EVALUATION OF NOVEL FINE COAL DEWATERING AIDS

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(ABSTRACT)

The costs of cleaning fine coal are substantially higher than those of cleaning coarse coal. Therefore, many many coal companies in the U.S. choose to discard fine coal (150 micron x 0) by means of 6-inch diameter hydrocyclones. The cyclone overflows are stored in fine coal impoundments, which create environmental concerns and represent loss of valuable national resources. The major component of the high costs of cleaning fine coal is associated with the difficulty in fine coal dewatering. Therefore, the availability of efficient of fine coal dewatering methods will greatly benefit companies

In the present study, three different novel dewatering aids have been tested. These include Reagents W (RW), Reagent U (RU), and Reagent V (RV). These reagents are designed to increase the contact angles of the coal samples to be dewatered, which should help decrease the Laplace pressure of the water trapped in filter cake and, hence, increase dewatering rate. They were tested on i) the fresh coal samples from Consolidation Coal Corporation's Buchanan Preparation Plant, ii) a composite drill core sample from the Smith Branch Impoundment, Pinnacle Mine Mining Company, and iii) a blend of coals from the Smith Branch Impoundment, thickener underflow, and thickener feed.

The coal samples were used initially for laboratory-scale tests using a 2.5-inch diameter Buchner vacuum filter. The results showed that the use of the novel dewatering aids can reduce the cake moisture up to 50% over what can be achieved without using any dewatering aid. The use of the dewatering aids also increased the kinetics of dewatering by up to 6 times, as measured by cake formation times.

On the basis of the laboratory test results, pilot-scale continuous vacuum filtration tests were conducted using a 2-feet diameter Peterson vacuum disc filter. The cake moistures obtained in the pilot-scale test work were similar to those obtained in the laboratory tests, while the fast dewatering kinetics observed in the laboratory tests was manifested as higher throughput. It was found that high-shear agitation is essential for achieving low cake moistures and high throughput.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Coal preparation plants consist of simple crushing, sizing and cleaning operations for coarse and intermediate coal size fractions but commonly involve complex cleaning circuits for fine size fractions which also require dewatering processes. These can be broadly classified into three groups; sedimentation, filtration and thermal drying. Since the market demand is increasing for low-sulfur, high grade coal as a result of economic and environmental considerations it causes processes to be extended towards the ultra fine range which accompanies an increase in the yield of ultra fine tailings. Ultra fine tailings are particularly difficult to dewater because of their large surface area. The performance of most types of dewatering equipment depends strongly on several parameters of particle-aqueous systems. Knowledge of these parameters would help the processor to make suitable modifications for achieving improved filtration and dewatering. These parameters include mineral type, particle size and distribution, surface characteristics of the materials, applied pressure, cake thickness, clay content, surface oxidation, solid /liquid ratio and presence of chemical additives.[1-6]

The coal preparation plants, in which the fine coal fraction is processed, utilize filtration technologies that typically include vacuum disc/drum filters, plate and frame filter presses and horizontal belt filter for dewatering. Filtering is a solid-liquid separation process where solid particles are separated from liquid by forcing the slurry to pass through a suitable filtering medium with the help of either vacuum or pressure force. This allows only the liquid to pass through, leaving the solid particles to form a “cake”. As the final step or when the efficiency of dewatering becomes so low, dewatered product is thermally dried in thermal dryer units to obtain the required moisture contents. [1, 2, 4-9]

To avoid the expensive and environmentally important thermal drying, efforts are being made in the coal preparation sector to counteract this trend both by improvement and further development of already known dewatering methods and equipment and testing those not previously used in coal preparation. The availability of efficient processes that can reduce the moisture of fine particles will greatly benefit companies if these processes can be applied to reduce the moisture content of fine coal. [1, 6, 9-13]

To better understand the problems associated with the the process of fine particle dewatering and to study the effects of the parameters affecting the process, bench-scale tests were conducted on fine coal samples. The novel dewatering aids, namely RU and RW were tested. Pilot-scale filtration tests were conducted on fine coal samples, and the results were compared with the the laboratory test results. It was found that the use of the novel dewatering aids can substantially reduce the cake moistures by up to 50%. The role of the reagents is to increase the hydrophobicity (or dewettability) of the coal. In the presence of these reagents, the contact angles of the coal samples increased, preventing the surface of the particles to be wetted by water molecules. It is suggested that the increase in contact angle is responsible for the reduction of the capillary pressure in a filter cake, which in turn should reduce the cake moisture. The novel dewatering aids also cause a decrease in the surface tension of water and increased cake porosity (or capillary diameter), both of which should contribute to lowering cake moistures. [1, 6, 9-16]

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Paper 1

Evaluation of Novel Fine Coal Dewatering Aids

Mining & Minerals Engineering
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ABSTRACT

Three different dewatering reagents were tested, coded as RW, RU and RV, on Consolidation Coal Corporation's Buchanan Preparation Plant's for the fine coal dewatering circuit (28 mesh x 0). The role of these reagents was to increase the hydrophobicity of the coal for dewatering. According to the Laplace equation, an increase in contact angle with the surfactant addition should decrease the capillary pressure in a filter cake, which should in turn increase the rate of dewatering and help to reduce the cake moisture. The use of the novel dewatering aids causes a decrease in the surface tension of water and an increase in the contact angle and porosity of the cake, both of which also contribute to improved dewatering. It was found that final cake moistures could be reduced by 20-40% by adding novel dewatering chemicals. It was also determined that the use of the novel dewatering aids could reduce the cake formation time by a significant degree due to the increased kinetics of dewatering. The Buchanan coal (Pocahontas seam) contains a large amount of calcium chloride. The Ca^{2+} ions present in the froth product cause coagulation of fine particles, which in turn traps moisture within the flocs that are formed. Several series of laboratory dewatering tests were conducted to determine if water chemistry was indeed a problem in dewatering and, if so, whether a viable solution could be found to eliminate or minimize the problem. The effects of various water treatment strategies were evaluated. These treatments included the addition of acid/base (to control pulp pH), sodium carbonate (Na_2CO_3), ethylenediamine tetraacetic acid (EDTA), sodium silicate (Na_2SiO_3) to precipitate Ca^{2+} ions, oxalic acid, succinic acid, ammonium oxalate, Na-hexametaphoshate, calcium oxide and hydrogen peroxide (H_2O_2). The results showed that the use of sequestrating reagents for water treatment in conjunction with dewatering aids reduced the cake moistures by a greater percentage than by using the reagents alone, the extent of which depend on the particle size, cake thickness, drying time, reagent dosage, conditioning time, reagent type,

water chemistry, etc. A number of tests were also performed to study the effect of physical parameters.

INTRODUCTION

In general, upgraded fine coal by flotation contains approximately 80% water. To begin the dewatering process, the slurry can be thickened to 35 to 75% in large settling tanks. For further dewatering, the product is subjected to a mechanical dewatering process such as filtration. Filtering is a solid-liquid separation process where solid particles are separated from liquid by forcing the slurry to pass through a suitable filtering medium with the help of either vacuum or pressure force. This allows only the liquid to pass through, leaving the solid particles to form a “cake”. As a final step, the dewatered product is thermally dried in thermal dryer units to obtain the required moisture contents[1-5].

In the absence of a fine coal cleaning circuit, a majority of coal preparation plants use screen bowl-centrifuge to dewater 1mm x 150 micron size clean coal. But the cost of the dewatering fines sharply increases when the particle is below 150 microns. For this reason it is often more economical to discard the minus 150 micron size fraction of the plant’s run of mine coal without any attempt to recover the clean coal content of this size fraction if it is only a small fraction (5 to 10%) of the product stream. The coal preparation plants, in which the fine coal fraction is processed, utilize filtration technologies that typically include vacuum disc/drum filters, plate and frame filter presses and horizontal belt filter for dewatering.[1, 2, 5-8]

The performance of most of the dewatering equipment that is used today depends strongly on several parameters of particle-aqueous systems. Knowledge of these parameters would help the processor to make suitable modifications for achieving improved filtration and dewatering. These parameters include mineral type, particle size and distribution, surface characteristics of the materials, applied pressure, cake thickness, clay content, surface oxidation, solid /liquid ratio and presence of chemical additives.[1, 9-11]

The availability of efficient processes that can reduce the moisture of fine particles will greatly benefit companies if these processes can be used to reduce the moisture content of fine coal without compromising product quality. To understand better and solve the problems associated with the fine particle dewatering and to study the effects of various parameters, bench-scale tests were conducted on fine coal samples.[12-14]

FILTRATION THEORY

Cake filtration and dewatering has been characterized over the years via the capillary pressure function, which is the relationship between the pressure and saturation. In this characterization, it is assumed that the filter cake consists of a number of capillaries of varying diameters. Such a filter cake is saturated with liquid initially and requires a minimum threshold pressure drop for the start of drainage of liquid from cake itself. One can use the Laplace – Young Equation, given below, as the most simple and predictive guide to characterizing the drainage of liquid from the capillary of radius `r`. [1, 15]

$$\Delta P = \frac{2\gamma_{LV}\cos\theta_{LS}}{r} \qquad [1]$$

where γ_{LV} is the liquid surface tension and θ_{LS} is the solid-liquid contact angle. In the case of a constant pore size distribution, the threshold pressure (ΔP_b) can approximately be estimated by $r = r_{max}$. For estimation of threshold pressure drop for a bed of packed spheres, Carman (1946) suggested an expression which was later used to define modified threshold pressure drop (ΔP_b^*). This in turn was later used to characterize dewatering properties of alumina trihydrate.

$$\Delta P_b^* \cong \Delta P = \frac{k(1-\varepsilon)\gamma_{LV}\cos\theta_{LS}}{\varepsilon d_p} \qquad [2]$$

where ε is the cake porosity, d_p is the specific mean surface diameter and k is a constant, the value for which was 6.0 (for the case of packed spheres) as estimated by Carman

(1946). Experiments conducted by Rushton and Wakeman (1977), showed that the value of `k` lies between 4.6 and 8.0.[1, 15, 16]

The process of draining liquid from a filter cake can be seen as consisting of three stages. At the beginning of a dewatering cycle, or the first stage, the drainage of liquid from the cake does not occur as long as ΔP is lower than ΔP_b, and the cake is said to be completely saturated (S=1.0). This means that all the pore spaces of the cake are completely filled with liquid. At pressures $\geq \Delta P_b$, saturation falls below 1.0 and eventually approaches irreducible saturation (S_∞) at pressure ΔP_∞. A further increase in vacuum will not lower the limit of saturation. The pressure ΔP_∞ could be viewed as the capillary pressure of minimum drainable pore ($r_{\min}$). For I intermediate pressures, there is a steady decrease in moisture content, and the cake will achieve an equilibrium saturation (S_p).It was defined the residual saturation (S_R) of cake by the following expression.

$$S_R = \frac{S_p - S_\infty}{1 - S_\infty} \qquad [3]$$

A number of empirical relations have been proposed by various researchers (Wakeman, 1975, 1976; Wainwright, 1986) to correlate the applied pressure differential and cake saturation.

$$S_R = \left[\frac{\Delta P_b^*}{\Delta P}\right]^{\xi} \qquad [4]$$

where ξ is the pore size distribution index and its value lies between 2 and 8. The residual saturation is related to the moisture content of the cake by the following relation.[1, 15]

$$\text{Moisture Content} = S_R \frac{\varepsilon}{1-\varepsilon} \frac{\rho_l}{\rho_s} 100\% \qquad [5]$$

EXPERIMENTAL

The objectives of this study were to i) identify the best possible reagents and combinations thereof for this specific coal, ii) identify the conditions under which a given dewatering aid can give the best performance, and iii) solve water chemistry problems caused by the Ca^{2+} ion. To meet these objectives, a series of laboratory dewatering tests were conducted by using novel dewatering aids, namely RW, RV, and RU, which were developed at Virginia Tech, and by using various sequestrating reagents such as EDTA, Na_2SiO_3, oxalic acid, succinic acid, ammonium oxalate, sodium-hexametaphoshate, calcium oxide, and hydrogen peroxide to control the water chemistry on Buchanan coal samples. Furthermore, a detailed study was performed to understand the effects of parameters such as pH, filter medium, rinsing/washing, desliming, cake thickness, mixing, cleaning and re-cleaning of samples under laboratory conditions. A few tests were also conducted using samples of aged coal to study the effect of oxidation on the performance of dewatering reagents.

The laboratory test work was conducted on three different samples taken from Consolidation Coal Corporation's Buchanan Preparation Plant in Mavisdale, Virginia. These samples were 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). Unless otherwise stated, the dewatering tests were conducted within three days of receipt of sample in order to minimize coal oxidation effects.

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. Reagents RW and RU, diluted to 33.3% in solvent, were used in these tests. Immediately prior to each filter test, a known volume of slurry was conditioned with the reagent in a mechanical shaker and then poured into a

Buchner funnel before applying vacuum. The following conditions were kept constant during the tests:

- Vacuum:………………68 kPa (20 inches Hg)
- Drying cycle time………………..2 minutes
- Cake thickness…………………….10-15 mm
- Volume of slurry………………………100ml
- Reagent conditioning time..………..5 minutes

A limited number of standard analyses (e.g., particle size analysis, ash analysis) were performed on selected samples to provide baseline data related to this particular sample.

For laboratory-scale batch dewatering tests, the samples were collected either in 5-gallon buckets or 55gallon drums. To be able to receive a representative sample, slurry samples were homogenized by 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 the dewatering studies.

A Buchner funnel, a ¾ HP Vacuum Pump and filter cloths of different porosities and diameters were used as laboratory-scale filter equipment. The Buchner funnel was used to test different dewatering and sequestrating chemicals in these experiments. For this particular study, all tests were conducted using a 2.5-inch diameter Buchner funnel with filter cloth and wire screen mesh supplied from Peterson Co. The height of the funnel was 8-inches. In a given experiment, a known volume of coal slurry was poured into the funnel and vacuum was applied to form a cake on the filter medium. Since the diameter of the funnel is fixed at 2.5 inches, it determines the cake thickness.

Figure 1 shows the apparatus used for the Buchner funnel filtration tests. 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 a slurry sample was poured into the funnel before opening the valve between the two flasks in order to subject the slurry to a vacuum pressure. In each experiment, the cake thickness, applied and actual vacuum pressures and cake formation time were recorded.

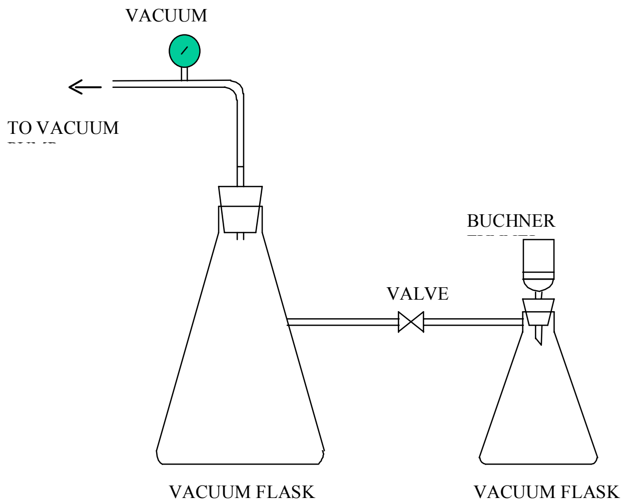

Figure 1 - Experimental setup for laboratory vacuum filtration tests

A known volume of coal or mineral slurry was transferred to a 250-ml flask, to which a known amount of a dewatering aid (or a mixtures thereof) was added by means of a Microliter syringe. The flask was attached to a mechanical shaker or high intensity motor mixer for a given period of time to allow for the reagent to adsorb on the surface of the particles to be dewatered. After the conditioning time, the slurry was transferred to the Buchner funnel. Filtration was commenced when a vacuum was applied to the slurry. The time it took for the bulk of the water to pass through the filtering medium is referred to as *cake formation time*. After cake formation, the vacuum pressure was maintained for a desired period of time to remove the residual water trapped in the capillaries formed between the particles in the cake. After allowing the reagent to be adsorbed on the surface of particles, sequestrating chemicals were added and agitated for a given time. After this period, which is referred to as *drying cycle time*, part of a representative filter cake was removed, weighed, and dried overnight in a conventional oven. The sample was weighed again after drying, and the moisture content was calculated from the difference between the dry and wet weights.

RESULTS AND DISCUSSIONS

1. Effect of Chemicals

Effects of RU and RW

Table 1 gives the laboratory test results obtained on the Buchanan plant flotation product using RU and RW 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 RU additions of 0.5 and 2.5 kg/mt, the moisture contents of the cake were reduced from 17.6% to 16.1% and 14.4%, respectively. Similar results were obtained with RW as a dewatering aid. These values corresponded to a 15-20% moisture reduction in the filter product.

Table 1 - Effect of reagent addition on dewatering Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	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

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 RW and RU as dewatering aids. Results for the filter feed sample are summarized in Table 2. The results show that the moisture content of the filter product again decreases with increasing RW and RU additions from 0.5 to 2.5 kg/mt (1 to 5 lb/ton). In this case, the addition of 2.5 kg/mt (5 lb/ton) of reagent RW 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 RU was almost 2 percentage units lower, i.e., 14.4% vs. 16.6% moisture in the filter cake (see Tables 1 and 2). The reasons for the relatively poorer behavior of reagent RU may be related to the presence of flocculant in this particular sample. Apparently, the polymer flocculant has an adverse effect on the performance of RU during dewatering. Those poor results are also due to the Ca^{2+} ions present in Buchanan plant water.

Table 2 - Effect of reagent addition on dewatering of Buchanan's filter feed

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	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

Effect of Soda Ash (Na_2CO_3)

One way of eliminating Ca^{2+} ions present in Buchanan plant water is to introduce CO_3^{-2} ions. This can be achieved by simply adding soda ash (sodium carbonate) to the feed pulp. To test this approach, dewatering tests were conducted using 0.5 kg/mt of soda ash in conjunction with Reagents RW and RU. The results are presented in Table 3. In general, sodium carbonate was not particularly effective when Reagent RW was used as the dewatering aid. In fact, the moisture values actually increased slightly when soda ash was added. Conversely, the addition of soda ash improved the performance of Reagent RU at dosages of 1.5 kg/mt or higher. The filter cake moisture was reduced to a very low value of just 12.3% when 2.5 kg/t of RU was used in conjunction with soda ash. The use of soda ash was not effective when lower dosages (0.5 kg/mt) of Reagent RU were used. The amount of Na_2CO_3 required to increase moisture reduction was high which probably indicates that the amount of Ca^{2+} ions present in the plant water was high

Table 3 - Effect of Na_2CO_3 addition at 0.5 kg/mt on dewatering of Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (%wt)			
	RW		RU	
	Without Na_2CO_3	With Na_2CO_3	Without Na_2CO_3	With Na_2CO_3
0	18.1	17.9	18.1	17.9
0.5	17.6	17.7	17.5	17.5
1.5	15.2	15.7	16.8	15.7
2.5	14.9	15.3	16.6	12.3

Effect of Ethylenediamine Tetraacetic Acid (EDTA)

Ethylenediamine Tetraacetic Acid (EDTA) is a well known complexing agent for metal ions. As such, this chemical can be used to eliminate the adverse effects of metal cations by forming complexes with them, i.e., Ca^{2+}. The test results, which are given in Table 4, showed that the filter cake moisture content was lowered by only about one percentage point after adding 0.2 kg/mt EDTA along with 0.75 kg/mt of Reagent RV. Therefore, the addition of ETDA was not effective in controlling the water chemistry problem.

Table 4 - Effect of using EDTA as the blocking agent for Ca^{2+} ions on dewatering of Buchanan's flotation product

EDTA Dosage (g/mt)	Moisture Content (%wt)
0	17.5
50	17.3
100	17.1
200	16.7

Effect of Hydrogen Peroxide (H_2O_2)

It is possible that coal particles are coagulated due to the hydrophobicity of the particles. This process is known as hydrophobic coagulation. Water may be trapped within the coagula, causing high moisture. One way of preventing hydrophobic coagulation is to make the coal less hydrophobic. Therefore a series of laboratory dewatering tests were conducted using hydrogen peroxide (H_2O_2) as an oxidizing agent. The test results, which are given in Table 5, indicated that very little improvement in filter cake moisture (only about one percentage point) was obtained when using H_2O_2 with Reagent RV.

Table 5 - Effect of using H_2O_2 as oxidizing agent on dewatering of Buchanan's flotation product

H_2O_2 Dosage (g/mt)	Moisture Content (%wt)
0	17.5
200	17.4
300	16.9
500	16.6

Effect of Sodium Silicate (Na_2SiO_3)

In order to control the water chemistry problem, a series of dewatering tests were conducted using sodium silicate ($Si_2O_5^{-2}$ ions) as a sequestering reagent for Ca^{2+} ions. The results are given in Table 6. The dosages of sodium silicate varied from 0.5 to 25 kg/t, while the dewatering aid (RW or RU) dosages were kept constant at 2.5 kg/t. The addition of sodium silicate generally improved the performance of the dewatering aids up to a dosage level of 3 g/t. For example, the addition of 3 g/t of sodium silicate improved the performance of Reagents RW and RU by 0.8 percentage points (i.e., 14.3% vs. 13.5% moisture) and 2.0 percentage points (15.2% vs. 13.2% moisture), respectively. However, further addition of sodium silicate above 3 kg/t caused an increase in moisture content. The results indicate that the use of sodium silicate increases moisture reductions beyond what can be achieved using dewatering reagents alone. It is believed that sodium silicate not only acts as the sequestering agent for the Ca^{2+} ions, but also as the dispersing agent for the colloidal clay particles that may be attached to the surface of coal particles.It can be said that Na_2SiO_3 may remove Ca^{2+} ions, increase ph and helps dispersion of particles.

Table 6 - Effect of Na_2SiO_3 addition on dewatering of Buchanan's flotation product sample

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	RW + Na_2SiO_3	RU + Na_2SiO_3
Baseline (No reagent)	17.3	17.3
2.5 kg/t dewatering aid	14.3	15.2
2.5 g/t dewatering aid + 1g/t Na-Silicate	14.1	14.6
2.5 kg/t dewatering aid +3 g/t Na-Silicate	13.5	13.2
2.5 kg/t dewatering aid + 5 g/t Na-Silicate	15.9	14.4
2.5 kg/t dewatering aid + 10 g/t Na-Silicate	16.2	14.4
2.5 kg/t dewatering aid +25 g/t Na-Silicate	16.3	14.5
2.5 kg/t dewatering aid + 50 g/t Na-Silicate	16.6	14.6

<u>Effect of Oxalic Acid</u>

A series of laboratory dewatering tests were conducted using oxalic acid $(COOH)_2$ to determine whether this reagent could sequestrate Ca^{2+} ions and eliminate the adverse effects of Ca^{2+} ions on filtration. The test results, which are given in Table 7, show that the moisture content of filter cake could be reduced from 17.3% to 13.3-13.4% by using 1-50 g/t oxalic acid along with 2.5 kg/t of Reagent RW. Likewise, a filter cake with as little as 13.3-13.4% moisture could be obtained by using 5-10 g/t oxalic acid along with 2.5 kg/t RU as dewatering aid. These data show that the use of oxalic acid in combination with the dewatering aids is a promising approach for overcoming the water chemistry problem at the Buchanan plant.

The following mechanism may be proposed for the function of oxalic acid in dewatering of fine mineral particulates. When oxalic acid is dissolved in water, it will ionize to $^{-}OOC—COO^{-}$. The di-carboxyl groups will then react with Ca^{2+} ions to form calcium oxalate in water. As a result, the performance of dewatering agent (i.e., Reagent U or Reagent W) is enhanced as the oxalic acid is used as the sequestering agent for the Ca^{2}.

Table 7 - Effect of Oxalic Acid addition on dewatering of Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	RW + Oxalic Acid	RU + Oxalic Acid
Baseline (No reagent)	17.3	17.3
2.5 kg/t dewatering aid	14.3	15.2
2.5 kg/t dewatering aid + 1 g/ Oxalic Acid	13.4	16.6
2.5 kg/t dewatering aid + 5g/t Oxalic Acid	13.3	13.4
2.5 kg/t dewatering aid + 10g/t Oxalic Acid	13.2	13.3
2.5 kg/t dewatering aid + 15 g/t Oxalic Acid	13.4	13.5
2.5 kg/t dewatering aid + 25 g/t Oxalic Acid	13.5	13.9
2.5 kg/t dewatering aid + 50 g/t Oxalic Acid	13.7	14.0

Effects of Succinic acid, Ammonium Oxalate and Na-Hexametaphoshate

As shown in Table 8, the addition of succinic acid, ($C_4H_6O_4$) generally improved the performance of the dewatering aids up to a dosage level of 50 g/t of succinic acid, where the dosages varied from 1 to 50 g/t, while keeping the dewatering aid RW dosage constant at 2.5 kg/t. For example, the addition of 10 g/t of succinic acid improved the performance of Reagents RW by 2.75 percentage points (i.e., 15.3% vs. 13.25% moisture). The same mechanism proposed above for the oxalic acid holds for the succinic acid as well.

The results show that the moisture content again decreases with increasing ammonium oxalate additions from 1 to 25 g/t. In this case, the addition of 25 g/t of ammonium oxalate in conjunction with Reagent RW reduced the cake moisture from 15.3 to 13.4%, giving a percentage moisture reduction of about 14%.

However, the results obtained by using Na-Hexamatephosphate, indicated that there was a very little improvement (only about less than one percent) in filter cake moisture.

Table 8 - Effects of Succinic acid, Ammonium Oxalateand Na-Hexamatephosphate on filtration of Buchanan's flotation product

Vacuum Pressure (inHg)	Sequestrating Reagent Dosage (g/ton)	Moisture Content (%wt)		
		RW (5 lb/ton) + Succinic Acid	RW (5 lb/ton) + Ammonium Oxalate	RW (5 lb/ton) + Na-Hexameta Phosphate
20	0	15.3	15.3	15.3
	1	14.33	15.01	15.22
	3	13.28	14.64	14.97
	5	13.08	14.5	15.27
	10	12.5	13.9	15.82
	25	12.8	13.4	15.28
	50	12.9	X	14.69

Effects of Calcium Oxide (CaO)

Similar dewatering tests were conducted to improve the performance of the dewatering aids by using calcium oxide. This reagent will increase the pH and may precipitate Ca^{2+} ions as $Ca(OH)_2$. The test results, which are given in Table 9, showed that the filter cake moisture content was lowered by about 2.7 percentage points after 10g/ton CaO along with 2.5kg/t of Reagent RW were added. This may be related to increasing pH or making the coal surface more basic so that the acidic dewatering aids (RU or RW) will adsorb on coal surface much more than at neutral pH.

Table 9 - Effects of Calcium Oxide (CaO) on filtration of Buchanan's flotation product

Vacuum Pressure (inHg)	Reagent Dosage (kg/ton) RW in Diesel	Moisture Content (%wt)				
		CaO (g/ton)				
		5(g/ton)	10(g/ton)	15(g/ton)	25(g/ton)	50(g/ton)
20	0	17.7	17.7	17.7	17.7	17.7
	0.5	15.2	15.35	14.92	15.1	16.02
	1.5	14.09	13.85	13.97	14.89	15.01
	2.5	13.4	13.25	13.67	14.31	14.09

Effect of pH

Table 10 shows the effect of pH on the filter cake moistures in the absence and presence of a dewatering aid (Reagent RW). In these tests, the pH of the slurry was adjusted using HCl and NaOH. Without a dewatering aid, the lowest moisture values were achieved around neutral or slightly acidic pH levels (from 6 to 8). The baseline moisture contents were increased for both the acidic (pH=4) and alkaline (pH=11) conditions when no reagent was added. Conversely, cake moistures in the 13.6-13.9% range were obtained for all pH values tested except for pH 8 (which gave a filter cake moisture of nearly 15%). This relatively high filter cake moisture corresponded to the pH at which the lowest baseline moisture was obtained, i.e., when no reagent was employed. These results suggest that a slightly basic (pH 8) solution may adversely affect the dewatering aids. Additional tests are needed to verify this observation

Table 10 - Effect of slurry pH on dewatering of Buchanan's flotation product sample

Slurry pH	Moisture Content (%wt)		Moisture Reduction (%)
	Without Dewatering Aid	With Dewatering Aid	
4	18.74	13.86	26.0
6	18.16	13.83	23.8
8	17.00	14.95	12.1
11	20.62	13.60	34.0

2. Effect of Physical Parameters

Effect of filter medium

Tables 11 and 12 show the results obtained with the flotation feed sample. As shown, the two series of tests conducted using either a steel wire mesh (40 x60) or filter cloth as a filter medium do not change the performance of the dewatering aids (RU or RW). However, the moisture content in the base sample (using no dewatering aid) changes depending on which filter medium was used. As presented in the tables, moisture content in the base sample was 19% when using a filter cloth, whereas it is only 17% when using steel wire mesh as the filter medium.

Table 11 - Effect of reagent addition on dewatering of Buchanan's flotation feed using a steel wire mesh as the filter medium

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	Reagent W	Reagent U
0	17.0	17.0
0.5	14.6	15.0
1.5	13.8	14.8
2.5	13.4	14.6

Table 12 - Effect of reagent addition on dewatering of Buchanan's flotation feed sample using a filter cloth as the filter medium

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	Reagent W	Reagent U
0	19.1	19.1
0.5	14.3	14.8
1.5	13.7	14.4
2.5	13.6	14.2

<u>Effect of flotation in laboratory</u>

As shown in Table 13, a filter product with significantly less moisture (13-14% moisture) could be obtained when laboratory tests were conducted using flotation feed samples taken from the plant and floated in the laboratory. This very low moisture could not be obtained using the plant flotation product.

Table 13 - Effect of flotation on dewatering of Buchanan's flotation feed

Reagent W Dosage (kg/mt)	Moisture Content (%wt)	
	Flotation Product(1)	Flotation Product(2)
0	17.0	17.6
0.5	14.6	16.2
1.5	13.8	16.2
2.5	13.4	15.0

Flotation Product (1): Floated in the laboratory
Flotation Product (2): Plant Flotation Product

The difference in the moisture levels between flotation plant product and flotation feed samples (floated in the laboratory) appears to be due to water chemistry problems The Ca^{2+} ions present in the froth product cause coagulation of fine particles, which in turn traps moisture within the flocs that are formed. The concentrations of polymer flocculant and flotation reagents in the plant water are also relatively high due to the circulation of plant filter effluent to the flotation cells. The circulation may be another reason why the performance of dewatering chemicals is poorer at the plant site. It is also interesting to note that the problems associated with the water chemistry are eliminated when the flotation plant product is brought back to the laboratory and aged for two weeks. The test data collected to date indicate that cake moistures in the 12-13% range could be achieved at the plant site if the water chemistry problem is resolved.

Effect of Rinsing/Washing with Tap Water

The next series of dewatering tests were conducted after rinsing/washing the flotation product with fresh tap water to remove any residual flotation reagents (collector and frother), other plant chemicals (polymer flocculant), and ionic species (Ca^{2+} etc.) that might be present in the flotation pulp. In this series of tests, a 2-liter sample of flotation product slurry from the Buchanan plant was filtered three times after adding 2 liters of tap water before each filtration step. After the final filtration step, the solids were adjusted to 25% solids by weight (which is the same as the Buchanan plant flotation product) by adding fresh tap water. The slurry was then subjected to dewatering tests using Reagents RU, RW and RV.

Table 14 shows that the moisture content of the baseline (no dewatering aid) increased to 23% after the plant flotation product was washed with fresh tap water. The baseline filter cake moisture content was normally about 18% when no treatment was used. Although the moisture content of the baseline jumped from 18% to 23%, the moisture content of the cake was reduced to 13-14% after the addition of dewatering aids. The results show that the lowest achievable moisture does not change appreciably regardless of the treatment employed. The only parameter that changes is the baseline moisture obtained when no dewatering aid is used. It should be noted that moisture reductions as high as 42% were achieved after rinsing/washing the flotation product with fresh water. These results verify that water chemistry can significantly impact the final cake moisture regardless of whether dewatering aids are utilized.

Table 14 - Effect of washing Buchanan's flotation product on dewatering results using RU, RW and RV dissolved in diesel at 1:2 ratios

Reagent Dosage (kg/mt)	Moisture Content (%wt)		
	Reagent U (1:2)	Reagent W (1:2)	Reagent V (1:2)
0	22.9	22.9	22.9
0.5	15.99	15.80	15.70
1.5	15.10	14.08	13.50
2.5	14.45	14.13	13.37

Effect of Aging Slurry

In the next series of tests, laboratory scale dewatering tests were conducted after aging the Buchanan plant flotation product for three weeks. The dewatering aid (Reagent RV) was added in pure form (no solvent) and was added as 1:1 and 1:2 ratios of Reagent RV dissolved in diesel solvent.

Table 15 gives the results of dewatering tests on the aged flotation product from the plant. As shown, the moisture content obtained in the baseline test (with no dewatering aid) was about 20%. This value was reduced to almost 13% using 1.5 kg/mt of dewatering aid and to a very impressive value of almost 12% using 2.5 kg/mt of dewatering aid. These results show that the performance of the dewatering aid can be substantially improved by simply aging the coal slurry. These results also indicate that the performance of Reagent RV is better when dissolved in a solvent (i.e., diesel).

Table 15 - Effect of aging slurry on dewatering of Buchanan's flotation product sample using RV as the dewatering aid

Reagent Dosage (kg/mt)	Moisture Content (%wt)		
	Reagent V (1:0)	Reagent V (1:1)	RV (1:2)
0	19.8	19.8	19.8
0.5	15.8	14.4	13.9
1	14.2	13.1	13.1
1.5	12.8	12.6	12.7
2.5	12.5	12.2	12.1

Similar dewatering tests were conducted by using Reagent U as the dewatering aid. The test results, which are given in Table 16, show that the filter cake moisture content is reduced from 14.7 to 12.8 and 14.9 to 13.3 respectively.

Table 16 - Effects of Aging on the filtration of Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	Reagent U	Reagent U
0	18.4	18.4
0.5	14.7	14.9
1.5	13.2	13.8
2.5	12.8	13.3

In this series of tests, the sample was aged by simply pumping air through the slurry for 12 hours. The results obtained were very similar to those obtained on the aged samples. The results are shown in Table 17.

Table 17 - Effects of Aeration on the filtration of Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (%wt)	
	Reagent W Aged sample	Reagent W As Is
0	18.1	17.6
0.5	15.7	16.2
1.5	14.1	16.2
2.5	13.17	15.0

Effect of Desliming

Several series of dewatering tests were conducted after desliming the filter feed slurry. The desliming step reduces the amount of ultrafine particles and may also remove unwanted ions that adversely impact the filter's performance. Particle size analysis conducted on the Buchanan plant flotation product showed that it contained a relatively high proportion (28-30% by weight) of ultrafine minus 400 mesh (minus 38 micron) material. The desliming was achieved by simply screening the sample at 400 mesh using a laboratory sieve. The undersize material that passed through the screen was added back to the oversize product retained on the sieve in the desired proportions. Three series of tests were conducted in which none (0%), all (100%) and half (50%) of the minus 400 mesh material in the filter feed was removed. Reason for desliming was to remove ultrafine particles that retain more surface water. Ultrafine particle may block the filtration paths, so preventing water from passing or decrease the capillary radii.

The test data, which are summarized in Table 18, showed that filter cake moistures as low as 10% could be achieved using 1.5-2.5 kg/mt of Reagent RW when 50% of the minus 400 mesh material was removed from the filter feed. The results also showed that when all of the minus 400 mesh material was removed, a filter cake with as low as 1.3% moisture could be obtained using only 0.5 kg/mt of RW as dewatering aid. Although very impressive, the data also showed that a filter product with single digit moisture levels (i.e., 5% moisture) could be produced without any dewatering aid when all of the minus 400 mesh material was removed. These results indicate that desliming may be a viable option for obtaining very low moistures in the Buchanan plant. However, depending on the size distribution of the feed coal sample, desliming could result in unacceptably high losses (>30%) of carbonaceous material that is now reporting to the clean coal product.

Table 18 - Effect of removing slimes (minus 400 mesh material) on dewatering of Buchanan's flotation feed

Reagent Dosage (kg/mt)	Moisture Content (%wt)		
	No desliming (600 micron x 0)	50% deslimed, from 38 micron	Completely deslimed, from 38 micron
0	18.1	16.08	5.00
0.5	17.6	11.10	1.33
1.5	15.2	10.36	--
2.5	14.9	10.12	1.73

Effect of High Speed Mixing

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

Table 19 - Effect of mixing intensity on dewatering of Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (wt%)			
	Reagent RU		Reagent RW	
	High Energy Mixing (1)	Low Energy Mixing (2)	High Energy Mixing(1)	Low Energy Mixing(2)
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

(1) The slurry was agitated at high speed (1000 rpm) using a propeller-type mixer for 5 minutes.
(2) The slurry was agitated at low speed using a laboratory wrist-action shaker for 5 minutes.

Effect of Cake Thickness

The data given in Table 20 show that the baseline moisture (without dewatering aid) was only slightly lower for the thin cake (18.2% moisture) than for the thick cake (18.5% moisture). However, the effectiveness of the dewatering aid was much more pronounced when used in conjunction with the thinner cake. According to the Laplace equation, the filtration rate is adversely proportional to the length of filtration paths. For example, the addition of 1.5 kg/t of Reagent RU reduced the cake moisture to 11.9% for the thin cake (8-11 mm). In contrast, the moisture content of the thick cake (18-20 mm) was reduced to only 16.0% at the same reagent dosage. The filter cakes typically produced by the industrial disc filters at the Buchanan plant have a thickness of 20-25 mm under normal operating conditions. It is possible that thicker cakes require longer drying cycle times.

Table 20 - Effect of filter cake thickness on dewatering of Buchanan's flotation product using RU

Reagent Dosage (kg/mt)	Moisture Content (wt %)	
	Thin Cake (100 ml slurry, 8-11 mm)	Thick Cake (200 ml slurry, 18-20 mm)
0	18.2	18.5
0.5	15.4	16.2
1.0	13.2	16.1
1.5	11.9	16.0
2.5	11.7	15.3

A 62.5 mm diameter Buchner funnel was used. The solid content of the sample was 25-26%. Vacuum was 68 kPa (20 inches Hg). Cake thickness: 8-11mm (thin cake), 18-20 mm (thick cake). Conditioning time: 5 minutes; drying cycle time: 2 minutes. The volumes of the slurries were 100 ml for thin cake and 200 ml for thick cake. The slurry was agitated using a high-speed mixer for 5 minutes before dewatering tests.

CONCLUSIONS

In the present work, dewatering aids were tested on the fine coal of Buchanan coal (Pocahontas seam). The role of the reagents is to increase the hydrophobicity (or dewettability) of the coal. It is suggested that the increase in hydrophobicity could be responsible for the reduction of the capillary pressure in a filter cake and should help reduce the cake moisture. The novel dewatering aids also decreased the surface tension of water and increased cake porosity (or capillary diameter), both of which could contribute to the lower cake moisture.

The test results showed that the use of the novel dewatering aids could substantially reduce the cake moistures by more than 50% as compared to the case of not using any dewatering aid. These dewatering aids also increased throughput since the very fine particles coagulated to become large particles due to hydrophobic coagulation. The results obtained with a Buchner funnel showed that cake moistures could be reduced substantially, the extent of which depends on the particle size, cake thickness, drying time, reagent dosage, conditioning time, reagent type, sample aging, water chemistry, etc. In addition, the effects of various water treatment strategies were evaluated. These treatments included the pH control and additions of various sequestrating agents such as sodium carbonate (Na_2CO_3), ethylenediamine tetraacetic acid (EDTA), sodium silicate (Na_2SiO_3), oxalic acid, succinic acid, ammonium oxalate, Na-hexametaphoshate, calcium oxide and hydrogen peroxide (H_2O_2).

The results showed that one way of eliminating Ca^{2+} ions present in the Buchanan plant water would be to introduce CO_3^{-2} ions. Dewatering tests were conducted using 0.5 kg/mt of soda ash in conjunction with Reagents RW and RU. In general, sodium carbonate was not particularly effective when Reagent RW was used as the dewatering aid. In fact, the moisture values actually increased slightly when soda ash was added. On the other hand, the addition of soda ash improved the performance of Reagent RU at dosages of 1.5 kg/mt or higher. The filter cake moisture was reduced to a very low value of 12.3% of 2.5 kg/t of RU in the presence of soda ash.

Hydrogen peroxide was used as an oxidizing agent, the test results indicated that very little improvement in filter cake moisture (only about one percentage point) was obtained. Similar behavior was observed when EDTA and sodium hexametaphosphate were used. On the other hand, the addition of sodium silicate generally improved the performance of the dewatering aids up to a dosage level of 3 g/t of sodium silicate. For example, the addition of 3 g/t of sodium silicate improved the performance of Reagents RW and RU by 0.8 percentage points (i.e., 14.3% vs. 13.5% moisture) and 2.0 percentage points (15.2% vs. 13.2% moisture), respectively. However, further addition of sodium silicate above 3 kg/t caused an increase in moisture content. The results indicate that the use of sodium silicate helps in moisture reductions beyond what can be achieved using dewatering reagents alone.

The moisture content of filter cake could be reduced from 17.3% to 13.3-13.4% by using 1-5 g/t oxalic acid along with 2.5 kg/t of Reagent RW. Likewise, a filter cake with as little as 13.3-13.4% moisture could be obtained by using 5-10 g/t oxalic acid along with 2.5 kg/t RU as the dewatering aid. Similar moisture reductions were obtained when calcium oxide, ammonium oxalate and succinic acid were used. For example, the addition of 10 g/t of succinic acid improved the performance of Reagent RW by 2.8 percentage points (i.e., 15.3% vs. 12.5% moisture). Ammonium oxalate improved the performance of Reagent RW by 1.9 percentage points.

Without a dewatering aid, the lowest moisture values were achieved around neutral or slightly acidic pH (from 6 to 8). The baseline moisture contents were increased for both the acidic (pH=4) and alkaline (pH=11) conditions when no reagent was added. On the other hand, cake moistures in the 13.6-13.9% range were obtained for all pH values tested except for pH 8 (which gave filter cake moisture of nearly 15%). This relatively high filter cake moisture corresponded to the pH at which the lowest baseline moisture was obtained, i.e., when no reagent was employed. These results suggest that a slightly basic (pH 8) solution may adversely affect the dewatering aids. Additional tests are needed to verify this observation.

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 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 may be necessary for high-energy conditioning. The feed slurry was conditioned for 5 minutes in both series of tests. The moisture reduction was substantially improved when using high-energy conditioning. 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 using high-energy agitation at the same reagent dosage of 2.5 kg/t. Similar results were obtained using Reagent RW 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 dewatering tests showed that 40% to 60% moisture reductions could be achieved from these samples since the hydrophobicity of the particles were increased in the presence of the dewatering aids. The test results have confirmed that the kinetics of mechanical dewatering was substantially increased in the presence of the reagents and increased the throughput of dewatering devices. The data obtained using sequestrating reagents along with the novel dewatering chemicals developed in Virginia tech show that the use of these sequestrating reagents is a promising approach for overcoming the water chemistry problem. The results indicate that the use of sodium silicate help reduce moistures beyond what can be achieved using dewatering reagents alone.

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Paper 2

Pilot Plant Evaluation of Novel Fine Coal Dewatering Aids

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ABSTRACT

In the absence of fine coal dewatering circuit, the majority of coal preparation plants use screen bowl-centrifuge to dewater 1mm x 150 micron size clean coal. But the cost of the dewatering fines sharply increases when the particle is below 150 microns. For this reason it is often more economical to discard this fine size fraction if it is only a small part (5 to 10%) of the product stream. The availability of efficient processes that can reduce the moisture of fine particles will greatly benefit companies if these processes can be used to reduce the moisture content of fine coal without compromising product quality.

To investigate the suitability of fine particle dewatering, the novel dewatering aids, namely RU and RW were tested. Pilot plant tests were conducted on fine coal samples in order to compare the bench scale dewatering test and the pilot plant test results.

The tests were carried out using continuous vacuum disc filter. Dewatering results obtained using the pilot-scale unit are similar with the laboratory dewatering results as obtained on the Buchanan plant flotation product and US Steel Mining Company's Pinnacle Plant's vibracore composite sample taken from the smith Branch impoundment, thickener underflow and thickener feed. The use of the novel dewatering aids could substantially reduce the cake moistures up to 50 % from the fine coal. The dewatering kinetics were also improved 4 to 6 times in the presence of dewatering aids

The effect of filter disc speed and vacuum pressure were also investigated in the pilot-scale tests. In the presence of dewatering aids, by simply increasing the filter speed form 3min/rev to 1min/rev, it is possible to increase the filter capacity by 28% without adversely impacting the moisture content of the filter cake.

INTRODUCTION

Coal preparation plants consist of simple crushing, sizing and cleaning operations for coarse and intermediate coal size fractions but commonly involve complex cleaning circuits for fine size fractions which also require dewatering processes. These can be broadly classified into three groups; sedimentation, filtration and thermal drying. Since the market demand is increasing for low-sulfur, high grade coal as a result of economic and environmental considerations it causes processes to be extended towards the ultra fine range which accompanies an increase in the yield of ultra fine tailings. Ultra fine tailings are particularly difficult to dewater because of their large surface area. [1-7]

In the absence of a fine coal dewatering circuit, majority of coal preparation plants use screen bowl-centrifuge to dewater 1mm x 150 micron size clean coal. The cost of dewatering fine particles sharply increases when the particle is below 150 microns. For this reason it is often more economical to discard this fine size fraction of the plant's run of mine coal without any attempt to recover the clean coal content of this size fraction if it is only a small fraction (5 to 10%) of the product stream. The dumping of tailings in the ponds is not very appropriate nowadays and in the future will be possible only in exceptional cases because of the lack of suitable sites and also for safety and environmental considerations.[4, 5, 8-11]

The coal preparation plants, which clean fine coal, utilize filtration technologies that typically include vacuum disc/drum filters, plate and frame filter presses and horizontal belt filter for dewatering. When efficiency of dewatering becomes so low, thermal drying may be required to further dewater fine product.[3, 8, 9]

To avoid the expensive and environmentally important thermal drying, efforts are being made in the coal preparation sector to counteract this trend both by improvement and further development of already known dewatering methods and equipment and testing those not previously used in coal preparation. [3, 8-10]

The availability of efficient processes that can reduce the moisture of fine particles will greatly benefit companies if these processes can be applied to reduce the moisture content of fine coal.[8, 9]

To address the problem based on the fine particle dewatering, the novel dewatering aids, namely RU and RW were tested. Pilot plant tests were conducted on fine coal samples in order to compare the bench scale dewatering test and the pilot plant dewatering test results. The test results showed that the use of the novel dewatering aids could substantially reduce the cake moistures up to half of the total moisture values from the fine coal. The role of the reagents is to increase the hydrophobicity (or dewettability) of the coal. In the presence of these reagents, the contact angles of the coal samples increased preventing the surface of the particles to be wetted by water molecules. It is suggested that the increase in contact angle could be responsible for the reduction of the capillary pressure in a filter cake and should help reduce the cake moisture. The novel dewatering aids also decreased the surface tension of water and increased cake porosity (or capillary diameter), both of which could contribute to the lower cake moistures.[3]

EXPERIMENTAL

The major objectives of these tests were comparison of pilot scale dewatering test results with the bench scale dewatering test results and confirm that the newly developed dewatering aids could be used in the pilot plant tests and through industrial applications. Reagents RW and RU were used as the dewatering reagents in the pilot scale dewatering tests. Each of the reagents was tested over a range of dosages that typically varied from 0 to 2.5 kg/ton (0 to 5lb/ton) of the dry coal. Samples were collected around the modules and analyzed for slurry flow rates and percent solids or moisture content.

Various samples were tested for dewatering tests taken from Consolidation Coal Corporation's Buchanan Preparation Plant in Mavisdale, VA and US Steel Mining Company's Pinnacle Plant Site near Pineville, WV.

In the tests, the Conditioner Module and Filter Module were required since the feed slurry for the tests was supplied directly from the Consolidation Coal Corporation's Buchanan Preparation Plant in Mavisdale, Virginia. The pilot-scale disc filter tests were conducted on flotation product samples.

The Column Flotation, Conditioner and Filter Modules were set up in the Virginia Tech's Plantation Road Pilot Plant Facility in Blacksburg and used to test three of the coal samples taken from the US Steel Mining Company's Pinnacle Plant Site near Pineville, WV. The samples were vibracore composite sample taken from the Smith Branch Impoundment, a slip stream sample of current thickener feed and thickener underflow.

The schematic diagram of the Column Module shown in Figure 2 consists of a 30-cm diameter by 3-m tall flotation column. The column is 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. Up to 100 liters/minute of air is supplied to the static mixer by a rotary air compressor. Coal slurry is fed to the column from an agitated tank using a variable-speed centrifugal pump. Pulp level in the column is maintained by adjusting the tailings flow rate using a pneumatic control valve. The valve actuates based on readings from a pressure transducer mounted in the side of the column. Wash water is added to the froth to minimize the entrainment of fine mineral matter. Chemical metering (reagent) pumps are used to add the desired dosages of frother and/or collector to the feed slurry.

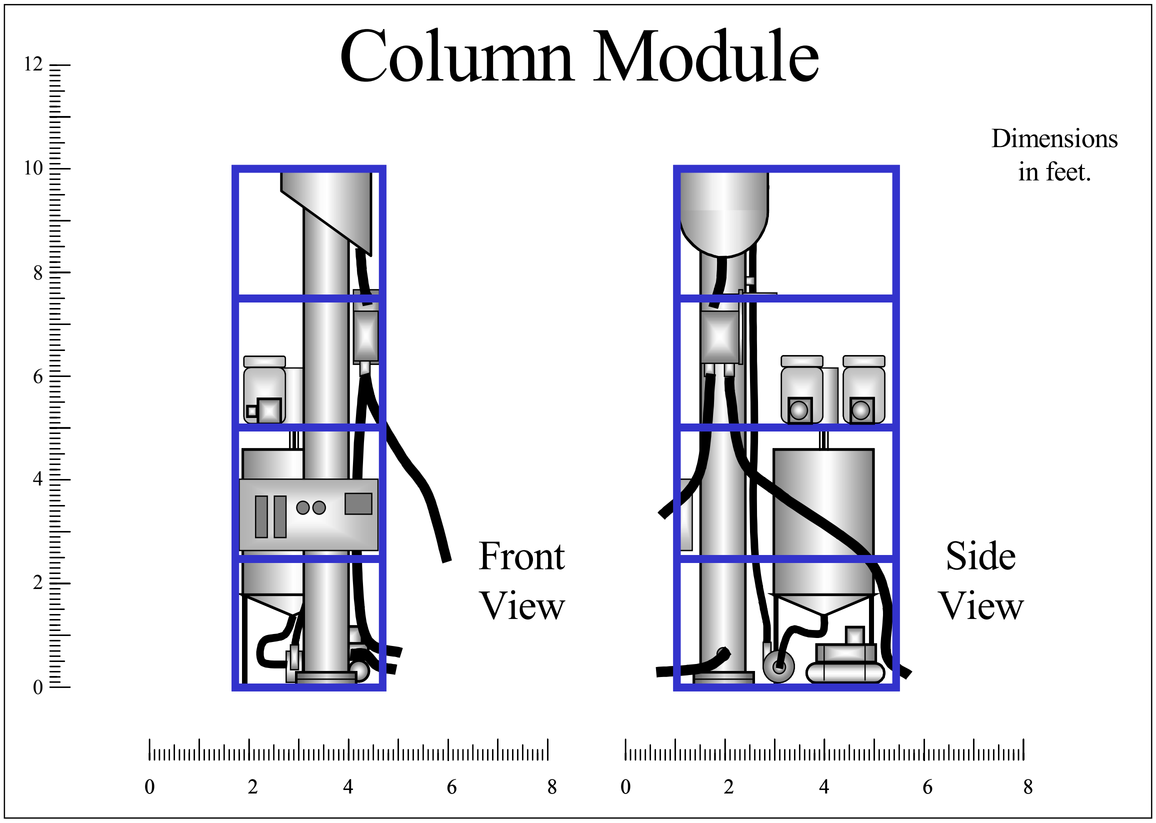

Figure 2. Schematic diagram of the Column Module

The pilot scale flotation column was capable of producing 22-34 kg/hr of concentrate grading 7-8% ash from a feed containing (on average) 42 % ash at recoveries of about 95%, and that the filter produced from 8 to 35 kg/hr of cake (depending on reagent dosage) from feed streams containing around 7-8% solids.

A schematic diagram of the Conditioner Module is shown in Figure 3. The module incorporates two 20-liter conditioning tanks that are operated in series to provide up to 10 minutes of conditioning time. The conditioning tanks are equipped with single-impeller mixers that can be varied in speed from 0 to 2500 rpm using electronic controllers. To ensure that coarser particles do not settle when low feed rates are used, the slurry in the conditioning tanks is continuously circulated through a head tank using a centrifugal pump. The head tank is equipped with an automated sampling system that consists of an electronic timer and a pneumatic sample cutter. During operation, the sampling system is used to divert a defined portion of circulated slurry to the Filter Module (or any other downstream operations). A chemical metering (reagent) pump is used to add the proper dosage of dewatering aid to the feed slurry as it enters 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.

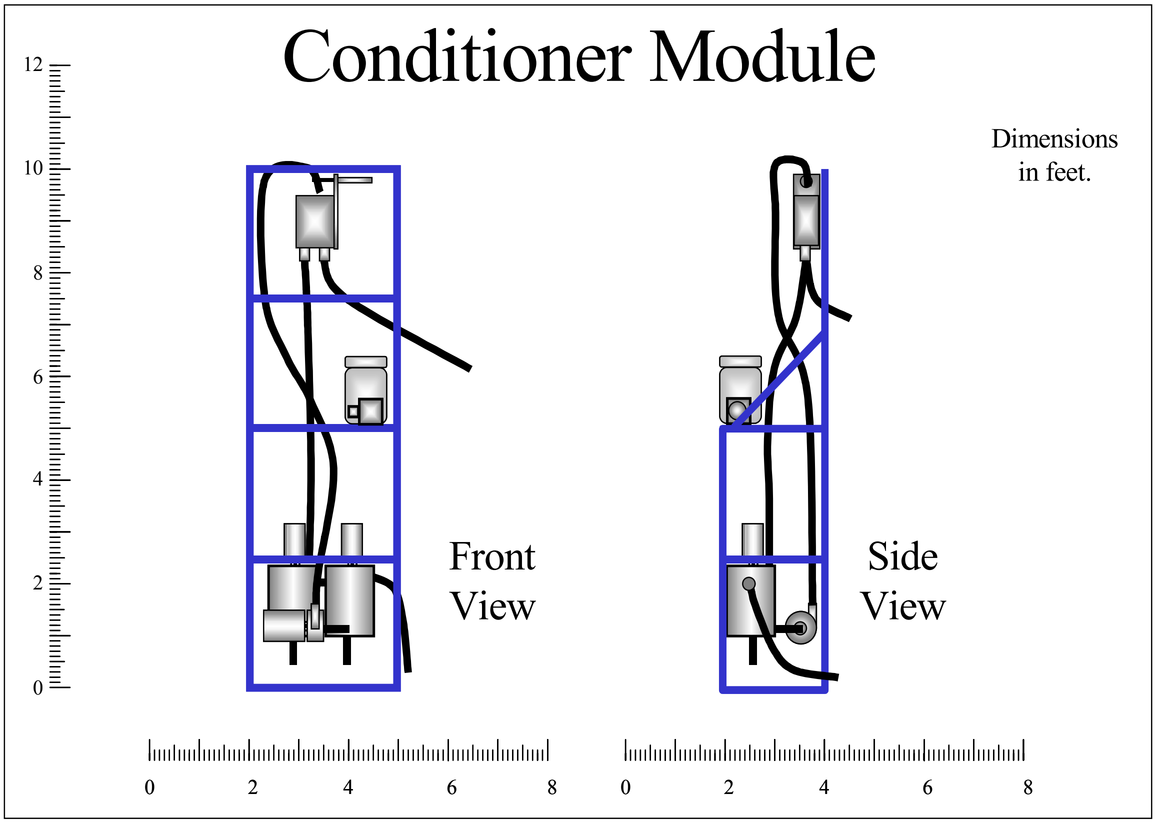

Figure 3. Schematic diagram of the conditionar module

The tests were conducted with a Pilot-Scale Disc Filter that was manufactured by Peterson Filter Company, Salt Lake City, Utah (Schematic diagram 4). The principle of construction of disc vacuum filter is a disc mounted on a horizontal shaft, having interchangeable elements which can be changed for fitting and removing filter cloths. It rotates the disc in a sump into which the suspension is fed (the sump also has two agitators to provide even cake formation), and applies vacuum through the core of the shaft. The submerged sector of the disc collects the cake and removes by blow-back air cake discharge system utilized in conjunction with a scraper just before re-entering to the sump.[12-14]

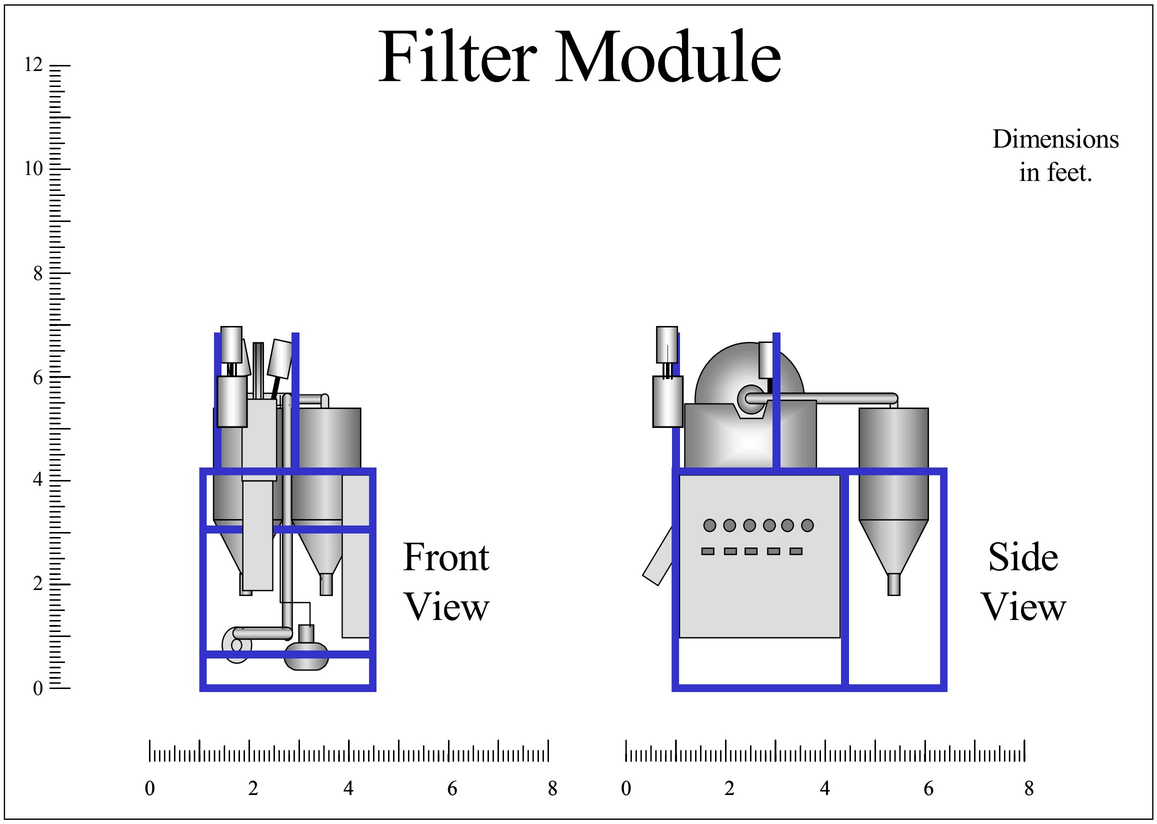

Figure 4 Schematic diagram of the peterson Disc Filter

The specifications of the equipment are

- 2 ft diameter with 10 removable sectors
- 0.2 - 2.0 ft^2 of adjustable filter area by varying number of filter sectors used
- Peterson “Syncro-Blast” air cake discharge system
- 0.5 - 12 minutes per revolution
- 29 inches Hg vacuum pressure at 2.5 cfm.

- Dual filtrate sumps: 25 gal capacity each
- Connected HP: 2.25
- Dimensions: 5ft. High x 5ft wide x 4ft deep.
- Weight: 1,800 lb.

In some cases, the use of the dewatering aids increased the rate of dewatering kinetics which results in a substantial increase in cake thickness, requiring a longer drying time to achieve desired cake moisture. To minimize this problem, the rotational speed of the disc filter can be increased, which will in turn shorten the drying cycle time. This may be referred to as a 'dilemma' faced in using disc filters for fast-dewatering materials. A solution to this problem was splitting a vacuum manifold into two separate lines; one directed to the submerged filter sectors and the other to those that are open to the air. The pilot-scale disc was modified to incorporate this "dual vacuum system," as shown in Figure 5. It is equipped with a pressure reducer, which allows the vacuum pressure for the bottom sectors of the disc to be reduced, while the upper sectors to have full vacuum pressure.

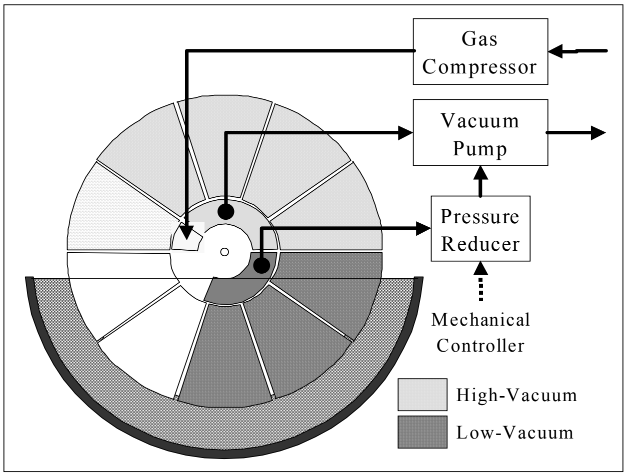

Figure 5 Figure illustrating the principle of the dual vacuum system

This property makes it possible to control the vacuum pressures during the cake formation (or pick-up) time and drying cycle time independently from each other. When the dewatering rate is high due to the high hydrophobic interactions, the pressure during the pick-up time is lower than that observed the drying cycle time. This allows control of cake thickness, which should help attain low cake moistures at a given drying cycle time.

RESULTS AND DISCUSSIONS

1. Dewatering Test Results on Consolidation Coal Corporation's Buchanan Preparation Plant's Coal Sample

Table 21 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/mt (5 lb/ton) of reagent RU and to 15.0% with reagent RW.

Table 21 - Effect of reagent addition on the pilot-scale dewatering of Buchanan's flotation product

Reagent Dosage (kg/mt)	Moisture Content (% wt)	
	RU	RW
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

Table 22 gives the laboratory test results obtained on the Buchanan plant flotation product using RU and RW 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 RU additions of 0.5 and 2.5 kg/mt, the moisture contents of the cake were reduced from 17.6% to 16.1% and 14.4%, respectively. Similar results were obtained with RW as a dewatering aid. These values correspond to a 15-20% moisture reduction in the filter product.

Table 22 - Effect of reagent addition on laboratory scale dewatering of Buchanan's flotation product

Reagent Dosage (kg/mt	Moisture Content (%wt)	
	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

Dewatering results obtained using the pilot-scale unit agreed well with the laboratory dewatering results as obtained on the Buchanan plant flotation product. As shown in Tables 21 and 22, the moisture contents of the filter products for both the laboratory and the pilot-scale test programs are 14.5% at approximately 2.5 kg/mt (5 lb/ton) of Reagent U.

The effect of filter disc speed was also investigated in the pilot-scale tests. Table 23 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 little 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.

Table 23 - Effect of pilot-scale filter disc speed on filter cake production rates and moisture content

Filter Disc Speed (mins/rev)	Product Rate (kg/h dry)	Moisture Content (% wt)
3.0	83.3	16.9
2.0	108.6	16.7
1.0	116.6	17.3

A series of pilot-scale dewatering tests were conducted to study the effects of different vacuum levels on moisture reduction. The results are presented in Table 24. The data show that it is possible to reduce the product moisture from 19.7% to 16.0% by simply increasing the vacuum level from 5 to 15 inches Hg. It seems that a further increase in vacuum from 15 to 20 inches Hg is not advantageous in terms of further lowering the moisture contents of the filter products. Tests were conducted on Buchanan plant flotation product without dewatering reagents

Table 24 - Effect of pilot-scale filter vacuum level on filter cake moisture contents

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

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 25 gives the pilot scale test results obtained on the Buchanan plant flotation product using RW 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 37kpa to 68kpa, the moisture contents of the cake were reduced from 18.2 to 16.8% and 16.3%, respectively.

Table 25 - Effect of pilot-scale filter vacuum level on filter cake moisture contents.

Reagent	Vacuum (inHg)	Moisture Content (% wt)
RW	37	18.2
(2kg/ton)	54	16.8
	68	16.3

The test results, which are given in Table 26, indicate that higher improvement in filter cake moisture (about two percentage point) was obtained when using RU as dewatering aid. As the vacuum levels increased from 37 to 68kpa, the moisture content of the cake were reduced from 16.8 % to 14.5% and 14.3%, respectively.

Table 26 - Effect of pilot-scale filter vacuum level on filter cake moisture contents.

Reagent	Vacuum (inHg)	Moisture Content (% wt)
RU	37	16.8
(2kg/ton)	54	14.5
	68	14.3

2. Dewatering Test Results on the US Steel Mining Company's Pinnacle Plant's Coal Samples

Table 27 gives the laboratory test results obtained on the Pinnacle pond sample using RW as the dewatering aid. At 0.5 and 2.5 kg/mt RW 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.

Table 27 - Effect of Reagent addition on dewatering of Pinnacle pond sample

Reagent Dosage (kg/mt)	Moisture Content (%wt)
	Reagent W
0	28.7
0.5	24.6
1.0	22.9
1.5	22.5
2.5	14.4

Similar tests were conducted on the thickener underflow and thickener feed samples using RW and RU as dewatering aids. Results for the thickener underflow sample are given in Table 28, which shows the moisture content of the filter product decreases with increasing RW and RU additions from 0.5 to 2.5 kg/mt. The RW addition rate of 2.5 kg/mt reduced cake moisture contents from 31.4% to 22.1%, giving a percentage moisture reduction of about 30%.

Table 28 - Effect of reagent addition on dewatering of Pinnacle thickener underflow sample

Regent Dosage (kg/mt)	Moisture Content (%wt)	
	Reagent W	Reagent U
0	31.4	31.4
0.5	30.3	28.8
1.0	28.0	28.2
1.5	22.7	--
2.5	22.1	27.8

Table 29 gives the results for the thickener feed sample. In this case, RW and RU gave similar results - cake moisture contents down 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/mt.

Table 29 - Effect of reagent addition on dewatering of Pinnacle thickener feed sample.

Regent Dosage (kg/mt)	Moisture Content (%wt)	
	Reagent W	Reagent U
0	29.5	29.5
0.5	26.5	27.3
1.0	24.3	25.2
1.5	22.2	23.1
2.5	21.1	21.8

Reagent W and U were used as dewatering aids in pilot scale dewatering tests. Table 30 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, at reagent dosage rates of 1.0-2.5 kg/mt of RW, filter cake moisture content was reduced from 28.4% to 17.7-16.3%. Cake thicknesses were as high as 16 mm when using RW as the dewatering aid. Even at this cake thickness, moisture reductions were significant. The percentage moisture reduction was 43%. Filter effluents were also much cleaner when dewatering aids were used, indicating that filter recoveries increased substantially in the presence of dewatering aid.

Table 30 - Effect of RW addition on the pilot scale dewatering of the Pinnacle-Smith Branch Impoundment sample.

Regent Dosage (kg/mt)	Moisture Content (%wt)
	Reagent W
0	28.4
0.5	19.6
1.0	17.7
1.5	17.2
2.5	16.3

Table 31 and 32 give the pilot scale dewatering results obtained on the Pinnacle coal thickener feed sample. In this series of tests, RW was used as the dewatering aid. As shown in Table 31, the moisture content of the filter cake is reduced from 29.4% to 21.5% by the addition of 2 kg/mt RW.

Table 31 - Effect of RW addition on the pilot scale dewatering of the Pinnacle-thickener feed sample.

Regent Dosage (kg/mt)	Moisture Content (%wt)
	Reagent W
0	29.4
0.5	--
1.0	--
2.0	21.4
2.5	--

Of particular note in these two mobile plant tests is that the filtration performance of both the pilot-scale filter and Reagent W are essentially identical to that achieved in the laboratory.

The test results given in Table 32 show that the moisture content of the filter cakes are significantly decreased when RW and RU are used as dewatering aids. For example, filter cake moisture contents were reduced from 28.0% to 23.4% at 0.95 kg/mt and 20.3% at a 3.7 kg/mt reagent dosage. As shown, RU performs as well as RW 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/mt RU. These results are in good agreement with those obtained in the laboratory test work reported earlier.

Table 32 - Effect of reagent addition on dewatering of Pinnacle coal thickener feed sample using the mobile unit.

Reagent Type	Regent Dosage (kg/mt)	Moisture (wt%)
RW	0	28.0
	0.95	23.4
	3.7	20.3
	4.45	21.8
RU	0	28.0
	3.1	20.6
	5.5	21.0

CONCLUSIONS

The objective of the dewatering tests at the pilot plant was to verify some of the results obtained from the laboratory-scale batch dewatering tests. The verification tests were carried out using continuous disc filter. Dewatering results obtained using the pilot-scale unit are similar with the laboratory dewatering results as obtained on the Buchanan plant flotation product. The test results showed that in some cases the moisture content of the pilot plant filters were 5 to 10% higher than laboratory dewatering tests. However, the final moisture reduction of both filters was closer to each other.

The effect of filter disc speed was also investigated in the pilot-scale tests. 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 little change in the moisture content of the filter cake. It is possible to increase the filter capacity by 28% without adversely impacting the moisture content of the filter cake.

Some pilot.-scale dewatering tests conducted to study the effects of different vacuum levels on moisture reduction show that it is possible to reduce the product moisture from 19.7% to 16.0% by simply increasing the vacuum level from 34 kPa to 51 kPa.

The bench scale dewatering test results obtained on the Pinnacle pond sample using RW as the dewatering aid at showed that the moisture content in the filter cake was reduced with increasing reagent addition. At 0.5 and 2.5 kg/mt RW 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.

Similar bench scale dewatering tests were conducted on the thickener underflow and thickener feed samples using RW and RU as dewatering aids. The RW addition rate of 2.5 kg/mt reduced cake moisture contents from 31.4% to 22.1%, giving a percentage moisture reduction of about 30%. This is less than the case of the impoundment sample, and can attributed to the different mean particle sizes of these two samples. Mean particle size was approximately 32 microns for the impoundment sample and 15 micron for the thickener underflow sample.

RW and RU gave similar results - cake moisture contents down 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/mt for the thickener feed sample.

The pilot scale dewatering results obtained on the Smith Branch Impoundment sample show that the moisture contents of the filter cakes are substantially decreased in the presence of dewatering aid, at reagent dosage rates of 1.0-2.5 kg/mt of RW, filter cake moisture content was reduced from 28.4% to 17.7-16.3%. Cake thicknesses were as high as 16 mm when using RW as the dewatering aid (vs. 3-6 mm without). Even at this cake thickness, moisture reductions are significant. Filter effluents were also much cleaner when dewatering aids were used, indicating that filter recoveries increased substantially in the presence of dewatering aid.

The pilot scale dewatering results obtained on the Pinnacle coal thickener feed sample shows that the moisture content of the filter cake is reduced from 29.4% to 21.5% by the addition of 2 kg/mt RW. The test results again show that the moisture content of the filter cakes are significantly decreased when RW and RU are used as dewatering aids. Filter cake moisture contents were reduced from 28.0% to 23.4% at 0.95 kg/mt and 20.3% at a 3.7 kg/mt reagent dosage. As shown, RU performs as well as RW 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/mt RU.

These results are in good agreement with those obtained in the laboratory test work and the pilot-scale filter and Reagent W are essentially identical to that achieved in the laboratory.

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