, mineral oils gave considerably better results than butanol. For one part of the dewatering aid, two parts of solvents were used. As shown, moisture reductions of approximately 50% were obtained at higher reagent dosages. Reagent dosages shown in the tables refer to the active ingredient only.

Table 4 shows the results obtained on a bituminous coal sample from Elkview Mine, British Columbia, Canada. The coal sample was a 0.21 mm x 0 flotation product, which was received as a slurry. The coal was oxidized during transportation; therefore, the sample was wet-ground in a ball mill for 1.5 minutes and re-floated using 1 lb/ton kerosene and 75 g/ton MIBC before filtration. A 2.5-inch diameter Buchner funnel was used at a vacuum pressure of 25 inches Hg and 2 min drying cycle time. The tests were conducted using Reagent HLB-2 as a low HLB surfactant (33% solution in diesel oil). At 5 lb/ton, the moisture reductions were 71.3 and 57.4%

Table 4. Effect of using Reagent HLB-2 for the filtration of Elkview (0.21 mm x 0) coal sample at 200 kPa of air pressure.

Reagent Dosage (lbs/ton)	Moisture Content (%)	
	Cake Thickness (inch)	
	0.25	0.50
0	24.0	26.3
1	10.3	15.2
3	7.8	12.6
5	6.9	11.2

Table 5. Effect of using Reagent HLB-3 on the filtration of an Elkview coal at 200 kPa air pressure.

Applied Pressure (kPa)	Reagent Dosage (lbs/ton)	Moisture Content (%)	
		Cake Thickness (inch)	
		0.25	0.50
200	0	25.8	27.1
	1	9.3	12.0
	3	7.4	10.4
	5	5.8	9.8

at 0.25 and 0.5 inches of cake thicknesses, respectively.

Table 5 shows the results obtained using another low HLB reagent (Reagent HLB-3) as a dewatering agent using the 2.5-inch diameter pressure filter at 200kPa air pressure. The coal sample was received as a 0.21 mm x 0 flotation product. By the time the sample was received, it was superficially oxidized. Therefore, it was refloated using 1 lb/ton kerosene and 75 g/ton MIBC. At 5lb/ton of dewatering aid and 0.25 inches cake thickness, the moisture was reduced from 25.8 to 5.8%, which represents a 77.5% reduction. The moisture was reduced to below 10% even at a thicker cake thickness of 0.5 inches.

The effectiveness of Reagent HLB-3 as a dewatering aid is due to the fact that it enhances the hydrophobicity of coal particles to be dewatered. Table 6 shows the contact angles measured on a Pittsburgh coal sample, along with the results of the Buchner filter tests conducted on the same coal sample and the surface tensions of the filtrate. The filtration tests were conducted at 25-inch vacuum pressure, 2 minute drying cycle time, and 0.45-inch cake thickness. The sample was a dense-medium product, which was crushed and ground to obtain a 0.5 mm x 0 fraction. The fine coal sample was floated using 1 lb/ton kerosene and 100 g/ton MIBC.

Table 6. Effect of Reagent HLB-3 on the surface chemistry parameters for the filtration of a Pittsburgh coal sample.

Reagent Type	Reagent Dosages (lb/ton)	Contact Angle (Degree)	Filtrate Surface Tension (mN/m)	Moisture Content (%)
None	0	12	71	28.4
Kerosene	1	40	70	25.3
Reagent A3	1	74	67	16.2
	2	84	65	14.0
	3	90	61	12.8
	5	92	57	11.9

As shown, the reagent addition caused a substantial increase in contact angle and a decrease in surface tension, both of which are conducive to improved dewatering. At 3 lb/ton, the contact angle increased from 12 to 90^o. According to the Laplace equation, the pressure of the capillary water should become negative at contact angle above 90^o.

It may be noteworthy that at 1 lb/ton kerosene the moisture was reduced from 28.4 to 25.3%, which is far less than the cases of using mixtures of Reagent HLB-3 and diesel oil. Even when the oil dosage was increased, the moisture reduction did not exceed more than 5%. When the oil dosage was increased to very large amounts, moisture content actually increased, because water is trapped within the flocs of coal created in the presence of large amounts of oil.

Table 7 shows the results of the pressure filter tests conducted on the Blackwater coal sample from Australia. The sample was a 0.6 mm x 0 flotation product. By the time the sample was received, it was oxidized; therefore, it was wet ground in a ball mill ground and floated using 1 lb/ton kerosene and 75 g/ton MIBC. The results in Table 6 show that moisture can be reduced to less than 10% with thin cake when using Reagent HLB-1. Even at 0.85 inch thickness, nearly 50% moisture reductions could be achieved at 200 kPa air pressure.

Table 7. Effect of using Reagent HLB-1 for the filtration of a Blackwater Coal (0.6 mm x 0) at different air pressures.

Applied Pressure (kPa)	Reagent Addition (lb/ton)	Cake Moisture (%) Cake Thickness (inch)		
		0.25	0.50	0.85
100	0	27.5	29.5	30.1
	1	17.3	21.6	22.5
	3	12.8	15.8	18.4
	5	9.4	14.6	16.7
200	0	24.5	26.2	27.8
	1	13.2	14.6	19.4
	3	8.4	11.9	16.4
	5	7.9	10.5	14.2

b) Effect of Vibration

The primary role of low HLB surfactants is to help destabilize and “liberate” the water molecules adhering to the surface of the coal particles to be dewatered by further increasing the particle hydrophobicity, but it plays no part in transporting the liberated water through a filter cake. The transportation problem becomes more serious with thicker cakes. In the present work, filter cake was subjected to vibration as a means of assisting the transportation of the liberated water. The vibration was created by placing an ultrasonic probe at the bottom part of the Buchner funnel. Table 8 shows the effects of vibration when using Reagent HLB-1 as a dewatering aid. The tests were conducted on a bituminous coal from Massey Energy at 2 minutes of drying cycle time. The coal sample was a spiral product wet-ground in a ball mill, and floated using 1 lb/ton kerosene and 75 g/ton MIBC. As shown, very low levels of cake moistures were obtained by combining the methods of using low HLB surfactants and mechanical vibration.

Table 8. Effect of ultrasonic vibration on the vacuum filtration of Massey coal (0.6 mm x 0) using Reagent HLB-1.

Reagent Addition (lb/ton)	Cake Moisture (%)			
	0.25 Inch Cake		0.5 Inch Cake	
	Without Vibration	With Vibration	Without Vibration	With Vibration
0	25.5	19.2	26.4	21.7
1	15.2	10.3	17.7	12.1
2	12.3	8.5	16.5	10.3
3	12.2	6.4	15.6	9.2
5	11.5	5.5	15.2	8.5

c) Effect of Surface Tension

As suggested by the Laplace equation (Eq. [5]), surface tension lowering is useful in decreasing capillary pressure and, hence, improving dewatering kinetics. Conventional wisdom is, therefore, to add surfactants to a feed slurry before it enters a filter. However, the bulk of the water present in the feed stream is easily removed at the beginning of a filtration process. It may be stated, therefore, that much of the surfactants added to the feed stream are wasted and do not contribute to reducing the final cake moisture. A more effective method of using a surfactant may, therefore, be to add some surfactant when it is needed most, i.e., during the drying cycle time. Some of the water trapped in finer capillaries could then be removed during drying cycle time. To demonstrate this, a series of experiments were conducted in which different surface tension lowering reagents were sprayed onto the filter cake during the drying cycle time.

Table 9 shows the results obtained by spraying approximately 2 lb/ton of butanol, ethanol, and diesel oil at the beginning of 2 min drying cycle time. The surface tensions of *n*-butanol and ethanol are 20.6 and 22.8 mN/m, respectively, at 20^{o}C. The surface tension of diesel

Table 9. Effect of spraying different reagents over Middlefork filter cake using Reagent HLB-1 and Reagent HLB-3.

Reagent Dosage (lbs/ton)	Moisture Content (%)					
	HLB-1		HLB-3			
	No Spray	Butanol Spray	No Spray	Diesel Spray	Ethanol Spray	Butanol Spray
0	23.1	18.1	22.3	20.7	20.1	17.4
1	13.8	8.3	12.4	11.9	11.4	7.3
2	12.2	7.1	11.8	10.0	9.5	6.2
3	10.1	6.1	10.3	8.5	8.1	5.2
5	9.7	5.6	10.0	7.7	6.9	4.8

oil is also low, as are most other hydrocarbon liquids. Therefore, spraying these reagents should lower the surface tension of the water left in filter cake and help reduce the moisture. The tests were conducted with a Buchner funnel filter on the 0.6 mm x 0 bituminous coal sample from Middlefork pond recovery plant in southwestern Virginia. Two sets of tests were conducted using Reagents HLB-1 and HLB-3 as dewatering aids at 0.45-inch cake thickness at 25-inch Hg vacuum pressure. Approximately 2.5 lb/ton of butanol was sprayed on the cake when using the former, while the target amounts of ethanol and diesel oil were sprayed when using the latter. As shown, the spray technique further reduced the cake moisture substantially.

d) Effect of Cake Thickness

It has been shown that the transport of capillary water can be facilitated by applying vibration and spraying surface tension lowering reagents. These techniques can be used to obtaining low cake moistures at high cake thicknesses. To demonstrate this, the height of the 2.5-inch diameter Buchner funnel was extended to 6 inches so that 300 ml of coal slurry (at 18%

solids) could be used in each test. This allowed the cake thickness to be increased to 1.2 inches. The coal sample used in these experiments was a DSM product from Massey Energy, which was crushed and wet-ground in a ball mill to minus 0.6 mm and floated using 1 lb/ton kerosene and 100 g/ton MIBC. The tests were conducted at varying amounts of Reagent HLB-3, 25 inch Hg, and 5 min drying cycle time. As shown in Table 10, the combined use of (i) a low HLB surfactant dissolved in diesel, (ii) butanol spray and (iii) mechanical vibration achieved very low moistures at a cake thickness as large as 1.2 inches.

e) Effect of Particle Enlargement

The Laplace equation (Eq. [5]) suggests that the capillary pressure can be reduced by i) decreasing surface tension (γ), ii) increasing capillary radius (r), and iii) increasing contact angle (θ). As discussed earlier, the major role of the nonionic surfactants tested in the present work is to increase θ. It has been found, however, that the use of the novel dewatering aids also causes a decrease in γ and an increase in r. Evidence for the latter is given by a decrease in vacuum

Table 10. Effect of using Reagent HLB-3, butanol spray, vibration, and combination thereof at 1.2-inch cakes thickness on a Massey coal.

Reagent Dosage (lbs/ton)	Moisture Content (%)			
	None	Spray	Vibration	Spray and Vibration
0	25.6	22.4	22.2	20.0
1	18.2	14.3	14.5	12.3
2	15.8	12.0	12.7	10.1
3	14.9	11.0	10.8	8.8
5	14.7	10.8	10.6	8.1

pressure when a novel dewatering aid is added, which can be attributed to hydrophobic coagulation. It was shown that hydrophobic particles coagulate with each other. Thus, an increase in particle hydrophobicity by the use of the novel dewatering aids should entail particle size enlargement and, hence, a decrease in capillary pressure.

One could also enlarge the particle size by adding flocculants or coagulants and, thereby, further decrease the capillary pressure. Therefore, a series of Buchner filter tests were conducted in the presence of various inorganic electrolytes. Similar experiments with polymeric flocculants were not conducted as these reagents are known to decrease hydrophobicity. Table 11 shows the results obtained with a bituminous coal sample (0.2 mm x 0) from Massey Energy using Reagent HLB-3 in the presence of Al^{3+}, Cr^{3+}, and Cu^{2+} ions. In each experiment, the coal sample was conditioned with an electrolyte for 5 minutes and then conditioned with Reagent HLB-3 dissolved in diesel oil (1:2 ratio) for 2 minutes. The tests were conducted at 25-inch Hg vacuum pressure with 2 minutes of drying cycle time, 0.4 inches cake thickness. The results show that the

Table 11. Effect of using electrolytes for the filtration of Massey coal (0.2 mm x 0).

Reagent Dosage (lb/ton)	Moisture Content (%)			
	None	Al^{3+} (10 g/ton)	Cr^{3+} (10 g/ton)	Cu^{2+} (50 g/ton)
0	28.1	23.2	23.0	23.4
0.25	22.5	18.2	17.6	18.4
0.5	20.6	16.3	16.0	17.2
1	19.3	15.4	15.2	16.2
2	17.2	14.2	14.7	15.4
3	16.0	13.6	14.2	15.3
5	14.6	13.5	13.8	14.8
pH	7.5	5.5-7.5	5.5-7.5	4.5-6.5

use of the electrolytes substantially decreases the amount of the novel dewatering aid required. For example, 3 lb/ton the reagent was required to achieve 16.0% cake moisture. In the presence of 10 g/ton Al^{3+} and Cr^{3+} ions, however, only 0.5 lb/ton Reagent HLB-3 was required to obtain 16.3% cake moistures. Divalent cations are not as efficient as the trivalent cations, which is consistent with the Schultze-Hardy rule.

Table 12 shows the results obtained using different amounts of Reagent HLB-1, 10g/ton $AlCl_3$, 2-3lb/ton butanol spray, and vibration. The tests were conducted on a bituminous coal sample using the 2.5-inch diameter Buchner funnel with a 6-inch height at 25-inch Hg vacuum pressure, and 2 min drying cycle time. The cake thicknesses were approximately 1-inch, and the coal sample was a DMS product, pulverized in a hammer mill, wet-ground in a ball mill to -0.6 mm, and floated with 1 lb/ton kerosene and 100 g/ton MIBC. The results show that very low levels of cake moisture could be achieved at an industrial cake thickness by using a combination

Table 12. Effect of using electrolyte, regent spray, and vibration on the filtration of a Moss 3 coal (0.6 mm x 0) at 1-inch cake thickness using HLB-1.

Reagent Addition (lb/ton)	Moisture Content (%)			
	HLB Reagent Only	Al^{3+}	Al^{3+} & Spray	Al^{3+}, Spray & Vibration
0	25.2	22.8	21.0	18.7
0.25	20.1	18.0	16.7	14.2
0.5	18.7	15.2	13.6	11.7
1	16.2	14.3	12.5	10.2
2	15.3	13.6	11.7	9.5
3	14.7	13.2	10.6	8.2
5	13.8	13.0	10.3	7.4

of different methods, including i) the use of a low HLB surfactant to destabilize (or liberate) the surface water, ii) the use of a coagulant to increase the capillary radius, iii) the addition of a short-chain alcohol to reduce the surface tension of the capillary water, and iv) the vibration of the filter cake to facilitate the transport of the destabilized surface water. For example 14.2% cake moisture can be achieved using only 0.25 lb/ton Reagent HLB-1, 10 g/ton aluminum chloride, 2 to 3 lb/ton butanol, and mechanical vibration.

4.1.3 Natural Products

a) Effect of Reagent Type

Natural products extracted from plant and animal sources can also serve as effective dewatering aids. The exact chemical compositions for these reagents are only listed in Appendix I for confidentially reasons. Most natural products are insoluble in water; therefore, they are used as solutions in appropriate solvents, such as light hydrocarbon oils and short-chain alcohols. Since some of these solvents are also insoluble in water, they may be referred to as "carriers".

Table 13 shows the results obtained using several different carriers. The tests were

Table 13. Effect of using Reagent NP-1 in various solvents on the vacuum filtration of a Pittsburgh coal (0.5 mm x 0).

Reagent Dosage (lbs/ton)	Cake Moisture (%)				
	Diesel Oil	Kerosene	Fuel Oil No. 4	Gasoline	Butanol
0	25.1	25.1	25.1	25.1	25.1
1	16.8	17.0	17.5	17.6	19.8
3	14.3	14.4	15.4	16.1	18.6
5	13.7	13.5	14.7	14.8	17.1

Table 14. Synergistic effect of using Reagent NP-1 and diesel oil for the vacuum filtration of a Blackwater coal (0.85 mm x 0).

Reagent Addition (lb/ton)	Moisture Content (%)		
	NP-1	Diesel Oil	Combination*
0	25.8	25.8	25.8
1	20.2	22.5	17.1
2	19.6	20.8	15.5
3	20.5	20.1	14.3
5	21.5	19.7	13.7
7	20.9	19.9	14.4

*1 part reagent NP-1 mixed with 2 parts of diesel oil by volume - reagent dosages for the combination refer to reagent NP-1 alone.

conducted on a coarse DMS product (Pittsburgh coal) from the Bailey plant, Consol Energy. It was pulverized by means of a jaw crusher, a roll crusher, wet-ground in a ball mill to minus 0.5 mm, and then floated with 1 lb/ton kerosene and 0.2 lb/ton MIBC. The flotation product was conditioned for 2 minutes in Elenmeyer flasks with different amounts of NP-1 dissolved in diesel oil, kerosene, Fuel oil No. 4, gasoline, and butanol. The ratio between NP-1 and the carriers were 1:2 by volume. The filtration tests were conducted using a 2.5-inch vacuum filter at 0.45-inch cake thickness, 2-minute drying cycle time, and 25-inch Hg vacuum pressure. The mineral oils gave better results than butanol. It is well known that mineral and vegetable oils by themselves can be used as dewatering aids.

Therefore, a series of Buchner funnel filtration tests were conducted on a bituminous coal sample using Reagent NP-1 and diesel oil individually, and compared the results with those obtained using a 1:2 mixture of the two. The tests were conducted on a bituminous coal sample from Blackwater Mine, Australia. It was a flotation product received in the form of slurry. The coal sample was superficially oxidized as received; therefore, it was wet-ground for 1.5 minutes and re-floated using 1 lb/ton kerosene 0.2 lb/ton MIBC. The filtration tests were conducted at 25 inches Hg vacuum pressure, 0.45-inch cake thickness, and 2 min drying cycle time. The results are given in Table 14.

At 1 lb/ton, Reagent NP-1 reduced the cake moisture from 25.8 to 20.2%, while diesel oil reduced it to 22.5%. At higher dosages, no further improvement in moisture reduction was obtained. Using 1:2 mixtures of the two oils gave greater degrees of moisture reductions. In this case, the reagent dosages given in the fourth column of Table 13 refer to the dosages of Reagent NP-1 (active ingredient) alone rather than the sum of the two. One may, therefore, compare the performance of the mixture at 1 lb/ton with that obtained with 3 lb/ton of Reagent NP-1 alone or diesel oil alone. Even then, the NP-1 and diesel oil mixtures outperformed either Reagent NP-1 or diesel oil individually. For example, the use of 1 lb/ton of Reagent NP-1 and 2 lb/ton diesel oil mixture gave 17.1% moisture, while 3 lb/ton of Reagent NP-1 alone and diesel oil alone gave 20.5 and 20.1% cake moistures, respectively. Thus, there exists a synergistic effect of using the mixtures. The synergism increased with increasing reagent dosage. As shown in Table 13, continued increase in the dosages of Reagent NP-1 alone and diesel oil alone did not significantly decrease the cake moisture, while an increase in the dosages of the Reagent NP-1 and diesel oil mixtures substantially improved the moisture reduction. At 3 lb/ton of Reagent NP-1 as an active ingredient, the cake moisture was reduced to as low as 14.3%. From a practical point of view, diesel oil is cheaper than Reagent NP-1; therefore, one may consider using the mineral oil as a low-cost facilitator, which can greatly enhance the performance of the natural product, i.e., Reagent NP-1.

Table 15 shows a set of vacuum filtration tests conducted on a bituminous coal sample (0.6 mm x 0) from Elkview Mine, British Columbia, Canada. The sample was received in the

Table 15. Effect of using different natural products as dewatering aids for the vacuum filtration of Elkview coal.

Reagent Addition (lb/ton)	Moisture Content (%)		
	NP-2	NP-3	NP-5
0	24.4	24.4	24.4
0.5	14.1	14.4	15.6
1	13.3	13.5	15.8
2	12.0	12.6	14.6
3	11.9	11.9	14.2

form of slurry and used as received. The tests were conducted using a 2.5-inch diameter Buchner funnel at 25 inches Hg of vacuum pressure with 2 min drying cycle time and 0.4 inches of cake thickness. Three different natural products were used as dewatering aids and the results compared. These oils were used as 10% solutions in butanol. Both Reagent NP-2 and Reagent NP-3 reduced the cake moisture by nearly 50% at 2 lb/ton of reagent addition.

Table 16 shows the results of the vacuum filtration tests conducted on a Pittsburgh coal sample using another type of natural product (Reagent NP-4) a dewatering aid. It was used as a 1:2 mixture by volume with diesel oil. The coal sample was a dense-medium product, which was pulverized, ball-mill ground and screened at 0.5 mm. The screen underflow was floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC before filtration. The filtration tests were conducted using a 2.5-inches diameter Buchner funnel at 25-inches Hg of vacuum pressure and 0.45 inches of cake thickness. At 3 lb/ton of Reagent NP-4, moisture was reduced from 28.2 to 15.4%.

Table 16. Effect of kerosene and Reagent NP-4 on the contact angle, filtrate surface tension, and final cake moisture for a Pittsburgh coal.

Reagents Added	Reagent Dosages (lb/ton)	Contact Angle (Degree)	Filtrate Surface Tension (mN/m)	Moisture Content (%)
None	0	12	71	28.2
Kerosene	1	44	69	24.9
NP-4	1	73	65	18.4
	2	86	62	16.2
	3	89	63	15.4
	5	91	56	15.5

Also shown in the table are the equilibrium contact angles of the Pittsburgh coal sample treated under different reagent conditions. In the absence of any reagent, the coal sample gave a contact angle of 12^o only, which should give rise to a relatively high capillary pressures and, hence, a high cake moisture. At 1 lb/ton kerosene, contact angle increased to 44^o. According to the Laplace equation, the increase in contact angle from 12^o to 44^o should reduce the capillary pressure by 1.36 times, which may be responsible for the modest reduction in cake moisture from 28.2 to 24.9%. In the presence of Reagent NP-4, the contact angle increased close to 90^o as shown in Table 15. At 2 lb/ton, it increased to 86^o, which should reduce the capillary pressure by 14 times as compared to the case of untreated coal. Such a large decrease in capillary pressure may be responsible for the substantial decrease in moisture from 28.2 to 16.2%.

Table 16 also shows the surface tensions of the filtrates. The decrease in surface tension with increasing reagent addition may be another factor in the observed decrease in cake moisture. Thus, the use of a natural product as a dewatering aid not only increase the contact angle, but also decreases the surface tension of water, both of which contribute to the substantial reduction in moisture.

b) Effect of Filter Pressure

A series of pressure filter tests were conducted using different coals to determine whether a higher driving pressure could be used to improve dewatering performance using naturally occurring products. The first series of tests were conducted using a flotation product from Peak Downs Mine, Australia, which was received in the form of slurry. Since the sample was superficially oxidized during transportation, it was wet-ground in a ball mill for 1.5 minutes and re-floated using 1 lb/ton of kerosene and 0.2 lb/ton MIBC. The flotation product was conditioned with Reagent NP-4 to enhance its hydrophobicity. The natural product was used as a 33.3% solution in diesel oil. The conditioned coal sample was subjected to a series of filtration tests using the 2.5-inch diameter pressure at 200 kPa air pressure and 2 min drying cycle time. The results are given in Table 17. At 0.25-inch cake thickness and 5 lb/ton of Reagent NP-4, the moisture was reduced from 23.4 to 9.4%, which represents a 59.8% moisture reduction. At lower reagent dosages and higher cake thicknesses, the moisture reduction became less substantial.

Table 17. Effect of using Reagent NP-4 on the filtration of Peaks Down coal (0.6 mm x 0) at 200 kPa of air pressure.

Reagent Addition (lb/ton)	Moisture Content (%) Cake Thickness (inch)		
	0.25	0.50	0.85
0	23.4	25.8	26.7
1	14.8	16.2	18.8
3	10.1	13.7	17.2
5	9.4	12.4	15.6

Another sample tested using the pressure filter was a flotation product (0.85 mm x 0) from Massey Energy. The tests were conducted at 200 kPa air pressure and 2 min drying cycle time. The coal sample was wet-ground in a ball mill for 1.5 minutes to remove superficial oxidation products and re-floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC. The results obtained using varying amounts of another natural product (i.e., Reagent NP-6) as dewatering aid were are given in Table 18. The dewatering aid was used as a 1:2 mixture with diesel oil. The moisture reductions were 64.7, 58.5, and 51.2% at 0.2, 0.4 and 0.8 inches cake thicknesses, respectively.

Table 19 shows another set of pressure filtration tests conducted using a low-cost natural product (i.e., Reagent NP-7). A clean spiral product was wet-ground in a ball mill. The fines fraction (0.85 mm x 0) was floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC as a means of initial hydrophobization. The hydrophobicity of the flotation product was enhanced using Reagent NP-7 and then subjected to filtration tests. Two sets of tests were conducted at 100 and 200 kPa of air pressures. Varying amounts of the dewatering aid were used as 25% solutions in

Table 18. Effect of using Reagent NP-6 for the filtration of a bituminous coal at 200 kPa of air pressure.

Reagent Addition (lb/ton)	Moisture Content (%)		
	Cake Thickness (inch)		
	0.2	0.4	0.8
0	21.8	23.4	24.8
1	12.4	14.2	16.2
2	10.1	11.9	14.5
3	9.0	10.4	12.8
5	7.7	9.7	12.1

Table 19. Effect of using Reagent NP-7 for the filtration of Massey coal (0.85 mm x 0) at 100 and 200 kPa air pressure.

Applied Pressure (kPa)	Reagent Addition (lb/ton)	Moisture Content (%) Cake Thickness (inch) 0.2	0.4	0.8
100	0	24.6	26.4	27.1
	1	14.0	16.3	19.1
	3	12.3	14.1	15.2
200	0	22.4	24.1	25.4
	1	10.8	12.6	14.3
	3	8.7	10.8	12.8

diesel oil. The tests were conducted using a 2.5-inch diameter filter at 2 min drying cycle time. As shown in Table 18, Reagent NP-7 works well as a dewatering aid. The moisture reduction improves with increasing reagent dosage and air pressure. Moisture reductions of 50 to 60% were obtained at lower cake thicknesses and at the higher air pressure. Even at the thicker cake, moisture reductions approaching 50% were obtained at higher reagent dosages.

Another set of pressure filtration tests was conducted using a mixture of a natural product and a low-HLB surfactant. One part by volume of Reagent NP-8 was blended with one part of HLB-1 and four parts of diesel oil, and the blend was used as dewatering aid. A DMS product from Massey Energy was crushed, ground, and screened to minus 0.6 mm, and floated with 1 lb/ton kerosene and 100 g/ton MIBC. The flotation product was used for the filtration tests using the 2.5-inch diameter pressure filter at 150 kPa air pressure at 2 min drying cycle time and 0.5 inches cake thickness. The results are given in Table 20, in which the results obtained with the reagent blend are compared with those obtained with its individual components. As shown, Reagent NP-8 gave considerably inferior results to those obtained with HLB-1. However, the

Table 20. Effect of using a natural product and low HLB surfactant blend for the filtration of a bituminous coal at 150 kPa air pressure.

Reagent Addition (lb/ton)	Moisture Content (%)		
	NP-8	HLB-1	Combination
0	25.7	25.7	25.7
1	16.2	13.4	13.0
2	14.2	10.3	10.4
3	12.0	9.5	9.3
5	11.7	9.0	8.7

results obtained with the blend were comparable to those obtained with HLB-1. Thus, blending a natural product with a low HLB surfactant provides a means of reducing reagent costs, as the former is substantially cheaper than the latter.

Table 21 shows the results of the pressure filtration tests using Reagent NP-1 as dewatering aid. The tests were conducted on the Elkview flotation product. The sample was re-floated using 1 lb/ton Kerosene and 75g/ton MIBC as a means of regenerating fresh hydrophobic surface. As shown, 50% moisture reductions could be achieved at a lower cake thickness, higher pressure, and/or a high reagent dosage.

Table 22 shows the results obtained using Reagent NP-4 as dewatering aid. It was used as a 33.3% solution in diesel oil. Dewatering tests were conducted on the 0.6 mm x 0 flotation product from Peak Downs Mine using the 2.5-inch diameter pressure filter at 100 and 200 kPa air pressures and 2 min drying time. The coal sample was superficially oxidized; therefore, it was wet-ground in a ball mill for 1.5 minutes and floated with 1 lb/ton kerosene and 0.2 lb/ton of kerosene prior to the filtration tests. At 0.25-inch cake thickness and 5 lb/ton of Reagent NP-4, the moisture was reduced from 23.4 to 9.4%, which represents a 59.8% moisture reduction. At

Table 21. Effect of using Reagent NP-4 on the filtration of Peak Downs (0.6 mm x 0) coal at 200 kPa of air pressure.

Reagent Addition (lb/ton)	Moisture Content (%)		
	Cake Thickness (inch)		
	0.25	0.50	0.85
0	23.4	25.8	26.7
1	14.8	16.2	18.8
3	10.1	13.7	17.2
5	9.4	12.4	15.6

lower reagent dosages and higher cake thicknesses, the moisture reduction became less substantial.

c) Effect of Vibration

Table 22. Results of the pressure filtration tests conducted on Elkview flotation product using Reagent NP-1.

Applied Pressure (kPa)	Reagent Dosage (lbs/ton)	Moisture Content (%)	
		Cake Thickness (inch)	
		0.25	0.50
100	0	28.4	30.8
	1	16.7	20.4
	3	13.8	18.3
	5	13.2	17.1
200	0	23.6	26.1
	1	14.3	16.7
	3	11.7	14.7
	5	10.3	13.5

Although the results obtained using natural products as dewatering aids, their effectiveness decrease with increasing cake thickness. This is due to the difficulty in transporting the water molecules liberated by the dewatering aids through filter cake. One solution to the problem would be to apply a mechanical vibration to the filter cake during drying cycle time. Table 23 shows the results obtained with and without using vibration when Reagent NP-8 was used as dewatering aid for the filtration of a coal sample (0.6 mm x 0) from Virginia. The reagent was used as a 33.3% solution in diesel oil. The coal sample was a dense-medium product, which was crushed, ground and floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC. The filtration experiments were conducted using a 2.5-inch diameter Buchner funnel at 25-inch Hg vacuum pressure. An ultrasonic probe was placed at the conical part of the Buchner funnel during the 5 minute drying cycle time. When the vibration was applied without the dewatering aid, the cake moisture was reduced from 22.6 to 19.2%. When 2 lb/ton of the dewatering aid was used in conjunction with the vibration, the cake moisture was reduced to 9.2% at 0.4-inch cake thickness. At 5 lb/ton, the moisture was reduced to as low as 7.7%.

Table 23. Effect of vibration on the filtration of a Virginia coal using Reagent NP-8.

Reagent Addition (lb/ton)	Cake Moisture (%)			
	Cake Thickness (inches)			
	0.2		0.4	
	Without Vibration	With Vibration	Without Vibration	With Vibration
0	19.6	16.1	22.6	19.2
1	12.5	10.7	14.3	10.7
2	10.2	7.3	12.6	9.2
3	9.6	6.0	12.0	8.3
5	8.2	4.8	11.7	7.7

d) Effect of Butanol Spray

A series of dewatering tests were performed by spraying butanol directly on to a filter cake during drying cycle time. Approximately 2 lb/ton of the reagent was added immediately after cake formation. The surface tension of butanol is 20.6 mN/m at 20^{o}C, which is much lower than that of water. Therefore, the role of butanol may be to reduce the surface tension of the water trapped in the finer capillaries. The coal sample used in this example was a Middle Fork dense-medium product, which was crushed, ground, and floated using 1 lb/kerosene and 0.15 lb/ton MIBC. The flotation product was conditioned with varying amounts of a natural product (Reagent NP-8) prior to filtration. The filtration tests were conducted using a 2.5-inch diameter Buchner funnel at 25-inch Hg vacuum pressure, 2-min drying cycle time, and 0.45-inch cake thickness. As shown in Table 24, the spray technique reduced the cake moisture by 4 to 5% beyond what can be achieved using the natural product as a hydrophobicity-enhancing reagent. Thus, the technique of using natural products and butanol spray provides a means of achieving deep moisture reductions. Any other surface tension lowering reagents may be sprayed in place

Table 24. Effect of combining Reagent NP-8 and butanol spray to achieve deep moisture reductions (0.45-inch cake thickness).

Reagent Dosage (lb/ton)	Moisture Content (%)	
	Without Spray	With Spray
0	22.2	18.0
1	15.3	11.2
2	13.2	9.4
3	12.7	8.3
5	12.5	7.6

of the butanol used in this example.

e) Effect of Cake Thickness

Table 25 shows the Buchner funnel filtration tests conducted on a DMS product from the Middle Fork coal preparation plant, Virginia The sample was crushed, ground, and screened to obtain a 0.6 mm x 0 fraction, which was floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC. The flotation product was filtered at 0.67-inch cake thickness and 5 min drying cycle time. As shown, the cake moisture obtained using both Al^{3+} ions and natural product are much lower than the case of using the latter alone. Consequently, the amount of natural product needed to achieve a given level of cake moisture was reduced substantially in the presence of Al^{3+} ions. For example, 5 lb/ton of Reagent NP-8 was needed to achieve 12.3% cake moisture in the absence of Al^{3+} ions. In the presence of Al^{3+} ions, however, only 0.5 lb/ton of Reagent NP-8 was needed to achieve a 12.6% cake moisture. When 2 lb/ton butanol was sprayed, dewatering became even

Table 25. Effect of combining Reagent NP-8, Al^{3+} ions, butanol spray, and vibration to achieve deep moisture reductions (0.67-inch cake thickness).

Reagent Addition (lb/ton)	Cake Moisture (%)			
	None	Al^{3+} Ion	Al^{3+} & Spray	Al^{3+} ions, Spray & Vibration
0	23.8	20.4	18.8	17.0
0.25	17.1	14.3	12.3	10.4
0.5	16.3	12.6	10.7	8.7
1	14.4	11.7	9.5	7.5
2	13.7	11.2	9.1	7.1
3	13.1	10.9	8.8	6.8
5	12.3	10.8	8.5	6.2

more effective. The amount of natural product needed to achieve 12.3% cake moisture was further reduced to 0.25 lb/ton.

Dewatering became even more efficient when filter cake was vibrated during the 5 min drying cycle time. As shown in the last column of Table 25, the cake moisture was reduced to 10.3% at 0.25 lb/ton of Reagent NP-8. At higher dosages of Reagent NP-8, single digit cake moistures were obtained. Thus, proper combinations of (ii) conditioning the slurry with trivalent (or divalent) cations, (ii) spraying appropriate surface tension lowering agent(s) during drying cycle time, and (iii) applying mechanical vibration during drying cycle time, can help achieve deep levels of moisture reduction when using small amounts of natural products as dewatering aids.

4.1.4 Modified Natural Products

a) Rationale for Modification

As shown in previously in this report, the performance of naturally occurring products is slightly inferior to that of the low HLB surfactants. Therefore, chemically modified natural products were developed in order to improve dewatering performance. The types of modifications employed and the exact chemical compositions for these reagents are only listed in Appendix I for confidentially reasons.

b) Modified Reagent Tests

Reagent NP-8 was modified (to form MNP-8) and used as a dewatering aid in a series of vacuum filtration tests. In each experiment, one part of the modified NP-8 was dissolved in three parts of diesel oil before use. All test were conducted using a 2.5-inch diameter Buchner funnel at 2 min drying cycle time, 0.4-inch cake thickness, and 25-inch Hg vacuum pressure. The filtration tests were conducted on a Meadow River coal sample from Virginia. It was freshly pulverized and floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC prior to the filtration tests. The pulp density of the flotation product was 16.9%. The results given in Table 26 show that the modified Reagent NP-8 gave considerably better results than the case of using the naturally occurring product without modification. The reagent dosages given in the table represent only the amount of the active ingredient (modified NP-8) used in each experiment and do not include the amount of the solvent (diesel oil) used. The results show that the modified NP-8 gave considerably better results than the case of using the naturally occurring product without modification.

Further testing was carried out on using another natural product (Reagent NP-9) with and without modification. The filtration tests were conducted using a 2.5-inch diameter Buchner filter at 2 min drying cycle time and 0.4 to 0.5 inch cake thicknesses. The tests were conducted on a coal sample from the Middle Fork coal preparation plant, Virginia. It was pulverized, wet-ground in a ball mill, and floated using 1 lb/ton kerosene and 0.2 lb/ton MIBC. In each

Table 26. Results of filtration tests conducted on Meadow River coal (0.5 mm x 0) using NP-8 and modified NP-8.

Reagent Dosage (lb/ton)	Moisture Content (%)	
	Unmodified	Modified
0	22.6	22.6
1	16.3	13.5
2	14.4	11.0
3	13.8	10.6
5	13.3	9.9

*not including diesel oil

Table 27. Results of vacuum filtration tests conducted on Middle Fork (0.5 mm x 0) coal using modified and unmodified NP-9.

Reagent Dosage (lbs/ton)	Moisture Content (%)	
	Unmodified	Modified
0	19.3	19.3
1	13.3	10.7
2	12.2	11.3
3	12.7	10.6
5	11.3	10.3

experiment, one part of the modified NP-9 was dissolved in two parts of diesel oil. The results given in Table 27 show that lower moisture filter cakes were obtained when the modified version of Reagent NP-9 was used as a dewatering aid.

Reagent NP-7 was also modified and used as a dewatering aid in a series of vacuum filtration tests. The tests were conducted on the Meadow River coal sample, which had been pulverized and ground in the same manner as above. As it can be seen from Table 28, the results show that the use of the modified NP-7 reduced the cake moistures substantially below the values obtained using Reagent NP-7 without modification.

4.1.5 Comparison with Conventional Dewatering Aids

The dewatering aids tested in this work included low-HLB surfactants, naturally occurring reagents and modified reagents. It would be of interest to compare the results obtained using some of these reagents with those obtained using conventional dewatering aids. Therefore, a series of Buchner funnel filter tests were conducted on a fine coal sample prepared from a coarse DMC product. The sample was a bituminous coal from Red River Coal Company,

Table 28. Results of filtration tests conducted on Meadow River (0.5 mm x 0) coal using modified and unmodified NP-7.

Reagent Dosage (lbs/ton)	Moisture Content (%)	
	Unmodified	Modified
0	21.5	21.7
1	16.9	14.4
2	16.6	12.4
3	16.2	10.7
5	15.7	9.9

Virginia. The sample was crushed, wet-ground in a ball mill, and floated using 100 g/ton MIBC. Part of the tests was conducted on the froth product immediately after the flotation, and part of the tests were conducted after aging the coal sample for one week.

Table 29 compares the results obtained using Reagent HLB-1, a low-HLB surfactant, with those obtained using diesel oil. The low-HLB surfactant was used as a 33.3% solution in diesel oil. The reagent dosages given in the table for Reagent HLB-1 represent only those of the active ingredient. As shown, diesel oil works reasonably well by itself when the coal sample was fresh. The cake moisture was reduced from 22.4% with no reagent to 17.0% at 3 lb/ton reagent addition. At 5 lb/ton, it increased slightly to 17.9%. The increase in moisture with increasing diesel oil dosage can be more clearly seen with the aged coal sample. It is believed that coal particles are coagulated in the presence of the oil, and the resulting coagula may entrap water within its fine structure. On the contrary, Reagent HLB-1 was able to reduce the cake moisture substantially even with the aged coal sample. However, its performance deteriorated considerably.

Table 29. Effect of aging Red River coal (0.6 mm x 0) using Reagent HLB-1 and diesel.

Reagent Addition (lb/ton)	Diesel		Reagent HLB-1	
	Fresh	Aged	Fresh	Aged
0	22.7	24.4	22.7	24.4
1	20.2	24.6	14.6	22.0
2	18.9	25.3	12.2	16.7
3	17.0	26.2	10.8	14.2
5	17.9	26.8	13.8	19.2

When the low-HLB surfactant was used in conjunction with diesel oil, the moisture was reduced to 10.8% at 3 lb/ton and then to 10.3% at 5 lb/ton. Thus, the effectiveness of using a low-HLB surfactant as dewatering aid is not due to the diesel oil that was used as solvent or carrier. As has already been noted, the novel dewatering aids can be used with any other solvent, including short-chain alcohols that do not have as much hydrophobizing effect as diesel oil. In fact, some of the low-HLB surfactants can be used without any solvent, provided that a longer conditioning time is employed.

Table 30 shows the results obtained using a conventional flocculant (Superfloc 16). The moisture was reduced to 18% at 40 g/ton reagent addition, and then increased at higher dosages. The increase in moisture at high dosages can be attributed to the entrapment of water within flocs, as is the case with diesel oil. With the aged coal sample, the performance of the flocculant deteriorated significantly.

Table 31 shows the Buchner filter tests conducted using diamine and dodecylamine hydrochloride, two well-known dewatering aids. The moisture reductions achieved using these high-HLB surfactants were reasonable, which may be attributed to the fact that these cationic

Table 30. Effects of aging Red River coal (0.6 mm x 0) using Superfloc 16.

Reagent Addition (g/ton)	Superfloc 16	
	Fresh	Aged
0	22.7	24.4
10	19.8	23.2
20	19.2	22.8
40	18.0	22.6
80	19.2	22.9
160	20.8	23.2
320	21.8	24.5

Table 31. Table 30 Comparison the Buchner filter tests conducted on Middlefork (0.6 mm x 0) coal using high- and low-HLB surfactants.

Reagent Dosage (lbs/ton)	Moisture Content (%)				
	Reagent Types				
	Diamine	Dodecylamine Hydrochloride	NP-8	HLB-1	HLB-3
0	22.6	22.6	22.6	22.6	22.6
0.5	20.6	19.1	17.1	16.5	16.9
1	20.5	18.6	16.2	15.0	15.3
2	19.7	17.9	14.3	12.6	12.2
3	19.8	17.4	13.2	11.4	11.1
5	20.9	17.1	12.6	10.9	10.2

* 2.5 inch diameter vacuum filter; 2 min drying cycle time; sample size -600 μm; sample crushed, ground and floated using 1 lb/ton kerosene and 100 g/ton MIBC and cake thick 0.45 inch

surfactants are known to adsorb on coal and increase its contact angle considerably. The results obtained using anionic surfactants (not shown here) were not as good as observed with the cationic surfactants. Also given in the table are the results obtained using three low-HLB reagents (i.e., NP-8, HLB-1 and HLB-3). All of these reagents performed substantially better than the high-HLB surfactants.

4.2 PILOT-SCALE TESTING

4.2.1 Overview

After completing the bench-scale tests, a variety of pilot-scale tests were conducted to further demonstrate the capabilities of the novel dewatering aids using continuous and semi-continuous processing equipment. The experiments were conducted using pilot-scale drum, disc and horizontal belt filters. The pilot-scale tests were carried out to (i) establish the effectiveness of the various dewatering aids, (ii) identify optimum reagent dosages, (iii) study the effect of drying cycle time, (iv) verify the effectiveness of using inorganic electrolytes in conjunction with the novel dewatering aids, and (iv) verify the effectiveness of spraying surface tension-lowering reagents during drying cycle time.

4.2.2 Drum Filter Tests

a) *Experimental*

Initially, a 7-inch diameter Westec drum filter was used, and later experiments were conducted using a 10-inch diameter Sepor drum filter. The coal samples used for this work included Red River coal (dense medium cyclone clean coal crushed ground and floated at 28 mesh), Elkview coal (disc filter feed minus 28 mesh) and Pittston's Moss No. 3 coal (dense medium cyclone clean coal crushed and ground and floated at 28 mesh). Five primary and two secondary reagents were used in the test program. Eight different sets of tests, comprising a total of 86 individual tests, were carried out.

b) *Effect of Reagent Type*

Table 32. Comparison of the batch and continuous vacuum filtration tests conducted on Middlefork coal using Reagent HLB-1.

Reagent Addition (lb/ton)	Cake Moisture			
	Buchner Filter (25-inch Hg)		Drum Filter (22-inch Hg)	
	Weight (%)	Reduction (%)	Weight (%)	Reduction (%)
0	25.4	-	29.8	-
1	18.2	28.3	22.3	25.2
2	15.0	40.9	18.9	36.6
3	13.2	48.0	17.1	42.6
5	12.5	50.1	14.8	49%

Table 32 compares the performance of the Westec drum filter with the results obtained using the Buchner filter. The comparison tests were conducted on the Moss No. 3 DMS product, which were crushed, ground to minus 100 mesh, and floated using 450 g/ton kerosene and 100 g/ton MIBC. Reagent HLB-1 was used as dewatering aid. It was used as a 1:2 mixture with diesel oil, whose role is one of solvent or carrier. Both sets of tests were conducted at 2 minute drying cycle time and at approximately 0.46 inch cake thickness. The percent solids in the feed was 17.5%.

The drum produced higher cake moistures than the Buchner filter at all reagent dosages tested, which may be attributed to the fact that vacuum pressure was lower with the drum filter. Nevertheless, the % reductions in moisture with increasing reagent dosage were about the same between the two sets of data given in Table 31.

Table 33 shows the test results obtained using the 10-inch diameter Sepor drum filter on a DMS product from Red River Coal Company, Virginia. It was crushed, wet ground in a ball mill

Table 33. Effect of using Reagent HLB-4 for filtration of Red River (28 mesh x 0) coal at 20-inch Hg vacuum.

Reagent Addition (lb/ton)	Moisture Content (%)			
	Drying Cycle Time			
	45 sec		90 sec	
	HLB-4	HLB-4 & Ethanol	HLB-4	HLB-4 & Ethanol
0	27.0	25.1	24.1	22.3
1	22.2	20.8	19.0	17.4
2	18.6	18.1	16.2	15.3
3	17.4	15.3	15.1	13.9
5	16.3	14.9	14.4	13.4
Cake Thickness (inch)	0.3		0.4	

to minus 48 mesh, and floated using 1 lb/ton kerosene and 100 g/ton MIBC. The percent solids of the flotation product was 18.9%. It was fed directly to the filter without thickening. The tests were carried out by changing drum speed to vary drying cycle time. Also, ethanol was sprayed over the cake at the beginning of the drying cycle time, so that the surface tension of the capillaries water is reduced. Two sets of tests were carried out, one at 45 and the other at 90 seconds of drying time.

The longer drying cycle time increased cake thickness and reduced cake moisture by three percentage points when no reagents were added. Although the longer drying cycle time clearly resulted in lower cake moisture, it should be noted that Reagent HLB-4 removed the same percentage of moisture from the filter cake at both drying cycle times. At 45 seconds and 5lb/ton of Reagent HLB-4, 39.6% of the base test moisture was removed and at 90 seconds 40.0% removed. When ethanol spray was added the percentage moisture removed was increased

Table 34. Effect of using Reagent HLB-1 for filtration of Red River (28 mesh x 0) coal.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-1	HLB-1 & Ethanol Spray
0	17.5	15.8
1	13.8	12.6
2	11.4	10.6
3	9.9	8.5
5	8.4	7.4

by approximately 4% for both drying cycle times.

Table 34 gives another set of test results obtained using the 10-inch Sepor drum filter on the 28 mesh x 0 Red River coal. The sample was prepared in the same manner as described in the preceding example. Reagent HLB-1 was dissolved in diesel oil as a 33.3% solution, and used as dewatering aid. The rotational speed of the drum was adjusted so that 2 minutes of drying cycle time was given. The vacuum pressure was 22-inch Hg, and the tests were conducted with and without ethanol spray.

Table 35 shows another set of test results obtained using the 10-inch Diameter drum filter on the 28 Mesh x 0 Red River coal sample using Reagent HLB-3 as dewatering aid. The test conditions were the same as the preceding example, and the cake thickness was approximately 0.3 inches. Comparing the results given in Tables 34 and 35, Reagent HLB-1 gave considerably better results than Reagent HLB-3. At 5 lb/ton, Reagent HLB-1 gave a 52.0% moisture reduction, while Reagent HLB-3 reduced the cake moisture by 43.6%. It appears, therefore, that HLB-1 is a better dewatering aid than HLB-3 for the Red River coal sample. One should note,

Table 35. Effect of using Reagent HLB-3 for filtration of Red River (28 mesh x 0) coal.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-3	HLB-3 & Ethanol Spray
0	23.6	22.1
1	18.5	16.7
2	16.0	15.3
3	14.2	13.7
5	13.3	12.8

however, that the tests conducted with HLB-3 were carried out about a week after the sample had been prepared. It is, therefore, possible that the difference in the performance of the two reagents may also be attributed to the difference in the surface hydrophobicity of the coal samples.

c) Effect of Electrolytes

The results of the Buchner funnel tests showed that use of appropriate electrolytes can substantially reduce the reagent consumption. To verify this finding, a series of filtration tests were conducted using Al^{+3} ions in conjunction with a couple of different dewatering aids. The tests were carried out using the Westec drum filter.

Table 36 shows the results obtained with the Pittston's Moss No. 3 DMS product. The sample was crushed, ball mill ground to -0.5 mm, and floated using 450 g/ton kerosene and 100 g/ton MIBC. The flotation product, whose %solids was 17.5%, was used as a feed to the filtration tests, which were conducted at 22-inch Hg vacuum pressure, 2 min drying cycle time, and 0.42-inch cake thickness. The Al^{3+} ions were added as alum ($Al_2(SO_4)\cdot 8H_2O$) in the amount of 20 g/ton, and conditioned for 5 minutes before adding Reagent HLB-3 as a dewatering aid and condition the slurry for another 2 minutes. With dewatering aid alone, 5 lb/ton of this reagent is required to reduce the cake moisture from 29.3% to 16.1%. With alum, only 2 lb/ton of dewatering aid was needed to reduce the moisture to 16.1%. When butanol was added in the amount of approximately 2 lb/ton, the reagent consumption was further reduced to 0.5 lb/ton to reduce the moisture to 16.7%.

Table 37 shows the results obtained using another low HLB surfactant (i.e., Reagent HLB-5) for a series of Westec drum filter tests. The tests were conducted on the Middle Fork DMS product, which was crushed, wet-ground in a ball mill to minus 0.5 mm, and floated using 450 g/ton kerosene and 100 g/ton MIBC. The cake thickness was approximately 0.42 inches. As shown, 3 lb/ton of Reagent HLB-5 was required to reduce the cake moisture from 28.4 to 17.3%. With alum, only 1 lb/ton was required to reduce the moisture to 17.6%. With butanol spray, only 0.5 lb/ton of Reagent HLB-5 was needed to achieve 17.2% moisture. At higher dosages of Reagent HLB-5, the cake moisture was reduced to 12% level, which was substantially lower than

Table 36. Effect of using Reagent HLB-3 for filtration of Moss 3 (0.5 mm x 0) coal in conjunction with 20 g/ton Al^{3+} ions and butanol spray.

Reagent Addition (lb/ton)	Moisture Content (%)		
	HLB-3	HLB-3 & Alum	HLB-3, Alum, & Butanol Spray
0	29.3	26.4	22.7
0.5	23.0	18.9	16.7
1	20.2	17.2	15.1
2	18.1	16.0	13.3
3	16.5	14.2	12.2
5	16.1	14.1	11.7

Table 37. Effect of using Reagent HLB-5 acid for filtration of Middle Fork (0.5 mm x 0) coal with 20 g/ton alum and 2 lb/ton butanol spray.

Reagent Addition (lb/ton)	Moisture Content (%)		
	HLB-5	HLB-5 and Alum	HLB-5, Alum & Butanol Spray
0	28.4	25.2	22.6
0.5	23.4	19.6	17.2
1	21.6	17.6	14.9
2	19.5	16.3	13.0
3	17.3	15.7	12.5
5	17.1	15.1	12.2

the base case of 28.4%.

4.2.3 Horizontal Belt Filter Tests

a) Experimental

The objective of this task was to test the novel dewatering aids for the vacuum filtration of fine coal using a pilot-scale horizontal belt filter (HBF). Several different coal samples were tested with various reagent types and at different dosage rates. Effects of using surface tension lowering reagents were also studied.

The coal samples used in this work included Pittsburgh coal (disc filter feed at Bailey Plant screened to obtain 28 mesh x 0 coal), Red River Coal (dense medium cyclone (DMC) product, crushed and ball mill ground to minus 28 mesh) and Elkview Coal (disc filter feed, received as slurry, minus14 mesh). Five different dewatering aids plus one surface tension lowering reagent were tested. The variables studied in the test program included reagent type, reagent dosage, cake thickness, drying cycle time, conditioning time, and spray of a surface

Table 38. Results of HBF tests conducted on Elkview coal using Reagent HLB-4 at 18- to 22-inch Hg vacuum.

Reagent Addition (lb/ton)	Moisture Content (%)		
	Cake Thickness (inches)		
	0.30	0.45	1.0
0	19.5	20.4	23.4
1	15.4	15.9	20.8
2	13.5	14.0	16.6
3	12.0	12.6	14.9
5	10.0	11.6	14.1

moisture reductions for the 0.3-, 0.45-, and 1.0-inch cakes were 48.7%, 43.1% and 39.7% respectively. The 1-inch cake is approaching the thickness of industrial operations, and moisture reductions of this magnitude are significant.

c) Effect of Drying Cycle Time

Two of the most important physical process variables affecting final cake moistures are drying cycle time and cake thickness. Table 39 shows the results of the pilot-scale HBF tests conducted on the Elkview coal sample using Reagent HLB-1 as dewatering aid. The tests were conducted by varying the drying cycle time at a relatively constant cake thickness (0.4-0.5 inches). The drying time was varied in the range of 1 to 4 minutes. The coal sample (14 mesh x 0) was a blend of water-only cyclone and flotation product, which was received at 50% solids. It was diluted to 17.6% solids and fed to the HBF, with dimensions of 1.5-m length and 10-cm width. As expected, moisture reductions improved with increasing reagent dosage. It is somewhat unexpected, however, that the reduction in moisture increased with increasing drying cycle time. This finding suggests that it is a slow process to move the water liberated (or

Table 39. Effect of drying cycle time on Elkview coal using Reagent HLB-1 with a pilot-scale horizontal belt filter.

Reagent Addition (lb/ton)	Drying Cycle Time					
	1 min		2 min		4 min	
	Moisture (%)	% Reduction	Moisture (%)	% Reduction	Moisture (%)	% Reduction
0	22.7	0	20.1	0	19.4	0
1	17.4	23.4	15.7	21.9	15.4	20.6
2	16.1	29.1	13.9	30.8	13.1	32.5
3	14.3	37.0	10.7	37.8	11.8	39.2
5	13.8	39.2	12.5	46.7	9.7	50.0

*18-22 inch Hg Vacuum

a series of filtration tests were carried out using the pilot-scale HBF on the Red River DMC coal, which had been crushed, ball mill ground to minus 28 mesh, floated using 1 lb/ton kerosene and 100 g/ton MIBC. The tests were conducted using Reagent HLB-3 as dewatering aid at 2 min drying cycle time and 0.3-0.4 inch cake thickness. The reagent was used as a 33.3% solution in diesel oil. The results, given in Table 40, show that the moisture was further reduced when the conditioning time was extended. Apparently, the pilot-scale tests require a longer conditioning time than the laboratory-scale tests, which may be attributed to short circuiting of particles in a continuous operation. On the other hand, Reagent HLB-3 was not the most typical dewatering aid used in the laboratory-scale tests. The two minutes of conditioning time was actually determined in laboratory experiments using Reagent HLB-4. It is possible that HLB-3 requires a longer conditioning time than HLB-4. In fact, these two reagents have very different chemistry.

Table 40. Effect of conditioning time on Red River (28 mesh x 0) coal using Reagent HLB-3 in pilot-scale HBF tests.

Reagent Addition (lb/ton)	Conditioning Time (min)	Moisture Content (%)
Control	0	22.4
3 lb/ton HLB-3	0	18.6
	1	15.2
	2	13.0
	4	12.0

*18-22 inch Hg vacuum

e) Testing of Low HLB Surfactants

The pilot-scale HBF was used to test three different low-HLB surfactants. These include HLB-1, HLB-4 and HLB-5. The coal sample used in this series of tests was the Pittsburgh DMS product, which was crushed and wet-ground in a ball mill close-circuited with a 28-mesh screen. The underflow was floated using a pilot-scale Denver flotation machine with 1 lb/ton kerosene and 100 g/ton MIBC. The flotation product with pulp densities in the range of 17.9-21.9% was used directly without thickening for the pilot-scale filtration tests. All of the filtration tests were conducted at 0.4 to 0.5 inches of cake thickness, and the vacuum pressures were in the range of 19-21 inch Hg.

Tables 41-43 show the results obtained using the three low-HLB dewatering surfactants. Also shown are the results obtained using ethanol to reduce the surface tension of the capillary water. Of the three low-HLB surfactants tested, HLB-5 (which had the lowest HLB number) gave the best results. At 3 lb/ton reagent addition, HLB-5 gave 40.7% reduction in moisture, followed by 38.2% reduction with HLB-4 and 37.4% with HLB-1. However, the moisture

Table 41. Effect of using Reagent HLB-4 on Pittsburgh (28 mesh x 0) coal using a pilot-scale HBF.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-4	HLB-4 & Ethanol Spray
0	27.2	23.6
1	20.9	19.2
2	18.4	17.1
3	16.8	16.0
5	16.0	15.2

Table 42. Effect of using Reagent HLB-5 on Pittsburgh (28 mesh x 0) coal using a pilot-scale HBF.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-5	HLB-5 & Ethanol Spray
0	27.3	24.1
1	21.7	18.9
2	17.6	16.7
3	16.2	15.5
5	19.4	18.1

reduction deteriorates at 5 lb/ton of HLB-5 addition. It is possible that at high reagent dosages, coal particles form coagula, which traps water. It shows also that ethanol spray becomes less efficient with increasing reagent dosage.

Table 44 shows another set of pilot-scale HBF test results conducted on the minus 14 mesh Elkview coal sample. At 5 lb/ton, the reduction in moisture was 47.8%. The coal sample was fed to the filter at 17.1% solids. Other test conditions were 2 min drying cycle time, 0.4-0.5 inch cake thickness, and 18-22 inch Hg vacuum pressure.

Table 43. Effect of using Reagent HLB-1 on Pittsburgh (28 mesh x 0) coal using a pilot-scale HBF.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-1	HLB-1 & Ethanol Spray
0	28.6	24.0
1	22.6	19.5
2	18.8	17.3
3	17.9	17.2
5	16.5	15.5

Table 44. Effect of using Reagent HLB-4 on Pittsburgh (28 mesh x 0) coal using a pilot-scale HBF.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-4	HLB-4 + Ethanol Spray
0	20.7	19.4
1	15.5	14.0
2	13.4	12.0
3	11.6	10.8
5	10.8	10.1

f) Testing of Modified Natural Products

Some of the low-HLB surfactants are highly purified reagents for human consumption or for manufacture of cosmetics. Therefore, the costs of using them can be prohibitive. For this reason, low-cost dewatering aids have been developed. One such reagent was synthesized by reacting a natural product (i.e., Reagent NP-7) with a weak acid. The advantage of using this reagent is that it is of low cost, as it was produced from a natural byproduct. Table 45 shows the results of the pilot-scale HBF tests conducted on the minus 28 mesh x 0 Pittsburgh coal. One can

Table 45. Effect of using modified NP-7 on Pittsburgh (28 mesh x 0) coal using a pilot-scale HBF.

Reagent Addition (lb/ton)	Moisture Content (%)	
	Modified NP-7	Modified NP-7 & Ethanol Spray
0	26.9	23.7
1	21.9	20.7
2	18.4	17.2
3	17.3	16.8
5	16.2	15.8

see that the performance of this low cost dewatering aid was as efficient as the low-HLB surfactants.

4.2.4 Disc Filter Tests

a) Experimental

The objective of this task was to carry out dewatering test work on the pilot-scale Peterson disk filter using the novel dewatering aids. Most of these tests were carried out using Pittsburgh coal (DMS product from Bailey plant, CONSOL Energy, crushed and wet-ground in a ball mill to minus 28 mesh). However, a limited number of experiments were also performed using Elkview coal (disk filter feed, combined water-only cyclone and flotation product, 28 mesh x 0, received in slurry form), Red River coal (DMS product from Big Stone Gap, Virginia; crushed, ball mill ground, and floated) and Moss No. 3 coal (DMC product from Pittston Coal, crushed and wet-ground in a ball-mill to minus28 mesh). The variables studied in the test program were reagent type, reagent dosage, cake thickness, vacuum pressures for cake formation and drying cycles, drying cycle time, and addition of surface tension lowering reagent during drying cycle time, etc.

b) Effect of Cake Thickness

Preliminary tests conducted using the pilot-scale disc filter showed that many of the novel dewatering aids tested increased the rate of dewatering by more than an order of magnitude. Unfortunately, conventional vacuum disc filters are not designed to handle materials with fast dewatering rates. With such materials, filter cake becomes too thick under normal operating conditions, in which case a longer drying cycle time is required to achieve low cake moistures. To increase the drying cycle time, it is necessary to reduce the rotational speed of a disc filter. This will result in an increase the cake formation time and, hence, produce even thicker cake, which in turn makes it difficult to achieve low cake moistures.

The problems associated with using conventional disc filters may be illustrated with the test results obtained on the Pittsburgh coal sample. The coal sample was a DMS product pulverized to minus 28 mesh in a 1-foot diameter ball mill. Table 46 shows the results from the pilot-scale Peterson disc filter tests using Reagent HLB-1 as dewatering aid. The samples from the product stream were analyzed independently by Virginia Tech and CONSOL. When no dewatering aid was used, the rate of dewatering was low. As a consequence, a relatively thin cake (0.35-inch) was obtained at a high moisture (24.5% by weight). At 2 lb/ton of dewatering aid, the cake thickness increased to more than 1 inch. Even at the large cake thicknesses, the moisture was reduced to 17.7 and 18.2% at 1- and 1.5-inch cake thickness, respectively. When a small amount of ethanol was sprayed at the beginning of dry cycle time, the moisture was further reduced to 16.8% at 1-inch cake thickness. If the cake thickness was controlled so that a thinner cake could be produced, the cake moisture would have been lower.

Table 46. Results of pilot-scale filtration tests conducted on DMS product pulverized in a ball mill to minus 28 mesh using Reagent HLB-1.

Reagent Dosage (lb/ton)	Cake Thickness (inches)	Moisture (%) Analysis by	
		Virginia Tech	Company
0	0.35	24.5	24.5
2	1.0	16.8[1]	17.7
	1.5	-	18.2

*Ethanol spray

A solution to the problem presented in the foregoing section would be to covert the single vacuum system that is normally supplied with disc filters to dual vacuum system, as has been discussed earlier. This modification made it possible to control the vacuum pressures during the cake formation (or pick-up) time and drying cycle time independently from each other. When dewatering rate is high, one can then have the pressure during the pick-up time lower than that during the drying cycle time. This will allow control of cake thickness, which should help attain low cake moistures at a given drying cycle time.

c) Effect of Reagent Type

Table 47 shows the results obtained on the Pittsburgh coal using Reagent HLB-1 as dewatering aid. At control test, the vacuum pressures were kept at 24-inch Hg during both pick-up and drying cycles. When using the novel dewatering aid, the vacuum pressure at the pick-up cycle was reduced to 18-inches Hg, while the pressure at the drying cycle was kept at the maximum attainable vacuum of 24-inches Hg. This adjustment prevented the cake from becoming too thick. Even then, the cake thickness increased from 0.4-inches at 1 lb/ton of dewatering aid to 0.8-inches at 5 lb/ton. Nevertheless, the dual vacuum system was helpful in reducing the cake moisture to 13.7%, which represents a 52.9% reduction in moisture from the control experiment. When approximately 2 lb/ton ethanol was sprayed the final cake moisture was further reduced as shown in the table. All tests were conducted at 2 min drying cycle time.

Table 48 shows similar results obtained using Reagent HLB-3 as dewatering aid. The tests were conducted on the 28 mesh x 0 Pittsburgh coal sample. Also, the test conditions were the same. As shown, Reagent HLB-3 is as effective as Reagent HLB-1 in obtaining 50% moisture reductions. A key to achieving this goal is to control cake thickness using the dual vacuum system.

Table 47. Effect of using Reagent HLB-1 for the pilot-scale vacuum disc filter tests conducted on Pittsburgh (28 mesh x 0) coal.

Reagent Dose (lb/ton)	Moisture Content (%)	
	HLB-1	HLB-1 & Ethanol Spray
0	29.14	24.02
1	17.48	16.01
2	16.08	14.29
3	14.22	13.15
5	13.73	13.03

Table 48. Effect of using Reagent HLB-3 for the pilot-scale vacuum disc filter tests conducted on Pittsburgh (28 mesh x 0) coal.

Reagent Dose (lb/ton)	Moisture Content (%)	
	HLB-3	HLB-3 & Ethanol Spray
0	27.36	25.05
1	19.25	17.99
2	17.61	15.39
3	14.86	14.06
5	13.77	12.80

The Peterson pilot-scale disc filter has a single disc with a diameter of 24 inches with 2 ft^2 of filter area. The disc is made of a total of 10 pie-shaped removable sectors. It can handle up to 120 lb/hour of coal. In order to minimize the amount of samples required to conduct a set of tests, the initial test work (data given in Tables 47 and 48) was conducted using a single sector. The next set of tests was conducted using four sectors in each test. Table 49 gives the results obtained on the 28 mesh x 0 Pittsburgh coal sample using 4 sectors at 2 min drying cycle time. Unlike the cases of producing the data shown in Tables 46 to 48, the coal sample was floated prior to the dewatering tests using 1 lb/ton kerosene and 100 g/ton MIBC. The dual vacuum system developed in the present work was used, with the bottom sectors at 16-inches Hg vacuum pressure and the top sectors at 24-inch Hg vacuum pressure. The dual vacuum system was used only when a novel dewatering aid (Reagent HLB-4 in this case) was used to increase the dewatering rate. The tests were conducted with and without using ethanol spray to further reduce the surface tension of the capillary water during the drying cycle time. Again, the results show that close to 50% moisture reductions were achieved using HLB-4 alone, with further improvements with the ethanol spray.

Table 50 shows the results obtained using 9 of the 10 sectors in the pilot-scale filtration

Table 49. Effect of using Reagent HLB-4 for the pilot-scale vacuum disc filter tests conducted on Pittsburgh (28 mesh x 0) coal.

Reagent Dose (lb/ton)	Moisture Content (%)	
	HLB-4	HLB-4 & Ethanol Spray
0	23.1	21.3
1	17.3	16.1
2	15.7	13.6
3	13.6	12.6
5	12.1	11.7

Table 50. Effect of using Reagent HLB-4 for the pilot-scale vacuum disc filter tests conducted on Pittsburgh (28 mesh x 0) coal.

Reagent Dose (lb/ton)	Moisture Content (%)	
	HLB-4	HLB-4 & Ethanol Spray
0	35.5	27.5
1	28.3	22.5
2	20.6	19.2
3	18.2	16.7
5	16.7	15.5

tests. Reagent HLB-4 was used as dewatering aid, and the coal sample was the DMS product from the Bailey plant, where Pittsburgh seam coal is cleaned. The coal had been crushed, ball mill ground, and floated using 1 lb/ton kerosene and 100 g/ton MIBC. The dual vacuum system was operated when using the novel dewatering aid, with the bottom sectors at 16-inch Hg vacuum pressure and the top sectors at 24-inch Hg vacuum pressure. The tests were conducted at 2 min drying cycle time. Even under the reduced pressure during the pick-up cycle, the cake thickness increased from 0.4 inches at control to 0.7 inches at 5 lb/ton. Despite the significant increase in cake thickness, the cake moisture was reduced from 35.5% to 16.7%, which represents a 52.9% reduction in moisture. Note here that the baseline moisture was higher than the previous results shown in Tables 46-47. Two possible explanations may be given. First, the use of the 9 sectors decreased the airflow rate per unit area of the filter. Second, the coal sample had been oxidized superficially, as the filtration tests were conducted about a week after the sample had been prepared. The first possibility can be addressed by using a larger vacuum pump, while the second possibility is not a concern in actual plant operation.

Table 51. Pilot-scale disc filter tests conducted on Pittsburgh (28 mesh x 0) coal using modified Reagent NP-7.

Reagent Addition (lb/ton)	Moisture Content (%)	
	Modified NP-7	Modified NP-7 & Ethanol Spray
0	29.6	26.5
1	23.3	20.9
2	20.8	17.4
3	18.0	17.4
5	16.4 (44.6%)	15.3 (48.3%)

Table 51 shows the results obtained using a natural product of modified Reagent NP-7. The tests were conducted on the minus 28 mesh x 0 Pittsburgh coal sample using the pilot-scale disc filter with 16- and 24-inch vacuum for cake formation and drying cycle times, respectively. All 9 sectors were used. The coal sample was a flotation product obtained with 1 lb/ton kerosene and 100 g/ton MIBC. The sample was fed at 18.6% solids, and the cake thickness varied in the range of 0.4 to 0.7 inches depending on the reagent dosage. All tests were run at 2 min drying cycle time. The results show 44.6 % reduction in moisture at 5 lb/ton of dewatering aid. The advantage of using this reagent is that this reagent is inexpensive as compared to many of the pure low HLB surfactants tested in the present work.

d) Effect of Drying Cycle Time

A set of tests was carried out to study the effects of varying drying cycle time. Table 52 shows the results obtained with the Pittsburgh coal sample at 1 and 2 min drying cycle times, respectively. It was a DMS product, which was crushed, ground and floated using 1 lb/ton kerosene and 100 g/ton MIBC. The froth product was used directly without thickening at 17.2%

Table 52. Table 50 Effect of drying cycle time on Pittsburgh (28 mesh x 0) coal using Reagent HLB-5.

Reagent Addition (lb/ton)	Moisture Content (%)			
	Drying Cycle Time			
	1 min		2 min	
	HLB-5	HLB-5& Ethanol Spray	HLB-5	HLB-5 & Ethanol Spray
0	32.8	25.9	30.2	24.9
1	25.6	22.5	22.8	20.8
3	20.6	19.0	18.1	16.6
5	18.4	17.6	16.7	15.2
Cake Thickness	0.45 inches		0.60 inches	

solids. The vacuum pressures were kept at 24-inch Hg at all sectors when no reagent was used. When a novel dewatering aid (Reagent HLB-5) was used, the vacuum at the submerged sectors was controlled at 12-inch Hg while the vacuum was kept at 24-inches Hg during the drying cycle time. The dewatering aid was used in as a 1:2 mixture with diesel oil. The Peterson disc filter was operated at its full capacity with all 10 sectors in place.

At 2 min drying cycle time, the final cake moistures were lower than obtained at the 1 minute drying cycle time. This was achieved despite the substantial increase in cake thickness. At 5 lb/ton, the moisture reduction was 43.9% at 1 min drying cycle time and without the ethanol spray. At the same reagent addition, the moisture reduction was 44.7% after 2 min drying cycle time. It may be stated, therefore, that the novel dewatering aid works better at a longer drying cycle time. At 5 lb/ton, 2 min drying cycle time and 2 lb/ton ethanol spray, the final cake moisture was 40.6% lower than the baseline case.

Thus, the use of the novel dewatering aids may require a longer drying cycle time. An implication for this may be that a disc filter should run at a lower rpm, which in turn suggests a lower throughput. It has been shown, however, that the slowing down the rotation speed results in a substantial increase in cake thickness and, hence, a higher throughput. Therefore, the loss of throughput due to the longer drying cycle requirement may not be significant.

e) Effect of Pulp Density

A series of dewatering tests was carried out at two different levels of percent solids in the feed. The tests were conducted on the Pittsburgh coal sample using the 24-inch diameter Peterson disc filter. It was a DMS product from the Bailey plant, which was crushed and ground to minus 28 mesh, and floated using 1 lb/ton kerosene and 100 g/ton MIBC. The filtration tests were conducted at 13.2 and 22.7% solids using Reagent HLB-5 as dewatering aid. The reagent was used as a 1:2 mixture with diesel oil. In the control test where no dewatering aid was used, the vacuum pressure was set at 24-inches Hg for both cake formation and drying cycle time. When using the reagent, the vacuum pressure was set at 15- and 23-inch Hg for the cake formation and drying cycle times, respectively. All 10 sectors were used to operate the filter at a full capacity, and 2 min drying cycle time was used. The results are given in Table 53.

As expected, cake thickness was higher at the higher percent solids. As a consequence, cake moistures were also higher at the higher percent solids. At the lower percent solids, the moisture was reduced from 22.6 to 13.1%, which represents a 42.0% reduction in moisture. At 22.7% solids, the moisture was reduced from 26.2 to 15.5%, representing a 40.8% reduction in moisture. Thus, feeding a flotation product directly to a vacuum filter may be the best in terms of achieving low cake moistures but at the expense of throughput.

Table 53. Effect of feed solids content on pilot-scale vacuum disc filter with Reagent HLB-5.

Reagent Addition (lb/ton)	Moisture Content (%)	
	13.2% solids	22.7% solids
0	22.6	26.2
1	17.2	20.4
3	14.8	18.0
5	13.1	15.5
Cake Thickness	0.35 inches	0.65 inches

f) Effect of Coal Source

Dewatering tests were conducted using coal samples from different locations in order to investigate the effects of coal source on the performance of the pilot-scale vacuum filter. The coals tested included samples from Elkview Coal, Red River Coal and Moss No. 3. Of these coals, the Elkview coal was one of the most responsive to the various novel dewatering aids. The mine is located in Sparwood, British Columbia, and has a design capacity of 5.2 million tons of clean coal per annum, approximately 35% of which is fine coal. The minus 28 mesh fine coal is cleaned by 2-stage water-only cyclones to remove shale, and the cyclone overflow is screened at 100 mesh. The undereflow is cleaned by flotation, and the froth product and screen overflow are combined and dewatered by vacuum disc filters. The filter discharge, assaying approximately 20% moisture, is further dewatered in a thermal dryer. The coal sample tested here was the feed to the disc filter. It was received is slurry form, and subjected to pilot-scale filtration tests as received.

Table 54 shows the results obtained using Reagent HLB-1 as dewatering aid. The reagent

Table 54. Effect of using Reagent HLB-1 for the dewatering of Elkview coal using a pilot-scale vacuum disc filter.

Reagent Dose (lb/ton)	Moisture Content (%)	
	HLB-1	HLB-1 & Ethanol Spray
0	24.2	20.3
1	16.8	15.2
2	14.3	13.7
3	12.9	12.2
5	13.4	12.9

was used as a 1:2 mixture with diesel. The reagent dosages given in the table represents only the active ingredient. The Peterson disc filter was used for the tests with vacuum pressure for the cake formation cycle at 12-inch Hg and the pressure at the drying cycle time at 24-inch Hg. At 5 lb/ton of dewatering aid, the cake moisture was reduced to 13.4 and 12.9% without and with ethanol spray, respectively. Such low levels of moisture would be sufficient to shutdown the thermal dryer if the technology is implemented full scale.

Several pilot-scale vacuum filter tests were also conducted using coal from the Red River operation. This coal is mined in Big Stone Gap, Virginia, and the company is planning to use the novel dewatering aids tested in the present work. At present, the minus 100 mesh fraction (about 5% of the original feed) is discarded, which represents a significant loss to company’s profit. Approximately 60% of the fine coal discarded is under 325 mesh; therefore, it cannot be recovered by screenbowl centrifuges.

Two tests were conducted on the Red River coal using the pilot-scale disc filter equipped with a dual vacuum system. A DMS product was crushed, ball mill ground to minus 28 mesh, and floated using 1 lb/ton kerosene and 100 g/ton kerosene. The flotation product was used as feed to the pilot-scale filter at 21.1% solids. One test was conducted using Reagent HLB-1 as dewatering aid. The filter was used at full capacity with all 10 sectors. For control tests, 24-inch Hg vacuum was used for both cake formation and drying cycles. For the tests conducted with the dewatering aid, 12- and 24-inch vacuums were used cake formation and drying cycle times, respectively. Cake thickness was in the range of 0.4-0.8 inches, increasing with increasing reagent addition. The results are given in Table 55. At 5 lb/ton, the cake moisture was reduced by 46% as compared to the control test. With the ethanol spray, the moisture was further reduced to 13% at 5 lb/ton, which represents a 50.6% reduction in moisture as compared to the control test results obtained without the ethanol spray.

Another set of tests was conducted on the Red River coal sample (Table 56). The procedures were the same except that Reagent HLB-4 was used as dewatering aid and that cake thickness was controlled in the range of 0.3-0.4 inches using the dual vacuum system. The cake moisture was reduced to as low as 10%. This coal gave much less moisture than the coal tested the previous set of experiments. The most likely reason was that the tests were conducted immediately after the sample preparation, so that the coal sample was not superficially oxidized

Table 55. Pilot-scale disc filter tests conducted on Red River (28 mesh x 0) coal using Reagent HLB-1.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-1	HLB-1 & Ethanol Spray
0	26.3	24.7
1	19.9	17.6
2	17.4	16.2
3	15.9	14.8
5	14.2	13.0

Table 56. Pilot-scale disc filter tests conducted on Red River (28 mesh x 0) coal using Reagent HLB-4.

Reagent Addition (lb/ton)	Moisture Content (%)	
	HLB-4	HLB-4 & Ethanol Spray
0	18.6	17.0
1	14.1	13.4
2	12.2	11.6
3	11.5	10.1
5	10.0	9.1

during storage.

4.2.5 Long-Duration Tests

a) Overview

The primary objective of this task was to test the effectiveness of one of the novel dewatering aids under continuous, steady state conditions. To achieve this goal, a mini-plant processing circuit was constructed within the pilot-plant facilities located on the Virginia Tech campus. The mini-plant included all unit operations for size reduction (optional), screening, cleaning and dewatering of various feed coals. The circuit was designed to operate at a continuous (or semi-continuous) capacity of approximately 50-100 lb/hr. In addition to providing scale-up data, the mini-plant made it possible to show whether other process reagents (such as flotation collectors and frothers) would have unexpected interactions that would be detrimental to the performance of the dewatering aids.

All of the mini-plant tests were conducted using a bench-scale disc filter (2 ft^2 filter area) equipped with the dual vacuum system. It was found that the disc filter system employed in the present work provided superior results, better operational stability, and lower capital costs than the other filters evaluated in the present work. In addition to the disc filter, a bench-scale screen-bowl centrifuge (15-inch long x 6-inch diameter) was installed in the mini-plant circuit. It was included so that comparative data could be obtained. The comparison is important to plant operators since screen-bowl centrifuges have become the standard unit operation for fine coal dewatering in most U.S. preparation plants. The recent popularity of the screen-bowl centrifuges can be attributed to the lower overall capital and operating costs and improved dewatering performance. However, centrifuges often suffer from low coal recoveries (70-80%) compared to filters (>98%). The mini-plant testing of both the disc filter and screen-bowl centrifuge provides a unique opportunity to conduct side-by-side comparisons of the two different mechanical dewatering devices under similar conditions.

The mini-plant was operated continuously for 2-8 hours in each series of tests. This duration varied depending on the availability of feed coal, type of test performed, and the type of data required. Unless otherwise noted, Reagent HLB-1 was employed in the mini-plant tests. Other details related to the design and operation of the circuit are described in the following sections of this report.

b) Experimental

Table 57 lists the four different coal samples that were evaluated as part of the mini-plant test program. The first two samples (Upper Banner and Pittsburgh No. 8) were clean coal products obtained from the dense-medium cyclone (DMC) circuits at operating industrial preparation plants. The samples were collected as relatively coarse products (50x10 mm) to minimize problems associated with surface oxidation of the coals. As has been shown in

Table 57. Coal samples used in the mini-plant tests.

Sample Type	Coal Seam	Acquired Size	Treated Size	Feed Ash	Feed Solids
Dense	Upper Banner	50x10 mm	- 0.6 mm	5.6%	15.0%
Medium	Pittsburgh No. 8	50x10 mm	- 0.6 mm	6.3%	12.7%
Cyclone	Taggart	- 0.15 mm	- 0.15 mm	26.2%	2.7%
Overflow	Dorchester	- 0.25 mm	- 0.25 mm	37.8%	3.3%

laboratory tests, the novel dewatering aids have difficulty in dewatering oxidized coal. For the mini-plant tests, the dense-medium samples were crushed in a jaw crusher to below 5 mm and then pulverized using a ball mill to below 0.6 mm (28 mesh). This procedure produced low-ash feed slurries with solids contents of 12-15%.

In addition to the two clean DMC products, two different samples (Taggart and Dorchester) of natural fines were used in the mini-plant testing. They were obtained from the classifying cyclone overflow streams at an industrial preparation plant. The Taggart seam coal have excellent liberation characteristics, which made it suitable to produce low ash solid fuels (<5% ash), while the characteristics of the Dorchester seam are more typical of steam coals that are common to southern Appalachian coals. The ash contents of both of the classifying cyclone overflow samples were relatively high (26-38%), and the solids contents were relatively low (2.7-3.3%). The top size of the Taggart sample was 0.15 mm (100 mesh), while the top size of the Dorchester sample was somewhat larger at 0.25 mm (65 mesh).

Two different circuit configurations were used in the mini-plant tests. Figure 18 shows

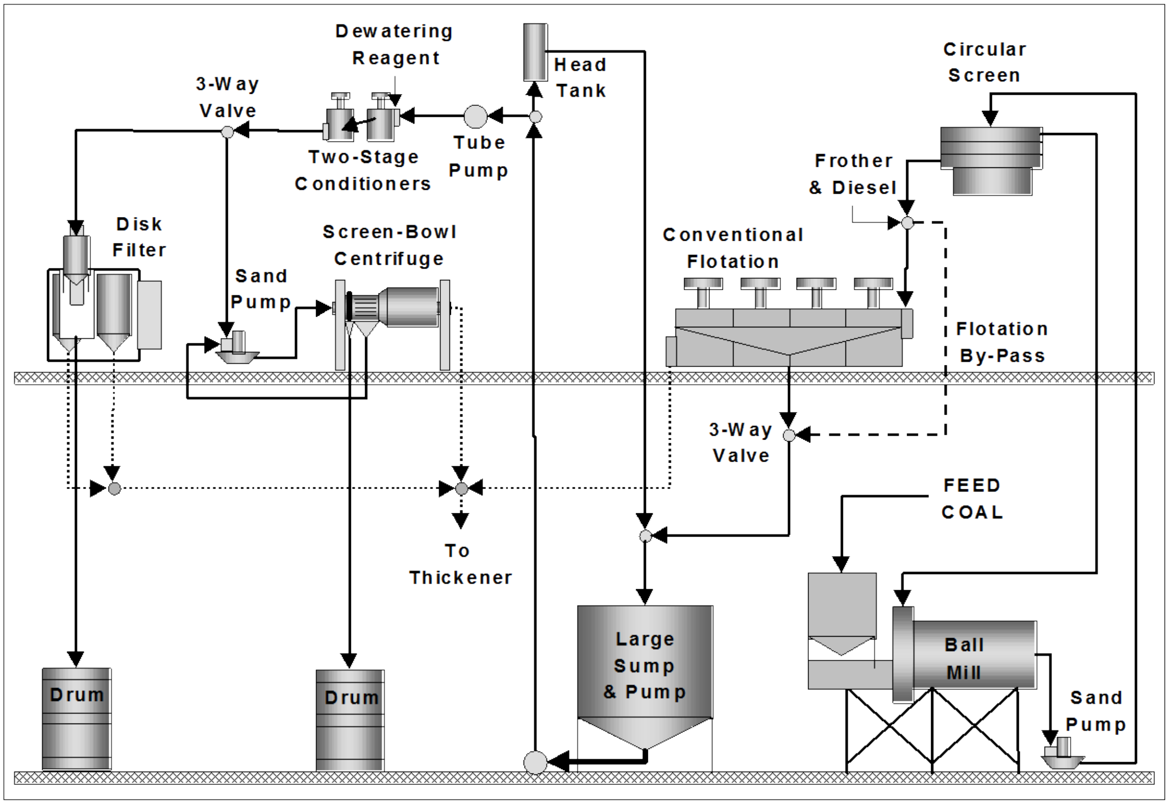

Figure 18. Mini-plant configuration used in the testing of dense medium products.

clean coal product, so that the potential impacts of these reagents on dewatering would be studied. The underflow from the primary sump was circulated by means of a centrifugal pump through a head tank that overflowed back into the sump. This arrangement was used in conjunction with an impeller-type mixer to keep particles in suspension and to minimize bias in the sampling of the slurry in the storage sump. A peristaltic (tube) pump was employed to provide a constant feed rate of slurry from the circulation loop to a two-stage bank of conditioners (i.e., two 5-gallon mixed tanks). A dewatering aid was added ahead of the conditioner by means of a chemical metering pump. The overflow from the conditioners was gravity-fed to either the disc filter or screen-bowl centrifuge, its flow rate was controlled by means of a three-way valve. The dewatered product was collected in drums, while the effluent streams were discarded to the water clarification circuit (i.e., thickener). Due to the high capacity of the screen-bowl centrifuge, many of the tests conducted with this unit operation were performed by recycling the centrifuge products (dewatered cake and bowl effluent) back to the primary feed sump. This arrangement greatly reduced the amounts of the samples required.

Figure 19 shows the second mini-plant configuration that was required to evaluate the two samples obtained from classifying cyclone overflows. In this case, the cyclone overflows were collected in drums and shipped to Virginia Tech. The drums were manually dumped into the secondary feed sump equipped with an impeller-type mixer and pump circulation loop. The secondary sump, which had a capacity of 110 gallons, was capable of storing two drums of feed

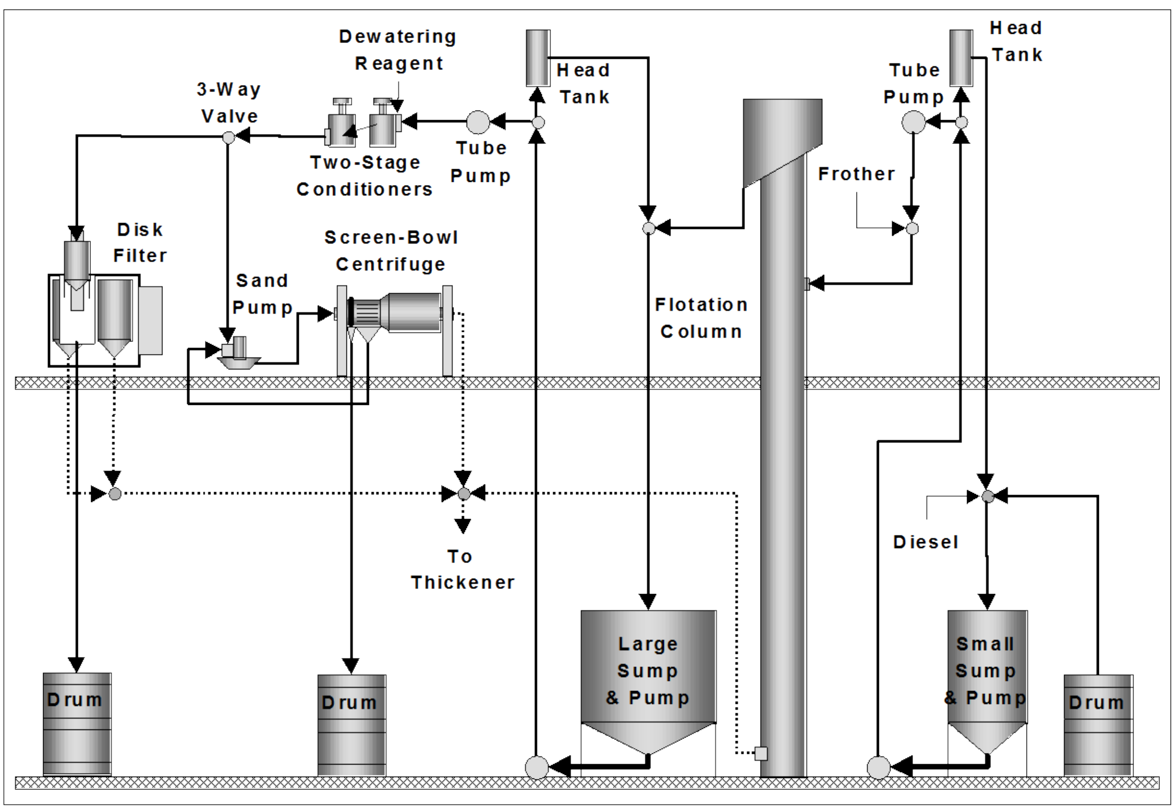

Figure 19. Mini-plant configuration used in the testing of classifying cyclone overflows.

slurry. The material from the circulation loop was fed at a constant rate *via* a peristaltic pump to an 8-inch diameter (15 ft tall) Microcel flotation column. The reject from the column was discarded, while the clean coal froth was collected in the large primary sump that supplied a feed to the dewatering equipment. The filter and centrifuge units employed in the remaining portions of the downstream circuits were identical to those used for the pulverized DMC products.

c) Disc Filtration of DMC Products

Tables 58 and 59 summarize the results obtained from the filtration tests conducted on the pulverized DMC products (i.e., Upper Banner and Pittsburgh No. 8 coals). The test data indicate a sharp reduction in moisture up to a dosage of approximately 2 lb/ton. At this dosage,

Table 58. Results of filtration tests conducted with dense medium products from the Upper Banner seam.

HLB-1 Dosage (lb/ton)	Product Moisture (%)	Product Yield (%)	Moisture Reduction (%)
0	36.50	99.61	0.0
0	35.79	99.56	0.0
0	36.00	99.67	0.0
1	21.58	99.74	40.9
1	22.33	99.78	37.6
1	24.68	99.84	31.4
2	17.95	99.72	50.8
2	18.83	99.86	47.4
2	20.05	99.84	44.3
4	17.40	99.85	52.3
4	16.26	99.88	54.6
4	16.85	99.67	53.2
4	18.10	99.85	49.7
8	15.85	99.70	56.6
8	15.19	99.88	57.6
8	15.00	99.84	58.3

Table 59. Results of filtration tests conducted with dense medium products from the Pittsburgh No. 8 seam.

HLB-1 Dosage (lb/ton)	Product Moisture (%)	Product Yield (%)	Moisture Reduction (%)
0	35.49	99.50	0
1	25.28	99.50	28.8
2	20.59	99.50	42.0
3	18.19	99.50	48.7
5	16.74	99.50	52.8

the average moisture was reduced from about 36.1% to 19.0%. This represents a total moisture reduction of 47.5%. An increase in reagent dosage to 8 lb/ton further reduced the moisture to 15.3%, which represented a 52.8% reduction in moisture. The percentage reductions in moisture in this series of mini-plant tests were consistent with those obtained in the bench-scale tests.

The data also show that total mass yield of filter cake was extremely high (i.e., >99.5%) regardless of the reagent dosage. The high yield indicates that minimal fines were lost through filter media. Note that three test runs were conducted for each filtration experiment conducted on the Upper Banner seam. The replicate tests were used to establish the variability in the experimental data. The lack of significant scatter in the test data indicates that the test results were reproducible.

The second DMC product evaluated in the mini-plant circuit was obtained from the Pittsburgh No. 8 seam. In this case, the coal was pulverized to minus 28 mesh and then treated by conventional flotation. The ash contents of the feed, clean coal and reject products were 6.30%, 4.30% and 42.1%, respectively. These product assays gave a total mass yield of 94.7% for the overall flotation circuit. The dewatering data for the froth product indicate that the total mass yield of filter cake was about 99.5% and was unaffected by the dosage of the dewatering aid (HLB-1). The results again indicate that the impact of using the novel dewatering aid was most pronounced up to a dosage of approximately 2 lb/ton. This dosage of reagent reduced the cake moisture from 35.5% to 20.6%, representing a total moisture reduction of 42%. By further increasing the dosage to 3 lb/ton, the total moisture content could be reduced to nearly half (48.7%) of its original value (i.e., 18.2 *vs.* 35.5% moisture). The moisture was further reduced to 16.7% at 5 lb/ton which was the highest dosage tested.

d) Disc Filtration of Cyclone Overflow

The second series of mini-plant tests were conducted using samples of naturally occurring fines obtained from the overflow stream of classifying cyclones at an industrial preparation plant. In these tests, the run-of-mine coal fines were first subjected to column flotation to remove high-ash clay that would adversely affect the performance of the novel dewatering aid (HLB-1) tested.

The column flotation results are summarized in Tables 60 and 61 for the Dorchester and Taggart seams, respectively. In each case, three sets of samples were taken throughout the one-day test period. The test data show that both coal seams responded very favorably to column flotation. The flotation cell reduced the ash content of the Taggart seam to 4.0-5.6% with a combustible recovery in the range of 97%. The Dorchester seam, which is known to be more difficult to clean, also responded well, with combustible recoveries of approximately 92% and a clean coal ash of 8.0-8.8%. Both sets of column data are considered impressive as can be seen by the high ash contents (87-91%) of the reject streams.

Table 60. Results of column tests conducted on the Dorchester seam (minus 65 mesh).

Test No.	Product Stream	Solid Rate (lb/hr)	Ash Content (%)	Percent Solids (%)	Mass Yield (%)	Combustible Recovery (%)
1	Feed	27.72	37.69	2.95	61.92	91.47
	Tails	10.56	86.05	0.66		
	Product	17.17	7.94	8.51		
2	Feed	33.78	38.13	2.93	63.00	92.84
	Tails	12.50	88.02	0.79		
	Product	21.28	8.83	5.13		
3	Feed	41.09	37.57	3.91	63.46	92.94
	Tails	15.01	87.94	1.04		
	Product	26.08	8.58	5.67		

Table 61. Results of column tests conducted on the Taggart seam (minus 100 mesh).

Test No.	Product Stream	Solid Rate (lb/hr)	Ash Content (%)	Percent Solids (%)	Mass Yield (%)	Combustible Recovery (%)
1	Feed	32.39	26.79	2.72	73.97	97.06
	Tails	8.43	91.73	0.57		
	Product	23.96	3.93	4.18		
2	Feed	32.72	25.20	2.84	77.34	97.55
	Tails	7.41	91.90	0.53		
	Product	25.30	5.65	4.32		
3	Feed	34.26	25.91	2.72	74.62	96.68
	Tails	8.70	90.31	0.57		
	Product	25.56	4.00	4.40		

After upgrading by column flotation, each of the two coals was subjected to dewatering tests using the disc filter. Each series of tests was conducted as a function of reagent dosage, and the tests were repeated three times to confirm the data reliability. The first set of tests was conducted using the coal sample from the Taggart seam. Unfortunately, the sample contained very little feed coal due to the low solids content of the classifying cyclone overflow stream.

Consequently, it was only possible to evaluate two reagent dosages (0 and 2 lb/ton) for the Taggart coal before the feed sample was depleted. In the second test run conducted with the Dorchester seam, twice the amount of sample was collected (i.e., eight 55-gallon drums) for use in the mini-plant tests. The larger amount of sample permitted three different reagent dosages (0, 2 and 4 lb/ton) to be evaluated. The dewatering test data for these samples are summarized in Tables 62 and 63.

Table 62. Results of filtration tests conducted with minus 100 mesh classifying cyclone overflow (Taggart seam).

HLB-1 Dosage (lb/ton)	Product Moisture (%)	Product Yield (%)	Moisture Reduction (%)
0	---	99.56	0
0	30.81	99.52	0
0	31.83	99.52	0
2	26.09	99.38	---
2	26.32	99.34	14.6
2	24.57	99.24	22.8

Table 63. Results of filtration tests conducted with minus 65 mesh classifying cyclone overflow (Dorchester seam).

HLB-1 Dosage (lb/ton)	Product Moisture (%)	Product Yield (%)	Moisture Reduction (%)
0	34.08	98.85	0.0
0	32.13	98.83	0.0
0	35.20	98.85	0.0
2	22.83	99.21	33.0
2	22.84	99.32	28.9
2	23.06	99.34	34.5
4	21.50	99.63	36.9
4	21.34	99.71	33.6
4	21.70	99.77	38.3

Table 62 shows that 2 lb/ton addition of Reagent HLB-4 reduced the moisture content for the Taggart seam from about 31.3% to 25.7%. On average, this result represents a moisture reduction of approximately 18%. Several explanations can be given for the poorer than expected results. First, the feed coal may have become oxidized since the sample was acquired nearly two weeks prior to being used in the test circuit. Oxidation is known to have a detrimental impact on the performance of the novel dewatering aids tested in this project. Second, a sieve analysis of the filter cake showed that nearly 70% of this sample mass was finer than 325 mesh. Thus, a larger dosage of reagent may be required when treating ultrafine particles.

In response to the problems listed above, the Dorchester sample was acquired at the plant site, transferred to the test facility by Virginia Tech personnel, and run through the mini-plant within 24 hours of collection. These steps were taken to minimize potential problems that may occur due to coal oxidation. In addition, modifications were made to the classifying cyclones at the preparation plant so that a slightly coarser sample could be obtained for testing (i.e., minus 65 mesh versus minus 100 mesh). Table 63 shows that this sample responded better to the dewatering aid (HLB-1). The addition of 2 lb/ton of dewatering aid reduced the moisture content of the filter cake by approximately one-third (32.1% average moisture reduction) from 33.8% to 22.9%. The filter cake obtained at this reagent dosage appeared very dry and was easily broken into small "non-sticky" chunks of filter cake. Doubling the reagent dosage to 4 lb/ton produced only marginal improvement in total cake moisture from 22.9% to 21.5%. Therefore, a dosage of 2 lb/ton appears to be most appropriate for this particular coal sample.

An analysis of the filter cakes obtained from the testing of the cyclone overflow products indicated that both the Taggart (70% minus 325 mesh) and Dorchester (60% minus 325 mesh) seam coals were very similar. In spite of the similarity in particle size distribution, the Taggart seam coal did not respond as well as the Dorchester coal to the novel dewatering aid tested. This finding suggests that the poorer dewatering results obtained using the Taggart sample were probably due to superficial oxidation that occurred during sample shipment and storage. Furthermore, these findings indicate that any future evaluations of the dewatering reagents should be conducted at the plant sites using fresh samples.

4.3 FIELD TESTING

4.3.1 Test Program Overview

After successfully completing the bench-scale and pilot-scale tests initiated in Phase I, a diverse set of field tests were undertaken in Phase II using the mobile test modules described previously. The on-site field tests were required in order to provide site specific operational information and scale-up data for the development of the POC plant. The field tests were conducted using samples comprised of different mixtures of coarse and fine coal obtained as flotation feeds (either cyclone overflow or underflow), flotation froth products or filter feeds (blends of flotation and spiral products). As a result, the various samples were tested as-received (if the sample was directly collected from filter feed stream), after upgraded with flotation (if it was cyclone overflow or cyclone underflow), or after blending at different mass ratios. In support of the field testing effort, numerous laboratory tests were also performed. The specific procedures used for conducting these laboratory dewatering tests have been described previously.

4.3.2 Mingo Logan Site

a) Site Description

The Mingo Logan Coal Preparation Plant is located in the counties of Mingo and Logan, WV. This is in Central Appalachia Region. As Arch's principal source of metallurgical coal, the plant produces approximately 3.9 million tons (2006) at a quality of 13,000 Btu/lb and, 1.1 lb SO_2/MM Btu. The preparation plant consists of two independent 800-ton circuits, each provided with separate surge bins to ensure uniform splitting of the plant feed. Each of the circuits consists of heavy media vessels for the 160 x 7.7 mm (6 x 0.3 inch) material, heavy media cyclones for the 0.3 x 16 mesh material, spirals for the 16 x 65 mesh material, and froth flotation for the 65 mesh x 0 material. Dewatering is accomplished through centrifuging for the various size fractions. However, the dewatering efficiency was not satisfactory due to (i) the fine particle size of flotation product, (ii) the screen bowl centrifuges were not capable of capturing the fines, and (iii) the accumulation of excessively stable foam over the screen bowl centrifuges. Also, the issues resulted in high final cake moistures and loss of considerable amount of valuable material that might be recovered by other means. If recovered and dewatered more efficiently, such losses could be turned into profits.

An extensive laboratory and pilot-scale dewatering test program was conducted to study the feasibility of new approaches on more efficient dewatering methods and the recovery of the fine particle size material which reports to the plant's discard stream as a result of centrifuge's lack of fine particle capturing capability. To meet the objectives, exploratory laboratory dewatering tests were conducted to evaluate the performance of various types and dosages of newly developed fine particle dewatering aid technology. Data from the laboratory studies were used to provide technical justification for the pilot-scale test program undertaken at a coal preparation plant using a horizontal belt vacuum filter. Investigations were incorporated the study for the possible utilization of these technologies in industrial applications for fine coal beneficiation.

b) Reagents

The investigation, both laboratory and pilot-scale, was performed with varying amounts of three types of dewatering aids supplied by Mineral and Coal Technologies (MCT), namely Reagents W, U, and V. The characteristics of these reagents were described previously in Table 2. Since these dewatering aids are insoluble in water, they were dissolved in a solvent. In both laboratory and pilot-scale experiments diesel was used as the solvent. The ratio of reagents-to-solvent was optimized in previous studies by varying the individual dosages (0.5 to 3 lb/ton), while maintaining the total blend dosage constant. For this test program, the optimum combination for a given dewatering aid and solvent is one to two (1:2) dewatering aid-diesel ratio. The flocculants, Nalco-9822 and Nalco-9806, were prepared at a 0.09 % solution and used both alone and in conjunction with dewatering aids. After examining various dewatering aid and flocculant combinations and their orders of additions, the best combination was found to be to add dewatering aids first, then to add flocculants. As it is going to be discussed in the following sections, the agitation and mixing intensity play an important role in determining the chemical performance. The dewatering aids require certain amount of mixing intensity; however, it may be excessive shear for a given flocculant. Excessive shear may lead to chain breakage, which reduces the effectiveness of a flocculant for bridging. Therefore, flocculant was added after mixing the dewatering aids; and the new combination was conditioned at a very low intensity for 15-20 seconds.

c) Coal Samples

Table 64. Size distribution of Mingo Logan flotation product.

Size (mesh)	Weight (%)
65	10.95
65X100	9.25
100X150	11.91
150X325	22.25
325	45.65
	100

The dewatering tests were conducted on feeds comprised of three different mixtures of coarse and fine coal feeds. The first series (Series A) was conducted using a fine coal sample from a classifying cyclone overflow that had been cleaned by flotation. The product contained about 23% by weight with approximately 45% finer than 325 mesh material. Table 64 shows the sieve analysis results on flotation product sample.

In some of the experiments, the cyclone overflow sample was also used to produce clean flotation product for dewatering tests. The second series (Series B) was conducted using a mixture of fine and coarse coal. The flotation product sample was mixed with a portion of the spiral product at a ratio of 3:1 (i.e., 75% fine coal and 25% coarse coal) to prepare the dewatering feed slurry for dewatering tests. The solid content of the combination of

Table 65. Size distribution of Mingo Logan mixture sample.

Size (mesh)	Weight (%)
35	17.80
35x100	22.25
100x325	23.25
325	36.71
	100

spiral/flotation product slurry was approximately 27% by weight. The third and final series (Series C) was performed with a feed comprised of 50% coarse coal from the spiral circuit and 50% fine coal from the conventional flotation circuit. Table 65 shows the size distribution of mixed clean spiral and flotation product (at 1:1 ratio) sample. The solid concentration of the slurry was about 25% by weight, while 36% of the solids were minus 325 mesh.

d) Laboratory Procedures

All the samples including the flotation product, obtained in the lab using cyclone overflow sample or collected directly from the preparation plant, and the mixture sample were conditioned with the dewatering aid before the dewatering tests. As stated earlier, a conditioning system is very important for the chemical dispersion and adsorption. The surfactants adsorb on the surface of the solid leading to an increase in the solid/liquid contact angle and a decrease in liquid surface tension. Each slurry sample subjected to mixing to ensure that proper chemical dispersion and adsorption was achieved. The sample was first agitated in a 300 ml Plexiglas cell equipped with a three-blade propeller-type mixer. The mixer was designed to control the mixing strength by adjusting the input current and voltage of its motor. Once the sample was mixed, it was transferred to a Buchner vacuum filter and subjected to dewatering tests. When flocculants were used, proper mixing was supplied. This ensured that that high shear conditions neither degraded nor rendered the flocculant ineffective. Essential test parameters affecting the final cake moisture and filtration performance, such as pressure level, specific cake weights, and filtration time were recorded. Upon receipt, all the samples were subjected to dewatering tests within 24 hours to minimize the effects of aging and artificial oxidation that can change surface properties rapidly and affect the filtration behavior.

e) Pilot-Scale Procedures

Pilot-scale dewatering tests were conducted on feeds comprised of mixtures of coarse and fine coal feeds. Feeds specifically used, for example, are fine flotation product or combinations of coarse spiral and fine flotation products. The coal feeds, flotation product/spiral product coal sample, were reasonably consistent for most test work. The blend sample contained approximately 28% of solids by weight and 12% ash on dry basis. Table 66 provides the particle size and ash analysis results. The particle size is almost uniformly distributed over the range of 18 mesh x 0, but obviously, the fine particles contain more ash. As shown, 68% ash is included in the fine fraction (325 mesh x 0). Table 67 shows the particle size and the ash contents of each

Table 66. Particle size and ash content analysis of Mingo Logan plant spiral/flotation product mixture (on-site samples).

Size (mesh)	Weight (%)	Ash (%)	Ash Distribution (%)
35	19.66	3.74	6.09
35x100	22.54	4.75	8.87
100x325	23.83	8.55	16.87
325	33.98	24.23	68.18
Total	100.00	12.08	100.00

Table 67. Particle size and ash content analysis of Mingo Logan plant flotation product (on-site samples).

Size (mesh)	Weight (%)	Ash (%)	Ash Distribution (%)
35	1.77	2.53	0.48
35X100	15.06	2.08	3.45
100X325	40.22	3.38	15.00
325	42.96	17.1	81.07
Total	100.00	9.06	100.00

size class of the flotation product. Of the sizes, 43% of the particles was passing 325 mesh (-44 μm), and more remarkably, 81% ash was distributed in this fine fraction.

The on-site pilot-scale test work was conducted using a conditioning tank and the pilot-scale horizontal belt filter built by WestTech/Delkor. The spiral/flotation product mixture intercepted from the screen bowl feed pipe was fed to a 35 gallon conditioner. Flotation sample was taken from the distribution box. After conditioned with the dewatering aids under test, a desired amount of coal slurry was then fed to the filter. The total feed rate to the conditioning tank was generally controlled at 13 about gal/min, allowing approximately 3 minutes of conditioning time for dewatering aids.

The dewatering aids, U and V, were used. The flocculant, R9822 from Nalco, diluted to 0.09% solution, was directly pumped to the horizontal belt filter's feed pipe. The belt speed of the filter was adjusted to allow the materials travel over the vacuum zone in the time interval between 65 to 184 seconds, which enables to investigate the effect of different cake thicknesses under certain filter feed rate, and of different dry cycle times. The cake sample was taken for moisture analysis periodically from the ending point of the belt when a steady-state was achieved after the test parameters were changed.

f) Laboratory Test Results (Series A – Fine Coal Only)

In this series of experiments, Mingo Logan's clean coal product from the conventional flotation circuit and cyclone overflow samples were used. The first dewatering tests were conducted to determine whether the flotation product coal samples provided by Mingo Logan Preparation Plant would respond well to the addition of the novel dewatering aids. The preliminary results showed that with the addition of dewatering aids, it is possible to reduce the final cake moisture content of fine coal cake by about 20%, while also increasing the rate of dewatering. The surface moisture was reduced down to about 19% using 3 lb/ton W, where it was approximately 23% for control tests at about 8-11mm cake thickness. As many factors influence the filtration performance, particle size distribution and corresponding ash contents were the dictating parameters. Considering the amount of material under 325 mesh size in the flotation product sample, a portion of ultra-fine particles was removed from the sample via desliming. The tests results on the deslimed sample showed that moisture was further decreased to 16.7 % at the same W dosage. This is another significant moisture reduction from a baseline of 21%. This moisture reduction in both baseline and with reagent tests is achieved by desliming of the ultrafine fraction that results in more freely draining filter cake capillaries. This also prevented the fines from forming an impermeable layer which might be positioned on the top of the cake.

The screen analysis results also showed that 81% of the ash was in the minus 325 mesh size fraction. This material, which consists of clays and slimes, is hydrophilic in nature and this affects the dewatering performance negatively. The use of flocculants may be another way to compensate the negative effects of the ultrafine particles. The principle of using of flocculants is to bring the fine particles together in the coal slurry and create looser packing in the filter cake. This loose packing results in larger capillaries between the aggregates and a more porous, permeable cake. This allows a rapid drainage of water from these voids, which, in turn, increases the filtration rate. To investigate the effects of flocculants on dewatering kinetics, a series of tests was conducted. To optimize the dosage, various amounts of flocculant were tested, from 5 g/ton to 75g/ton. It was determined that 25 g/ton was the most appropriate flocculant amount when being used alone or in conjunction with other chemicals. The test results showed that in most cases, the addition of flocculant did not improve the final cake moisture, due to the water trapped inside the flocculants. Instead, the dewatering kinetics increased significantly i.e., 30% to 75%.

Another way of lowering the moisture may be to clear out the excessive amount of ash-forming minerals in the fines. To investigate this idea, prior to laboratory dewatering tests, the plant's clean coal product was subjected to another step of flotation using 1 lb/ton (454g/t) V (in Diesel (1:2)) as collector and 100 g/t MIBC as frother. The particle size analysis results showed that the 37.6% of the re-floated sample was minus 325 mesh. Dewatering test results showed after its addition, Reagent W, at about 3 lb/ton, can reduce the moisture to 15.5%, where the baseline was approximately 20%. In addition, the dewatering kinetics of the coal sample was also increased by 50% as a result of the increased hydrophobicity.

As stated earlier, the surfactant adsorption is very important so that it can lead to an increase in solid/liquid contact angle and a decrease in liquid surface tension. For this reason, it is very important to have an effective conditioning system. To investigate and optimize the effectiveness of the dewatering aids and their performances, two series of filtration tests were conducted at various mixing intensities and times. Table 68 gives the laboratory test results obtained on the flotation product sample using W at 3 lb/ton at about 20-24 mm cake

Table 68. Effect of mixing intensity and conditioning time on Mingo Logan flotation product (0.61 bar vacuum and 3 lb/ton reagent W).

Speed Level	Moisture @ specified conditioning time	
	1 min	2 min
0	30.02	30.02
Low	25.98	25.29
Medium	25.45	23.91
High	20.26	18.66

thicknesses. As shown, the moisture reduction was substantially improved when mixing intensity was increased. The use of W at 3 lb/ton reduced the filter cake moisture from baseline value of 30.02% to 25.98% and 25.45% when using low and medium-energy agitation at one minute, respectively. The cake moisture was further reduced to 20.26% moisture when using high-energy agitation at the same reagent dosage of 3 lb/ton. The moisture reduction showed a similar trend, but improved final cake moistures were obtained when the agitation time was increased to two minutes. The final cake moisture was reduced to 23.91% and 18.66% using medium and high-energy conditioning, respectively, at the same dewatering aid dosage. It was found out that two minutes of conditioning at high intensity mixing was optimum. Beyond two minutes of conditioning, there was no change in the residual moisture of the cake. These results clearly demonstrate that the importance of proper conditioning when using the novel dewatering aids.

In the light of the results obtained in the initial laboratory filter tests, using dewatering aids were believed to be a promising method because it could not only remove water but also increased the filtration kinetics. To evaluate the filtration performance in detail as a function of cake formation time, dry cycle time, and specific cake weight in the absence and presence of different types of dewatering aids, a series of vacuum filtration tests was carried out. It is very informative to know the effects of these physical parameters for scale up of using chemicals, optimization of total filtration time, production rate, and, consequently, the final cake moisture. These parameters would also provide general suggestions to meet the desirable filtration efficiencies.

The dewatering tests were carried out using a fixed amount of dewatering aids (3lb/ton) and flocculants (25g/ton) after the optimum dosage was determined. The tests were conducted at a fixed setup vacuum pressure and pre-measured amount of slurry was added to the Buchner funnel for dewatering tests. The dry cycle times were changed randomly, varying from 14 to 120 seconds. The cake weights were changed by increasing the slurry volume from 50 ml to 300 ml. The cake formation time, dry cycle time, cake weights, amount of filtrate, and solid contents for each test were recorded for production rate calculations. The filter cake production rates were investigated in the absence and presence of dewatering aids and flocculants.

Figure 20 is a plot of the final cake moisture percent as a function of pounds of dry solids per hour per square foot, or the production rate. The filtration kinetics without the surfactants and flocculant addition were observed to be very slow, and the residual cake moisture of the cake was found to be in the range of 31-36% at about 60-100 lb/hr/ft^2 throughput, which corresponds

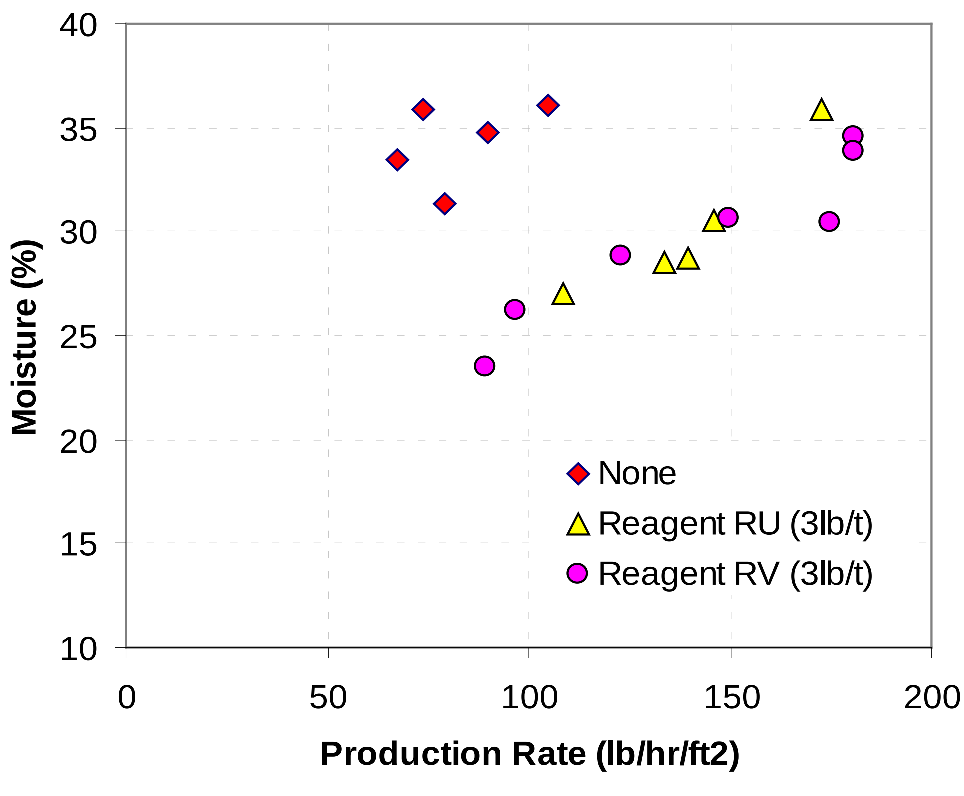

Figure 20. Normalized product rate (lb/hr/ft^2) versus cake moisture.

to approximately 5-20 mm cake thickness. The filtration time used for the calculations was the sum of cake formation time and dry cycle time. In the absence of dewatering aids, a production rate greater than 100lb/hr/ft^2 was found to be impractical, as achieving a dry cake was no longer possible. There was also segregation of particles in the filter cake and a considerable amount of solid loss – up to 10% - in the filtrate. As expected, the cake moisture increased proportionally with increased production rate; however, the results showed that using dewatering aids lead to very significant reductions in the final cake moistures and increase in the filtration rate by several times. The addition of reagents outperformed baseline to a great extent because it gave the same or lower cake moisture at a higher production rate with almost 97% to 99% solid recovery. Also given in the Figure 20, Reagent U and V produced very similar results.

The results obtained with the plants flotation product showed that moisture values as low as 25-30% at improved throughputs – as high as 100-150 lb/hr/ft^2 – could be achieved. When the production rate was further increased at the expense of final cake moisture, it became possible to increase the throughput almost 2.5 times (compared to baseline) in the presence of dewatering aids. The test work demonstrated that the use of dewatering aids provided an outstanding dewatering performance on Mingo Logan's flotation clean coal product and produced significantly lower final cake moisture values, as well as a higher rate of dewatering, and improved the filtration efficiency.

If the other operating parameters are kept constant, the effectiveness in productivity of filtration is related to the time required to complete a full solid-liquid separation cycle, consisting of cake formation time and dry cycle time. The correlation between the cake moisture and total filtration time, normalized with cake weight, is shown in Figure 21. Test results showed that when the dewatering aids and flocculant were used in a combined manner, the time consumed

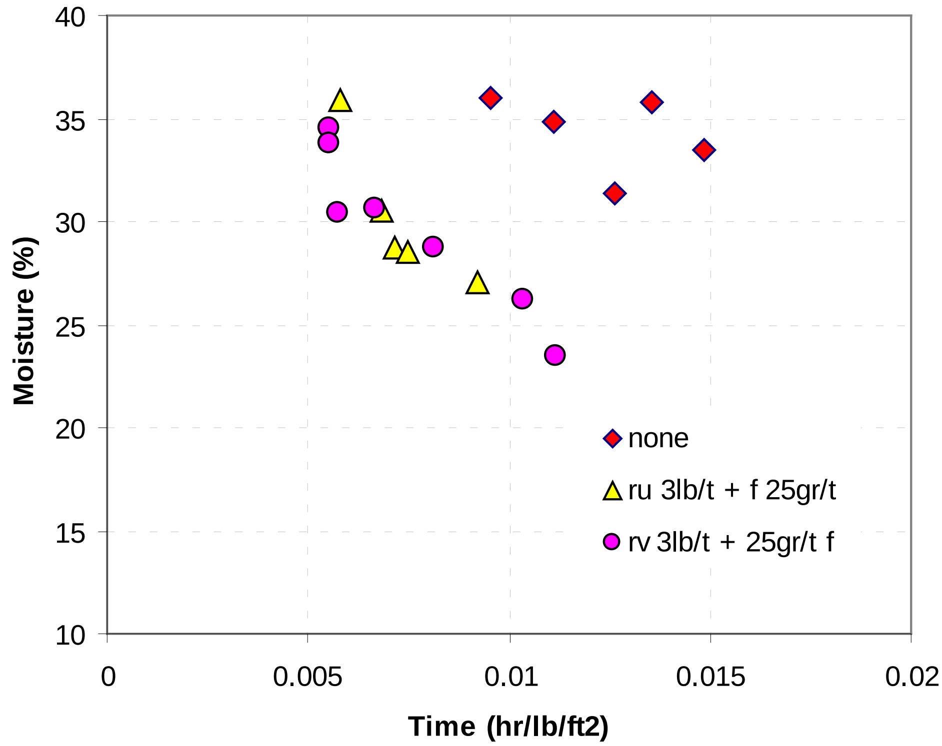

Figure 21. Cake moisture versus normalized drying cycle time.

for filtration of a given amount of material was reduced, which, in turn, increased the production rate by several factors. There was also significant moisture reduction in the presence of dewatering aids; however, it appears that even when the filtration time was increased in the absence of dewatering aids, the reduction in final cake moisture content was very small. The results suggest that there is an increase of 100% in solids throughput at a fixed moisture value or 5-10% moisture reduction at approximately the same solid throughput.

Figure 23 shows the effect of chemicals on cake formation time and, eventually, the filtration kinetics. A strong correlation was observed between cake formation time and the throughput of the filter. In the presence of Reagent U and Reagent V, even at higher specific cake weights, the formation times were much shorter than what was seen in the baseline tests.

Approximately 100-140 seconds were required to produce 3.5-4.5 lb/ft^2 of coal in baseline tests; however, for the same coal production, using dewatering aids, approximately 30-60 seconds was needed. Above 5 lb/ft^2, obtaining a baseline value was impossible because the filter time was impractically prolonged, while 6-7lb/ft^2 of coal could be produced when using dewatering aids. The test data indicated that cake formation time was a significant parameter in throughput and residual cake moisture; however, formation time can be altered by using dewatering aids. In addition, in daily practice, decreased cake formation time allows a longer dry cycle time to complete the full filtration operation, increasing the throughput of the filter at a lower final cake moisture.

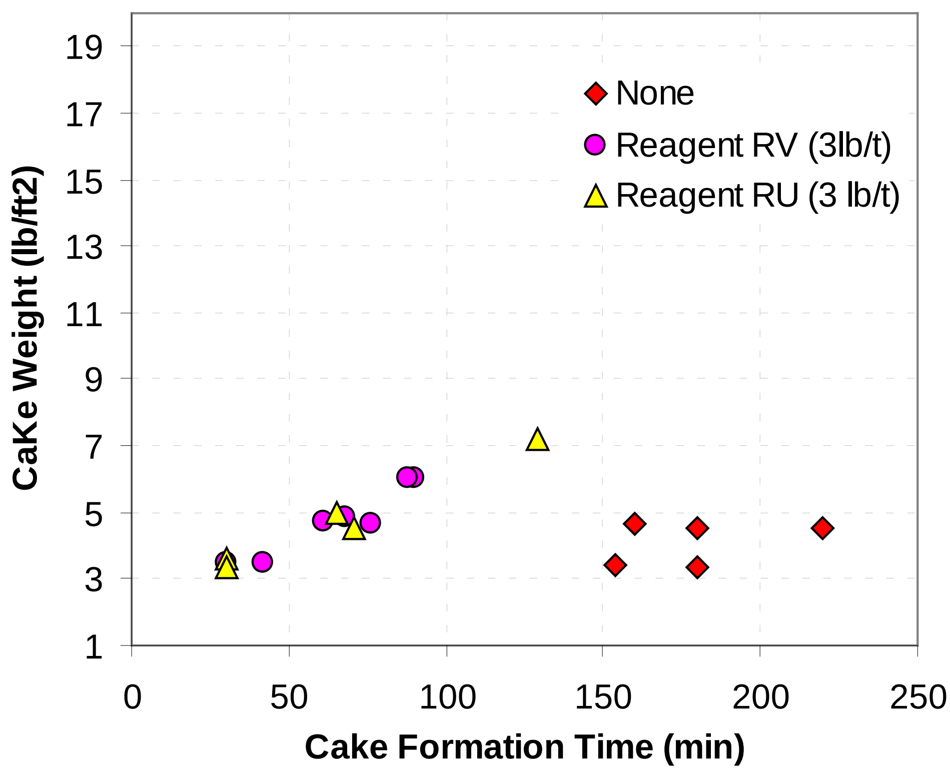

Figure 23. Cake moisture versus cake formation time.

After completing the tests using the fine clean coal sample from Mingo Logan, a second set of tests were performed using a fine cyclone overflow sample that had been subjected to froth flotation to minimize the adverse effects of high ash content. The tests were conducted by floating the cyclone overflow sample using diesel (300 gm/ton) as collector and MIBC (150 g/ton) as frother. Both conventional laboratory-scale flotation and bench-scale column flotation equipment were used to produce ash-free clean coal. Both products were tested in the absence and presence of dewatering aids.

The first series of clean coal samples were produced using lab scale Denver cell. The solid concentration of the product was about 15% by weight, while maintaining approximately 44% of minus 325 mesh particle size. The test results on this sample showed that the control cake moisture was 25.31%, and with W addition at about 3 lb/ton, the final cake moisture was reduced approximately to 19.5% at 7-10 mm cake thickness. Another set of flotation tests was run on the plant's flotation product to discard ash-forming minerals, and the product of the flotation tests was subjected to the same type of dewatering tests. The results indicated that the floated cyclone overflow and re-floated samples, using the laboratory-scale Denver flotation machine, gave considerably better results compared to the plant's as-is flotation product sample. This may be the result of discarding ash-forming minerals and removing ultra-fine particles more efficiently from the coal slurry compared to plant operation.

Using a laboratory scale column flotation unit produced another series of clean coal samples. In this set of tests, the flotation feed/cyclone overflow sample was floated using 300 g/ton diesel as collector and 100 g/ton MIBC as frother. The solid concentration of the column flotation product was about 10% by weight, and approximately 39% of particles were minus 325 mesh size. The dewatering tests were conducted using a 2.5inch-diameter Buchner funnel at 20 inch Hg set-up vacuum pressure with 2 minutes drying cycle time and about 11 mm cake thickness. Reagents U and V were used as dewatering aids with several of dosages ranging from 0.5-3 lb/ton. Vacuum filtration results on both column and Denver unit clean coal products showed that Reagent V alone was capable of both reducing the moisture and cake formation time significantly; therefore, flocculant addition was unnecessary. The cake formation time for control tests was 94 seconds, whereas it was approximately 10 seconds in the presence of the dewatering aid, Reagent V. The presence of dewatering aids also made it possible to reduce the final cake moisture content of the cake by about 35%. The dewatering test results from the column flotation's clean coal product are represented in Table 69. The final cake moisture for control tests was approximately 22.80%. With V addition, the moisture was reduced to 14.91%, and with U addition, the cake moisture was lowered to 14.55%, giving approximately 36% overall moisture reduction. When the dry cycle time was lowered to one minute, the baseline was 26.9%, and with about 1 lb/ton U and V addition, the moisture was lowered down to 20.44% and 17.95%, respectively.

The influence of cake thickness on final cake moisture was also investigated. To study the effect of dewatering aids on a thicker filter cake, the thickness was increased to

Table 69. Effect of reagent addition on Mingo Logan flotation feed sample (cleaned using bench-scale column).

Reagent Dosage (lb/ton)	Moisture (%)	
	V	U
0	22.80	22.80
0.5	16.51	19.20
1	16.99	17.02
3	14.91	14.55

approximately 20 mm by increasing the slurry volume that was added to Buchner funnel. As expected, thicker cake resulted in increased baseline moisture and cake formation time. The addition of U and V at 3 lb/ton lowered the cake moisture to 17.81% and 15.08%, respectively, from the baseline moisture 24.8% with 2 minutes of dry cycle time. These results correspond to 22% and 33% total moisture reduction. The test results indicated that even with thick cake, dewatering aids showed improvements with final cake moisture.

Another set of tests was performed to investigate the effect of flocculant on the dewatering of the laboratory column flotation product (Table 70). The same procedure was applied, and the same types of collector, frother, and dosages were used to produce clean coal. For this series of dewatering tests, the moisture results for the baseline tests were considerably higher than what was obtained previously. This might be attributed to the excessive amount of fine material associated with this fine fraction. The baseline values for the tests were around 27.30% at approximately 10 mm cake thickness. The addition of flocculant alone at about 25 g/ton was capable of reducing the final cake moisture to 20% and decreasing the cake formation time from 120 seconds to 25 seconds at about 7-9 mm cake thickness and 20 inch Hg vacuum pressure. For lower vacuum pressure, about 15 inch Hg, flocculant additions were capable of reducing the moisture to 23% from 28.1%, and significant improvement in dewatering kinetics was present, as well. The cake formation time was lowered significantly to 26 seconds from 310 seconds. The final cake moisture was also lowered down to 15.52% and 17.02% at addition of 5 lb/ton U and V, respectively, in conjunction with flocculant addition. These results show that, in terms of producing a cleaner product, column floatation is superior to the Denver test. The results illustrate how dewatering aids can lower the final cake moisture significantly.

Table 70. Effect of flocculant and dewatering aid addition on Mingo Logan floation feed sample (cleaned using bench-scale column).

Reagent (lb/ton)	Flocculant (lb/ton)	Moisture (%)	
		V	U
0	0	27.30	27.30
0	25	19.99	19.99
0.5	25	18.78	18.55
1	25	19.66	17.41
3	25	19.99	16.55
5	25	17.02	15.52

g) Laboratory Test Results (Series B – Mixture of 75% Fine and 25% Coarse)

A limited number of dewatering tests were conducted using a mixture of 75% fine coal and 25% coarse coal as a function of various dosages of W, U and V. The solid content of the combination of spiral/flotation product slurry was around 27% by weight and it was subjected to dewatering tests using novel dewatering aids at various dosages. The test results showed that the final cake moisture was about 16% to 17% when dewatering aids were added at about 1lb/ton dosage. The moisture content for the control test was approximately 20% at about 8-11 mm cake thickness. Tests were also performed in the presence of flocculant alone and in conjunction with dewatering aids; however, increases in the dewatering kinetics were close to those obtained with reagents. Even though the preliminary dewatering test results were promising, due to the Plant's request dewatering tests were focused more on flotation or flotation/spiral mixture samples. Thus, no further tests were done.

h) Laboratory Test Results (Series C – 50% Mixture of Fine and Coarse Coal)

The fine and ultra-fine size fraction of a stream to be dewatered is very influential on dewatering, which affects the filtration performance. In the dewatering of such particles, lower moisture percentages are always desirable; however, mechanically, there is a limit to the level of moisture achievable, regardless of operating parameters, such as the length of the filtration time or the applied pressure. In filtration, most of the water is held between and on the surfaces of the particles. Finer particles will create a larger overall surface area and smaller inter-particle openings, which, in turn, keep more water than coarser size distributions do. As the capillary filtration model suggests, a filter cake consists of numerous capillaries with a range of diameters. When the capillary radii are increased, the filtration rate should also increase. This can be achieved either by desliming or coarse particle addition into the stream or, in this case, into the slurry. As mentioned earlier, when the coal slurry was partially or fully deslimed the drainage of the filter cake was much more efficient, thus lowering the final cake moisture and increasing the kinetics. Blending coarse particles with fine particles will also increase the capillary radii and improve the filtration performance. In some coal preparation plants, this is already applied to increase the dewatering efficiency as an alternative to other means. In fact, currently, Mingo Logan Coal Preparation Plant has been blending spiral clean coal (1-0.15 mm in diameter) with the finer flotation clean product (less than 0.15 mm in diameter) at about 1:1 ratio before filtration in dewatering centrifuges.

The preliminary dewatering test results using W, U and V on one-to-one spiral/flotation blend product showed that significant cake moisture reduction can be obtained using novel dewatering aids by about 20.5-28%, while also increasing the rate of dewatering so much that the formation time could be reduced by as much as 50%. A set of three preliminary tests was conducted to investigate the effectiveness of the dewatering aids (Table 71). The dosages used were 1, 3 and 5 lb/ton. The baseline tests produced an average of 19% final cake moisture at about 8mm cake thickness. Even at low dosage, 1lb/ton, when W, U and V was used, the cake

Table 71. Effect of reagent addition on dewatering of Mingo Logan mixture sample (50% flotation product and 50% spiral product).

Reagent Dosage (lb/ton)	Moisture Content (%)		
	Reagent W	Reagent U	Reagent V
0	19.0	19.0	19.0
1	15.6	14.4	14.8
3	15.7	13.8	14.9
5	15.1	13.7	14.3

moisture was decreased to 15.6%, 14.4%, and 14.8%, respectively, and the filtration kinetics were increased by 30-50 %. Of the reagents and dosages being tested, U was the most effective for the cake moisture reduction. In this case, the addition of 5 lb/ton Reagent U reduced the cake moisture from 19.00% to 13.7% which corresponds to 20-30 % overall moisture reduction.

Similar dewatering tests were conducted to evaluate the filtration performance with different types of dewatering aids as a function of filtration time and specific cake weight. Filtration tests were done at the same vacuum level; however, the dry cycle times were varied from 15 to 100 seconds. U and V were prepared at 2:1 active solvent ratio, and the dosage amount was fixed at 3 lb/ton. The coal slurry was conditioned with the dewatering aids for 2 minutes. Then, flocculant was added at a 25g/ton dosage and conditioned at a very low intensity for 15-20 seconds. Tests were conducted on a pre-measured amount of slurry to differentiate the specific cake weight. This, in turn, varied the cake thickness from 5 to 20 mm. The cake formation time, dry cycle time, and cake weights were recorded for each test. The filter production rate was plotted as pounds of dry solids per hour per square foot, and the filtration time used for filtration rate calculations was the sum of cake formation time and dry cycle time.

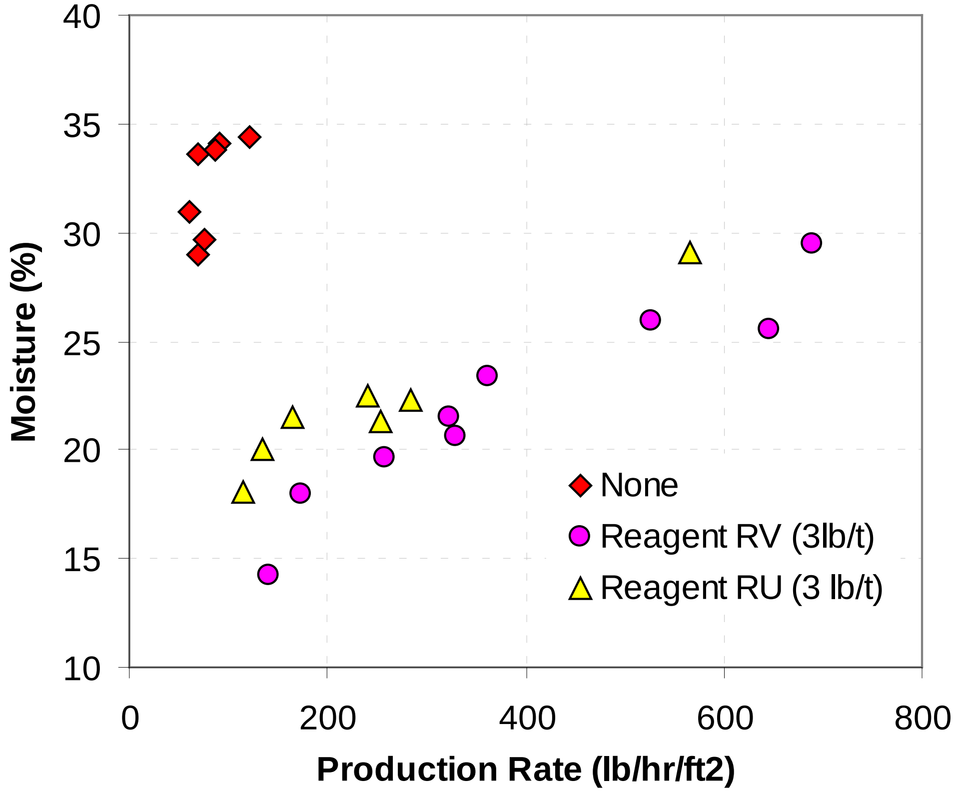

Figure 24. Cake moisture versus normalized filter cake production rate.

Figure 24 shows the relationship between production rate and cake moisture for the spiral/flotation mixture sample.

The baseline tests were conducted without reagents and produced a cake of 29-34% moisture at about 5-20 mm thickness, yielding a production rate in the range of 60-120lb/hr/ft^2. Throughput greater than 120 lb/hr/ft^2 was found to be impossible because the cake formation time was being prolonged to impractical limits. The additions of V and U, along with 25 g/ton flocculant, surpassed the baseline throughput to a great extent. The usage of Reagent V reduced the final cake moisture to 14-18%, and the usage of Reagent U reduced the final cake moisture to 18-21%. The production rates were also increased by multiples of 1.5 to 2.5, corresponding to 150-190 lb/hr/ft^2. The results also showed that the throughput could be increased at the expense of cake moisture. When the production rate was increased to the 200-400 lb/hr/ft^2 range, the cake moisture increased to 20-25%; however, final cake moistures were still 5-15% lower compared to baseline. Further increases in production rate were also achieved i.e., the 550-650 lb/hr/ft^2 range was achieved at a 25-30% moisture range. It was obvious that the addition of reagent outperformed baseline, and it was possible to increase the production rate with significantly lower final cake moisture values. The results also showed that the use of V represented better performance than U because it gave higher filtration rates at the same, or lower, final cake moisture values.

Further data evaluation was carried out on the effect of filtration time on final cake moisture. Figure 25 shows the correlation between the cake moisture and total filtration time (normalized with cake weight) in the absence and presence of dewatering aids. In the baseline tests the total filtration time varied between 130 and 360 seconds. On the other hand, the total filtration times in the presence of U and V were 65 to 120 seconds and 50 to 118 seconds, respectively. As seen, the dewatering aids that were tested decreased the filtration time, which, in turn, produced higher production rates. It is also noteworthy that these outstanding times were achieved while maintaining very low moisture levels.

The test data also indicated that cake formation time is an important factor in determining dry cycle time and, thus, cake moisture and throughput, as well. Figure 26 shows the effects of dewatering aids on cake formation time and, eventually, the filtration kinetics. The formation times were found to be much shorter in the presence of Reagents U and V. When used with a flocculant, even at higher specific cake weights, the formation times were shorter than those that were recorded during the baseline tests.

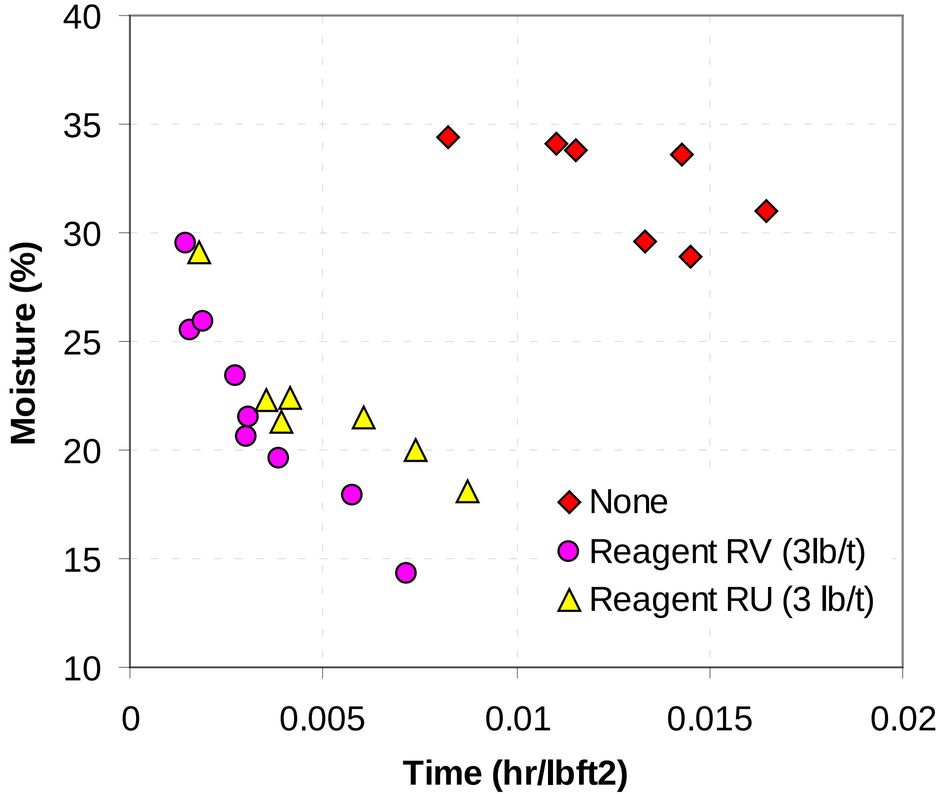

Figure 25. Cake moisture versus normalized filtration time.

As seen in Figure 26, only 10-15 seconds were required to produce 4.5 lb/ft^2 of coal when dewatering aids were used; however, in baseline tests, approximately 100-120 seconds were needed for the same coal production. When the cake weight was increased to 7 lb/ft^2, the cake formation time was 20 seconds using dewatering aids, where it was 340 seconds for baseline test. Cake weights above 5 lb/ft^2 were found to be impractical for dewatering in the absence of dewatering aids. Conversely, it was still possible to produce a cake weight of 11 lb/ft^2 while maintaining a short cake formation time. The results showed that the use of dewatering aids decreased the cake formation time by several multiples. The usage of dewatering aids also

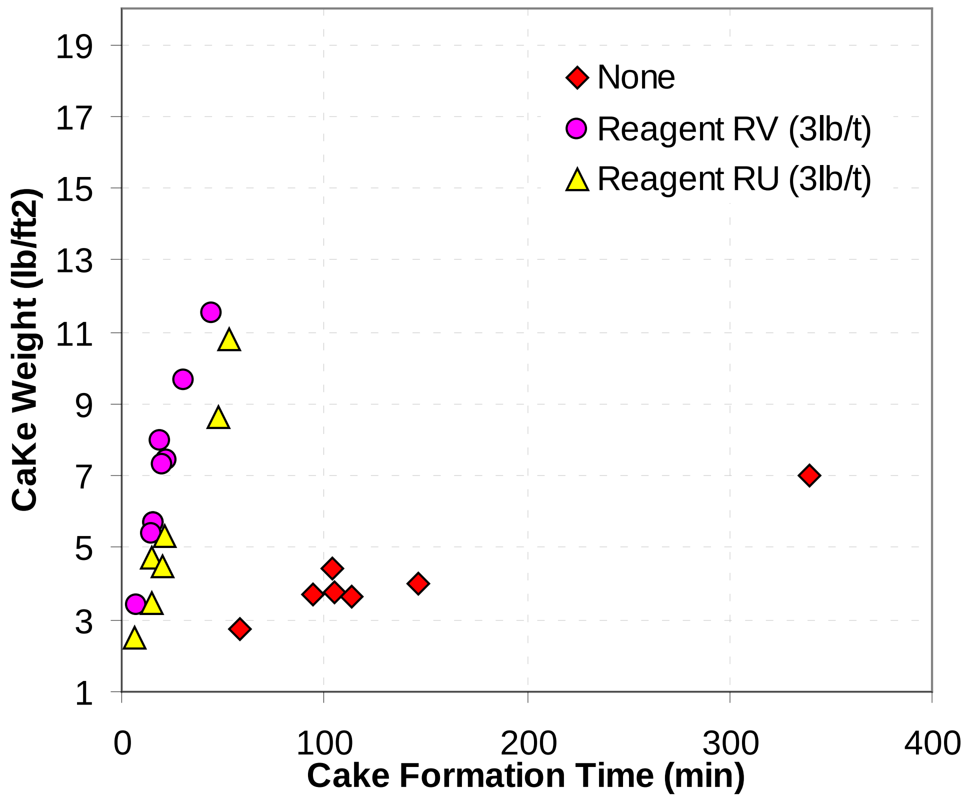

Figure 26. Cake moisture versus total cake formation time.

substantially improved the throughput. This is a strong indication that in the presence of dewatering aids, more material can be treated.

i) Pilot-Scale Test Results (Series A – Fine Coal Only)

The pilot-scale dewatering tests were conducted using two feeds intercepted from the plant's main stream (i.e., flotation concentrate and blended products). The first set of tests focused on dewatering of the flotation product, which is very difficult to dewater because of the amount of fine size particles and high ash content. As mentioned earlier, nearly 43% particles of this product was passing 325 mesh (-44 μm) and contained 81% ash. The tests were conducted over a range of filter feed rate that typically varied at 2, 3, 4 and 7 gal/min of coal slurry. The preliminary analysis showed that of the feed rates, 4 to 7 gal/min were at optimal ranges for the filtration tests and also adequate to produce 0.33 to 1.0 inch cake thicknesses. The pilot-scale test procedure was same as the mixture sample tests except that the flotation product was intercepted from the distribution box pipeline.

The first set of dewatering test were conducted with a pilot-scale horizontal belt filter (HBF) at the feed rate of 4 gal/min Baseline tests provided a filter cake with 31~32% moisture. With 25 g/ton flocculant addition to the feed, even though a slight decrease in cake formation time was observed, the cake moisture increased to 34~36%. On the other hand, at 0.5 lb/ton Reagent V addition, the cake moisture was reduced down to approximately 26~28% (see Table 72). The results also showed that, in this set of tests, the belt speed had a slight effect on the dewatering when flocculant and reagent were added; however, it did not appear to influence the cake moisture for the control tests (it only caused changes in cake thickness and formation time).

During the tests, it was observed that even though the filter feed rate was kept constant, using V increased the cake thicknesses. This can be attributed to increased porosity, which in turn creates more permeable cake. This phenomenon also caused a cake-cracking problem. As a

Table 72. Effect of V on Mingo Logan flotation product sample.

Filter Time (sec)	Cake Thickness (mm)	Cake Moisture (%)					
		Control	25 g/t Floc	0.5 lb/ton V	0.5 lb/ton V*	1.0 lb/ton V	1.0 lb/ton V*
184	25	31.49	34.61	27.11	26.13	-	-
120	15	31.59	34.13	25.92	25.95	31.73	23.59
85	10	31.18	-	28.49	-	28.12	24.45
65	8	31.63	36.2	-	-	28.9	26.67

*With Roller

result, the vacuum pumps also lost pressure. To overcome this problem, a roller was attached on the belt to press down the cake, presumably to prevent the cracking. The test results clearly showed that the cake moisture was further reduced to 23~26% when a roller was applied to the dry cake to help seal the pores inside the cake. Overall, the use of roller resulted in additional moisture reductions from 3-4% to 15% at 0.5 lb/ton and 1 lb/ton of V addition, respectively.

Table 73 shows another series of tests were conducted to investigate the effect of the flocculant addition. The effect of roller was also tested in the presence of dewatering aid. The cake moisture was in the range of 24 to 29% with combined use of 5 g/t of flocculant and 1 lb/ton of V. Yet again, increased cake porosity and the cracking was a problem; however, when the roller was applied in some cases moisture was lowered.

j) Pilot-Scale Test Results (Series B – 50% Mixture of Fine and Coarse Coal)

The next set of tests was conducting using an equal mixture of fine and coarse coal. The fine coal was obtained from the froth concentrate, while the coarse coal was intercepted from the screen-bowl feed containing approximately 28% solids by weight and 12% ash on dry basis. The

Table 73. Effect of V on Mingo Logan flotation product sample (with 5 g/t of flocculant).

Filter Time	Cake Thickness	Final Cake Moisture (%)				
(sec)	(mm)	Control	1 lb/ton V	1 lb/ton V*	3 lb/ton V	3 lb/ton V*
184	25	31.49	28.65	26.32	25.69	26.93
120	15	31.59	29.05	25.61	29.03	25.19
85	10	31.18	28.63	28.01	29.13	27.12
65	8	31.63	24.85	26.81	27.37	28.25

*With Roller

tests were conducted over a range of filter feed rate that typically varied from 2, 3, 4 to 7 gal/min of coal slurry. Unlike the flotation product, it was found out that the 3 gal/min feed rate was optimal for the blend filtration tests, which would be sufficient to produce 1/3 to 1 inch cake thicknesses. Table 74 shows a summary of the pilot-scale test data obtained at the Mingo Logan plant spiral/flotation product mixture sample using Reagent U at 3lb/ton and flocculant at 25g/t dosage at the feed rate of 3gal/min. Each series of tests were conducted as a function of total filtration time.

This reagent reduced the cake moisture from about 30% down to 21% at 3 lb/ton dosage. Meanwhile, the cake formation time decreased by 20~50% with the addition of Reagent U as dewatering aids. When used alone, it could produce a low-moisture cake (approximately 21~22% moisture), and the cake formation time was significantly reduced down to 14~75 seconds from approximately 85 seconds. The flocculant alone was not capable of reducing the moisture content to the level that Reagent U achieved; although, they could reduce the formation time more significantly. The use of flocculants resulted in loss of vacuum pressure in the pump, an indication of increased cake porosity, but did not help to remove the surface water that was

Table 74. Effect of U and flocculant on Mingo Logan flotation product sample.

Filter Time (sec)	Cake Thickness (mm)	Final Cake Moisture (%)			
		Control	25 g/t Floc	3 lb/ton U	25 g/t Floc & 3 lb/ton U
184	25	34.38	26.6	25.05	24.96
120	15	29.62	26.9	21.8	24.66
85	10	30.78	29.1	21.3	18.7
65	8	29.99	28.81	21.5	21.7
Vacuum (Inch Hg)		16-14	11-5	15-11	7-5

Table 75. Effect of V and flocculant on Mingo Logan flotation product sample.

Filter Time (sec)	Cake Thickness (mm)	Final Cake Moisture (%)			
		Control	25 g/t Floc	3 lb/ton V	25 g/t Floc & 3 lb/ton V
184	25	34.38	26.6	28.11	24.56
120	15	29.62	26.9	28.9	24.74
85	10	30.78	29.1	29.78	22.63
65	8	29.99	28.81	26.34	21.4
Vacuum (Inch Hg)		16-14	11-5	16-15	8-4

entrapped inside the floccus. However, the combined use of flocculants and Reagent U could achieve a very short cake formation time. When used together with 25 g/t flocculants, Reagent U reduced the cake formation time further to 7~24 seconds, while the final cake moisture remained at almost the same level. In this case, the cake formation time was reduced by 50~75% over the belt speed range under test, and the moisture was reduced from 30-34% down to 21~24%. Test work performed using Reagent U showed that a filter cake with good handling characteristics could also be produced.

In comparison, Reagent V was tested and the results showed that Reagent V was less effective in reducing moisture and increasing the kinetics of dewatering. However, the difference between Reagents U and V was narrowed when each of these two reagents were used together with low dosage (25 g/t) of flocculants. It was also noticed that in the presence of dewatering aids, change in belt speed made a slight difference in the moisture reduction, especially while operated at lower speeds. When the filter feed rate was fixed, the short retention time of the materials over the vacuum zone was compensated by the thin cake thickness at higher belt speed, and thick cake at lower belt speed.

4.3.3 Coal Clean Site

a) Site Description

The Coal Clean Panther Preparation Plant is located in Dry Branch, approximately 15 miles south of Charleston, West Virginia. The Panther Preparation Plant currently processes 63 mm x 0 raw coal for ultimate use in the metallurgical and steam markets. The minus 325 mesh size fraction material reports to the discard stream without any type of processing method. However, if this size fraction is recovered and dewatered, loss of valuable source could be turned into profit. For this reason the plant management looked for alternatives for the recovery of the minus 325 mesh coal that is presently discarded to refuse. To evaluate the feasibility of the recovery and dewatering of this size fraction, extensive pilot scale flotation and dewatering tests were conducted. A number of tests with pilot scale centrifuge tests were conducted for comparison reasons.

b) Reagents

In this investigation, majority of the pilot scale dewatering tests were performed with varying amounts of three types of dewatering aids, namely W, U and RA. Diesel was used as solvent at one to two (1:2) ratio (dewatering aid:solvent). Each of the reagents were tested over a range of dosages typically ranging from 0 to 20 pounds per ton for the ratios of the ultra-fine and fine products in the feed to the Filter Module and the Centrifuge Module.

c) Coal Samples

For this particular test site, pilot-scale dewatering tests were conducted on feeds comprised of different mixtures of coarse and fine coal feeds. These included (i) 100 mesh x 0 feed stream from the overflow of the primary classifying cyclones, (ii) 325 mesh x 0 feed raw stream, and (iii) blends of 100 mesh x 325 and minus 325 mesh product from the flotation column. The blends were established at ratios of 1:1 and 3:1 of minus 325 mesh material to the 100 x 325 mesh product.

d) Pilot-Scale Procedures

The column flotation, conditioner, disc filter, and centrifuge modules were set up at the Coal Clean Plant to accommodate the pilot-scale testing program. A total of 115 tests were run over a one month period to establish optimum conditions for the proposed plant upgrades that were under consideration to accommodate the proposed POC-scale test circuit. The arrangement of the modules for the tests is presented in Figure 27. For the majority of the test work, the plant supplied a relatively consistent feed stream of minus 325 mesh material to the Column Module from the overflow of the secondary classifying cyclones. The secondary classifying cyclones were fed from the overflow of the primary classifying cyclones which were separating a 16 mesh x 0 slurry stream at a nominal size of 100 mesh. The underflow from the secondary classifying cyclones reported to a bank of conventional flotation cells and the overflow was discarded to the refuse thickener. A series of tests was also conducted on the 100 mesh x 0 feed stream from the overflow of the primary classifying cyclones. The minus 325 mesh raw feed was cleaned in the Column Module, with the clean coal routed to the Conditioner Module. The conditioned slurry was then dewatered in either the Filter Module or the Centrifuge Module.

The Panther Preparation Plant offered a unique opportunity to conduct a series of tests with various blends of 100 mesh x 325 mesh conventional flotation product added to the minus 325 mesh product from the Column Module. The projected blends were established at ratios of 1:1

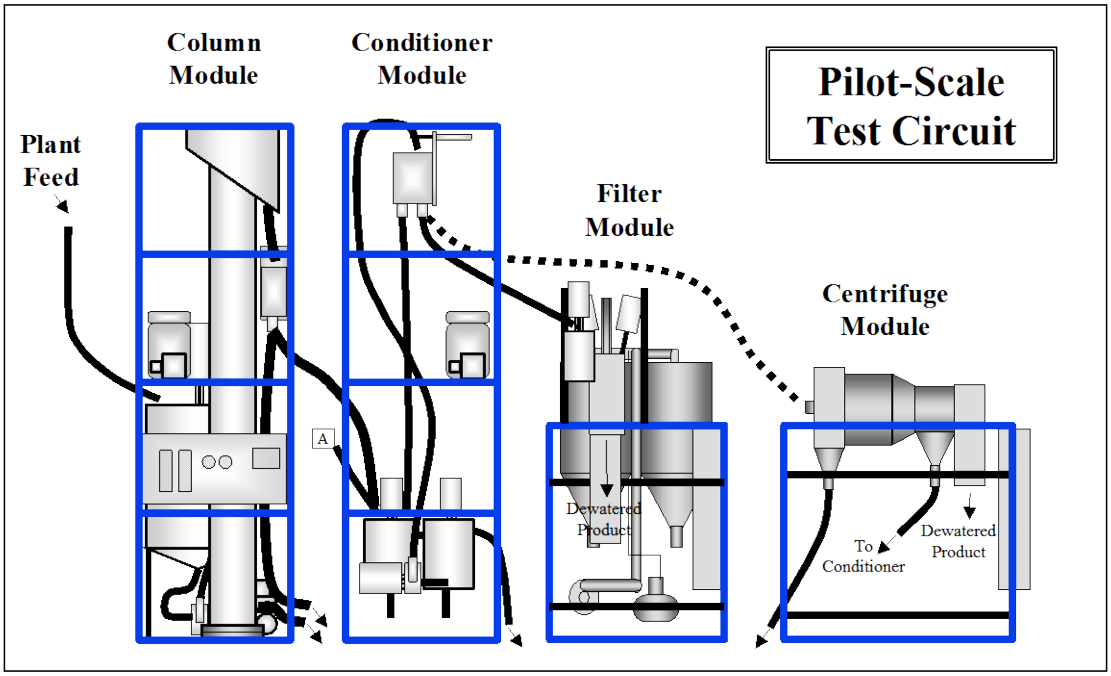

Figure 27. Configuration of the mobile unit test modules evaluated at the Panther Preparation Plant site.

and 3:1 of minus 325 mesh material to the 100 x 325 mesh product. Maintaining the blend at the various ratios proved somewhat difficult due to the changing flows for the products, but most of the tests were conducted within 5% of the projected blend. Although the Filter Module and the Centrifuge Module were not operated at the same time, the tests included almost the same sweep of reagent tests for both modules.

e) Pilot-Scale Test Results

Table 76 presents the results for dewatering tests with various reagents while dewatering the minus 325 mesh product in the Filter Module. The sample was first floated using a mixture of Nalco 01DU113 (0.25 unit) + 01DU145 (1.0 unit) as collector and Nalco-948 as frother (9 units) in a flotation column. The solids content in the filter feed ranged from 4-5% by weight. For

Table 76. Coal Clean coal (minus 325 mesh) dewatered using Reagents W, U, and RA dispersed in Nalco 01DW110.

Reagent Dosage (kg/t)	Moisture Content (%)		
	W (1:4 Ratio)	U (1:2 Ratio)	RA (1:2 Ratio)
0.00	29.10		
3.08	27.01		
6.08	26.04		
9.75	24.66		
0.00		29.28	
2.80		27.28	
5.48		24.71	
9.43		23.42	
0.00			29.05
1.62			28.47
2.19			27.49
7.50			27.49

dewatering tests, W, U and RA were used as dewatering aids at various dosages. The vacuum pressure was approximately 20.5 to 23.0 inches Hg; and the cake thickness was around 6-7 mm. The results indicate that the baseline moisture content of the filter cake (with no reagent) was very consistent and it was approximately 29.0%. This value was reduced to 27.5%, 24.7% and 23.4% with Reagent RA, W, and U, respectively. As such, U provided the best overall performance for dewatering of the minus 325 mesh product. Considering the amount of the minus 325 size fraction in this feed, U was capable of reducing the final cake moisture by 20%.

Table 77 presents the results for dewatering tests using the Filter Module for a blend of the minus 325 mesh product with the 100 x 325 mesh product from the conventional flotation cells at a ratio of 1:1. For flotation tests, same procedure and collector and frother dosages were employed. As shown, the addition of the coarser material had a dramatic effect on the moisture content of the product. With no reagent added, the addition of coarser material reduced the

Table 77. Coal Clean coal (50% minus 325 mesh and 50% 100x325 mesh) dewatered using Reagents W and U dispersed in Nalco O1DW110.

.

Reagent Dosage (kg/t)	Moisture Content (%)	
	W (1:2 Ratio)	U (1:2 Ratio)
0.00	19.98	
1.98	19.82	
4.47	17.76	
0.00		19.98
2.80		18.26
5.40		17.93
7.95		17.65

baseline moisture from 29% (Table 77) to 20% (Table 78). As the reagent dosage was increased, the 20% moisture content was further reduced to 17.8% with Reagent W and to 17.6% with Reagent U.

Table 78 presents the results for the dewatering tests using the Filter Module for a blend of the minus 325 mesh product with the 100 mesh x 325 mesh product from the conventional flotation cells at a ratio of 3:1. The solids content in the filter feed ranged from 5% to 6%. As seen, when the amount of the minus 325 size material was increased, the baseline moisture value was also increased. The results, as expected, lie between those obtained in the two test series noted above. Of the dewatering aids, U was the most effective and capable of reducing the cake moisture from 24.78% to 20.77 % which correspond to 17 % overall moisture reduction.

Table 79 presents the results for dewatering tests for a minus 325 mesh product in the Filter Module with the filter disc speeds ranging from 4 to 1.5 min/rev. The sample was floated using a mixture of 01DU110 as collector and Nalco 01DU009 as frother in a flotation column. The solids content in the filter feed ranged from 9-10% by weight. The product rate increased

Table 78. Coal Clean coal (75% minus 325 mesh and 25% 100x325 mesh) dewatered using Reagents W, U and RA dispersed in Nalco 01DW110.

Reagent Dosage (kg/t)	Moisture Content (%)		
	W (1:2 Ratio)	U (1:2 Ratio)	RA (1:2 Ratio)
0.00	24.78		
0.92	23.57		
1.98	24.83		
3.36	22.49		
0.00		24.78	
0.84		23.01	
1.72		22.55	
3.50		20.77	
0.00			24.78
0.92			23.00
1.62			23.82
3.85			23.68

Table 79. Effect of disc speed on product rate and moisture content for Coal Clean coal (minus 325 mesh) from the Filter Module.

Disc Rotation Speed (min/rev)	Filter Cake Production (kg/hr dry)	Moisture Content (%)
4.0	19.90	27.49
3.0	20.39	27.76
2.0	23.77	28.63
1.5	26.89	28.47

from 19.9 to 26.9 kg/h with only a slight increase in the moisture content from 27.5 to 28.5% when using U at approximately 1.0 kg/t (2.0 lb/ton).

Table 80 presents the results for pilot scale dewatering tests using Reagent U for a blend of the minus 325 mesh product with the 100 x 325 mesh product at a ratio of 1:1 using the Centrifuge Module. The sample was floated using mixture of 01DU110 as collector and Nalco 01DU009 as frother in a flotation column. The solids content in the centrifuge feed ranged from

Table 81. Effect of Nalco 01DW145 on Coal Clean coal (50% minus 325 mesh and 50% 100x325 mesh) from the Centrifuge Module.

Reagent Dosage (kg/t)	W in 01DU113 (1:2 Ratio)	
	Moisture Content (%)	Solids Yield (%)
0.00	33.24	87.20
1.05	33.86	93.40
1.95	35.79	89.60
2.95	34.46	93.20

9-10% by weight. The 150 mm diameter centrifuge operated at approximately 480 rpm with a differential of 95:1 for the conveyor. The moisture of the product increased from 33.2 to 34.5% as the solids yield increased from 87.2 to 93.4% with the increase in reagent dosage. The higher moisture and improved yield appear to be mostly due to an increase in the recovery of the ultra-fine material.

Table 81 presents the results for dewatering tests using Reagent 01DW133 for a blend of the minus 325 mesh product with the 100 x 325 mesh product at a ratio of 1:1 using the Centrifuge Module. The sample was again floated using a mixture of 01DU110 as collector and Nalco 01DU009 as frother in a flotation column. The solids content in the centrifuge feed ranged

Table 80. Table 6. Effect of Reagent 01DW133 on Coal Clean coal (50% minus 325 mesh and 50% 100x325 mesh) from the Centrifuge Module.

Reagent Dosage (kg/t)	Nalco 01DW133 in 01DU110 (1:2 Ratio)	
	Moisture Content (%)	Solids Yield (%)
0.00	33.24	87.20
1.05	33.94	89.60
2.05	33.36	90.30
2.80	33.86	86.00

from 9-10%. The moisture of the product increased slightly from 33.2 to 33.8% and the solids yield increased from 87.2 to 90.3% with the increase in reagent dosage. Once again, the increases in moisture and yield were attributed to increases in the recovery of ultra-fine material.

During the continuous test work conducted at the Panther Preparation Plant site, a series of timed samples were collected periodically from various points around the pilot plant so that complete mass balances could be established for the different unit operations. The samples included representative splits for the column cell (feed, product and tails), filter (feed, product and filtrate), and the screen bowl centrifuge (feed, product, effluent and drain. The series of tests for the minus 325 mesh feed showed that the 300 mm (1 ft) diameter Column Module produced an average of 31 kg/hr of concentrate. Depending on the particular operating conditions, the clean coal capacity ranged from a low of 17 kg/hr to a high of 58 kg/hr. The grade of the concentrate averaged 10.4% ash and ranged from 3% to18% ash, while the combustible recovery averaged 83.0% and ranged from 35.7% to 92.9%. The feed ash averaged 40.8% ash and ranged from 32.6% to 53.6% ash. The 0.2 m^2 (2 ft^2) Filter Module produced from 15 to 27 kg/hr of cake and the 150 mm diameter Centrifuge Module produced from 4.6 to 23.8 kg/hr of product from feed streams containing between 2.1-16.7% solids by weight.

4.3.4 Concord Site

a) Site Description

The Concord Coal plant is located near Birmingham, Alabama. This facility processed 50 mm x 0 coal for the metallurgical and steam markets, with a design plant feed rate of 1,000 tph and typical clean coal yields of 55%-60%. The intermediate/fine coal circuit consists of primary classifying cyclones (PCC), spirals, secondary classifying cyclones (SCC), froth flotation, and screen bowl centrifuges. The overflow from the PCCs is fed to the SCCs; the SCC underflow is the feed stream to flotation (4 banks of five 180-ft^3 cells), while the SCC overflow is piped to a refuse thickener. The coal being processed is very soft and fine in size consist and the feed to the flotation cells can be as much as twice that of the design flowsheet rate (design 54 t/hr vs. actual 80-100 t/hr). The feed to the flotation cells is approximately 80% minus 325 mesh (0.045 mm). The flotation and spiral clean-coal products are combined and then dewatered via four 44” x 132” screen bowl centrifuges with a total design feed rate of 2,200 gal/min and 242 t/hr.

The primary objectives of the test program were to determine whether (i) a thick and low-moisture filter cake and (ii) a filter cake with good material handling characteristics could be produced from the minus 100 mesh flotation feed stream (primary cyclone overflow) that is currently processed in conventional flotation cells and centrifuges at this plant. To meet these objectives, extensive laboratory and pilot scale flotation and dewatering test program was conducted at Virginia Tech Mineral Processing Facility in Virginia, and at the Concord coal preparation plant in Alabama. The laboratory tests included the performance evaluation of various types and dosages of dewatering aids to collect dewatering data that could be used in direct support of pilot-scale test work. The data obtained from the laboratory tests were used to provide a technical guidance for the pilot scale test program.

b) Reagents

The laboratory and pilot scale tests included both the flotation and dewatering tests. For laboratory flotation tests, diesel and MIBC were used as collector and frother, respectively. The floated sample was then subjected to dewatering tests using Reagent W3 and V. For pilot-scale flotation tests W, U, V and diesel as collectors and Nalco DU009 as frother were used. The same reagents were used as the dewatering aids in filter tests. Each of the reagents was tested over a range of dosages that typically varied from 0 to 5.0 kg/t (0 to10 lb/ton) of dry coal. As mentioned elsewhere, these dewatering aids are insoluble in water. For all the tests, flotation and dewatering, diesel was used as solvent at one to two (1:2) dewatering aid-to-diesel ratio.

c) Coal Samples

The coal slurry samples for the flotation and dewatering tests were collected from the minus 100 mesh flotation feed stream (primary cyclone overflow) that was processed. The same coal slurry feed was used for the pilot-scale flotation and dewatering tests.

d) Laboratory Procedures

The flotation feed sample (minus 100 mesh) from the Concord plant was first floated in a laboratory mechanical flotation cell using 300 g/t of diesel and 150 g/t of MIBC to remove ash-forming minerals. The floated product was then subjected to dewatering tests at about 13.5% solids by weight. In these tests, Reagents V and W3 (both diluted to 33.3% in solvent) were used as dewatering aids. Immediately prior to each filter test, a known volume of slurry was conditioned for 5 minutes with the reagent in a mechanical shaker and then poured into a Buchner funnel before applying vacuum of 68 kPa (20 inches Hg). A constant drying cycle time of 2 minutes was used in all tests. The thickness of the filter cake varied from 7 to 9 mm.

e) Pilot-Scale Procedures

The on-site test work was conducted using the Column, Conditioner, and Filter Modules. In each test, the cyclone overflow from the plant was first upgraded using the Column Module (a 305 mm or 12-inch diameter Microcel column) using diesel and W, U and V as collectors and

Nalco DU009 as frother. The plant feed was reasonably consistent for most of the test work and contained 3.5-5.5% solids by weight and 23.3-26.5% ash. The column produced a clean coal product with 7-11% ash and 84-87% combustible recovery, depending on the reagent type and dosage used. The froth product was then dewatered using the Filter Module (i.e., 0.186 m^2 (2 ft^2) filter area, 10 sector Peterson disc filter). The same reagents listed above, namely W, U and V, were also used as the dewatering aids in the filter tests. Each of the dewatering aids were tested over a range of dosages that typically varied from 0 to 5.0 kg/t (0 to 10 lb/ton) of dry coal. Timed samples were collected periodically from various points around the test modules to establish typical material balances and reagent addition rates for this particular coal.

f) Laboratory Test Results

Several series of laboratory dewatering tests were conducted to collect data that could be used as guidance for the pilot scale dewatering tests. Table 82 shows the laboratory test results obtained on the Concord Plant flotation feed sample using V and W3 as the dewatering aids. A 62.5 mm diameter Buchner funnel was used. The solid content of the flotation feed sample was

Table 82. Effect of reagent addition on Concord flotation feed (100 mesh x 0) using Reagents V and W3.

Reagent Dosage (kg/t)	Moisture Content (%)	
	Reagent V	Reagent W3
0	24.6	24.6
0.5	21.3	23.2
1.5	19.6	21.0
2.5	18.1	19.4
10.0	18.2	18.6

6%. It was increased up to 13.5% after flotation. 300 g/t diesel and 150 g/t MIBC was used during flotation. Vacuum setup point was 68 kPa (20 inches Hg). Cake thickness: 7-9 mm. Conditioning time: 5 minutes; drying cycle time: 2 minutes. The volume of the slurry was 100 ml. As shown, the moisture content of the filter cake was reduced as the reagent dosage increased. At dosages of 0.5 kg/t and 2.5 kg/t of Reagent V, the moisture contents of the filter cake were reduced from 24.6% down to 21.3% and 18.1%, respectively. Similar results were obtained when Reagent W3 was used as the dewatering aid. These values correspond to a 10-26% moisture reduction in the filter product.

g) Pilot-Scale Test Results

The first series of dewatering tests were conducted at various levels of vacuum pressures applied. The feed slurry was first floated using diesel collector and Nalco DU009 frother in flotation column. As shown in Table 83, there was a strong correlation between the cake moisture and vacuum pressure. The results showed that when the vacuum pressure was increased the cake moisture was decreased from 31.12% down to 24.18%.

Table 84 provides an overall summary of the pilot-scale test data obtained at the Concord

Table 83. Pilot-scale test results obtained on the Concord flotation feed sample (100 mesh x 0) using various vacuum pressures.

Vacuum Pressure (Inch Hg)	Moisture Content (%)
10	31.12
15	26.83
20	24.18

plant. In the first series of tests, Reagents W, U and V were evaluated over a wide range of reagent dosages at a constant disc speed of 4 min/rev. The test data show that Reagent W was the most effective of the three dewatering aids (Table 84a). This reagent reduced the cake moisture from 25.5% down to 20.2% at the highest reagent dosage of 2.7 kg/t. Reagent U, which was rather less effective than Reagent W, was not capable of reducing the moisture content to less than 21.5% (Table 84b). However, this moisture level was achieved at a very low reagent dosage level of just 0.4 kg/t. In fact, higher dosages of Reagent U did not appear to be as effective in reducing moisture in this particular series of tests. Reagent V was generally the least effective in reducing moisture (Table 84c). In some cases, the cake moisture actually increased after this

Table 84. Pilot-scale test results obtained on the Concord flotation feed sample (100 mesh x 0) using various reagent combinations.

Flotation	Disc Filtration		Feed	Cake	Cake
Diesel (kg/t)	Reagent Type	Dosage (kg/t)	Solids (%)	Thickness (mm)	Moisture (%)
(a)					
0.48	None	0.0	4.22	2.5	25.47
0.49	1:2 W/Diesel	0.3	6.01	5.5	23.10
0.49	1:2 W/Diesel	0.5	6.01	4.5	21.70
0.49	1:2 W/Diesel	2.7	6.01	5.5	20.24
(b)					
0.38	None	0.0	6.24	2.5	24.63
0.38	1:2 U/Diesel	0.4	6.24	5.0	21.50
0.38	1:2 U/Diesel	1.1	6.24	7.5	21.89
0.38	1:2 U/Diesel	1.9	6.24	4.0	22.79
(c)					
0.48	None	0.0	4.22	2.5	25.47
0.49	1:2 V/Diesel	0.9	6.01	6.0	23.97
0.49	1:2 V/Diesel	2.4	6.01	8.0	25.49
0.49	1:2 V/Diesel	4.4	6.01	12.0	25.79
0.49	1:2 V/Diesel	5.2	6.01	8.0	22.83

*4 min/rev disc speed

reagent was added to the filter feed.

Although less effective in reducing moisture, Reagent V generally provided the best overall cake thicknesses (up to 12 mm) when compared to Reagents W and U. The thick cakes produced using Reagent V also possessed the best material handling characteristics and were cited by plant personnel as the most suitable for their particular needs. Therefore, several additional tests were conducted using Reagent V to determine whether lower moistures could be achieved by adding the reagent directly to the flotation column feed in place of the diesel collector. As shown in Table 85, this strategy significantly improved the moisture reduction and greatly reduced the total reagent requirement. More importantly, the lower moistures were obtained at relatively large cake thicknesses (i.e., 9-10 mm). In one test run, the cake moisture was reduced from 25.1% down to 20.9% (a moisture reduction of 16.5%) while maintaining a cake thickness of 9 mm. The total reagent dosage required to achieve this moisture was just over 1.0 kg/t (i.e., 0.44 kg/t for flotation and 0.6 kg/t for filtration).

Further improvements in moisture content were obtained by reducing the disc speed from

Table 85. Pilot-scale test results obtained on the Concord flotation feed sample (100 mesh x 0) using various reagent combinations.

Column Flotation		Disc Filtration		Feed	Cake	Cake
Reagent Type	Dosage (kg/t)	Reagent Type	Dosage (kg/t)	Solids (%)	Thickness (mm)	Moisture (%)
Diesel	0.43	None	0.0	5.23	2.5	25.05
1:10 V/DU009	0.23	None	0.0	16.12	9.0	23.27
1:2 V/Diesel	0.44	None	0.0	7.10	6.0	21.04
1:2 V/Diesel	0.44	1:2 V/Diesel	0.3	5.71	10.0	21.30
1:2 V/Diesel	0.44	1:2 V/Diesel	0.6	8.09	9.0	20.92
1:2 V/Diesel	0.44	1:2 V/Diesel	1.2	6.46	7.0	21.36

*4 min/rev disc speed

Table 86. Pilot-scale test results obtained on the Concord flotation feed sample (100 mesh x 0) using various reagent combinations.

Column Flotation		Disc Filtration		Feed	Cake	Cake
Reagent Type	Dosage (kg/t)	Reagent Type	Dosage (kg/t)	Solids (%)	Thickness (mm)	Moisture (%)
Diesel	0.39	None	0.0	8.55	3.0	21.78
1:2 V/Diesel	0.59	None	0.0	7.34	12-15	20.37
1:2 W/Diesel	0.42	None	0.0	11.42	12-15	19.25
1:2 U/Diesel	0.45	None	0.0	13.07	12-15	18.66

*6 min/rev disc speed

4 min/rev to 6 min/rev (Table 86). The addition of reagent to the flotation feed combined with the slower disc speed made it possible to achieve moistures of 20.7%, 19.3% and 18.7% for Reagents V, W and U, respectively. These low moisture values were obtained at very low total reagent dosages of less than 0.5 kg/t and with relatively large cake thicknesses of 12-15 mm.

4.3.5 Buchanan Site

a) Site Description

Consolidation Coal Company's Buchanan Mine #1 is an underground coal mine located two miles south of Route 460, adjacent to State Route 632, at Mavisdale, Buchanan County, Virginia. Consol Energy Inc., located in Pittsburgh, Pennsylvania, is the parent company of Consolidation Coal Company. The Buchanan preparation plant processes approximately 5 million tons of 37.5 mm x 0 raw coal (2006) from the Pocahontas 3 Seam for use in the metallurgical and steam markets.

The objectives of this study were to (i) identify the best possible reagents and combinations thereof for this specific coal and (ii) identify the conditions under which a given dewatering aid can give the best performance. To meet the objectives, laboratory and pilot scale tests were conducted to evaluate the performance of various types and dosages of dewatering aids.

b) Reagents

The investigation, both laboratory and pilot-scale, was performed with varying amounts of three types of dewatering aids, namely Reagent W, U and V. Since these dewatering aids are insoluble in water, they were dissolved in a solvent. In both laboratory and pilot scale experiments diesel was used as the solvent. The ratio of reagents-to-solvent was optimized in previous studies by varying the individual dosages (0.5 to 3 lb/ton), while maintaining the total blend dosage constant. For this test program, the optimum combination for a given dewatering aid and solvent is one to two (1:2) dewatering aid-to-diesel ratio.

c) Coal Samples

The test work was conducted on different samples taken from Consolidation Coal Corporation's Buchanan Preparation Plant in Mavisdale, Virginia. These samples included (i) a flotation feed sample, (ii) a grab sample of current flotation product, and (iii) a slip-stream sample of filter feed (all taken on various dates).

d) Laboratory Procedures

Prior to experiments sieve analysis was conducted for each sample by wet screening using 600, 300, 150, 75 and 45 micron sieves. Dewatering tests were mostly conducted on filter feed and flotation product samples. The solid concentration of Buchanan's flotation product was about 25% by weight while maintaining approximately 25-30% of minus 45 micron material. Table 87 shows the sieve analysis results on flotation product sample. The flotation product

Table 88. Screen analysis of the Buchanan flotation product used for dewatering tests.

Particle Size (Microns)	Pipe 1 Weight (%)	Pipe 2 Weight (%)	Pipe 3 Weight (%)
Plus 600	3.6	3.4	7.7
600x300	19.0	15.8	27.3
300x150	23.0	18.0	24.1
150x75	14.9	13.2	13.2
75x45	8.1	25.3	6.9
Minus 45	31.4	24.3	20.7

sample was occasionally mixed with a portion of the spiral product at the plant at a ratio of 1:1 to have better dewatering kinetics. Table 88 shows the sieve analysis results of spiral/flotation product slurry collected from the plant.

For the laboratory-scale batch dewatering tests, the samples were collected in 5-gallon buckets and to be able to receive a representative sample, samples were homogenized by mixer. When the plant flotation feed sample was used in the dewatering tests, the sample was first floated in a laboratory mechanical flotation cell using 300 g/t of kerosene and 150 g/t of MIBC to remove ash-forming minerals. The floated product was then subjected to the dewatering tests at about 20% solids by weight. Immediately prior to each filter test, a known volume of slurry

Table 87. Screen analysis of the Buchanan filter feed used for dewatering tests.

Particle Size (Microns)	Pipe 1 Weight (%)	Pipe 2 Weight (%)	Pipe 3 Weight (%)
Plus 600	6.0	6.3	5.5
600x300	23.4	23.3	21.8
300x150	21.7	22.5	19.9
150x75	14.7	14.8	14.6
75x45	8.2	6.9	8.9
Minus 45	26.0	26.2	29.3

(whether flotation product or mixture sample) was conditioned with the reagent in a mechanical shaker and then poured into a Buchner funnel before applying vacuum. The dewatering aids W and U, diluted to 33.3% in solvent, were used in these tests. The following conditions were kept constant during the tests: 68 kPa (20 inches Hg) of vacuum, 2 minutes of drying cycle time, 10-15 mm of cake thickness, 100 ml volume of feed slurry and 5 minutes of conditioning time.

e) Pilot-Scale Procedures

In the pilot-scale dewatering tests, the Conditioner Module and Filter Module were required since the feed slurry for the tests was supplied directly from the Buchanan Preparation Plant. The pilot-scale disc filter tests were conducted on flotation product samples.

f) Laboratory Test Results

Table 89 gives the laboratory test results obtained on the Buchanan plant flotation product using U and W as the dewatering aids at 68 kPa (20 inches Hg) vacuum. As shown, the moisture content in the filter cake was reduced with increasing reagent addition. At U additions of 0.5 and 2.5 kg/t, the moisture contents of the cake were reduced from 17.6% to 16.1% and 14.4%, respectively. Similar results were obtained when W was used as dewatering aid. These

Table 89. Effect of reagent addition on dewatering Buchanan's flotation product.

Reagent Dosage (kg/t)	Moisture Content (%)	
	Reagent W	Reagent U
0	17.6	17.6
0.5	16.2	16.1
1.5	16.2	14.9
2.5	15.0	14.4

values corresponded to a 15-20% moisture reduction in the filter product.

Similar dewatering tests were conducted on the filter feed sample (which contains approximately 10 g/t of Nalco 9806 polymer flocculant as the dewatering aid) using W and U as dewatering aids. Results for the filter feed sample are summarized in Table 90. The results show that the moisture content of the filter product again decreases with increasing W and U additions from 0.5 to 2.5 kg/t (1 to 5 lb/ton). In this case, the addition of 2.5 kg/t (5 lb/ton) of reagent W reduced the cake moisture from 18.1 to 14.9%, giving a percentage moisture reduction of about 20%. The moisture reduction is quite similar to that obtained for the flotation product, except that the moisture content of the filter cake product obtained using reagent U was almost 2 percentage units lower, i.e., 14.4% vs. 16.6% moisture in the filter cake (see Tables 89 and 90). The reasons for the relatively poorer behavior of reagent U may be related to the presence of flocculant in this particular sample. Apparently, the polymer flocculant has an adverse effect on the performance of U during dewatering. Those poor results are also due to the Ca^{2+} ions present in Buchanan plant water.

Two series of laboratory filtration tests were conducted to determine the effects of agitation intensity on the dewatering performance of the Buchanan filter feed. The first series of

Table 90. Effect of reagent addition on dewatering of Buchanan's filter feed.

Reagent Dosage (kg/t)	Moisture Content (%)	
	Reagent W	Reagent U
0	18.1	18.1
0.5	17.58	17.5
1.5	15.2	16.78
2.5	14.9	16.58

Table 91. Effect of mixing intensity on dewatering of Buchanan's flotation product.

Reagent Dosage (kg/t)	Moisture Content (%)			
	Reagent U		Reagent W	
	High Energy Mixing	Low Energy Mixing	High Energy Mixing	Low Energy Mixing
0	18.2	18.2	18.2	18.2
0.5	15.4	17.1	13.5	15.5
1.0	13.2	14.9	13.4	14.9
1.5	11.9	14.6	13.1	14.7
2.5	11.7	14.6	13.1	14.3

tests were conducted using a laboratory shaker to condition the feed samples. The shaker was a low-energy conditioner that uses reciprocating motion (similar to wrist-action shaking) to gently mix slurry contained in a 100-ml glass conditioning flask. A second series of tests were conducted using a 100-ml Plexiglas cell equipped with a three-blade propeller-type mixer at 1000 rpm. The rotary mixer provided an intense agitation that is necessary for high-energy conditioning. The feed slurry was conditioned for 5 minutes in both series of tests.

As shown in Table 91, the moisture reduction was substantially improved when high-energy conditioning was used. For example, the use of 2.5 kg/t of dewatering aid reduced the filter cake moisture from a baseline value of 18.2% (no reagent added) down to 14.6% when using low-energy agitation. The cake moisture was further reduced to 11.7% moisture when high-energy agitation was used at the same reagent dosage of 2.5 kg/t. Similar results were obtained using Reagent W as the dewatering aid. With this reagent, the final cake moisture improved from 14.9% to 13.4% at 1.0 kg/t of dewatering aid and from 14.3% to 13.1% at 2.5 kg/t of dewatering aid. These results clearly demonstrate the importance of proper conditioning when using the novel dewatering reagents. The results also indicate that the high-intensity

Table 92. Effect of reagent addition on the pilot-scale dewatering of Buchanan's flotation product.

Reagent Dosage (kg/t)	Moisture Content (%)	
	Reagent U	Reagent W
0.0	16.9	
0.65	15.7	
1.40	15.2	
2.75	14.5	
0.00		16.9
0.67		15.8
1.45		15.5
2.87		15.0

conditioning increases the adsorption density of dewatering reagents; as a result, lower moisture filter cake product can be obtained.

g) Pilot-Scale Test Results

Table 92 gives the results of pilot scale dewatering tests which were obtained using various dewatering reagents at different addition rates. The data indicate the moisture content of the filter cake decreased from a baseline (no reagent) value of 16.9% to 14.5% with 2.5 kg/t (5 lb/ton) of reagent U and to 15.0% with reagent W. Likewise, Table 93 gives the laboratory test results obtained on the Buchanan plant flotation product using U and W as the dewatering aids at 68 kPa (20 inches Hg) vacuum. As it can be seen from the table, the moisture content in the filter cake was decreased with increasing reagent addition. At U additions of 0.5 and 2.5 kg/t, the moisture contents of the cake were reduced from 17.6% to 16.1% and 14.4%, respectively. Similar results were obtained when W was used as a dewatering aid. These values correspond to a 15-20% moisture reduction in the filter product.

Table 93. Effect of reagent addition on laboratory scale dewatering of Buchanan's flotation product.

Reagent Dosage (kg/t)	Moisture Content (%)	
	Reagent W	Reagent U
0	17.6	17.6
0.5	16.2	16.1
1.5	16.2	14.9
2.5	15.0	14.4

The effect of filter disc speed was also investigated in the pilot-scale tests. Table 94 summarizes the results obtained by increasing the filter disc speed from 3 to 1 min/rev for dewatering of the plant flotation product. The product rate increased from 83.3 to 116.6 kg/hr, with a small change in the moisture content of the filter cake. The results show that it would be possible to increase the filter capacity by 28% without adversely impacting the moisture content of the filter cake. Tests were conducted on Buchanan plant flotation product without dewatering reagents.

A series of pilot-scale dewatering tests were conducted to study the effects of different vacuum levels on moisture reduction. The initial results, which are presented in Table 95, were

Table 94. Effect of pilot-scale filter disc speed on filter cake production rates and moisture content.

Filter Disc Speed (min/rev)	Product Rate (kg/hr)	Moisture Content (%)
3.0	83.3	16.9
2.0	108.6	16.7
1.0	116.6	17.3

Table 95. Effect of pilot-scale filter vacuum level on filter cake moisture contents.

Applied Vacuum (kPa)	Moisture Content (%)
34	19.7
51	16.7
68	17.1

obtained without dewatering aid addition. The data show that it is possible to reduce the product moisture from 19.7% to 17.1% by simply increasing the vacuum level from 34 to 68 kPa (5 to 15 inches Hg). It seems that a further increase in vacuum is not advantageous in terms of further lowering the moisture contents of the filter products. It should be mentioned here that the disc filters in the Buchanan preparation plant are currently operated at vacuum levels of only 10.5-11.0 inches Hg. Because of such low vacuum levels, the plant filter product typically contains 21-22% moisture. The present work shows that by increasing the vacuum levels from 36 to 51-54 kPa, the plant could probably obtain a filter product with 17-18% moisture. Besides dewatering aid addition, vacuum level is one of the important operating conditions determining the final product moisture in the filter cake.

Table 96 gives the pilot-scale test results obtained on the Buchanan plant flotation product using Reagent W as the dewatering aid at various vacuum pressures. As shown, the moisture content in the filter cake was reduced with increasing vacuum pressure. At vacuum pressure increasing from 37 kPa to 68 kPa, the moisture contents of the cake were reduced from 18.2 to 16.8% and 16.3%, respectively.

Table 96. Effect of pilot-scale filter vacuum level on filter cake moisture contents (2 kg/t Reagent W).

Applied Vacuum (Inch Hg)	Moisture Content (%)
37	18.2
54	16.8
68	16.3

Table 97. Effect of pilot-scale filter vacuum level on filter cake moisture contents (2 kg/t Reagent U).

Applied Vacuum (Inch Hg)	Moisture Content (%)
37	16.8
54	14.5
68	14.3

The test results given in Table 97 indicate that a further improvement in filter cake moisture (about two percentage points) was obtained when using Reagent U as dewatering aid. As the vacuum levels increased from 37 to 68 kPa, the moisture content of the cake were reduced from 16.8 % to 14.5% and 14.3%, respectively.

4.3.6 Elkview Site

a) Site Description

The Elkview coal cleaning plant, B.C Canada, is processing 1,400 metric tons per hour (t/hr) of run-of-the-mine (ROM) coals. The materials that are floated and dewatered are classifying cyclone products. The cyclone overflows (O/F) are fed to five banks of mechanically agitated flotation cells, while the underflows (U/F) are fed to sieve bends (60 mesh). The sieve bend U/F joins cyclone O/F and are fed to the flotation cells, while the sieve bend O/F bypasses the flotation cells. The froth product and the sieve bend O/F's are combined and fed to vacuum disc filters to reduce the moisture to approximately 21.5%. The filter cake is then fed to a thermal dryer to further reduce the moisture to 8.4%. Typically, the thermal dryer is operating at its maximum capacity, i.e., 65 t/hr of water evaporated, and cannot handle additional froth product. Under this condition, operators cannot pull the flotation cells hard, causing a significant loss of fine coal.

The primary objective of the project was to develop appropriate methods of reducing the filter cake moisture to the level that can eliminate the situation where the thermal dryer is acting as a bottleneck for increased production. These novel dewatering aids are designed to increase hydrophobicity. As such,, the dewatering aids can be added to a flotation cell displacing some, or perhaps even all, of the conventional collector (kerosene) that is currently used. This can result in a higher flotation recovery while at the same time improving dewatering. However, the novel dewatering aids would work better if they were added to a separate conditioner with a strong agitation since the energy dissipation in a flotation cell is generally less than that in a well-designed conditioner. Therefore, the extent of moisture reduction may be less when the froth cell is used for conditioning. Adding the dewatering reagent in place of collector for flotation may be sufficient since relatively small moisture reduction may be sufficient in eliminating the bottleneck at the thermal dryer and thereby allowing operators to pull the flotation cell hard and increase the recovery. To meet this objective, a series of dewatering tests have been conducted at Virginia Tech. The present work was limited to testing the novel dewatering aids to reduce the moisture of the filter cakes produced from the vacuum disc filters at Elkview.

b) Reagents

The investigation, both laboratory and pilot-scale, was performed with varying amounts of three types of dewatering aids, namely Reagent W, U and V. Since these dewatering aids are insoluble in water, they were dissolved in a solvent. In both laboratory and pilot scale experiments diesel was used as the solvent. The ratio of reagents-to-solvent was optimized in previous studies by varying the individual dosages (0.5 to 3 lb/ton), while maintaining the total blend dosage constant. For this test program, the optimum combination for a given dewatering aid and solvent is one to two (1:2) dewatering aid-to-diesel ratio. When flotation feed was used, the sample was subjected to laboratory flotation tests using 300 g/t of kerosene or V as collectors and 200 g/t of MIBC as frother.

c) Coal Samples

Two types of samples were received from the Elkview site, i.e., a standard metallurgical coal (Std-Met) and a medium-volatile metallurgical coal (Mid-Vol Met). In each case, both flotation feed (minus 60 mesh, 2-3% solid by weight) and vacuum filter feed (67% froth product and 33% sieve bend overflow, 25% solids by weight) samples were received.

d) Laboratory Procedures

Most of the laboratory filtration tests were conducted using a 2-inch diameter Buchner vacuum filter at 20-inch vacuum pressure (68 kPa) and 2 minutes of drying cycle time. To compare the effect of pressure drop on filtration, a few tests were also conducted using a 2-inch diameter pressure filter at a 30 psi of compressed air. In each dewatering test, a coal sample was conditioned in a mixing tank for 2 minutes. The cake thicknesses were varied in the range of 15 to 25 mm by varying the slurry volume.

To prepare the test samples, a series of flotation tests were conducted using a Denver laboratory flotation cell. In each test, a known amount of a dewatering/flotation aid was added to the flotation cell and the slurry was agitated (or conditioned) for 2 minutes before introducing air to the slurry to initiate flotation. When the froth product was to be used for dewatering tests, the flotation tests were conducted until exhaustion and the froth product was used for filtration tests in the same manner as described above. In this procedure, the flotation cell was used effectively as a conditioner. In this series of tests, the flotation products were not analyzed for ash to determine the recovery.

e) Laboratory Test Results (Filter Feed – Standard Metallurgical Coal)

Table 98 gives the results obtained on the filter feed sample using W and V as dewatering aids. The tests were conducted at 22-24 mm cake thickness by varying the reagent dosages. The reagents were used as 1:2 blends with diesel, and the dosages given refer to the active ingredients only. As shown, the cake moistures decreased from 20.17% to 12-14% range.

Table 99 gives the results of the laboratory vacuum filter tests conducted on the filter

Table 98. Effect of reagent addition on dewatering of Elkview's filter feed sample (standard metallurgical coal).

Reagent Dosage (lb/ton)	Moisture (%)	
	Reagent W	Reagent V
0	20.17	20.17
0.1	17.92	17.72
0.5	15.82	16.06
1	14.73	15.43
2	13.11	13.88
3	12.73	13.84

Table 99. Effect of using Reagents W, U and V on the dewatering of Elkview's Filter Feed (STD Met Coal).

Reagent Dosage (lb/ton)	Moisture (%)		
	Reagent W	Reagent U	Reagent V
0	25.56	25.56	25.56
0.1	18.04	17.69	17.99
0.5	15.83	15.45	15.49
1	14.39	13.73	15.36
2	11.93	12.97	13.82
3	11.93	12.32	12.92

feed (STD met coal) sample using W, V and U as dewatering aids. The tests were conducted at approximately 15 mm cake thicknesses. The moisture was reduced from 25.56% to the 12-13% range, which represents approximately 50% moisture reduction. The higher moisture obtained at the control test was probably due to the fact that the tests were conducted a few days after receiving the sample. The results show that Reagent W was most effective, followed closely by Reagents U and V.

f) Laboratory Test Results (Filter Feed – Medium Volatile Metallurgical Coal)

Table 100 gives the laboratory test results obtained on the Mid-Vol filter feed using Reagents W, V and U as dewatering aids. The tests were conducted at approximately 15 mm cake thickness by varying the reagent dosages. Cake moistures were reduced from 23.34% to 13-14% range, representing approximately 43% moisture reductions.

Table 100. Effect of using Reagents W, U and V for Elkview's filter feed (Mid-Vol Met Coal).

Reagent Dosage (lb/ton)	Moisture (%)		
	Reagent W	Reagent U	Reagent V
0	23.34	23.34	23.34
0.1	19.07	19.81	19.60
0.5	15.89	17.52	17.58
1	13.98	15.51	15.80
2	13.96	14.32	15.23
3	13.18	13.95	14.36

Table 101 shows the laboratory test results obtained on the filter feed using Reagents W, V and U as dewatering aids. The tests were conducted at about 22-24 mm cake thicknesses. The moistures were reduced from 23.37% to the 15-16% range, which corresponded to approximately 35% moisture reductions.

g) Laboratory Test Results (Flotation Feed)

The two flotation feed samples (Std-Met and Mid-Vol-Met) were subjected to a series of

Table 101. Effect of Using Reagents W, U and V on Elkview's filter feed sample (Mid-Vol Met Coal).

Reagent Dosage (lb/ton)	Moisture (%)		
	Reagent W	Reagent U	Reagent V
0	23.37	23.37	23.37
0.1	20.11	17.99	19.86
0.5	17.50	17.69	17.86
1	15.70	16.09	16.46
2	15.42	15.69	15.92
3	15.42	15.00	16.44

dewatering tests. As shown in the previous sections of this report, cake moistures can be reduced to the 12-14% range by weight using 2 to 3 lb/ton (active ingredient) of the novel dewatering aids. This was achieved by adding the dewatering aid to a conditioning tank so that it is readily dispersed in the slurry. It was found in our previous work that moisture reduction improves with increasing energy input during conditioning. Figure 28 shows a relationship between moisture reduction and energy input. The results presented in this figure have been obtained on a clean bituminous coal sample (from Moss 3 preparation plant, Virginia) that has been pulverized before dewatering tests.

In the present work, it was decided that dewatering tests be conducted without using a stand-alone conditioning tank. Instead, the coal samples were conditioned during flotation with varying reagent dosages. The energy dissipation imparted by a flotation cell is substantially lower than that of a conditioner. Therefore, the results would not be as good as the case of using

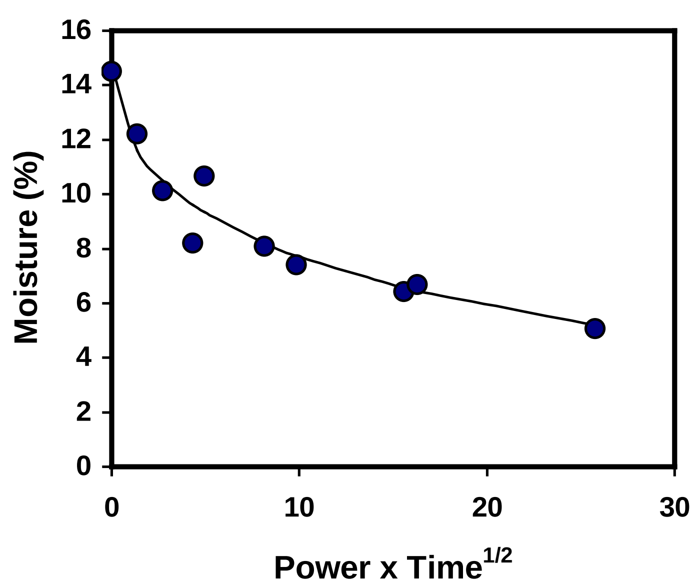

Figure 28. Effect of conditioning on moisture (Middlefork coal).

a conditioner, but the moisture reduction may suffice the needs at Elkview. One concern we had with this approach was the possibility that we would have to use a higher dose of frother when using a higher dose of collector/dewatering aids.

Figure 29 shows the results obtained with the standard metallurgical coal and the Mid-vol coal using Reagent V. The reagent dosages given in the figure include both active ingredient and solvent. The ratio of the active ingredient and solvent ratio was 1:2. Cake thicknesses were approximately 20 mm and two minutes of drying cycle time was employed. In the control test conducted with kerosene as collector, the cake formation time was one minute, which was reduced to 25-35 seconds when using Reagent V.   The tests were conducted on the flotation

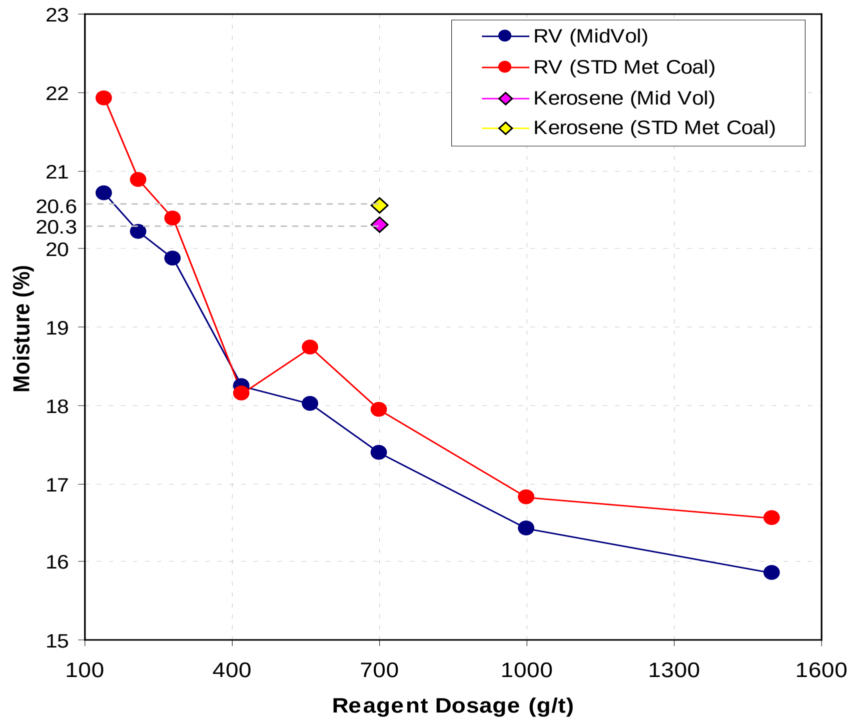

Figure 29. Results of the low-pressure pressure filter tests conducted on the Elkview coal sample (filter feed).

products without conditioning. The flotation tests were conducted using various amounts of collectors. In all flotation tests, 150 g/t of MIBC was used as frother. With this coal, it was not necessary to increase frother dosage at higher collector dosages. As expected, moisture reductions improved substantially with increasing collector dosage. The reagent dosages given are inclusive of the solvent, which comprised 66% of the total reagent addition. At 1,500 g/t , which was the highest dosage employed in these series of tests, the cake moistures were 15.9% for the Mid-Vol coal and 16.6% for the standard metallurgical coal. These values are comparable to those obtained with the filter feeds. At the 1,500 g/t dosage, which is equivalent to 500 g/t (or 1 lb/ton) active ingredient, the dewatering tests conducted on the filter feeds after stand-alone conditioning gave moistures of 15.56% for the standard metallurgical coal (Table 99) and 16.46% (Table 101) for the Mid-Vol coal. Note that the moistures of the floated products are comparable to those of the filter feeds despite the facts that the separate conditioning step was omitted and that particle size was finer. Recall that the filter feed was 0.6 mm x 0 while the flotation product was 0.3 mm x 0. It appears, therefore, that the conditioning step can be omitted for the Elkview coal, which is a significant advantage.

It would be of interest to compare the results obtained with Reagent V with those obtained with kerosene. The froth products obtained using 700 g/t (1.4 lb/ton) of kerosene gave moistures of 20.6 and 20.3% for the standard metallurgical coal and medium volatile coals, respectively. At present, Elkview is using 600 g/t kerosene as collector and 60 g/t of MIBC as frother. At 700 g/t V and 120 g/t MIBC, we obtained 17.9 and 17.4% moistures for the standard metallurgical coal and Mid-Vol coal, respectively. Thus, the use of V can reduce moistures by 2.7 to 2.9 percentage points absolute over the case of using kerosene as collector at dosage levels that are currently employed at Elkview. Figure 29 shows that further reductions in moisture can be achieved at higher reagent dosages.

4.3.7 Smith Branch Site

a) Site Description

One of the most promising coal samples evaluated in this project was obtained from the Smith Branch impoundment located near the Pinnacle Mine Complex. The complex, which is owned by Cleveland Cliffs Mining, consists of an underground mining operation, a surface wash plant, and the waste coal impoundment. The Pinnacle site contains approximately 100 million tons of unmined coal reserves of which 3.3-4.0 million tons are processed annually by the wash plant. The waste coal from the plant is diverted to the Smith Branch Impoundment, which is believed to contain 2.85 million tons of potentially recoverable fine coal.

b) Coal Samples

A number of coal samples were used to conduct dewatering tests during the evaluation and scale-up tests. Samples were taken from the PinnOak Company's Pinnacle Plant site and Smith Branch Impoundment near Pineville, WV. The samples consisted of a Vibracore composite sample taken from the Smith Branch Impoundment, a grab sample of current thickener underflow (taken in 2002), and a slip-stream sample of current thickener feed. All of these samples were tested in both in the laboratory and pilot scale using newly-developed dewatering aids. Shown below is an overview of the samples used in dewatering tests.

i) Laboratory Tests

Smith Branch Vibracore Composite Sample (68% solid, 30% ash)

Plant's Thickener Underflow Sample (12% solid, 33% ash)

Plant's Thickener Feed Sample (1.6% solid, 46% ash) *ii) Pilot Scale Tests*

Smith Branch Vibracore Composite Sample (68% solid, 30% ash)

Plant's Thickener Feed Sample (1.6% solid, 46% ash)

Vibracoring is a technology used to extract core samples of underwater sediments and wetland soils. The vibrating mechanism of a “vibracorer,” sometimes called the "vibrahead," operates on hydraulic, pneumatic, mechanical, or electrical power from an external source. The attached core tube is drilled into sediment by gravitational force and boosted by vibrational energy. When the drilling is completed, the vibracorer is turned off, and the tube is pulled out with the aid of hoist equipment. Extracting core samples via the vibracore sampling method assessed the quality of fine coal contained in the impoundment. The 2.5 inch diameter cores were extracted down to depths of 25 to 30 ft. and subjected to size and ash analyses.

Figure 30 shows a typical set of size-by-size analyses that were obtained from one set of core samples. Error bars are provided to illustrate the high, average, and low values obtained for

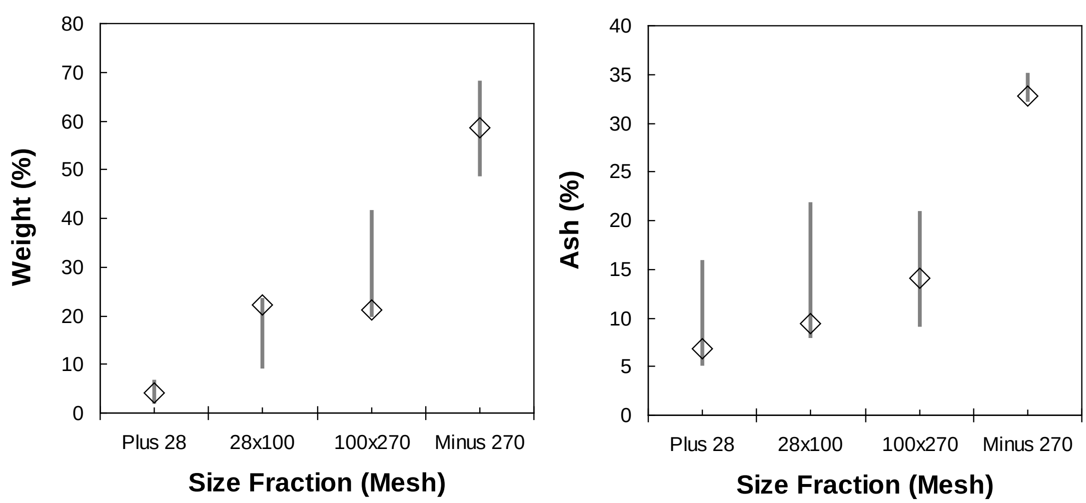

Figure 30. Weight and ash distributions of slurry from the Smith Branch impoundment.

each size class. This particular set of data shows that the minus 270 mesh fraction contains about 60% of the coal tonnage, with an average ash content of about 33-35%. The raw quality within the impoundment was found to vary greatly, dependent on the distance from the discharge point into the impoundment. In general, coal extracted near the discharge point was found to be coarser and higher in ash, while the coal extracted farther away from the discharge point was finer and lower in ash. Also, coal fines extracted from a greater depth were found to be of better quality than coal taken from more shallow locations. This was expected because the coal fines deposited earlier in the life of the mine were discarded before several improvements were made to the fine coal circuits in the existing preparation plant. The average ash content of the remaining 40% had an ash content of less than 15%.

c) Laboratory Procedures

The laboratory flotation and dewatering equipment consists of a Denver laboratory flotation cell, a vacuum pump, a mechanical shaker, a stand-alone mixer – in some cases – and a Buchner Funnel with a fitted filter medium. All the vacuum filtration tests were conducted using a 2.5 inch diameter Buchner Funnel at 20-25 inch Hg (68 kPa) with a 40 x 60 wire screen mesh filter medium.

The dewatering tests were conducted to determine the best reagents and dosages for different samples and to investigate under what conditions a given dewatering aid can give the best performance. All the coal samples were tested within three days of receipt in order to minimize any artificial negative effects of aging or surface property changes on dewatering. Because the samples were taken from the waste pond, thickener feed discharge, and thickener underflow discharge, they possessed high impurities. For this reason, a cleaning step was employed before the filter tests. Depending on the solid content, the samples were prepared first by either diluting or decanting to 16-17% solids and floated in a laboratory Denver flotation cell approximately at 1000 rpm using 400 g/t kerosene and 150 g/t MIBC to remove ash. A limited number of flotation feed and product samples were analyzed for ash. Then, the samples were collected in a separate container to be used in filtration tests. The dewatering aids (W, U, and V) were tested and diluted to 33.3% in solvent. When using the dewatering aids, conditioning is critical, and increased energy input in conditioning yields improved moisture reductions. For this reason, prior to each filter test, a known volume of slurry was conditioned with the dewatering aids in the mechanical shaker and, in some cases, the stand-alone mixer. When the mechanical shaker was used, the conditioning time was kept at 5 minutes, and when the stand-alone mixer was used, the conditioning time was kept at 2 minutes. Then, the conditioned sample was poured into the Buchner funnel for filtration. During the tests, the cake thickness was determined by the amount of the slurry sample used. Some of the conditions were kept constant during the tests. For example, a 7-10 mm cake thickness was determined for 2 minutes of drying time.

d) Pilot-Scale Procedures

The continuous dewatering test rig used at the Smith Branch site incorporated three main components, a column module, conditioner module, and a disc filter module, along with some other ancillary components. The details about the modules were described previously. For the pilot-scale tests, feed slurry was supplied from either the existing preparation pond reclaim facilities or in barrels and directed into the circuit feed sump. During the tests, the slurry was fed at a constant rate into a 12 inch diameter column by means of a peristaltic pump and flexible piping. The flotation column was used to produce a filter feed and reject ultra-fine hydrophilic clay that negatively impacts the effectiveness of some of the dewatering aids. Then, the clean coal froth was routed to the multi-stage conditioner module by gravity while the column reject slurry flowed, also by gravity, to a refuse sump. After adding appropriate dewatering reagents, the conditioned slurry was pumped at a constant rate into the filter test module. Next, the conditioned slurry was dewatered in the filter module. The filter cake was discharged into a container and immediately transferred to an oven for moisture analysis while the filter effluent was pumped to the reject sump. In addition, if any excess feed problems occurred, the column feed sump and conditioner tanks were allowed to overflow in a controlled manner.

e) Laboratory Results (Vibracore Samples)

The objective of the test series was to conduct preliminary investigations that evaluate the performance of dewatering aids. The laboratory tests were conducted on the Pinnacle Smith Branch Vibracore Composite Sample. Prior to the dewatering tests, the sample was cleaned using a Laboratory Denver Flotation Cell using 400 g/t kerosene and 150 g/t MIBC at 16.7 % solid content. Of the samples, the vibracore sample was very important because the data from the laboratory studies was also used to provide practical justification for the pilot scale test program which would soon to be carried out using Peterson Disc Filter.

A series of initial batch laboratory filter dewatering tests was conducted to determine whether the floated vibracore coal would respond well to the addition of the novel dewatering aids. A 62.5 mm diameter Buchner filter was used for these tests. The solids content of the sample was 16.0%. and a vacuum setup point of 20 inches Hg was utilized. The tests typically provided a cake thickness of 7-8 mm without reagent and 8-10 mm with reagent. A conditioning time of 5 minutes and a drying cycle time of 2 minutes was used. The volume of the slurry was

Table 102. Table 11 – Effect of W addition on the Pinnacle pond sample.

Reagent W Dosage (kg/t)	Moisture Content (%)	Moisture Reduction (%)
0	28.7	--
0.5	24.6	14.28
1.0	22.9	20.20
1.5	22.5	21.60
2.5	14.4	49.82

*62.5 mm diameter Buchner filter was used. The solid content of the sample was 16.0%. Vacuum setup point was 68 kPa (20 inches Hg). It was not changed during the experiment. Cake thickness; base: 7-8 mm, with reagent: 8-10 mm. Conditioning time: 5 minutes; drying cycle time: 2 minutes. The volume of the slurry was 100 ml. The impoundment sample was floated at 16.7% solids using 400 g/t kerosene and 150 g/t MIBC before the filter tests.

100 ml. The impoundment sample was floated at 16.7% solids using 400 g/t kerosene and 150 g/t MIBC before the filter tests. Table 102 gives the laboratory test results when W was used as the dewatering aid. As shown, the moisture content in the filter cake was reduced when reagent addition was increased. At 0.5 and 2.5 kg/t W additions, the moisture contents of the cake were reduced from 28.7% to 24.6% and 14.3%, respectively. The lower value corresponds to a 50% moisture reduction in the filter product.

f) Laboratory Results (Thickener Underflow Samples)

At the preparation plant after cleaning the coal, the residue was sent to a thickener and then pumped to the slurry impoundment. Because it was an active impoundment, the feed sample, thickener underflow, was also investigated, and similar tests were conducted on this sample using Reagents W and U. Results for the thickener underflow sample are given in Table 103, and the moisture content of the filter product again decreases with increasing W and U additions from 0.5 to 2.5 kg/t. Here, the W addition rate of 2.5 kg/t reduced cake moisture

Table 103. Table 13 – Effect of reagent addition on dewatering of Pinnacle thickener underflow sample.

Reagent Dosage (kg/t)	Moisture Content (%)		Moisture Reduction (%)	
	Reagent W	Reagent U	Reagent W	Reagent U
0	31.4	31.4	--	--
0.5	30.3	28.8	3.5	8.28
1.0	28.0	28.2	10.82	10.19
1.5	22.7	--	27.71	--
2.5	22.1	27.8	29.61	11.5

*A 62.5 mm diameter Buchner funnel was used. The solid content of the sample was 16.0%. Vacuum setup point was 68 kPa (20 inches Hg). It changed to 61-68 kPa during the experiment. Cake thickness: base: 7.0 mm, with reagent: 8-8.5 mm. Conditioning time: 5 minutes; drying cycle time: 2 minutes. The volume of the slurry was 100 ml. The underflow sample was first floated using 400 g/t kerosene and 150 g/t MIBC before the filter tests.

contents from 31.4% to 22.1%, giving a percentage moisture reduction of about 30%. This is much less than what was observed in the case of the impoundment sample and can attributed to the different mean particle sizes of these two samples. Mean particle size, as determined by Microtrac particle size analyzer in Beard Technologies' laboratory, was approximately 32 micron for the impoundment sample and 15 micron for the thickener underflow sample. The reasons for the relatively poor behavior of U are unclear but may be related to the presence of flocculant in the sample.

Another set of tests was conducted on a deslimed thickener underflow sample to investigate the effect of particle size distribution. Before the dewatering tests 50% of minus 45 micron material was removed by wet screening. Table 104 shows the effect of the desliming on dewatering of this sample. The final cake moisture was reduced down to 22.0% moisture 2.5 kg/t dosage of Reagent W. When Reagent U was used as dewatering aid, the moisture could be reduced down to 21.4% moisture at the same dosage of 2.5 kg/t.

Table 104. Effect of desliming on dewatering of Pinnacle thickener underflow sample.

Reagent Dosage (kg/t)	Moisture Content (%)		Moisture Reduction (%)	
	Reagent W	Reagent U	Reagent W	Reagent U
0	29.38	29.38	--	--
0.5	23.98	25.28	18.38	13.96
1.0	23.39	23.17	20.38	21.13
1.5	22.77	22.16	22.49	24.58
2.5	22.00	21.37	25.11	27.26

*A 62.5 mm diameter Buchner funnel was used. The solid content of the sample was 16.0%. Vacuum setup point was 68 kPa (20 inches Hg). It changed to 61-68 kPa during the experiment. Cake thickness: base: 7.0 mm, with reagent: 8-8.5 mm. Conditioning time: 5 minutes; drying cycle time: 2 minutes. The volume of the slurry was 100 ml. The underflow sample was first floated using 400 g/t kerosene and 150 g/t MIBC before the filter tests.

Table 105. Effect of reagent addition on dewatering of Pinnacle thickener feed sample.

Reagent Dosage (kg/t)	Moisture Content (%)		Moisture Reduction (%)	
	Reagent W	Reagent U	Reagent W	Reagent U
0	29.5	29.5	--	--
0.5	26.5	27.3	10.17	7.46
1.0	24.3	25.2	17.63	14.58
1.5	22.2	23.1	24.75	21.70
2.5	21.1	21.8	28.48	26.10

*62.5 cm diameter Buchner filter was used. The solid content of the sample was 11.0%. Vacuum setup point was 68 kPa (20 inches Hg). It changed to 61-68 kPa during the experiment. Cake thickness; base: 7.0 mm, with reagent: 8-8.5 mm. Conditioning time: 5 minutes; drying cycle time: 2 minutes. The volume of the slurry was 100 ml. The thickener feed sample was floated using 400 g/t kerosene and 150 g/t MIBC before the filter tests.

g) Laboratory Results (Thickener Feed Samples)

Table 105 gives the results for the thickener feed sample. In this case, W and U reduced the cake moistures from 29.5% to 21.1% and 21.8%, respectively, and percentage moisture reductions of about 28% and 26% at addition rates of 2.5 kg/t. Again, these reductions are much less than those that occurred with the impoundment sample. Due to the preferential removal of fine clay during flotation, the mean size of the test sample was probably also around 15 microns.

h) Pilot-Scale Results (Vibracore Samples)

Reagent W was used as the dewatering aid in these sets of pilot scale dewatering tests. Table 106 gives the pilot scale dewatering results obtained on the Smith Branch Impoundment sample. These results show that the moisture contents of the filter cakes are substantially decreased in the presence of dewatering aid. For example, at reagent dosage rates of 1.0-2.5 kg/t of Reagent W, filter cake moisture content was reduced from 28.4% to 17.7%-16.3%. Cake thicknesses were as high as 16 mm when using Reagent W as the dewatering aid versus 3-6 mm without a reagent. Even at this cake thickness, moisture reductions were significant. Additionally, filter effluents were much cleaner when dewatering aids were used, indicating that filter recoveries increased substantially in the presence of the dewatering aid.

Table 106. Effect of W addition on the pilot scale dewatering of the Pinnacle-Smith Branch Impoundment sample using the mobile units.

Reagent W Dosage (kg/t)	Moisture Content (%)	Moisture Reduction (%)
0	28.4	--
0.5	19.6	30.99
1.0	17.7	37.68
1.5	17.2	39.43
2.5	16.3	42.61

* 10 sector single disc Peterson filter was used in the experiments. The solid content of the filter feed was 17.0%. The vacuum setup point was 81.27-84.66 kPa (24-25 inches Hg). It dropped to 67.73-77.89 kPa (20-23 inches Hg) during the experiment. Cake thickness; base: 6-8 mm, with reagent: 12-16 mm..

i) Pilot-Scale Results (Thickener Feed Samples)

Table 107 gives the pilot scale dewatering results obtained on the Pinnacle coal thickener feed sample tests. In this series of tests, W was used as the dewatering aid. As shown below, the moisture content of the filter cake is reduced from 29.4% to 21.5% by the addition of 2 kg/t of Reagent W. Likewise, the test results given in Table 108 show that the moisture content of the

Table 107. Effect of W addition on the pilot scale dewatering of the Pinnacle thickener feed sample using the mobile test units.

Reagent W Dosage (kg/t)	Moisture Content (%)	Moisture Reduction (%)
0	29.4	--
0.5	--	--
1.0	--	--
1.5	21.5	27.2
2.5	--	--

* 10 sector single disc Peterson filter was used in the experiments. The solid content of the filter feed was 12.3%. Vacuum setup point was 81.27-84.66 kPa (24-25 inches Hg). It dropped to 71.11-74.50 kPa (21-22 inches Hg) during the experiment. Cake thickness; base: 6-8 mm, with reagent: 12-16 mm.

Table 108. Effect of reagent addition on dewatering of Pinnacle thickener feed sample.

Reagent Type	Reagent Dosage (kg/t)	Moisture Content (%)	Moisture Reduction (%)
W	0	28.0	--
	0.95	23.4	16.43
	3.7	20.3	27.5
	4.45	21.8	22.14
U	0	28.0	--
	3.1	20.6	26.43
	5.5	21.0	25

* 10 sector single disc Peterson filter was used in the experiments. The solid content of the filter feed was 8-9%. Vacuum setup point was 71.11-88.05 kPa (21-26 inches Hg). It dropped to 47.41-77.89 kPa (14-23 inches Hg) during the experiment. Cake thickness; base: 5-6 mm, with reagent: 10-20 mm.

filter cakes are significantly decreased when Reagents W and U are used as dewatering aids. For example, filter cake moisture contents were reduced from 28.0% to 23.4% at 0.95 kg/t and 20.3% at a 3.7 kg/t reagent dosage. Reagent U performs as well as Reagent W in terms of moisture reduction. The moisture content in the filter cake was reduced from 28% to 20.6% in the presence of 3.1 kg/t of Reagent U. These results are in good agreement with those obtained in the previous laboratory tests.

4.4 PROCESS SCALE-UP AND DESIGN

4.4.1 Overview

The work conducted under this task involved the conceptual design of two proof-of-concept (POC) flowsheets that incorporate the dewatering technologies developed in the present work. To maximize the potential for moisture reduction, both of the POC circuits have been designed to incorporate the advanced flotation processes together with the dewatering technologies developed in this project. The test data shown in previous sections of this report indicate that advanced flotation equipment, such as column cells, are generally needed to reject hydrophilic clay particles that adversely impact the performance of some of the low cost dewatering chemicals.

The first POC flowsheet (Circuit I – Plant Retrofit) was developed to recover fine coal from a classifying cyclone overflow steam that is currently discarded at an existing preparation plant. This circuit was designed based on the mini-plant test data collected in Task 4 using samples from the Red River preparation plant. This plant, which is located in Big Stone Gap, Virginia, is a regional producer of high-quality specialty coals for the industrial, metallurgical and utility markets. The second POC circuit (Circuit II – Pond Reclaim) was developed to recover waste coal fines for a pond reclaim facility. Operational data used in the design of this circuit were obtained from Beard Technologies, Inc., a company specializing in the recover of coal waste impoundments.

The conceptual circuits shown in this section of the report were developed by personnel at Virginia Tech using standard process design and cost estimation procedures. Detailed engineering and financial analyses have also been performed by Red River Coal Company and Beard Technologies for each of their sites. However, these confidential analyses will not be presented in order to protect the financial interests of these industrial participants. The numerical values included in this report are preliminary estimates and should only be used to evaluate the potential impacts of the dewatering technologies developed as part of this project.

4.4.2 Equipment Specification

Scale-up projections were made for the two primary unit operations (i.e., flotation and filtration) to be installed at each POC facility. The scale-up calculations for the flotation columns are summarized in Table 109. The scale-up projections were based on the specific capacities of clean coal product established for each site. A somewhat more conservative value of specific capacity was used for the pond reclaim flowsheet (Circuit II) due to the greater uncertainly associated with this site (i.e., 0.10 versus 0.12 tph/ft^2). In addition, the flowsheet projections indicate that the POC circuit installed for pond reclamation would produce more than twice as much clean coal as the retrofit circuit (i.e., 31.8 tph versus 68.7 tph). Therefore, the flowsheet for the plant retrofit (Circuit I) required only two 4.0-meter diameter columns, while the pond reclaim flowsheet (Circuit II) required four 4.5-meter diameter columns. Screw compressors were also required at each site for gas sparging. This included a single 1000 scfm air compressor

Table 109. Scale-up calculations for the POC column flotation installation.

	Base Units	POC Circuit I	POC Circuit II
Scale-Up Factors:			
Specific Capacity	tph/ft^2	0.12	0.10
Specific Gas Rate	cfm/ft^2	3.8	3.8
Specific Wash Rate	gpm/ft^2	3.4	3.4
Residence Time	min	5.0	5.0
Number of Columns	---	2	4
Column Circuit Production:			
Feed Tonnage	tph	49.0	98.2
Feed Slurry Rate	gpm	5974	4749
Feed Slurry Rate	cfm	799	635
Clean Tonnage	tph	31.8	68.7
Clean Slurry Rate	gpm	1240	3704
Clean Slurry Rate	cfm	166	495
Refuse Tonnage	tph	18.3	29.5
Refuse Slurry Rate	gpm	5641	3456
Refuse Slurry Rate	cfm	754	462
Column Geometry:			
Required Area/Column	ft^2	132.3	171.8
Required Diameter	ft	12.98	14.79
Required Diameter	m	3.96	4.51
Required Volume/Column	ft^3	1885	578
Required Height	ft	31.2	22.2
Required Height	m	9.5	6.8
Flow Rate Projections:			
Gas Rate/Column	cfm	502.7	653.0
Water Rate/Column	gpm	449.8	584.2

for Circuit I and two 600 scfm air compressors for Circuit II. The compressors were selected based on a specific gas rate of 3.8 scf/ft^2 of column cross-sectional area.

Table 110 provides the preliminary scale-up calculations for the disc filter. The calculations were performed based on a target capacity of 40 tph/ft of disk filter area. Therefore, a standard two-sided 12 x 6 filter disc (220 ft^2 filter area) can produce 4.4 tph of dry filter cake. Based on these figures, the plant retrofit flowsheet (Circuit I) required only a single 8-disc filter

Table 110. Scale-up calculations for the POC disc filter installation.

	Base Units	POC Circuit I	POC Circuit II
Scale-Up Factors:			
Specific Capacity	$lb/hr/ft^2$	40.0	40.0
Specific Vacuum Rate	cfm/ft^2	7.0	7.0
Specific Power Consumption	HP/cfm	0.04	0.04
Number of Filters	---	1	2
Area/Disc (12 x 6 disc)	ft^2	220	220
Filter Production:			
Feed Tonnage	tph	31.8	68.7
Feed Slurry Rate	gpm	1240	3704
Feed Slurry Rate	cfm	166	495
Cake Tonnage	tph	31.5	68.0
Cake Slurry Rate	gpm	130	270
Cake Slurry Rate	cfm	17	36
Effluent Tonnage	tph	0.2	0.7
Effluent Slurry Rate	gpm	1110	3434
Effluent Slurry Rate	cfm	148	459
Filter Geometry:			
Total Area	ft^2	1588	1718
Total Area/Filter	ft	1588	859
Total Number Discs	---	7.2	7.8
Total Number Discs	---	8	8
Vacuum & Power:			
Vacuum Pump Rate	cfm	12320	12320
Power Requirement	HP	493	493

to produce the desired capacity of 31.5 tph. Two 8-disc filters were required to achieve the target capacity of 34.0 for the pond reclaim flowsheet (Circuit II). Appropriate vacuum and filtrate pumps were also selected to provide a total gas flow rate of 7 cfm/ft^2 of disc surface. Consequently, one 12,350 cfm vacuum pump was needed for Circuit I and two for Circuit II. An "enhanced" disc filter equipped with a dual vacuum system was selected for the POC facilities. The dual vacuum system, which was evaluated as part of this project, makes it possible to properly control the thickness of the filter cake and optimize the performance of the dewatering chemicals.

4.4.3 Circuit Design

In this task, conceptual flow diagrams were developed for each of the two POC circuits developed in this project. The flowsheets were specifically tailored for each site identified by the industrial participants in this project. The flowsheets were based on average feed rates (dry basis) of 50 tph for the plant retrofit site (Circuit I) and 103 tph for the pond reclaim site (Circuit I). Each POC flowsheet was assumed operate for two 8-hour shifts per day and 250 days per year with 90% availability. Mass yields and product moistures were established based on performance data obtained from the bench-scale tests.

Figure 31 shows the conceptual flowsheet for the POC facility (Circuit I) that was designed to treat classifying cyclone overflow of an operating coal preparation plant. This stream is typically discarded into waste impoundments by steam coal producers since the particle size is considered too fine to be economically upgraded and dewatered using conventional technologies. As shown, the POC circuit developed in this project includes column flotation cells and an enhanced disc filter (which incorporates the dual vacuum system). The column cell is fed with dilute slurry produced by the overflow of an existing bank of classifying cyclones. Although the existing preparation plant cyclones cut at 0.15 mm (100 mesh), the POC circuit has been designed to accept minus 0.25 mm feed (minus 65 mesh). Modification of the plant classifying cyclones to accommodate this coarser cut size will have the added benefit of unloading tonnage from the existing water-only cyclone circuit. A pulping tank has been included to provide flotation surge capacity and collector conditioning time. The froth product from the column is

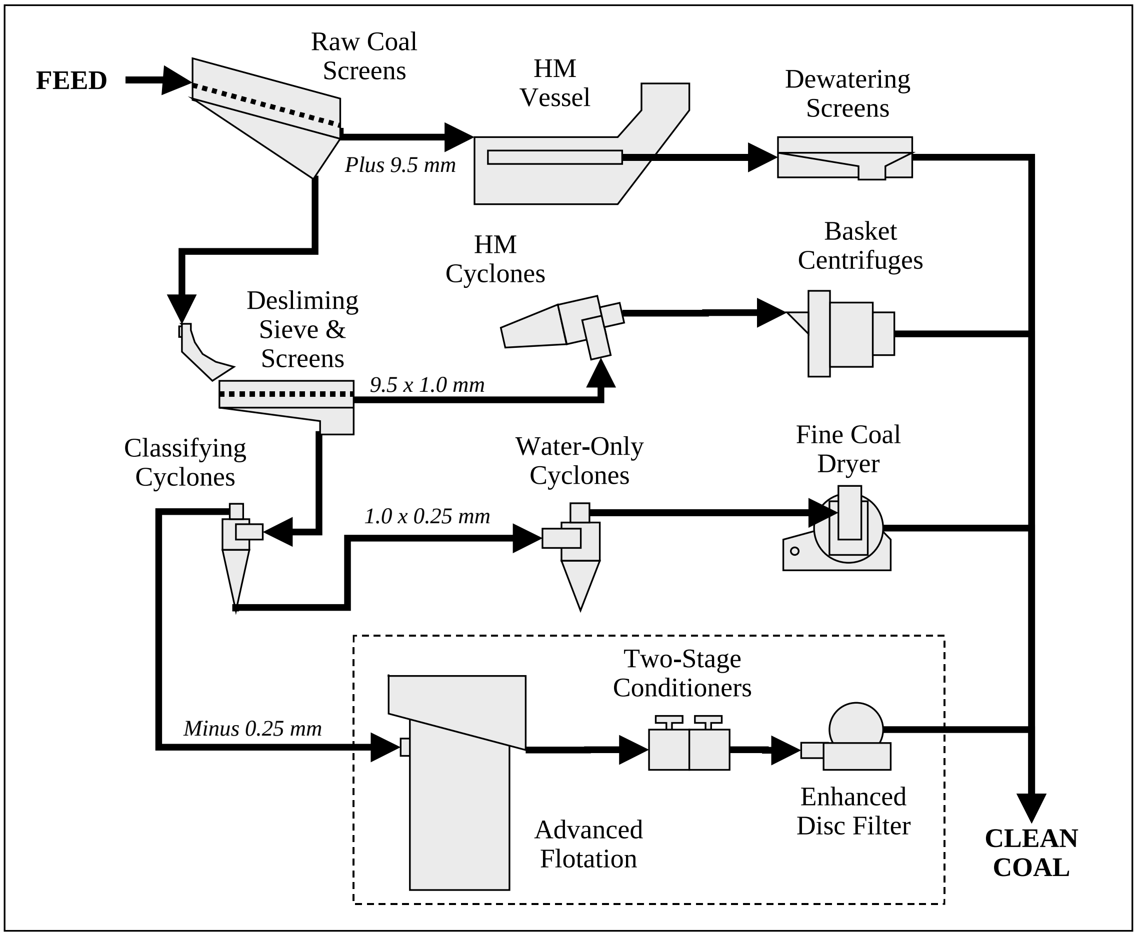

Figure 31. Generic POC flowsheet for treating classifying cyclone overflow from existing plants (Circuit I). (POC circuit enclosed within dashed box.)

directed into a deaeration tank before flowing into a two-stage conditioner where appropriate dewatering chemicals are added. The conditioned slurry is then pumped to the filter station where it is dewatered. The filter cake is discharged onto a clean coal conveyor and combined with the clean coal from the coarse coal circuits. Moisture balances conducted for the site indicate that the filter cake moisture must be maintained below 23-24% to remain below the contractual moisture limit of 7% for the overall plant product. The test data collected in this project show that this level of moisture could be achieved at a 2 lb/ton dosage of dewatering chemical (HLB-1). The flowsheet calculations indicate that the POC facility will increase clean coal production by more than 30 tph.

Figure 32 shows the conceptual flowsheet for the POC facility (Circuit II) designed to process feed coals from a pond reclamation site. This facility will be capable of treating approximately 188 tph of fine coal (minus 6 mm). The feed coal will be supplied either from a pond reclaim operation (dredge) or as thickener underflow from an existing preparation plant. The raw plant feed will be screened at 6.3 mm and the oversize discarded. The minus 6.3 mm fraction will be directed to a buffer tank that feeds a bank of 14-inch classifying cyclones. The coarse (6.3 x 0.25 mm) underflow from the cyclones will be treated by coal spirals, while the

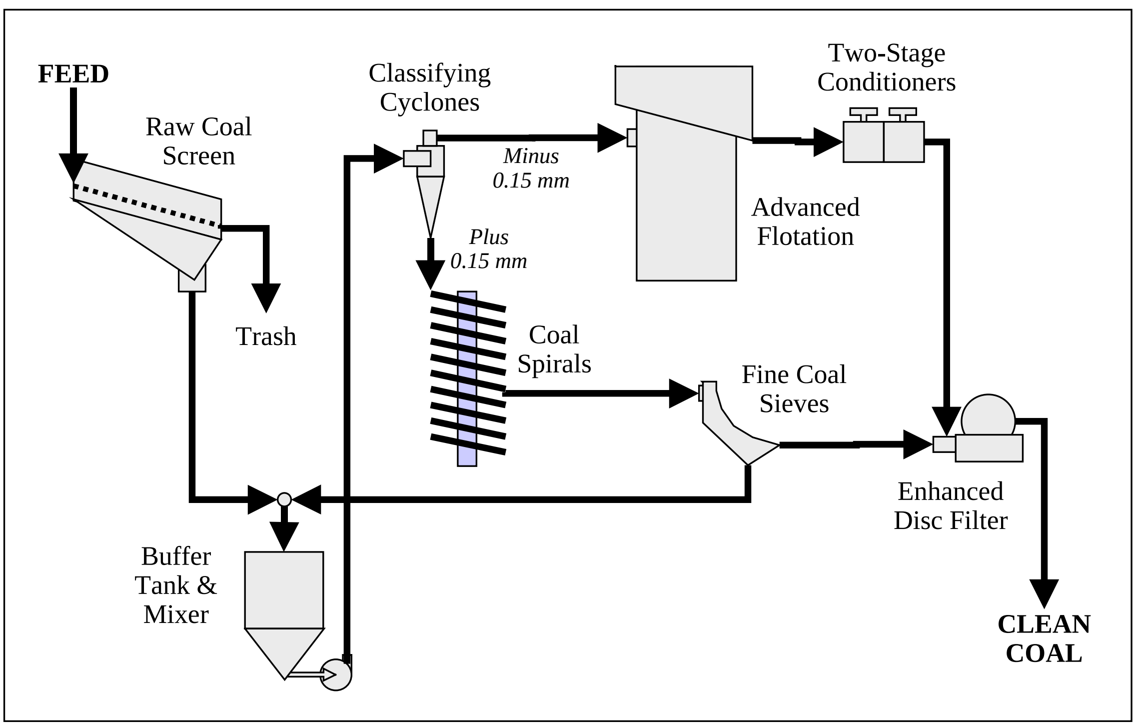

Figure 32. Generic POC flowsheet for treating pond reclaim material (Circuit II).

fine (minus 0.25) overflow will be passed to the advanced flotation circuit. The spiral and flotation circuits have been designed to handle 90 tph and 98 tph, respectively. The clean coal froth will be conditioned with appropriate dewatering reagents and passed along with the clean coal spiral product to the enhanced disc filter. Analyses conducted in this project indicate that the disc filter will produce approximately 68 tph of clean coal with 22% total moisture content.

4.4.4 Preliminary Cost Analysis

The objective of this task was to determine the estimated cost of the POC circuitry described above. The cost of the 4.0-meter diameter column unit required by Circuit I, including associated instrumentation and controls, was estimated to be $160,000. Likewise, the cost of each 4.5-meter unit required by Circuit II was valued at $180,000. For estimation purposes, it was assumed that Circuit I required one $78,000 gas compressor, while Circuit II required two identical units. Capital costs for the disc filter (including ancillary components such as vacuum and filtrate pumps) were determined to be $498,000 and $1,076,00 for Circuit I and Circuit II, respectively.

In addition to the flotation cells and disc filters, several ancillary operations were also included in the listing of capital costs. These included a two-stage conditioner, cake conveyor, various feed and product sumps, reagent tanks and pumps, piping and chutes, and instrumentation. An additional capital outlay of $20,000 was allocated to cover heat/lighting. This value was increased to $32,000 for the pond reclaim site (Circuit II). The total installed cost of equipment was estimated by multiplying the total equipment cost by an installation cost factor of one. This estimation procedure is routinely used by local fabricators. Other costs considered in the capital estimation included a 5% fee for engineering/permitting and an overhead rate of 5%.

Based on these estimates, the total fixed costs for each site were determined to be $2.82 MM and $5.85 MM for Circuits I and II, respectively.

Annual operating costs for the POC circuits were estimated for power consumption, equipment maintenance, personnel and miscellaneous consumables (dewatering reagents, flotation reagents and lubricants). Electrical power consumption was estimated for the columns, air compressor, disc filters, vacuum pumps, slurry pumps, cake conveyor, reagent feeders and heat/light. For the primary unit operations, a power load factor of 80% was used to estimate actual power requirements, while a power factor of 15% was used for heat/light and small reagent pumps. Power costs were estimated at an industrial rate of $0.04/kW-hr. Annual power costs for each site were estimated to be $132,571 for the plant retrofit (Circuit I) and $279,335 for the pond reclaim (Circuit II).

Labor costs were also estimated for each of the two POC sites. The POC circuits were assumed to require a part-time operator ($55,000/yr) for each of the two 8-hr working shifts. Personnel benefits were estimated as 100% of the base salary. The utilization of manpower required for operation and maintenance of the circuitry was assumed as 50% of direct labor expenses. Based on these estimates, the yearly labor costs amounted to $110,000 for each site.

The major consumable items included in the annual operating costs were the flotation reagents (i.e., frother @ $0.86/lb and fuel oil collector @$0.11/lb) and dewatering chemicals (i.e., dewatering aid @ $0.54/lb and diesel fuel carrier @ $0.12/lb). The frother and fuel oil dosages were fixed at 0.70 and 0.50 lb/ton of flotation feed. The dewatering chemical was added at a rate of 2 lb/ton of filter feed. Since the dewatering chemicals are not soluble in water, the reagent was blended with a diesel fuel carrier in a 2:1 ratio. Based on these figures, the total annual reagent costs for the plant retrofit were estimated to be $254,546 ($76,238 for flotation and $178,308 for dewatering). Likewise, the total annual reagent costs for the pond reclaim site were estimated to be $551,060 ($165,046 for flotation and $386,014 for dewatering). Annual equipment maintenance costs were estimated as 10% of the total capital cost of the proposed circuitry.

After completing the cost estimates, cost-benefit analyses were conducted for each site over an effective life span of 20 years. An inflation rate of 4% was assumed and that 75% of the debt was carried forward after the first year of operation (i.e., no loan was necessary to cover the capital expenditure). Tax payments were estimated using a 20 year depreciation period and 38% corporate tax rate. In addition, additional payments were made at a rate of 6.5% for coal royalties and 6.7% for miscellaneous taxes/fees (4.5% severance tax, 1% black lung tax and 1.2% reclamation fees). A straight-line depreciation schedule was assumed in each case. A discount rate of 10% was assumed in calculating the rate-of-return on the capital investment.

The various coal products were assumed to have a market value of $25/ton (as received FOB) with a $0.20/100 BTU adjustment for heating values above (premium) or below (penalty) a 12,500 BTU base value. This price adjustment, which is common to nearly all steam coal contracts, makes it possible to correct for different heating value of the shipped products based on differences in product moisture. Shipping costs were estimated to be $10/ton of clean coal for this particular case study. Mining costs (i.e., the cost of fine feed coal) was not considered for the plant retrofit case (Circuit I) since this stream is currently being discarded by the plant as a waste stream. In fact, this stream represents a cost item since it must be treated by the water clarification circuit within the plant. For the pond reclaim operation (Circuit II), a coal cost of $5.00/ton was assumed. This is believed to be conservative given the fine size and high ash content of the unprocessed pond material. In addition, a cost of $1.50/ton was included to cover expenses associated with the dredging operation. Thus, the total cost of coal for the pond reclaim would be $6.50/ton.

The results of the cost-benefit analyses for the two POC plants are summarized in Table 111. The production costs for the two circuits were $6.81/ton of clean coal for the plant retrofit (Circuit I) and $6.17/ton of clean ton for the pond reclaim (Circuit II). The lower production cost for Circuit II can be largely attributed savings in capital and operating costs per unit of capacity due to the economy-of-scale of the larger plant. However, the unit costs per ton of feed are nearly identical at $4.28/ton of raw coal. However, the lower coal cost allowed Circuit I to achieve the best overall return on the capital investment. In this case study, the plant retrofit flowsheet (Circuit I) offered a 145% internal rate of return and a corresponding payback period of less than three years (2.82 years). In contrast, the POC circuit for the pond reclaim site (Circuit II) provided a 68% internal rate of return with a payback of slightly more than 6 years (6.20 years). The return for this site is probably significantly better than these values indicate since they do not take into account the additional coal production associated with the spiral

Table 111. Cost-benefit analysis for the POC circuits.

Cost Indicator	Circuit I (Plant Retrofit)	Circuit II (Pond Reclaim)
Production Cost:		
($/ton clean coal)	$6.81	$6.17
($/ton raw coal)	$4.29	$4.28
Economic Indicators:		
Internal Rate of Return	145%	68%
Payback Period	2.82 yrs	6.20 yrs

circuits that are also included in the POC plant. In any case, both POC circuits appear to be financially attractive, yielding internal rates of return significantly greater than the 30-40% target often used by mining companies for allocation of capital.

Finally, economic sensitivity studies were conducted using the cost-benefit model developed in this project. These studies were performed to evaluate the impacts of potential variations in reagent costs on the profitability of the POC circuits. Figure 30 shows the cost of dewatering reagents (reported as $/ton of filter feed) on the economic indicators for Circuit II (pond reclaim). In this case, the total cost of the reagent package must be less than approximately $4.50/ton to maintain the internal rate of return above 50%. However, Figure 33 shows that the internal rate of return for Circuit I (plant retrofit) remains above 50% even if the reagent costs

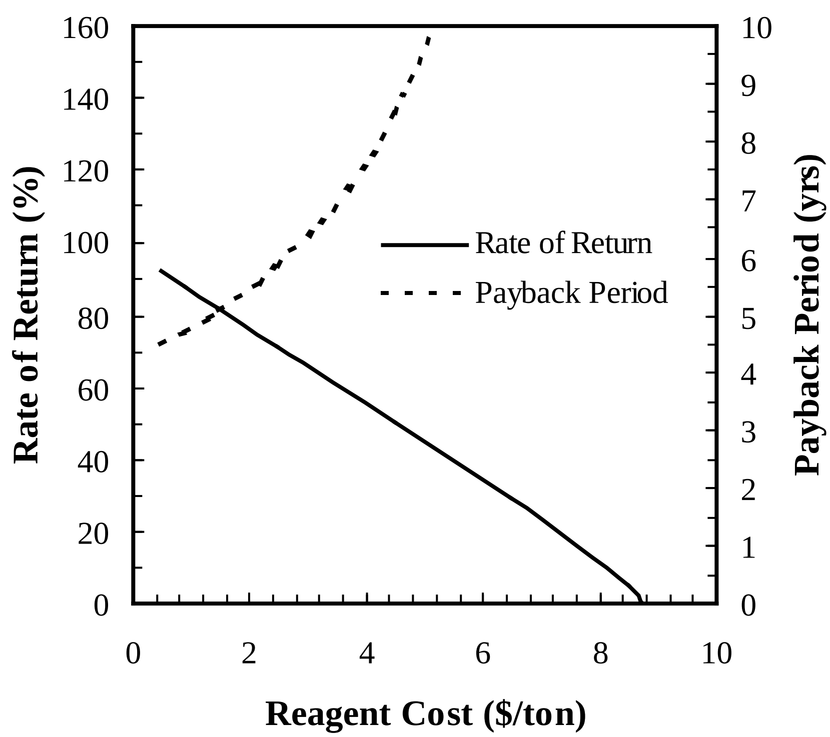

Figure 33. Effect of dewatering chemical cost on the economic indicators for Circuit II (pond reclaim).

reach the extreme case of $10/ton. The favorable economics for this application can be largely attributed to having no mining fees associated with the plant waste stream. In fact, the costs of the dewatering chemicals for this application are expected to be only $1.56/ton. Consequently, the economic feasibility of each of the POC circuits is extremely attractive.

4.5 PROOF-OF-CONCEPT DEMONSTRATION

4.5.1 Background

Based on the feasibility studies described above, a decision was made to demonstrate the capabilities of the novel dewatering aids at the Smith Branch impoundment site by constructing a proof-of-concept (POC) facility. This site was ideally suited for a demonstration project since the dewatering aids made it possible to convert the waste coal impoundment at this site from environmental liability into a profitable resource. The Smith Branch impoundment is located in Wyoming Country, West Virginia. At the time of this project, Beard Technologies Inc. owned the permit to remine and recover coal from this site. The impoundment currently serves the Pinnacle mining complex, which is now owned by Cleveland Cliffs Mining. The waste coal impoundment is estimated to contain 2.85 million tons of potentially recoverable fine coal (see Figure 34). The impoundment is an active site and continues to receive coal slurry refuse from the existing Pinnacle preparation plant as thickener underflow. Approximately 200,000 tons of additional fine coal is discharged into the impoundment annually by the existing Pinnacle preparation plant.

4.5.2 POC Engineering and Circuit Design

The data compiled by Beard Technologies Inc. was used to quantify the amount of potentially recoverable coal present within the impoundment and to formulate the best possible processing strategies for sizing, cleaning and dewatering of the coal fines. Based on these analyses, a detailed flowsheet was prepared for the POC facility by E.T. Kilbourne and Associates of Kingsport, Tennessee. The flowsheet was prepared in close cooperation with personnel from Beard Technologies and Virginia Tech. The detailed flowsheet included mass and flow balances, equipment specifications, and size distributions for the various process streams. A proof copy of the POC flowsheet is provided in Figure 35 as an AutoCAD drawing.

Once the flowsheet was completed, detailed listings of required unit operations, such as equipment type, unit size, throughput capacity, reagent/chemical requirements, power requirements, air/water requirements, operating limitations, vendor cut-sheets, were produced by

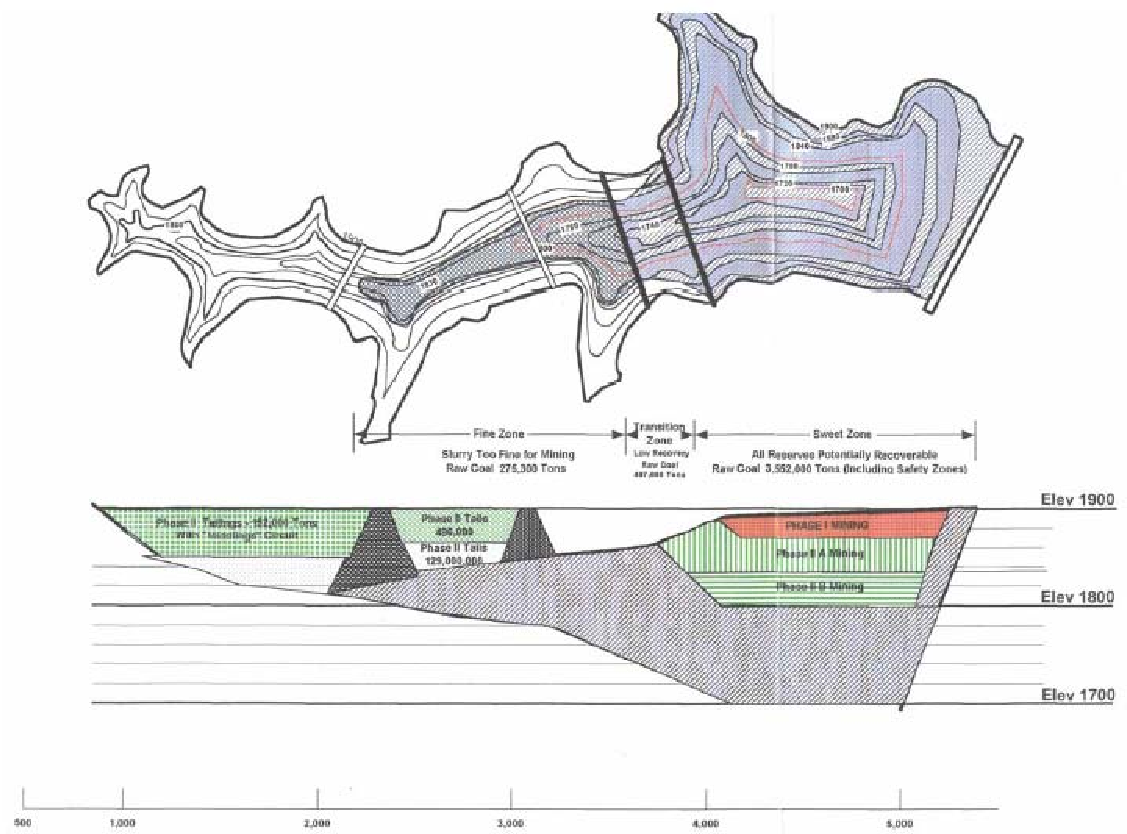

Figure 34. Pinnacle waste coal impoundment cross-section from vibracore analysis.

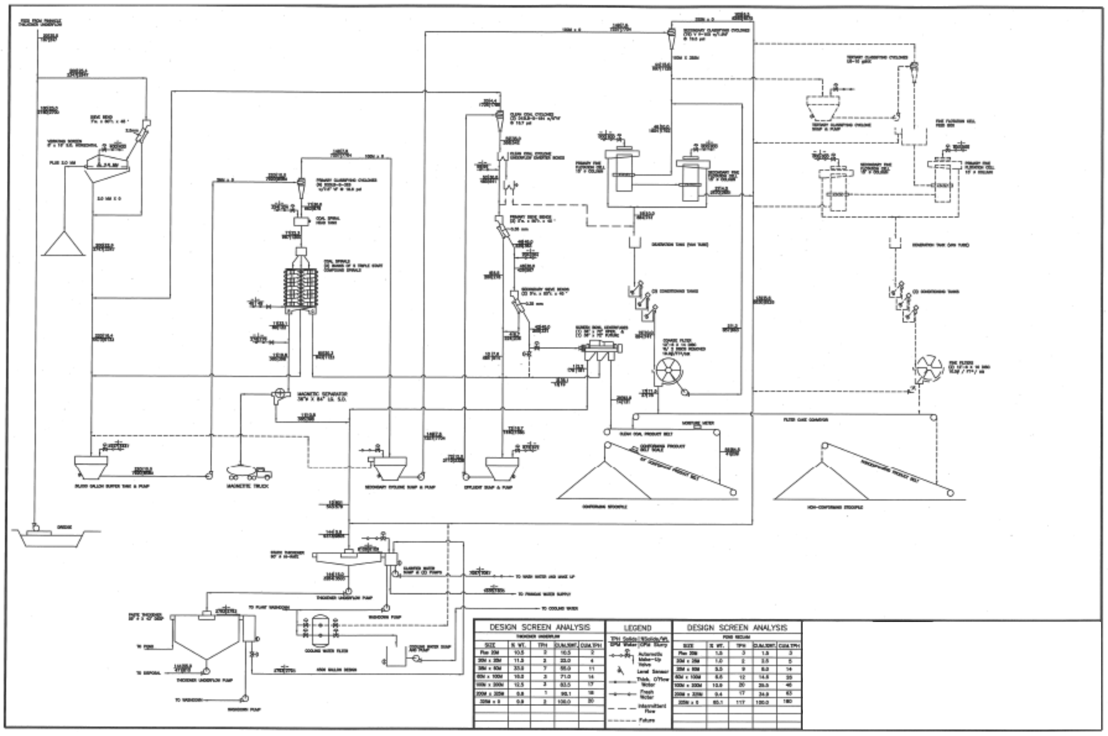

Figure 35. Engineering flowsheet for the POC-scale pond reclaim facility.

technical personnel at Beard Technologies. Detailed plant layout diagrams were prepared by Boyce, Graybeal and Sayre (BGS), Inc. of Slab Fork, West Virginia. The layout diagrams specified the physical arrangement of all primary operations, ancillary processing units, connecting streams, location of electrical wiring, arrangement of piping and plumbing, and other pertinent electrical/mechanical requirements. The engineering drawings and specifications were of sufficient detail to permit mechanical/electrical subcontractors to fabricate, construct, and assemble the proposed POC circuitry.

4.5.3 POC Fabrication and Installation

Bid packages were prepared for soliciting bids for major purchases of equipment, materials, fabricated components, and services necessary to complete the installation of the POC circuitry. Upon receipt, the bid packages were reviewed, and appropriate vendors were selected based on cost, availability, and suitability. This work included (i) fabrication of all required components associated with the various POC circuits, (ii) shipping of POC modules, ancillary equipment and construction materials to the POC site, (iii) inspection of all purchased POC modules, ancillary equipment and materials to ensure that they are of suitable workmanship and are structurally, mechanically and/or electrically operational, and (iv) preparation of operation, maintenance, and safety manuals for each unit operation.

After developing the flowsheet, the installation of all unit operations, piping, electrical wiring, and instrumentation were undertaken. The on-site construction work was contracted and managed by Boyce, Graybeal and Sayre (BGS), Inc. of Slab Fork, West Virginia. The fabrication and on-site construction activities required approximately one year to complete. The plant incorporates some of the most advanced technologies available to the coal preparation industry as POC circuits. The most significant of these included a two-stage advanced column flotation circuit for fine coal separation, a three-stage bank of agitated mixing tanks to condition the dewatering bank developed in Phase I of this project, and a paste thickener to convert the fine high-ash wastes into a high-solids product for disposal with minimal environmental impact.

A simplified process flow diagram of the as-built plant incorporating the POC dewatering circuitry is provided in Figure 36. A photograph of the nearly completed plant is shown in Figure 37. The plant was designed with a raw feed nameplate capacity of approximately 200 tph of dry solids. The plant sizes/classifies the feed from the dredge into four nominal size fractions, plus28 mesh, 28 x 100 mesh, 100 x 325 mesh, and minus 325 mesh. The initial separation occurs on a sieve bend and single deck vibrating screen. The plus28 mesh material (screen oversize) is discharged to a stockpile outside the plant, and the minus 28 mesh reports to a 30,000 gallon surge tank. Material

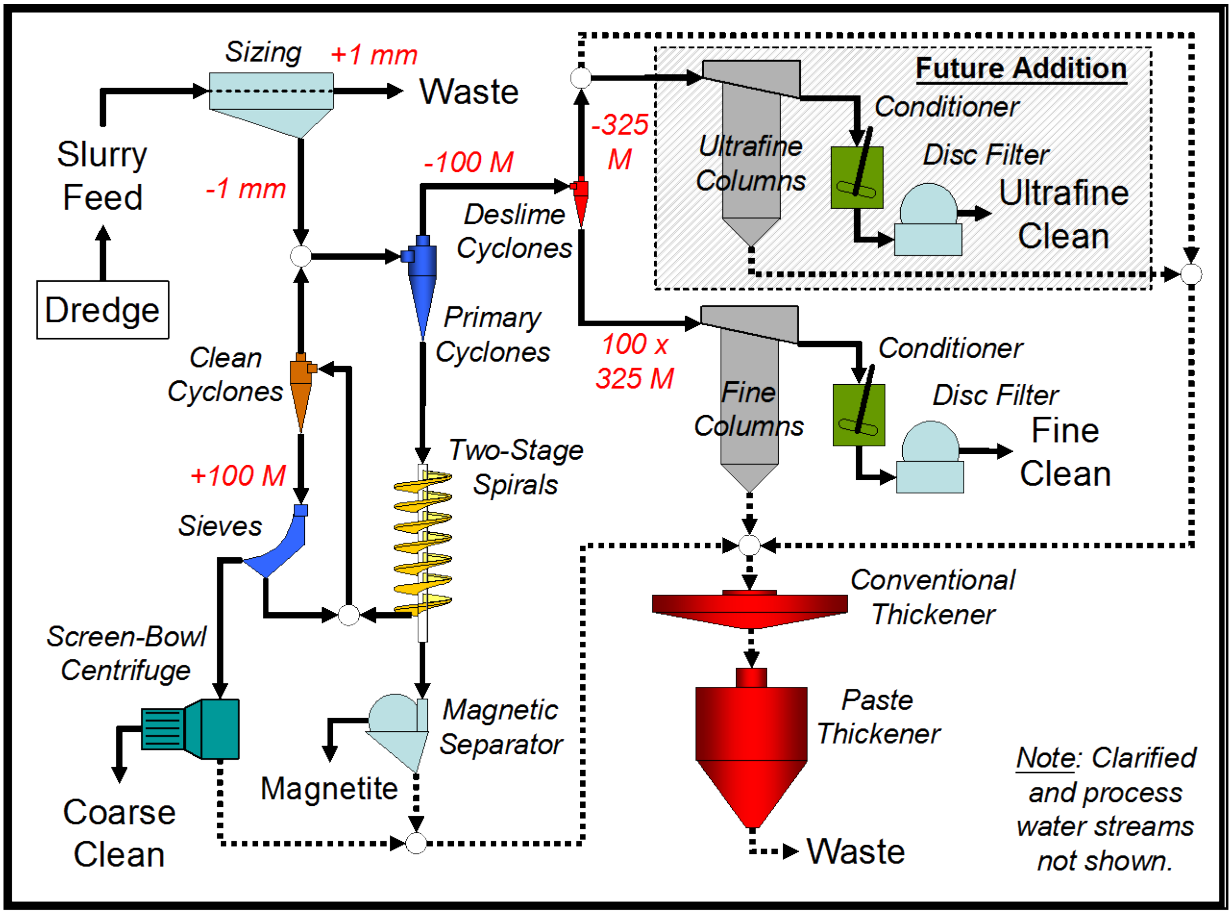

Figure 36. Simplified process flow diagram for the pond reclaim facility.

from the surge tank is pumped into 20 inch diameter classifying cyclones, which nominally sizes the feed at about 100 mesh.

The plus 100 mesh underflow from the classifying cyclones (Figure 38) reports to two banks of compound spirals. The spiral product is discharged to a clean coal sump and pumped to a bank of 15-inch diameter clean coal classifying cyclones. The underflow from the clean coal cyclones is passed across a two-stage rapped sieve bend system to remove high-ash minus 100 mesh solids from the spiral product. The clean coal product from the spirals is dewatered using two 36 x 72 inch triple-lead screen-bowl centrifuges (Figure 39). The dewatered product is

Figure 39. Nearly completed plant incorporating the POC circuitry.

Figure 40. Classifying cyclones used to provide a 100 mesh cutsize.

dropped to a clean coal collection belt and transported to a radial stacker stockpile. The spiral reject passes through a magnetic separator to recover any magnetite that may have been present in the slurry before being discarded as waste.

The minus 100 mesh overflow from the classifying cyclones is pumped through two banks of 4 inch diameter classifying cyclones (Figure 39). The "deslime" cyclones make a

Figure 37. Deslime cyclones used to perform a nominal 325 mesh cutsize.

Figure 38. Screen-bowl centrifuge used to dewater 100x235 mesh product.

nominal size separation at 325 mesh. The deslimed underflow reports to a two-stage advanced column flotation bank. The deslime overflow is currently discharged as waste, but provisions are included in the flowsheet design to incorporate a secondary advanced flotation bank, dewatering aid conditioners, and disc filter to recover the ultrafine coal that is now lost in this stream. The cleaned froth product from the column units passes into a de-aeration tank to promote breakdown of any residual froth.

The froth product is then passed through three agitated mixing tanks (Figure 41) where dewatering aids are added. After conditioning for several minutes, the treated slurry is fed to a bank of disc filters (Figure 42) for final dewatering. Previous test work conducted in this project has shown that adequate mixing, both in terms of time and intensity, is critical to the performance of the dewatering aids. The dewatered froth product is discharged to a reversible product collection belt. The coal product can be directed to either a clean coal collection belt or a noncompliant conveyor system, if the moisture of the filter product is higher than the

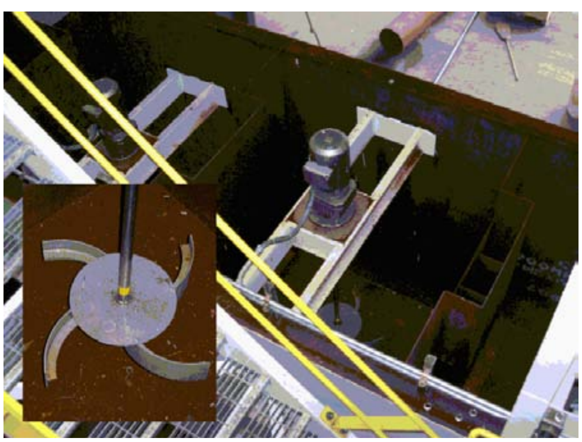

Figure 41. Three-stage conditions used for conditioning the dewatering aid.

Figure 42. Bank of disc filters used to dewater the fine coal froth product.

Figure 43. Static thickener used to thicken solids and clarify process water.

Figure 44. Paste thickener used to further thicken wastes for disposal.

specifications allow. The total product moisture is continuously monitored using an on-line moisture analyzer located on the clean coal collection belt.

The refuse from the various plant circuits is treated using a two-stage thickener system. The first stage consists of a 90 ft. diameter high-rate static thickener (Figure 43) into which coagulant and flocculant is added to promote aggregation and rapid settling of the fine solid waste. The overflow from this unit is taken back into the plant as clarified process water. The underflow is pumped to a 60 ft. diameter paste thickener (Figure 44) for secondary densification. The bed depth is maintained between 12 and 25 ft and has a retention time between 11 to 15 hrs.

4.5.4 POC Circuit Testing

a) Shakedown Testing

At the completion of the POC design and construction, preliminary shakedown tests were conducted to resolve operational problems that arose during start-up of the POC plant. Initial test runs were conducted to ensure that pumping capacities, pipe sizes, electrical supplies, control systems, and instrumentation were adequate. After completing start-up activities, exploratory tests were conducted to validate the design capacities of the various unit operations used in the POC circuits. Data obtained from these tests were used to identity key operating parameters that should be investigated in detailed testing. This work was followed by detailed testing of the plant circuitry and, in particular, evaluation of the fine coal vacuum filters where the dewatering aides were utilized.

In general, the in-plant testing of the POC circuitry showed that the sizing, cleaning, dewatering and disposal circuits performed as expected. During these tests, the plant was fed the design capacity of 200 ton/hr of raw feed and produced an average of 58 ton/hr of fine clean coal. Of this tonnage, 39 ton/hr was plus 100 mesh and 17 ton/hr was nominal 100 x 325 mesh. The final product (nominal plus 325 mesh fraction) generally met the product quality specifications of 5.5% ash, 0.8% sulfur, and 17% moisture; however, some fluctuations in product qualities were observed from time to time due to the widely varying characteristics of the feed material extracted from the impoundment. Size-by-size summaries of the performance data for the shakedown tests are provided in Figures 45 and 46 for the coarse and fine plant circuits, respectively.

The test data indicate that the 20-inch diameter classifying cyclones provided a nominal cut size of 100 mesh. The underflow contained about 75.05% of the plus 100 mesh solids at an ash content of 7.70%. 24.95% of the plus 100 mesh solids containing 36.36% ash was misplaced material. The overflow contained 2.87% of the plus 100 mesh solids at 2.50% ash, which reported to the deslime cyclone circuit. The compound spirals generated a coal product containing 80.15% plus 100 mesh at 2.98% ash, with 19.85% minus 100 mesh at 21.49% ash reporting with the product. The spiral middlings product was found to be of a sufficient quality

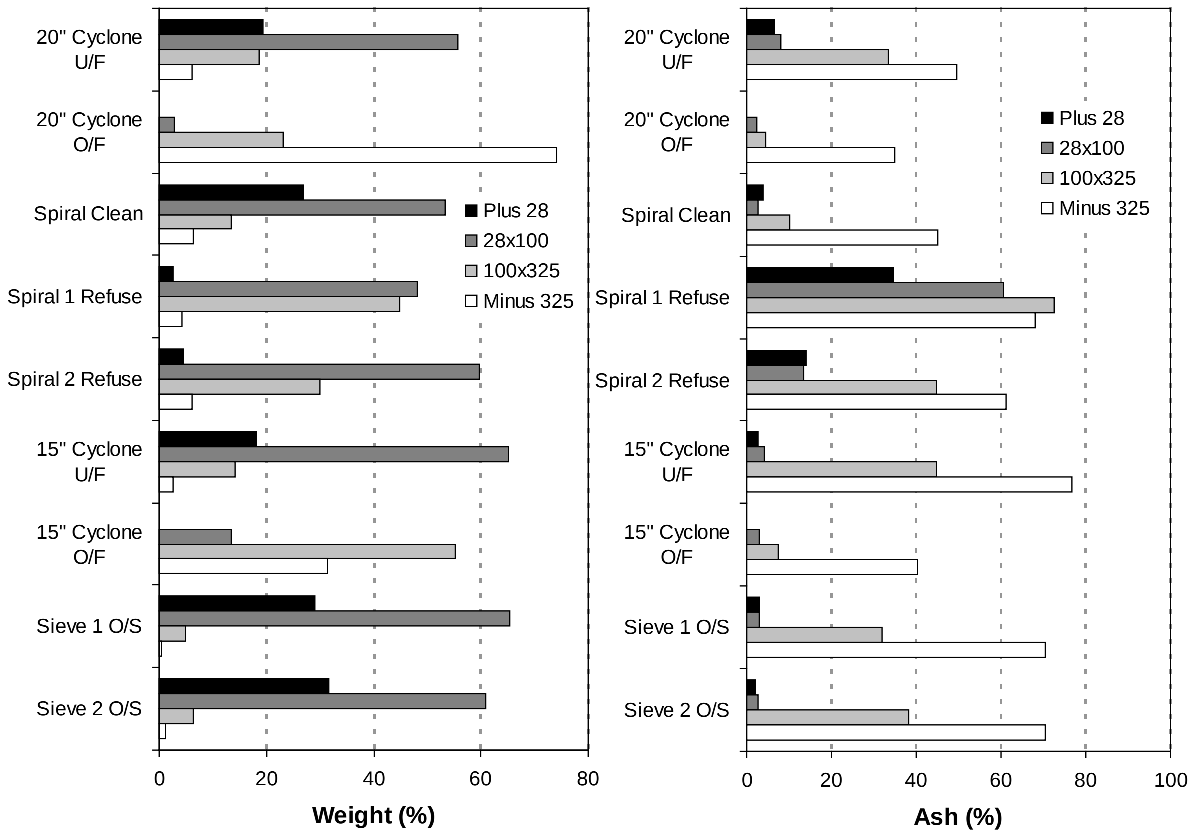

Figure 45. Weight and ash distributions for samples collected from the shakedown tests conducted on the coarse coal treatment circuits.

to be recovered without additional treatment. So, the splitter was closed to direct this stream into the product. The primary and secondary spiral reject streams contained 50.73% and 64.11% plus 100 mesh solids at 59.08% and 13.42% ash, respectively, and 49.27% and 39.89% minus 100 mesh solids at 72.09% and 42.72% ash, respectively.

The spiral product was pumped into the clean coal cyclone circuit to provide desliming of the plus l00 mesh product. The circuit incorporates 15-inch diameter classifying cyclones and a two-stage rapped sieve bend system. The cyclone underflow contained 83.25% of plus 100 mesh solids at 4.10% ash. A total of 16.75% of minus 100 mesh solids at 49.73% ash were contained

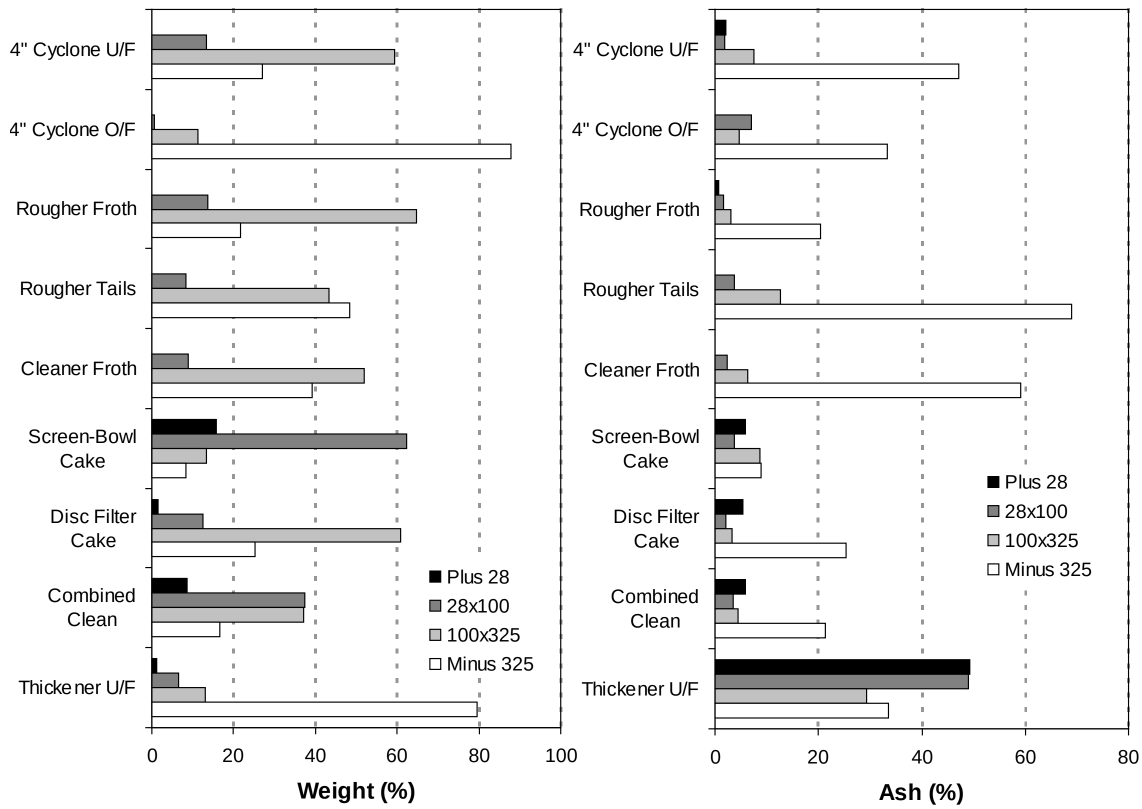

Figure 46. Weight and ash distributions for samples collected from the shakedown tests conducted on the fine coal treatment circuits.

in this stream. The overflow, which reports to the deslime cyclone circuit, contained 13.51% of plus 100 mesh at a 2.84% ash. The two-stage rapped sieve was used to remove minus 100 mesh contamination and associated ash from the coarse circuit product. The higher quality of the oversize product produced by the primary and secondary rapped sieve bends reduced the amount of minus 100 mesh in the product from 16.75% to 7.46% with a corresponding ash reduction from 11.74% to 5.47%. The undersize solids from the rapped sieve bend circuit were circulated back to the clean coal sump.

The product from the cyclone/spiral circuit was dewatered through two 36 x 72 inch screen bowl centrifuges. The coal product from the screen-bowl was 5.18% ash, which contained 78.29% plus 100 mesh at 4.17% ash and 21.71% minus 100 mesh at 8.82% ash.

The shakedown test data showed that the 4-inch diameter classifying cyclones provided a nominal cut size of 325 mesh. The deslimed underflow contained 73.06% plus 325 mesh (6.52% ash) and 26.94% minus 325 mesh (47.12% ash). The deslime overflow, which was discarded to the static thickener as waste, contained 12.05% plus 325 mesh (4.77% ash). The loss of low-ash material in this stream was expected because the ultrafine cleaning circuit had not yet been added to the plant circuitry. The clean froth product from the entire column flotation circuit was found to contain 6.66% ash. This product contained 78.34% plus 325 mesh at 2.84% ash and 21.66% minus 325 mesh at 20.45% ash. The rougher column reject (i.e., feed to the cleaner column) was found to contain 39.12% ash. Of the rougher column reject, 51.72% was plus 325 mesh (11.17% ash) and 48.28% was minus 325 mesh (69.05% ash). The ash content of the cleaner column froth was 26.69%, and of that percentage, 60.81% at a 5.72% ash is plus 325 mesh and 39.19% at 59.22% ash is minus 325 mesh. The high ash content of the minus 325 mesh fraction can be attributed to problems associated with the entrainment of fine clay in the column froth. As such, the froth quality is expected to improve after modifications are made to the wash water system. So, more minus 325 mesh clay is eliminated from the froth products.

As indicated previously, the product from the deslime cyclone/column flotation circuit is dewatered by using a twelve-disc 12.5 ft diameter vacuum disc filter. In the shakedown tests, the filter product was found to contain 8.76% ash (74.88% plus 325 mesh at 3.21% ash and 25.12% minus 325 mesh at 25.30% ash). The higher ash in the minus 325 mesh size fraction was found to have a major impact on both the final ash quality of the filter product and on the overall product moisture. On average, the moisture of the filter cake was found to be approximately 26% in the absence of dewatering aids. The addition of dewatering aids reduced the filter moisture to below 18%.

The 90 ft diameter, high-rate thickener required modifications to allow optimum operation during the shakedown tests. The required modifications were to raise the flume above the liquid level in the thickener unit to avoid surface froth entering into the clarified water tank, flatten the slope and increase the width of the flume for capacity to slow the velocity and minimize the agitation of the slurry material, and divert the slurry flow down into the center well at the end of the flume to reduce short-circuiting of slurry out of the center well into the main body of the thickener. The underflow from the static thickener provided the feed for the paste thickener. The paste thickener, which is still being subjected to shakedown testing, appears to be capable of handling the varying feed rates, size distributions, and qualities of waste slurry from the processing plant.

b) Detailed Testing

After completing the shakedown tests, several series of detailed tests were performed for the POC dewatering circuit. For comparison, a set of laboratory dewatering tests were conducted during the detailed testing. Both the laboratory and POC-scale tests were completed using Reagent V. The laboratory filtration tests were conducted using a 2.5- inch diameter Buchner funnel. After establishing the optimum operating conditions and reagent blends using the laboratory filter, the dewatering aid was added to the feed of the three-stage conditioners that were located just ahead of the vacuum disc filter. As indicated previously, adequate mixing is critical because previous studies showed that the moisture reduction improves with increasing energy input during conditioning. For this reason, the full three-stages of conditioners were used in all of the POC-scale dewatering tests.

It was also found that the quality and size distribution of the coal within the impoundment varied greatly at different locations. These variations affect the cleaning and dewatering processes. For that reason, some parallel dewatering tests were also conducted during the plant testing. In this case, the sample was collected directly from the plant's cyclone overflow stream and floated at the lab using the Denver Flotation cell to produce the filter feed sample to be used in laboratory filtration tests. Table 112 shows the results of dewatering test using W and V as dewatering aids. The moisture reduction corresponds to an approximate 40% decrease; however, as shown below, the results are seven to eight points higher compared to previous results. This change in the moisture can be attributed to the particle size distribution. The flotation feed sample collected from the cyclone overflow contained approximately 70 % minus 325 mesh particles.

Another set of tests was conducted with another sample collected a different day. The results are shown in Table 113. The moisture reduction was again around 40%; however, the minus 325 percent material in the feed was too high. The reagents were greatly effective, but the sample was not representative of their effectiveness. To simulate the average plant filtration

Table 112. Effect of Reagents V and W (dissolved in diesel at 1:2 ratio) at various dosages.

Reagent Dosage (lb/ton)	Moisture Content (%)		Moisture Reduction (%)	
	Reagent W	Reagent V	Reagent W	Reagent V
0	34.03	34.03	--	--
0.5	33.05	24.58	2.9	27.77
1.0	26.03	22.91	23.50	32.68
3	23.97	20.76	29.56	38.99
5	23.33	20.15	31.44	40.79

Table 113. Effect of Reagents V and W (dissolved in diesel at 1:2 ratio) at various dosages on dewatering of floated sample.

Reagent Dosage (lb/ton)	Moisture Content (%)		Moisture Reduction (%)	
	Reagent W	Reagent V	Reagent W	Reagent V
0	32.92	32.92	--	--
3	20.59	19.21	37.45	41.67
5	19.27	19.14	41.46	41.86

operation the sample was deslimed by removing either all (totally deslimed) or just two-thirds (partly deslimed) of the minus 325 mesh solids from the test sample. Table 114 shows that the deslimed samples gave moisture contents below the target value of 17% moisture.

4.5.5 SCALE-UP ASSESSMENT

A comparison of the laboratory and POC-scale filtration test results is given in Figure 47. Because the baseline moisture was different in each case (i.e., 26% vs. 24%), the data have been plotted again in Figure 48 as percentage moisture reduction for each reagent dosage. The experimental data clearly demonstrate that the addition of dewatering aid substantially reduced the moisture contents of the filter products. In the POC-scale tests, the total moisture content was reduced from 26% to 20% at a dosage of approximately 0.5 lb/ton and farther down to 17.5% at

Table 114. Effect of Reagent V (dissolved in diesel at 1:2 ratio) at various dosages on dewatering of deslimed samples.

Reagent Dosage (lb/ton)	Moisture Content (%)		Moisture Reduction (%)	
	Total Deslimed	Partly Deslimed	Totally Deslimed	Partly Deslimed
0	20.90	26.41	--	--
3	13.22	17.01	36.75	35.56
5	13.08	16.99	37.42	35.67

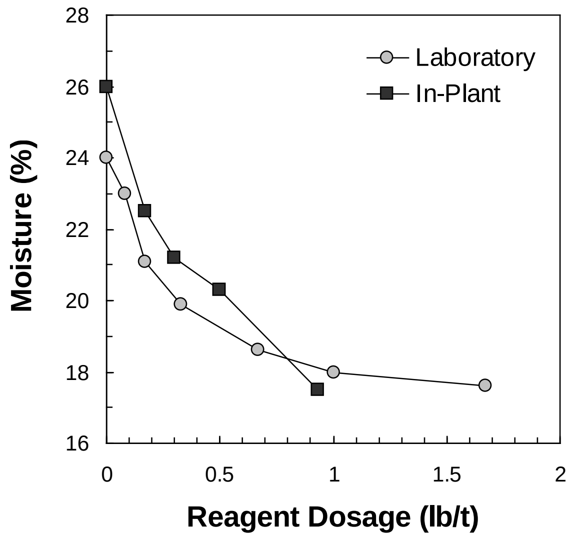

Figure 47. Moisture content versus dewatering aid dosage (Reagent V).

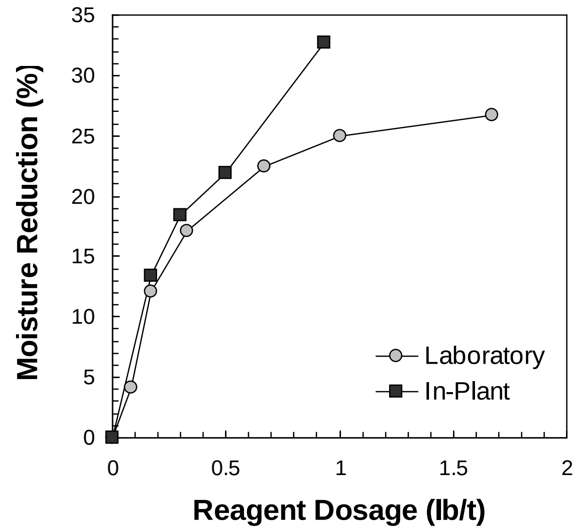

Figure 48. Moisture reduction versus dewatering aid dosage (Reagent V).

about 1 lb/ton. The 17.5% moisture represents a moisture reduction of nearly one-third compared to the baseline moisture of 26%. For example, the cake thicknesses observed in some of the POC-scale tests were as large as 3 inches. These POC-scale results compare favorably with the laboratory data. The apparent gap between the laboratory and POC-scale results obtained at higher dosages of dewatering aid may be explained by differences in particle size, cake thickness, drying time, etc., used in the two test programs.

Another important observation made during the detailed test program was that the power draw for the disc filter vacuum pumps dropped dramatically upon addition of the dewatering aid. An example of this behavior is shown in Figure 49 for one of the test runs performed at the plant. The power draw dropped from a normal baseline value of about 160 to 115 amps after the addition of the dewatering aid. This represents a power savings of nearly one-third for the vacuum filter system.

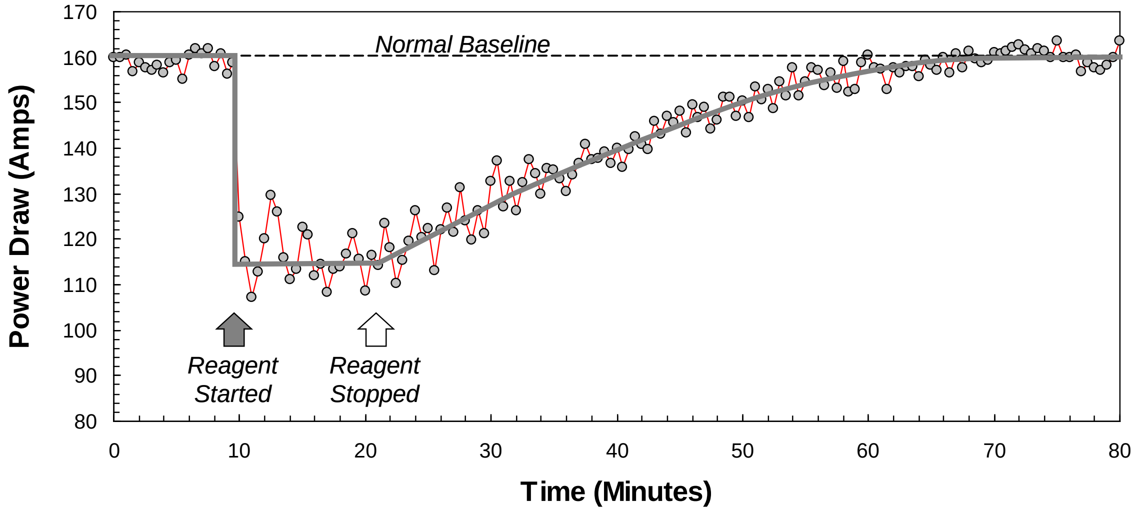

Figure 49. Effect of dewatering aid addition on vacuum filter pump power demand.

SUMMARY AND CONCLUSIONS

Novel dewatering aids were tested in present work. These include low-HLB surfactants, naturally occurring products, and modified natural products. The role of these reagents is to increase the hydrophobicity of the coal particles. In the presence of these reagents, the contact angles of coal can be increased up to 90^o or more. This increase in contact angle was responsible for the reduction in capillary pressure in a filter cake, which should help reduce the cake moisture. The novel dewatering aids also decreased the surface tension of water and increased cake porosity, both of which also contribute to lowering the cake moisture.

The Buchner funnel tests conducted on a variety of coal samples showed that the novel dewatering aids can reduce cake moistures substantially. They can also increase the rate of dewatering so that cake formation time is decreased by an order of magnitudes. The use of the novel dewatering aids can reduce the cake moistures to one half of the values obtained without using the reagent.

Several different pilot-scale filters were evaluated to verify the results obtained from the Buchner funnel tests. In addition, a dual vacuum system was developed for a vacuum disc filter in order to control the cake thickness. Its use in conjunction with the novel dewatering aids made it possible to achieve low cake moistures. This system was used in mini-plant tests with and without using novel dewatering aids. The results were consistent with those obtained from the laboratory and bench-scale tests.

Based on the bench- and pilot-scale test results obtained in the present work, a proof-of-concept (POC) plant was designed and commissioned. Testing of the full-scale facility demonstrated that the novel dewatering aids made it possible to achieve low moisture contents from fine coal products produced via remining of a waste coal impoundment. The cost-benefit analyses conducted on the POC plant showed favorable internal rates of return when using the novel dewatering aids. The successful completion of this demonstration project has substantially reduced the risk of undertaking industrial projects of this type in the future.

REFERENCES

1. Aksoy, B.S., “Hydrophobic Forces in Free Thin Films of Water in the Presence and Absence of Surfactants,” Ph.D. Thesis, 1997.
2. Carman, P.C., “Fluid Flow through Granular Beds,” Trans. Ins. Chem. Eng., Vol. 15., pp. 150-166, 1937.
3. Gray, V.R., “The Dewatering of Fine Coal,” J. Inst. Fuel, Vol. 31, p.96-108, 1958.
4. Kozney, “Uber Kapillare Leiling des Wassers in Boden,” Wein Akad. Wiss. Sitz. Berichte, Vol. 136 (IIa), pp.271-306, 1927.
5. Singh, B.P., “The Influence of Surface Phenomena on the Dewatering of Fine Clean Coal,” Filtration and Separation, March, 1997, pp.159-163.
6. Zeitsch, in *Solid-liquid Separation*, 3rd Edition, edited by L. Svarovsky, Buttreworth, London, p.476, 1990.

LIST OF ACRONYMS AND ABBREVIATIONS

AR	As Received
ASTM	American Standard Testing Methods
BTU	British Thermal Unit
COR	Contracting Officer's Representative
DAH	Dodecylammonium Hydrochloride
DB	Dry Basis
DMC	Dense Medium Cyclone
DMS	Dense Medium Separator
DOE	Department of Energy
HBF	Horizontal Belt Filter
HLB	Hydrophilic-Lipophile Balance
ISO	International Standards Organization
MIBC	Methyl Isobutyl Carbinol
OSP	Office of Sponsored Programs
POC	Proof-of-Concept
PRDA	Program Research and Development Announcement
SDS	Sodium Dodecylsulfate
VT	Virginia Tech