Addressing the envelope

by P. Hand* and D. Wiseman†

Synopsis

Most coal plants must run under conditions of varying feed conditions or are asked to produce qualities different from that used in the design. This can cause overloaded conditions as the 'bottlenecks' within the plant, depending on plant operation or as the feed changes.

During plant design, geological information can be used to determine washability envelopes and blends that may be expected. Historical data can also be used to develop a size distribution envelope as well as to assign reasonable models for each of the unit processes. In operation, a plant can be sampled to determine changes and to refine process models. The information obtained can then be used in an accurate simulation to define how the plant can deal with the changing environment.

This paper uses Limn:The Flowsheet Processor to simulate the coal plant in detail and will produce an accurate model, in terms of equipment sizing as well as water, medium, and solids balance, for each change in feed condition. It will show examples of running the simulation through complete density and size ranges and will determine the equipment required to address each part of the performance envelope.

Introduction

Simulations of coal washing plants are used for many reasons, from investigation of difficult to wash coals, to the effect of using different separation equipment on yield and quality of product (Clarkson, Edward, and Lahey 1998). In addition, since simulation packages such as Limn:The Flowsheet Processor (Leroux and Hardie. 2003, Wills and Napier-Munn, 2006) carry stream property information such as mass flow, volume and density of slurries as part of the simulation, this information can be used to determine 'on the fly' the equipment required to wash the feed coal.

This paper shows an example simulation of coal from three sources, each with a different washability, and with two types of particle size distribution (PSD). Use is made of a 'scenario solver' to examine the equipment required to process the washability and PSD envelopes that may be sent to the plant.

The use of efficiencies for each piece of equipment enables a true estimate of washing performance and the development of a 'practical washability'. This will depend on equipment used and fines and slimes treatment, unlike the theoretical washability generated from geological models, to which 'fudge factors' or 'plant factors' are normally applied.

The plant flowsheet

For the purposes of simplification of options for this paper, fines and slimes treatment consists of classifying into fines and slimes fractions. The fines are dewatered on a high frequency screen then discarded while the slimes are thickened and the underflow discarded. In more complex studies, treatment of both fractions can be (and often are) simulated.

In addition, also for simplification, the dense medium cyclones are fixed at 810 mm diameter. Once again, in practice the effect of larger or smaller cyclones can be simulated with changes to the model E_{pm} based on cyclone diameter and particle size. This is a critical area, particularly when washing difficult coals such as those from South Africa and India. Figure 1 shows the model of E_{pm} and actual cutpoint versus particle size for a 810 mm dense medium cyclone.

The plant flowsheet used for the simulations in this paper is shown in Figure 2.

The plant model is balanced in circuit in coal and reject solids as well as magnetite and water (Hand and Wiseman 2008). This is achieved by calculations within the equipment models as well as by using constraint

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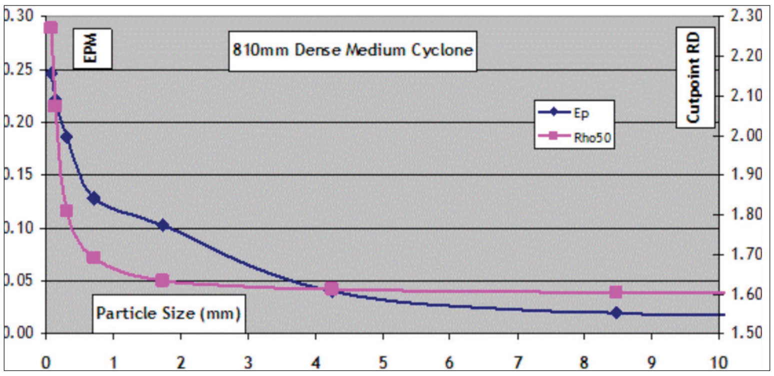
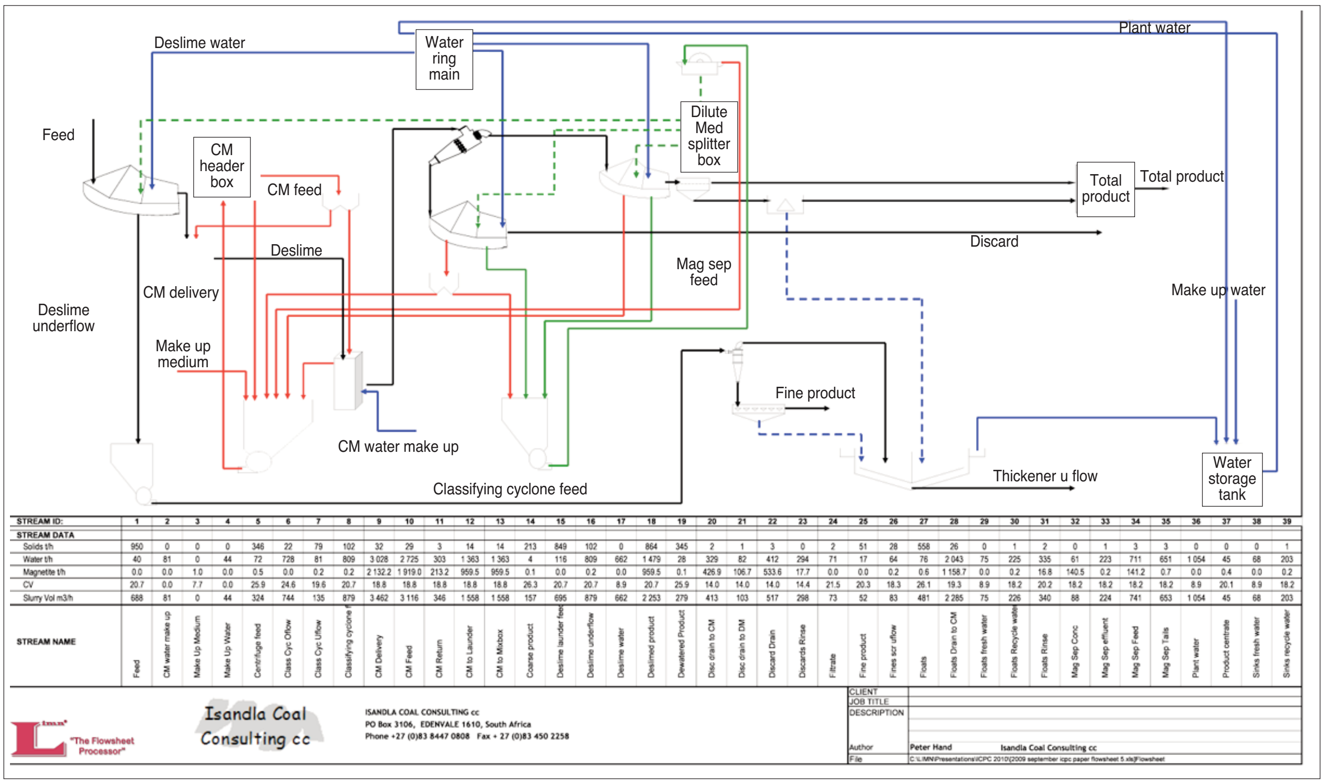


Figure 1—Size variation of E_{pm} and cutpoint RD (Rho50) parameters used in 810 mm dense medium cyclone model



STREAM ID:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
STREAM DATA																				
Solids t/h	950	0	0	0	346	22	79	102	32	29	3	14	14	213	849	102	0	864	345	2
Water t/h	40	81	0	44	72	728	81	809	3 028	2 725	303	1 363	1 363	4	116	809	662	1 479	28	329
Magnetite t/h	0.0	0.0	1.0	0.0	0.5	0.0	0.2	0.2	2 132.2	1 919.0	213.2	959.5	959.5	0.1	0.0	0.2	0.0	959.5	0.1	426.9
CV	20.7	0.0	7.7	0.0	25.9	24.6	19.6	20.7	18.8	18.8	18.8	18.8	18.8	26.3	20.7	20.7	8.9	20.7	25.9	14.0
Slurry Vol m3/h	688	81	0	44	324	744	135	879	3 462	3 116	346	1 558	1 558	157	695	879	662	2 253	279	413
STREAM NAME	Feed	CM water make up	Make Up Medium	Make Up Water	Centrifuge feed	Class Cyc Oflow	Class Cyc Uflow	Classifying cyclone f	CM Delivery	CM Feed	CM Return	CM to Launder	CM to Mixbox	Coarse product	Deslime launder feed	Deslime underflow	Deslime water	Deslimed product	Dewatered Product	Disc drain to CM

STREAM ID:	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
STREAM DATA																			
Solids t/h	1	3	0	2	51	28	558	26	0	1	2	0	1	3	3	0	0	0	1
Water t/h	82	412	294	71	17	64	76	2 043	75	225	335	61	223	711	651	1 054	45	68	203
Magnetite t/h	106.7	533.6	17.7	0.0	0.0	0.2	0.6	1 158.7	0.0	0.2	16.8	140.5	0.2	141.2	0.7	0.0	0.4	0.0	0.2
CV	14.0	14.0	14.4	21.5	20.3	18.3	26.1	19.3	8.9	18.2	20.2	18.2	18.2	18.2	18.2	8.9	20.1	8.9	18.2
Slurry Vol m3/h	103	517	298	73	52	83	481	2 285	75	226	340	88	224	741	653	1 054	45	68	203
STREAM NAME	Disc drain to DM	Discard Drain	Discards Rinse	Filtrate	Fine product	Fines scr uflow	Floats	Floats Drain to CM	Floats fresh water	Floats Recycle water	Floats Rinse	Mag Sep Conc	Mag Sep effluent	Mag Sep Feed	Mag Sep Tails	Plant water	Product centrate	Sinks fresh water	Sinks recycle water

Figure 2—The plant flowsheet used for the simulation studies described in this paper

controllers on the water ring main to achieve a balance for water, as shown in Figure 3.

The equipment models used can be either rigorous or rule of thumb, depending on necessity and the available data (Osborne 1988). An example of a dense medium cyclone data page is shown in Figure 4 and an example of the Excel VBA code used in the calculations is shown in Figure 5.

Varying feed conditions

It has been said that 'constant change is the only true constant' and this is particularly true of coal washing plant feeds.

Proper blending facilities are needed before a wash plant attempt to remove large variations in feed in terms of both washability and particle size distribution. However, variations will still occur and judgements must be made about the size of envelope that can be allowed to ensure minimal reduction in plant throughput while minimizing plant capital expenditure.

Real world washing plant simulations

Having set up the flowsheet and the feed characteristics, the simulation can be used to obtain information on the equipment required to 'wash the envelope'.

Practical washability

Figures 6 and 7 show the results of a series of simulations, resulting in the 'practical washability' over a blend of the three coal types. A wash is carried out in medium of RD 1.2 to 1.85. From this the cutpoint is calculated at each RD and

Distribution Basis
○ Solids
◉ Water
○ Magnetite

Model Parameters		
Mass of Solids in each Product Stream	Required	Available
Flow to Floats fresh water	78.75	78.476
Flow to Sinks fresh water	67.50	67.265
Flow to Deslime water	661.842	659.539
Flow to Water return	250.00	249.13
Total Water t/h	1 058.092	1 054.41
Excess Water t/h		-3.682

Water Make Up	
Change the Independent Variable linked to this cell	44.105
to make the Value in this cell (Measurement)	-3.682
equal this required Value (Setpoint)	0
Limit the Independent Variable to a Maximum of	2000
and a Minimum of	0
Controller K (gain)	0.1
$Error_{t-1}$	-0.119
Control Enabled	☑
Iterations Between Control Actions	1
Start Control at Iteration	1

Figure 3—Constraint controller setup for determining water make up requirement

Model for Unit: Dense medium cyclone

Model Summary	Feed	DMC Floats	DMC Sinks	Audit Check
Solids t/h	878.0	585.5	292.4	OK
Water t/h	2 629.6	2 154.3	475.3	OK
% Solids	25.0	21.4	38.1	-
Magnetite t/h	1 727.1	1 175.9	551.2	OK
Solids SG	1.468	1.382	1.674	-
Medium SG	1.470	1.398	1.764	-
Slurry SG	1.470	1.396	1.743	-
Slurry Vol m3/h	3 561.6	2 805.1	756.5	OK
CV	20.7	25.8	10.4	-
NCVAR	1 107	1 209	757	-
Ash	30.8	16.0	60.6	-
IM	3.0	3.0	3.0	-
Vols	0.0	0.0	0.0	-
FC	0.0	0.0	0.0	-
TotSulph	0.0	0.0	0.0	-

Cyclone Parameters	
Cyclone Diameter (mm)	810
Inlet Diameter (mm)	203
Vortex Finder Diameter (mm)	365
Spigot Diameter (mm)	310
Medium Density	**1.422**
Head Pressure (Cyclone diameters)	9.00
Medium ratio	3.00
Medium Solids Size (microns)	34
Average Cutpoint Density	1.534
Cyclone Slurry Split to Spigot	0.216
Density Shift	0.113
Underflow Density	1.691
Overflow Density	1.309

Cyclone Flow Calculations	Feed	Overflow	Underflow	
Solids SG	1.485	1.388	1.68	
Solids Vol. Flowrate	591.153	421.817	174.12	m3 / Hr
Cyclone Pulp Capacity	2 814.882	2 207.759	607.123	m3 / Hr
Medium Volume only	2 223.729	1 785.941	433.003	m3 / Hr
Water / medium volume ratio	8.902		5.041	
Water Volume	1 999.161	1 637.831	361.329	m3 / Hr
Medium Solids Volume	224.568	148.11	71.673	m3 / Hr
Slurry Flowrate	2 364.611		510.007	m3 / Hr
InletType	ab	AB Type is 0.25 times cyclone diameter		
Maximum Particle Feed Size	59.8	B Type is 0.2 times cyclone diameter		
No. of Cyclones (Feed)	4.20			Max
No of Cyclones (Spigot)			2.894	4.20
Calculated No of Cyclones	5.00	☑ Use calculated number?		5
No. Of Cyclones (If not calculated)	3			
Actual Number of cyclones	5			
Actual slurry flowrate	1 992.905	1 563.069	429.836	
Actual Medium ratio	3.762	4.234	2.487	
Actual medium flowrate (m3/Hr)	2 223.729	1 785.941	433.003	
Magnetite	1 162.139	791.229	370.91	TPH/Hr
Water	1 999.161	1 637.831	361.329	TPH/Hr
Density Check	1.422	1.356	1.691	
Feed Pressure KPa	102			

Figure 4—Dense medium cyclone model input

```
Public Function DMC_FeedCapacity(CycloneDiameter As Double, _
                                      InletDiameter As Double, _
                                       VortexFinderDiameter As Double, _
                                        HeadPressure As Double) As Double
    On Error Resume Next                ' ignore errors!!
    Dim Capacity_9D As Double
    Dim HeadUpratingFactor As Double

    If CycloneDiameter < 850 Then
        Capacity_9D = 0.000345 * InletDiameter * VortexFinderDiameter * _
                      (CycloneDiameter ^ 0.5) * _
                       (2.1265 - (0.2017 * Log(CycloneDiameter)))
    Else
        Capacity_9D = 0.000345 * InletDiameter * VortexFinderDiameter * _
                      (CycloneDiameter ^ 0.5) * _
                       (1.6157 * (CycloneDiameter ^ -0.1109))
    End If

    HeadUpratingFactor = -0.0009 * (HeadPressure ^ 2) + 0.0707 * HeadPressure + 0.438

    DMC_FeedCapacity = Capacity_9D * HeadUpratingFactor

End Function
```

Figure 5—Example VBA Code

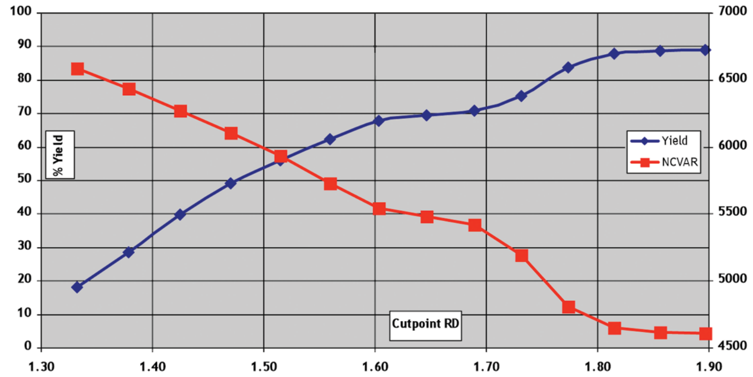


Figure 6—Practical washability

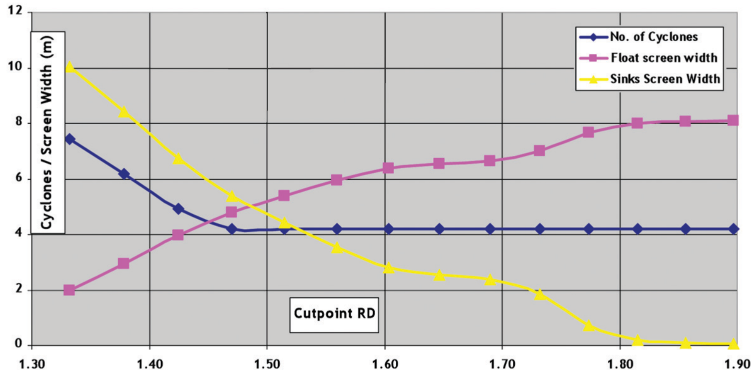


Figure 7—Practical washability and required equipment

Seam 1	Seam 2	Seam 3	Uprated fines = 1	Medium RD	Cutpoint RD	Yield	Ash	CV	No. of Cyclones	Float screen width	Sinks Screen Width	Deslime width	Thickener Diameter	Mag sep width
0.00	0.00	1.00	2.00	1.334	1.456	39.592	15.003	26.204	4.942	3.984	6.791	5.778	22.00	5.294
0.00	1.00	0.00	2.00	1.604	1.693	73.496	15.00	25.77	4.296	6.997	2.049	5.911	22.00	7.248
0.00	1.00	1.00	2.00	1.42	1.533	59.747	15.00	25.841	4.212	5.723	3.933	5.842	22.00	5.70
1.00	0.00	0.00	2.00	1.425	1.537	56.786	15.002	26.558	4.159	5.445	4.279	5.793	22.00	5.524
1.00	0.00	1.00	2.00	1.376	1.493	48.944	15.00	26.295	4.144	4.725	5.405	5.784	22.00	5.333
1.00	1.00	0.00	2.00	1.473	1.58	65.73	15.00	26.199	4.217	6.258	3.077	5.851	22.00	5.734
1.00	1.00	1.00	2.00	1.422	1.534	58.774	15.00	26.067	4.188	5.621	4.044	5.825	22.00	5.64
0.00	0.00	1.00	1.00	1.332	1.454	37.151	15.00	26.224	5.121	3.988	7.031	6.263	26.00	5.344
0.00	1.00	0.00	1.00	1.602	1.691	69.656	15.00	25.761	4.482	7.314	2.123	6.411	26.00	7.295
0.00	1.00	1.00	1.00	1.419	1.532	56.473	15.00	25.846	4.395	5.985	4.093	6.337	26.00	5.727
1.00	0.00	0.00	1.00	1.423	1.535	53.65	15.00	26.573	4.34	5.697	4.452	6.284	26.00	5.546
1.00	0.00	1.00	1.00	1.373	1.491	46.129	14.999	26.318	4.326	4.947	5.627	6.274	26.00	5.329
1.00	1.00	0.00	1.00	1.472	1.578	62.217	15.00	26.199	4.401	6.545	3.199	6.347	26.00	5.774
1.00	1.00	1.00	1.00	1.42	1.533	55.552	15.001	26.075	4.371	5.879	4.208	6.319	26.00	5.665
1.00	1.00	1.00	1.00	1.42	1.533	55.547	15.00	26.076	4.37	5.879	4.208	6.319	26.00	5.665

Figure 8—Scenario solver showing different feed washabilities (blended before the plant) and two PSDs

the resultant coal qualities determined. Figure 6 is the practical washability showing yield and NCVAR, and Figure 7 shows the number and size of the equipment required to wash at any density. The selected equipment then defines the envelope within which the plant can operate.

For this feed consist and product size distribution, the point at which equipment is adequate to wash the coal can simply be read off the graph. A combination of coal types and feed size ranges can be fed to the simulation using the scenario solver. An example is given in Figure 8.

The graph in Figure 9 shows the yields and CV obtained by washing for a consistent 15% ash, controlled within the simualtion using a constraint controller.

Figure 10 shows the total widths required (in metres) for the desliming, float, and sink screens as well as the total width of the 0.9 m diameter magnetic separators required.

Figure 11 then shows the number of 810 mm dense medium cyclones needed and the thickener diameter based on volumetric and solids loading possible obtained from settling tests.

The information gleaned can then be used to determine the number of modules required or the simulations can be repeated using different cyclone diameters, banana screen factors, etc. to match changing design or operating specifications.

Plant balance

The plant consumption of consumables can also be estimated using expected magnetite and water losses from magnetic separators, products, and discards. An example is shown in Figure 12.

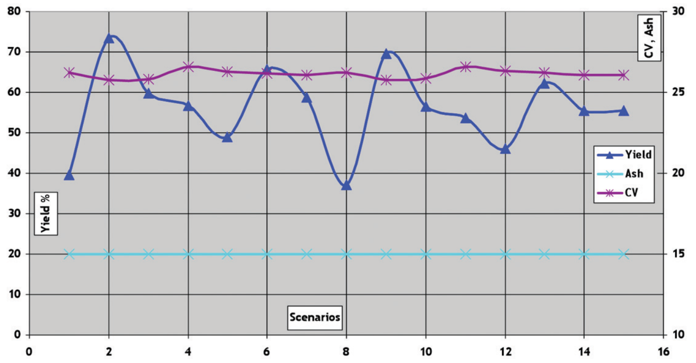


Figure 9—Yields and CV for consistent ash but varying feeds

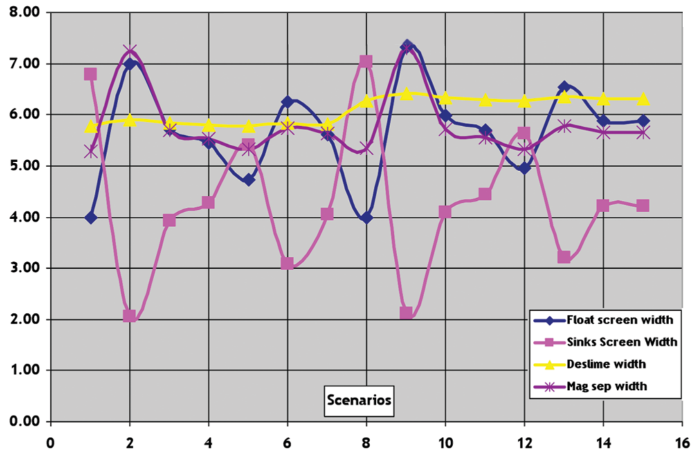


Figure 10—Screen and magnetic separator dimensions required to wash the envelope

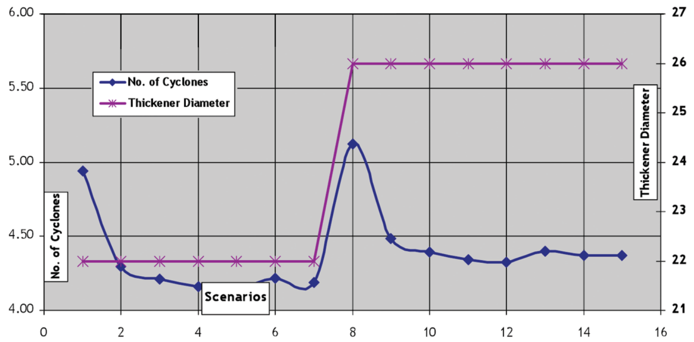


Figure 11—Number of cyclones and thickener diameter

		Total circuit Loss Calculations		
			Water	**Magnetite**
	In	Feed	-39.5833	0.0000
	out	Total Product	31.4481	0.1564
	out	Discards	39.5393	0.1740
	out	Fine Product	17.1053	0.0387
	out	Thickener uflow	76.3290	0.6055
		TOTAL	124.8384	0.9745
Consumption per feed tonne (Kg / Tonne)			0.131	1.026

Figure 12—Magnetite and water consumption calculations

Conclusions

The paper has given an illustration of the use of a simulation package to determine the equipment required in a wash plant needed to accommodate varying feeds, in terms of washability and PSD, plant layout, and indeed any variable that may be encountered.

The plant simulation can be set up to be fully balanced in terms of material, water, and magnetite. The 'practical washability' can also be used, even at an early stage in the mine planning process, to give a true estimate of yield at a given quality, particularly with difficult to treat coals.

All plants have bottlenecks; the key is in moving them to where they are less important. The use of a simulation package can facilitate the design of wash plants to 'address the envelope' while minimizing overdesign.

References

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