Froth flotation and subsequent dewatering circuit optimization

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Abstract. The proper selection of dewatering equipment downstream of flotation is vital in maximizing preparation plant yield. As such, mismatched flotation and dewatering equipment can lead to catastrophic reductions in plant profitability. This paper covers optimum flotation and subsequent dewatering circuit configurations for thermal and coking coal worldwide. The benefits of using deslime column flotation together with screen bowl centrifuges for thermal coals will be discussed, with numerous successful applications mentioned. Likewise for coking coals, conventional versus column flotation applications will be reviewed. The benefits of the Australian practices of dewatering "by-zero" froth concentrates using disc or horizontal belt vacuum filters will also be quantified. The advantages of using pressure filtration in the USA and Canada compared to using centrifuges on by-zero froth concentrates will be discussed in detail, with industrial examples. In particular, the frothing problems seen in many plants using centrifuges to dewater conventional by-zero froth, and more particularly column froth concentrates, will be highlighted. The paper will conclude with a section describing successful applications of slimes flotation followed by pressure filtration.

1 Evolution of flotation circuitry and subsequent product dewatering

Historically, froth flotation of coal fines was performed in plants processing metallurgical coals only. Initially, minus 0.5 mm coal was treated in mechanical froth cell banks, with concentrate being dewatered on vacuum disc or drum filters. Thermal drying of the product was usually necessary in the USA to meet the stringent moisture content requirements of domestic steel customers. In Australia, with more relaxed export moisture quality specifications, thermal drying was and still is not necessary. The ease of flotation of these high rank metallurgical coals made the flotation relatively simple.

For many years, fines were discarded in plants washing coal for thermal markets. The need to capture some of these coal fines became more pressing as the level of mine mechanization increased, and with it, the increased generation of coal fines. Also on the coking side flotation recovery is superior below 0.25 mm, and problematical above 0.5 mm.

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The desliming circuits ahead of flotation with 0.5 mm wedge wire screens inevitably place considerable quantities of slow floating plus 0.5 mm to the froth circuits. In the USA, circuits were initially installed to capture plus 0.25 mm material with the evolution of circuitry from water-washing cyclones through 4-turn spirals to compound spirals, and currently where low-density cuts are required, low-density spirals or teetered bed separators such as the Reflux Classifier [1].

A good example of the move to 0.25 mm top size for flotation from 0.5 mm wedge wire top size flotation feed occurred with the expansion of the McClure Metallurgical Coal Processing Plant from 600 to 1,000 tons per hour. This expansion was achieved by opening up desliming to 1.25 mm with 1.25 mm x 0.25 mm passing to a new two-stage spiral circuit. This allowed the top size feeding froth flotation to be reduced to 0.25 mm, achieving a far more efficient outcome [2].

South Africa has also had success with fine dense media circuits (DMC) on the 1 mm x 0.25 mm size fraction [3].

Historically, the 1 mm x 0.25 mm product was typically dried in a scroll-type centrifuge. However, the improvement in design capacity and reliability for screen bowl centrifuges (SBCs) saw their increasing popularity. The SBC had a further major advantage over the scroll basket centrifuge, its ability to dewater ultrafine (minus 0.25 mm) as well as fine (1 mm x 0.25 mm) material together, something scroll basket centrifuges and the filters could not do. Improving SBC technology also allowed the SBC machines to compete with the high-moisture, high-maintenance vacuum filter systems, which had traditionally been the only effective drying technique for ultrafines previously. Unfortunately, ultrafine particle capture in SBCs is inferior (approximately 50% capture of minus 45 micron material). Very efficient dewatering of a deslimed froth product is however achieved with the SBC machine.

Another method for dealing with ultrafines (minus 0.045 mm) is to deslime ahead of flotation using classifying cyclones.

This eliminates the ultrafine (minus 0.045 mm) material from flotation. Often this size fraction has little recoverable coal. Desliming ahead of flotation provides several major advantages, including lower product ash levels, lower moisture products, as well as greatly reduced circuit capital and operating cost. Countering these positives is the loss of recoverable fine material. This fine coal loss can, in many circumstances, particularly for thermal coals, be readily overcome with coarser circuit yield improvements. This is very much dependent on coal washability characteristics and the coal quality required by the market [4], [5].

With ever increasing plant rejects, clay levels in many plant feeds have risen substantially. The inability of conventional flotation circuitry to deal effectively with clays causes high ash, high moisture froth products. This shortcoming is due to the entrainment of clays in the froth concentrate [6]. Economic analyses on the financial impact of capturing ultrafine material of high-moisture and high-ash content often show that the ultrafines have severely negative financial value and should be discarded, particularly for thermal coals. The relatively recent successful introduction of column flotation has greatly improved selectivity without sacrificing recovery. The column cells allow ultrafine clean coal to be recovered but minimize the undesirable entrained clays which pose such a problem for conventional flotation circuits. This is done with counter current wash water and deep froth [7] (Fig. 1).

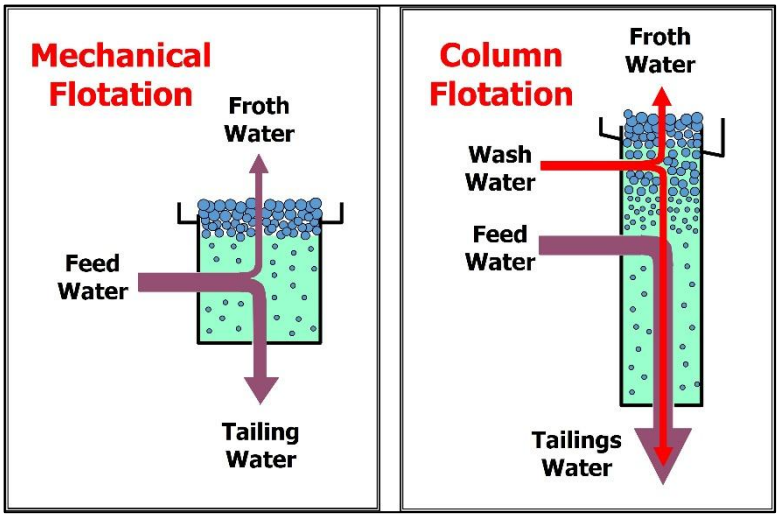


Fig. 1. Benefits of froth washing from column flotation

On the dewatering side, the introduction of horizontal belt vacuum filters, new superior disc filtration and hyperbaric filtration has occurred. Also to improve moisture content of clean coal products, pressure filtration has gained traction [8].

Effectively, the point has now been reached where the technological advances are in place to allow circuitry to be optimized financially, based on coal market requirements and plant feed characterization.

The positives and negatives of conventional flotation, column flotation, by zero and deslimed flotation, and slimes recovery flotation will now be considered. Coupled with these flotation options, consideration of the various dewatering options available to produce a marketable end product will occur. This will include vacuum filtration, pressure filtration, and SBC utilization.

2 Coal markets served and their impact on flotation (and dewatering circuit design)

2.1 Plants feeding metallurgical coal markets

Metallurgical coals are typically sold on as-received moisture and dry ash, and dry sulphur specifications. Consequently, to maximize plant yield and profitability, plant moisture levels need to meet moisture specifications at the same time that dry ash and dry sulphur levels hit the required dry ash and sulphur specifications.

For USA or Canadian plants employing thermal dryers, it is usually possible to obtain high fine circuit recoveries (at relatively high fine circuit moisture content) without breaching contract specifications. However, particularly for USA domestic metallurgical coal sales which require low moisture specifications (7-8.5%), it is very difficult, if not impossible, to achieve contract moisture specifications while maximizing flotation recovery in non-deslimed circuits without thermal drying. This is due to the fineness of the processed coal and accompanying high moisture contents, particularly in the minus 0.25 mm size fractions. This high moisture content can be overcome by using the newly emerging pressure filtration systems or by using SBCs and accepting the losses of ultrafine coal in these units. Recent advances in pressure filtration have provided a good option -- the use of plate-and-frame filters to treat the froth product, enabling the fines to be blended back with the coarser clean

coal material and still make moisture specification. Australian and Mozambican coking coal moisture contract requirements are less rigorous (+10% total) and full coal recovery can be achieved in flotation followed by vacuum filtration, maximizing coal recovery without breaching moisture targets [9].

2.2 Plants feeding thermal coal markets

Thermal coal processing plants feed supply contracts which are based on delivered calorific value (C.V.). Although maximum ash (as-received [A.R.] basis) and moisture (A.R. basis) levels are specified, minimum C.V. normally comprises the major hurdle to plant yield maximization. The effect of this difference in contract specifications is to make ash and moisture virtually interchangeable provided that neither maximum contract specification is exceeded. Effectively, for a 6,000-Kcal/kg specification being met by a coal with 7,500 Dry Ash Free C.V., the contract can be met equally well by shipping 8% moisture and 12% ash (both on an A.R. basis) giving 20% inerts, or by 6% moisture and 14% ash (A.R.) also providing 20% inerts. The major advantage of minimizing moisture is that for every tonne of water eliminated by lowering plant moisture, typically 2+ tons of middlings (35%-40% ash) can be added back by raising plant gravities in the 1.55–1.65 specific gravity (SG) range.

Conventional flotation circuits treating minus 0.25 mm feed will generate concentrates having minus 0.045 mm material with incremental moistures in the 40%+ range. As discussed, entrained clays in the froth can have 60%+ ash dry basis (D.B.). On an A.R. basis, this equates to up to 80% inerts passing to the product. Even column circuits treating minus 0.25 mm material with low minus 0.045 mm ash levels (10% D.B.) will have incremental inerts of 45–50% (40–50% moisture and 5% ash A.R.) through an SBC or vacuum filter.

As long as plant operating gravities are below +1.70 SG and the total product ash content is below specification maximums, it will be unlikely to economically recover ultrafines in plants processing thermal coals. This is typically the case in Central Appalachia in the USA, where thermal (steam) coal processing plants treat high-clay coals and operate in the 1.50–1.60 heavy media SG range. Most plants do not have thermal drying. Consequently, maximum plant yield and the best financial returns can be obtained by designing a deslime column flotation circuit with SBC dewatering.

Examples of circuit optimization for coking and thermal products can be seen in the 2005 ICPC paper [10] as Tables 6 and 7.

3 Basic flotation and dewatering circuit types

3.1 To deslime or not to deslime with columns or conventional cells

3.1.1 The decision process

Several variables have to be very carefully studied before embarking on a new circuit design or plant modification. Major factors to be considered include:

a) Coal Market to be sourced (primarily metallurgical or thermal).
b) Plant feed coal characteristics (size breakdown, washability, percentage fines, level of clay slimes in feed).
c) Projected alternative fine circuit product qualities and yields.
d) Impact of the fine circuit product on total plant quality and yield. A holistic approach must be taken, considering all streams contributing to the plant product and maximizing the total yield at customer-specified quality.

e) For plants treating clay rich coals, column flotation should be considered as a means of selective desliming. Major improvement in coal recovery and ash reduction by replacing conventional flotation with column flotation at Pittston's Middlefork facility occurred [7]. Column flotation has been shown to be capable of eliminating most entrained material through the use of a counter-current wash water to the froth. Surprisingly, column flotation has significant advantages even in deslimed flotation circuits. Classifying cyclone efficiencies typically will only enable approximately two-thirds of the ultrafines (minus 0.045 mm) to be eliminated to overflow [11]. Even with deslime flotation, entrainment can still be a problem. Column flotation minimizes this problem, allowing plant heavy media circuit gravities to be raised. This makes it possible to replace +60% ash entrained clay with coarse 'middlings' in the 25% – 45% ash range.

f) Insertion of a small diameter cyclones circuitry to deslime in the +0.045 mm size range will typically allow plant moisture specifications to be met while letting the froth cells be "pulled hard". Elimination of the minus 0.045 mm fraction also coarsens the size distribution and improves handleability. However, yield loss compared to the by-zero circuitry will occur. This is a particular problem for coking coal processing plants where product ash cannot be raised whilst lowering product moisture.

For plants where clay entrainment to froth concentrate is not a problem, conventional flotation cells are a good, lower-cost option. Individual conventional froth cell capacity has greatly increased over the last 40 years from under 3 m^3 per cell to over 30 m^3. Conventional circuitry typically uses a single pass process with four (4) or five (5) cells in a bank with four (4) minutes plus residence time. Coal flotation is typically reasonably easy and does not warrant scavenging of tailings. However, for column flotation, rougher-scavenger circuits are becoming more popular to increase overall coal recovery. With improving dewatering and column flotation technology, it has been possible in some cases, in a strong coking coal market, to recover slimes previously discarded. This will be covered later. Conventional cells are typically provided by Wemco, Metso, and Jet cells.

Column flotation installations in coal comprise mainly Microcells, Slamjet cells, Stack cells, Jameson Cells and Concorde cells.

3.2 Dewatering circuit options

For the minus 0.25 mm froth product alone, vacuum and pressure filtration options are available. Vacuum filtration mainly centers around horizontal belt vacuum filtration and disc filtration. Hyperbaric filters are also widely used in China. Disc filter technology has advanced with new, higher-capacity equipment, such as the Bokela filter (Fig. 2).

Fig. 2. Bokela filter.

Obviously, the cake moisture content is driven by the applied pressure, which is limited to less than one (1) bar for vacuum filtration.

Pressure filtration on the other hand can deliver seven (7) bars which allows far smaller capillaries in the cake to be dewatered leading to significantly lower product moistures.

Operational considerations with pressure filtration, plate-and-frame style (and others), are that they are a batch process. Effective metering of filtercake into clean coal product streams can pose challenges especially when dealing with a filter cake product surge even at relatively low moistures.

The SBC has gained wide acceptance in the USA dewatering fines, particularly with superior performance and capacity compared to typical screen scroll dewatering centrifuges. It also has the added advantage that froth can be handled with the 1 mm x 0.25 mm material.

The nominal 0.25 mm x 0.045 mm material is handled very efficiently in SBCs with high coal recoveries. Slimes recovery (-0.045 mm) in SBCs is poor, typically 50%. The lost coal reports with excess frother to the SBC main effluent and, hence, typically the tailings thickener. This material often causes severe frothing problems on the thickener and subsequently back into process sumps in the plant. This then prevents the flotation circuit reaching its full potential. Frother dosage is cut back to minimize frothing problems, which simultaneously leads to coal losses.

This problem is minimized when the flotation product feeding the SBC is from a deslimed flotation circuit.

4 Circuit combinations those that work and those that do not

To date, how market specifications and washing and PSD characteristics of the coal to be washed drive circuit design have been reviewed.

Now flotation/dewatering options, their applicability and success rates by market type will be discussed.

4.1 A Thermal coal flotation / dewatering circuits

4.1.1 A By-zero Conventional Flotation followed by screen bowl centrifugation.

These plants are characterized by high moisture content in the SBC product. Also, typically frothing problems occur in the thickener and elsewhere unless rigorous froth spraying and the use of a froth boom on the thickener is present. The conventional flotation will produce a reasonable product quality as long as the froth cell feed is relatively low in ash and is clay free. Often the flotation cells are cut back due to frothing throughout the plant causing major yield losses. A classic example of this type of circuit and associated problems is the Iron Senergy's Cumberland Plant in Pennsylvania USA. Due to severe frothing issues plant wide, the frother dosage has to be limited resulting in actual coal recoveries of the order of 60% - 65%% instead of the 85% possible with no frothing issues. Local management is developing plans to convert the circuit to a deslime flotation circuit. As discussed earlier, the incremental moisture content on the 50% of coal slimes captured in the screen bowl centrifuges is high, making the captured slimes uneconomical [11]. By desliming ahead of flotation, slimes are minimized, plant moisture content is reduced, and total plant yield increased by raising Dense Medium Cyclone and Dense Medium Bath circuit densities (replacing 100% inerts moisture with 40% inerts middlings).

4.1.2 Deslime conventional flotation followed by screen bowl centrifuges

This circuit type uses secondary classifying cyclones ahead of the flotation circuit to remove slimes. This circuit type allows full recovery in the flotation circuit, with minimal frothing downstream of the SBC. Also, the flotation circuit capacity required is typically one-third of that required in by-zero circuits. Incremental moisture content of the froth product and its ash level tend to make it accretive. (Can be added to the regular plant product without hurting quality or causing the DM densities to be lowered). This circuit works well for low feed ash, clay-poor coals.

4.1.3 Deslime column flotation circuitry with SBC

As mentioned above, secondary classifying cyclones are used ahead of the flotation circuit to remove nominal minus 45-micron material. Required column capacity is minimized, and due to the PSD of the feed material to the column cell, carrying capacity (the mass of coal which can be lifted by the air bubbles per unit of surface area) is high. The cells can be pulled hard. A low-ash concentrate can be generated with running deep froth (500 mm) along with positive bias counter-current wash water. Moisture contents through the SBCs are low for the incremental froth product and coal recoveries therein are high (+95%).

The circuitry is simple as shown in Fig. 3 and high levels of performance usually are easy to establish and maintain.

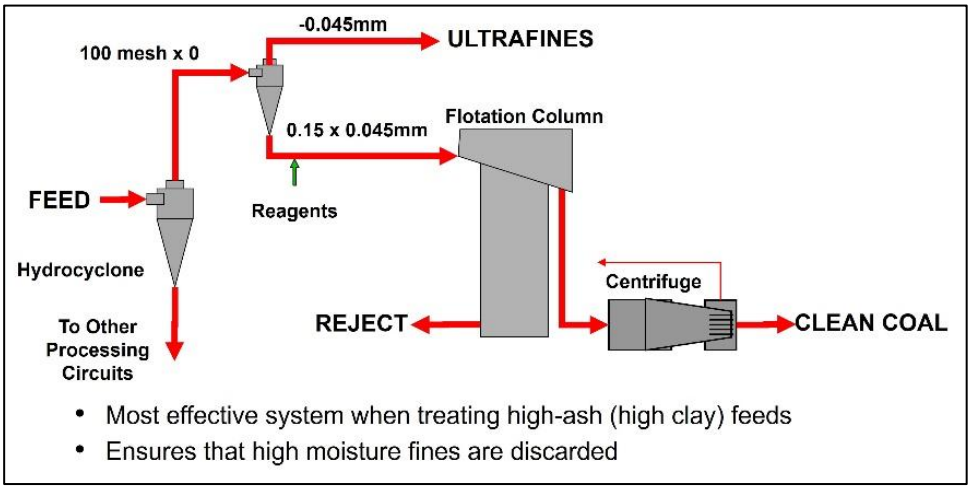


Fig. 3. Froth flotation column deslime

Many of these circuits have been retrofitted to plants or installed as part of a new plant. Examples of retrofits include the circuit additions at Lone Mountain Processing [4] and Pardee [12]. Successful new circuit additions include the Cardinal Plant [10] in West Virginia and the Cline Resources plants in Illinois (Mach Mining and Sugar Camp).

Typically, the retrofit plants have increased plant yields by 2 to 3 percentage points, providing very attractive paybacks.

Lone Mountain column upgrade successfully installed a column/SBC circuit, which has:

1) Generated 20+ tph additional coal recovery.
2) Generated a lower total product moisture content.
3) Provided less than 6-month payback on capital spent.

4.1.4 Column flotation by-zero with pressure filtration

In South Africa, successful flotation circuitry incorporating column flotation (Enprotec cells) coupled with plate-and-frame pressure filters have been in place at Goedehoop, Greenside and Ikwezi. The low moisture content filter cake makes the column cell / pressure filter circuitry economically attractive.

4.2 Coking coal flotation /dewatering circuits

4.2.1 Conventional flotation cells and vacuum filtration

Historically, in the USA, this circuit type performed well when backed up by a thermal dryer. The fineness of the plant feed coal precluded the possibility of running without the thermal dryer. Excellent coal recovery could be obtained on clay lean coals in flotation cells, followed by high efficiency on vacuum disc filters. Simple control systems to maximize throughput by adjusting filter speed and flocculant addition provided maximum throughput.

With the difficulty of obtaining and maintaining thermal dryer permits and the high thermal dryer capital and operating costs, these circuits were largely superseded by conventional flotation followed by SBC dewatering of concentrate.

Differences in market moisture tolerances for Australian and Mozambican coals allowed their coking coal plants to run by-zero flotation [9] (column or conventional) with vacuum

filtration. Many Australian plants use clean coal thickeners to increase the % solids in the filter feed, thereby reducing the required filter size.

Properly sized and operated equipment allows high levels of efficiency and coal recovery to be achieved.

4.2.2 Column flotation cells and vacuum filtration

Due to significant levels of near-density material in most Australian coking coal seams, plant DMC densities need to be run at low levels (less than 1.5 SG cutpoint). This favours very selective flotation to avoid further DMC density drops.

Many plants in Australia use some form of column flotation to get maximum selectivity and high coal recovery. Typically, Jameson cells, Eriez Coalpro, Microcells or Stack cells are used. To maximize efficiency and minimize short-circuiting many of the column installations use cells in a rougher scavenger mode with rougher tailings being refloated in scavenger cells. A classic example of this type of circuit is the successful application of rougher scavenger Jameson cells in conjunction with a horizontal belt vacuum filter at the Foxleigh Mine in Queensland Australia.

Excellent coal recovery is achieved in the Jamesons followed by good coal recovery on the horizontal belt vacuum filter. Typically, plus 80% flotation coal recovery is achieved, with high thickener underflow ash levels commensurate with excellent coal slimes recovery on the vacuum filter, as shown in Table 1

Table 1. Foxleigh Dailey plant samples (December 29, 2024)

Item	Sample	Target	Achieved
FF Con			
Ash%	1	8	7.1
	2	8	8.4
FF Cr%			
	1	80	82.2
	2	80	84.6
FF Solids			
in Froth	1	20	21.6
	2	20	18.4
HBVF			
Ash%	1	8	8.3
	2	8	7.0
Moisture%	1	25	28.1
	2	25	27.0
Thickener Underflow			
Ash %	1	60.0	68.1
	2	56.4	66.9

4.2.3 Conventional flotation with screen bowl centrifuge dewatering

Typically, these circuits are used in the USA where coal seams are relatively free of clays. Flotation is typically constrained as mentioned earlier by frothing issues downstream of the screen bowl centrifuge where the main effluent reaches the thickener, froths and causes further frothing issues in the plant. These frothing issues can be mitigated by the use of water sprays on the thickener and a boom attached to the thickener rakes, which drags froth to the sprays to be broken up Fig. 4.

Fig. 4. Sprays and booms on thickener to break up froth

However, as discussed previously, the SBCs only capture 50% of the minus 45-micron material, which for coking coals will usually exceed 50% of the froth. Consequently, the thickener underflow ash levels are considerably below the froth tailings ash (loss of low ash minus 45-micron coal in the SBC). A classic example of this circuit type is the Arch Beckley plant. The original circuit had conventional WEMCO froth cells with SBCs dewatering a combination spiral/froth product. Froth tails ran 70%+ash, whilst thickener underflow ash assayed in the mid-fifties (50) percent. The froth product was moved to a pressure filter, with 95% ultrafine coal recovery. Thickener underflow ash levels increased to 70%+ash. Ten (10) ton per hour (tph) (D.B.) of additional prime coking coal was recovered [13]. See the following section.

4.2.4 Column flotation with screen bowl centrifuge dewatering

This circuit type provides the most challenging operating circumstances. Column flotation works well in producing a selective product at good coal recovery. This is done by using copious wash-water volumes and a deep froth to rinse off entrained clays. To sustain the deep froth, more persistent frothers are typically used (including a percent of glycols to supplement the usual alcohol frothers). Also, much higher dosages of frother are required because of the above. Typically, 10 ppm of frother (minimum 8 ppm) will be needed for column cells to get good recovery compared to 2 to 4 ppm for conventional flotation with a more brittle frother.

The additional frother dosage of a more persistent frother causes severe frothing problems downstream in the column / SBC circuits. This inevitably leads to major cutbacks in frother dosage and consequently coal recovery to avoid “frothing out” the plant. This is compounded by the aforementioned loss of minus 45-micron particles in the SBCs.

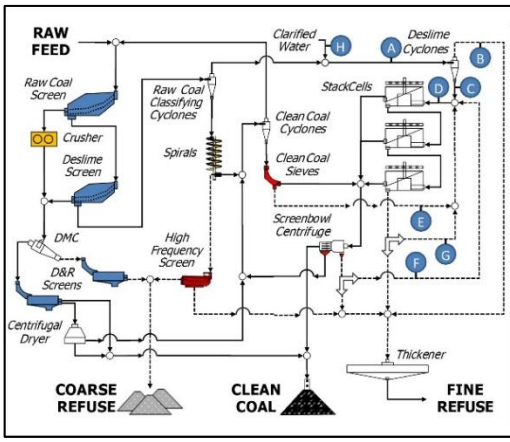
One solution to this major problem is to convert the circuit to a deslime flotation circuit, albeit at ultrafine coal losses. Most of the slimes are discarded (some theoretical coal loss), coal recovery in the plus 45-micron froth can be maximized, with much lower frother

consumption, and minimal frothing from the SBCs. Several Pennsylvania coking coal plants have switched from by-zero to deslime flotation, due to the aforementioned severe frothing problems plantwide.

Somerset, in their attempts to recover SBC main effluent solids [14], have identified many of the problems dealing with SBC main effluent. These include extremely low % solids of this material, frothing, high ash levels of the main effluent (the main effluent contains both low ash froth ultrafines, but also high ash slimes from spiral products). Major difficulties are encountered trying to separate the ultrafine coal from clay slimes in SBC effluent flotation (low carrying capacity, extremely stable froth, low froth % solids) to reduce ash levels ahead of feeding their SBCs.

A major success with this retrofitting desliming in place of by-zero column flotation approach occurred at Kanawha Eagle Mine in West Virginia [15]. Due to massive frothing problems, the original "by zero" Stack Cell Column / SBC circuit had extremely low coal recovery. Frother dosage had to be severely curtailed. Subsequently, desliming cyclones were inserted ahead of the Stack cells, and several process streams (SBC main effluent, some froth cell tailings) were recycled to froth cell feed. This minimized frothing issues, allowed the cells to be pulled hard and resulted in a gain of coal yield of 10+ short tons per hour. Payback for the capital spent was less than three months.

The revised deslime flotation circuit and the before and after modification yields and recoveries are also shown in Fig. 5 and Fig. 6.



ID	Process Stream	Flow (m³/hr)	Flow (GPM)	% of Feed
A	Deslime Cyclone Feed	800	3477	100
B	Deslime Cyclone O/F	687	2989	86
C	Deslime Cyclone U/F	112	488	14
D	Flotation Feed	690	3000	100
C	Deslime Cyclone U/F	112	488	16
E	Seive Screen U/F	115	500	17
F	Screenbowl Effluent	242	1050	35
G	Flotation Tail Make-up	173	750	25
H	Clarified Make-up	49	212	7

Fig. 5. Post deslime cyclone addition to Kanawha Eagle plant flowsheet

Circuit	Dry Solids (t/hr)			Ash (%, dry)			Yield (%)		Recovery (%)	
Layout	Feed	Froth	Tails	Feed	Froth	Tails	Froth	Tails	Froth	Tails
Pre-Upgrade	54.5	8.4	46.1	51.50	6.20	59.80	15.5	84.5	29.9	70.1
After Upgrade (Eagle Seam)										
Average	30.8	16.8	13.9	40.93	6.50	83.91	55.4	44.6	87.5	12.5
After Upgrade (Peerless Seam)										
Average	36.5	19.6	16.9	43.05	9.00	82.62	53.8	46.2	86.1	13.9

Fig. 6. Coal recovery pre and post deslime cyclone circuit addition

4.2.5 Conventional / column flotation with pressure filtration

The ultrafine coal losses and frothing issues associated with the by-zero circuits with SBCs have been discussed. Also mentioned was the high moisture associated with vacuum filtration. To get around both of these issues, the use of pressure filtration to dewater the minus 0.25 mm froth has been very successful. As mentioned previously, the Beckley Plant of Arch Coal (Core Resources) installed a 121-plate pressure filter to handle froth only. Excellent coal recovery was seen with cake moisture of 22% allowing the cake to be back blended into the total product while still being within the customer total moisture specification.

Below, major improvement can be seen in the thickener underflow ash at Beckley with the capture of sub 45-micron coal particles in the pressure filter.

A major decline in solids in the SBC main effluent can also be seen: 4% solids dropping to 0.4% solids.

Table 2. Beckley West Virginia plant performance before and after pressure filter addition.

Before Press		
Thickener Underflow		
Fine Refuse	Thickener Product	
	16.12%	%Solids
Size	**%Wt.**	**%Ash**
COMP	100.00	53.75
	SBC	
	Main Effluent	
	4.5%	%Solids
	%Wt	**%Ash**
COMP	100.00	11.40

After Press		
Thickener Underflow		
Fine Refuse	Thickener Product	
	7.00%	%Solids
Size	**%Wt.**	**% Ash**
COMP	100.00	73.46
	SBC	
	Main Effluent	
	0.41%	%Solids
	%Wt.	**%Ash**
COMP	100.00	20.12

At the Coronado Buchanan Plant in Virginia USA, a significant benefit was seen by eliminating an SBC treating frothed product and instead upgrading and using flocculation on three disc filters to allow them to handle the full froth product tonnage. Thickener underflow ash increases were seen and significant yield gains as well (10 tph). This was due to the capture of the coal lost in the SBC main effluent by the filters. This plant incorporates thermal drying.

A similar circuit to the Beckley circuit was recently commissioned by Conuma at their Quintette Plant at Tumbler Ridge BC Canada. Here Jet cell flotation was followed by a 160-plate JingJin pressure filter. Recovery of the slime portion of the froth in the plant was excellent, with minimal frothing in the plant allowing full recovery of the froth fraction.

Yield gains for each of the Quintette 450 tph modules by using pressure filtration technology versus SBCs were estimated to be 10+ tonnes per hour.

Many successful flotation/pressure filtration plants have been installed in South Africa, as mentioned, but mainly on the thermal side.

5 Slimes flotation

Situations sometimes present themselves where original deslime flotation can be supplemented by froth floating the slimes and then pressure filtering the concentrate. Increases in coking coal pricing, coupled with improved flotation and dewatering technology, and slimes with reasonable recoverable coal contents allow such projects to be very successful.

An example of this is an installation of slimes flotation on the isolated deslime cyclone overflow stream at Arch's Leer Plant. This circuit is viewed as the last step in full plant

optimization of this particular operation, building off of the originally installed deslimed column flotation that was successfully employed to float the nominal +45-micron material. The deslimed column flotation is dewatered with SBCs for the reasons mentioned prior. This circuit was left intact to maintain existing efficiencies and moisture minimization on the +45 micron that the SBC can successfully capture and dewater.

As the existing circuit was left in place, the overflow stream of the secondary classifying (deslime) cyclones was targeted and fed to Stackcell flotation. This stream is a low in solids, high volume stream with any of coal present being typically low in ash content. Conventional flotation cells were eliminated as a possibility as the requisite for froth washing was necessary due to the high clay entrainment on the minus 45-micron material. The decision was left between the Stackcell flotation or traditional columns. The Stackcell was chosen as it provides the benefits and selectivity of the column while minimizing capital outlay, cell size and operating costs, especially on a high volume, low solids feedstock [16].

The generated froth product from the slimes was then successfully dewatered with pressure filtration. The filtration provided excellent recoveries and product moistures achieved levels that still allowed the product to be fully back blended into the coking product.

The design of the circuit where selected flotation technology was optimized by treated size along with the selection of the most efficient dewatering equipment for the ideal size fractions ensured the moisture specifications were achievable.

As discussed previously, the SBCs only capture 50% of the minus 45-micron material, deslimed column flotation will discard the minus 45-micron material. Naturally, the thickener underflow ash levels are considerably below the froth tailings ash due to this cyclone discard stream. Prior to the circuit addition, thickener underflow ash on this minus 45-micron fraction was in the 40%–50% range. With the addition of the slimes flotation and the pressure filtration, thickener underflow ash levels on the slimes fraction have been increased to the +/- 70% ash range.

The initial and the revised slimes flotation are shown in Fig. 7.

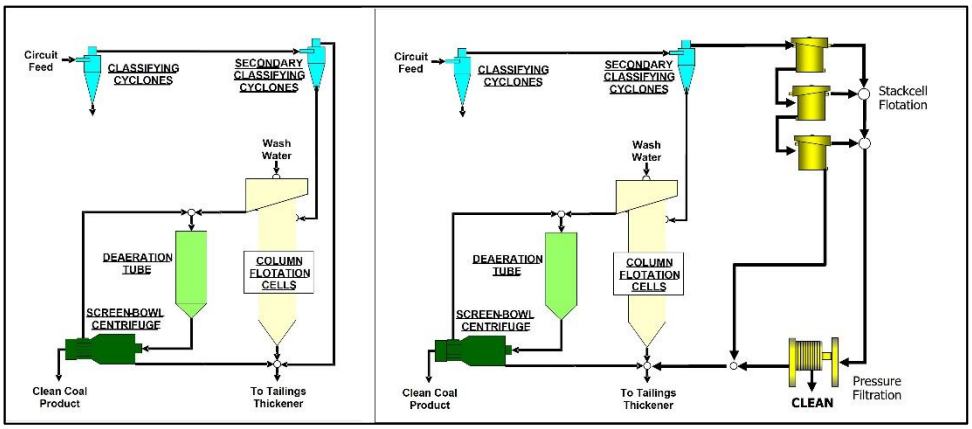


Fig. 7. Leer process flowsheet

6 Conclusions

The optimization of froth flotation and dewatering circuit selection is driven by the markets to be served. Advancements and evolution in both flotation technology and dewatering equipment availability have provided opportunities for increased plant efficiencies and product recoveries [17].

For all coal markets, the characterization of the feedstock and ultimate contract specifications will drive the ideal selection of flotation technology. For clay-rich feedstocks,

a column or stackcell with washwater would typically be the ideal selection to maximize total plant yield. Regardless of froth flotation equipment selection, for plants serving thermal markets the circuitry where moisture minimization via desliming prior to flotation in conjunction with SBC for dewatering would end up being the optimal circuit to maximize total plant yield and profitability.

For the coking markets, the evolution of technology has created opportunities for increased coal recoveries, especially of finer particles. As discussed, it is common for efficient circuits to be in operation with a combination of conventional or column flotation and vacuum filtration to serve existing markets particularly where higher product moisture contents can be tolerated (Australia, Mozambique). The challenge has been optimizing the circuits where limitations of existing equipment such as SBCs have created operational inefficiencies. This problem is particularly pronounced in column flotation/screen bowl centrifuge circuits. Here not only do major slimes losses occur in the SBCs, but also flotation recovery is severely hampered by frothing issues throughout the plant leading to major reductions in frother dosing giving very poor flotation performance. The recent applications of pressure filtration technology to treat the froth products while leaving the 1 mm x 0.25 mm in SBCs have shown the circuits to not only efficiently capture more product but also minimize moisture content of total products generated, with minimal frothing issues. This configuration lends itself to right sizing dewatering equipment for the specified circuit required and maximizes unit operations efficiency.

Within the coking coal market, isolated slimes flotation and capture with pressure filtration is another step towards plant circuitry optimization. This circuit adds a level of complexity to a new or existing flowsheet, but this approach allows for the targeting of both the optimized flotation technology for the size class and the harmonization of the dewatering equipment for that specified size class.

Balancing the flotation technology selection with the dewatering devices allow for the maximum product capture efficiency while minimizing product moisture to meet market specifications.

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