Washability modelling and estimation techniques used to improve coal handling preparation plant beneficiation

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ABSTRACT

Predicting how coal seams will be beneficiated through the coal handling processing plant (CHPP) has long been challenging within BHP Coal. Various coal seams from different areas are mined and stockpiled separately, often depending upon a deleterious coal quality parameter; high/low trace elements for example. These stockpiles are then fed in different ratios into the CHPP to produce the desired product/s. In understanding the washability characteristics of the feed source, mine geologists and process engineers work together to improve the beneficiation of different coal materials through the CHPP.

For the majority of the BHP Coal deposits, the washability data is available for the coal seams across the deposits. However, no previous standardised modelling and prediction technique existed that could ensure the correct information was available for forecasting and refining CHPP processes. This paper will discuss the steps undertaken to implement a geometallurgical prediction tool that simplified and streamlined the washability modelling and yield estimation process. The value realised to the BHP Coal assets resulting from this process was:

- improved compliance to plan
- increased throughput
- increased CHPP recovery through improved efficiencies and increased revenues.

INTRODUCTION

In general, coals are classified according to three main characteristics: rank, grade (physical) and chemical characteristics.

In simplified terms, coal rank refers to the degree of metamorphism that the coal seam has undergone; grade refers to the percentage of combustible, organic (coal) versus non-combustible, in-organic (ash) components and density properties, and chemical refers to how the coal product will react in a boiler or a blast furnace.

All three components are needed to classify a coal seam, but this paper will concentrate on the grade aspect. To determine how a coal seam will beneficiate through a preparation plant is constrained to the coals grade/physical characteristics. To understand the grade of a coal seam and ultimately how a feed coal will behave through a coal handling preparation plant (CHPP) (coal yield), the following characteristics need to be determined:

- sizing distribution
- amount of in-organic, non-combustible material (ash) present
- density characteristics (washability) of the coal seam.

Coal sizing

Once mined from open cut or underground operations, coals are placed onto different prefeed stockpiles. The physical and chemical properties of the many coals mined often determine the stockpiling locations. As such raw feeds in the CHPP are often sourced from different operational areas and ultimately behave differently though the CHPP. Some particles of coal tend to breakup into smaller fractions, while others remain *Coarse*. This size relationship is a function of the physical characteristic of the individual particles (macerals) that make up the coal. In general, the more favourable sizes for coking coal products tend to be the brighter, brittle, *Fine*r ones and the duller, *Coarse*r fractions tend to be used for pulverised coal injection (PCI), or thermal product types.

The CHPP's utilised across the coal assets are therefore set-up to exploit these size differences. Modern coal preparation plants typically incorporate a series of sequential unit operations for sizing, cleaning and dewatering. This sequence is repeated for each of the different size fractions. This subdivision is necessary since the cleaning processes used in modern plants have a limited range of applicability concerning particle size. As a result, modern CHPP's may include as many as four separate processing circuits for

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treating the *Coarse* (plus 50 mm), small (50 × 1 mm), *Fine* (1 × 0.25 mm) and ultra*Fine* (minus 0.25 mm) material.

Currently, the resultant range of particle sizes of a coal seam sample is assessed through a series of drop shatter and dry/wet tumbling analysis (generally on borecore). These tests simulate mining practices and stockpile movements. Results from this type of testing program are best viewed in Rosin-Rammler graphs (example Figure 1) whereby the percentage passing different top sizes is displayed.

Knowing the size distribution of coal feeds enables a CHPP to be optimised for the highest productivity at the lowest cost.

Coal ash

The amount of non-combustible, inorganic material (ash) present within a coal seam is related to the amount of sediment influx into the swamp during deposition of the peat (forbearer of coal). As such, the amount of ash within a coal measure can be highly variable from one area to another. The amount of ash (grade) in a coal seam is assessed through combusting a sample and comparing weights prior and after. The difference is the proportion of non-combustible material (ash) present. Preparation plant yield is therefore very dependent upon (trade-off) washing out the non-combustible materials – ash.

Density (washability)

In commercial practice, coal cleaning (or removal of non-combustible materials – ash) is conducted primarily by processes that take advantage of a relationship between non-combustible (ash) particle percentage and particle relative density. By floating a coal seam at a de*Fine*d density the yield (or resultant mass proportion of material) can be established. Float and sink testing is the standard laboratory method for determining, with respect to density, the washability characteristics of a wide range of coal samples. A varied range of sample types can be assessed in this process; from bore core to mine production and coal preparation plant feeds. Washability data from this analysis technique is derived for many different purposes and forms the basis on which to:

- establish theoretical limits attained by density separations, often used as a reference base and in initial assessment of resource potential during exploration of coal deposits
- predict and compare results of simulated plant operations for various types and combinations of processing equipment, facilitating selection of optimum process arrangement
- designing CHPP (in conjunction with appropriate non-density based washability data)
- examine products from an operating plant for routine quality control purposes, or to assess separation performance critically against established criteria.

The liquids utilised in float-sink type analysis have relative densities (RD) ranging from 1.25–2.00 g/cc (in 0.05 g/cc increments). The coal samples are immersed firstly in the liquid with the lowest RD, with the floating fraction being skimmed off, dried, weighed and analysed. The sinking fraction from this test is transferred to the next liquid in the series and the operation repeated (from AS 4156.1–1994 (R2013)).

A program of washability and froth flotation analyses is routinely undertaken on bore cores to simulate the CHPP processes. This analysis includes the sizing and ash analysis. A typical washability and froth flotation analysis program that is currently undertaken on borecore includes:

- Pretreatment:
  - drop shatter
  - dry/wet tumbling
  - sizing.
- Raw and quick floats analysis:
  - Raw: a proportion of the air dried samples have a simple set of coal quality analysis undertaken to proxy the *in situ* conditions: proximate analysis etc.
  - Quick floats: a representative portion of the air dried samples are immersed in a set density fluid (1.5 SG, 1.35 SG etc), and the float fraction is analysed. This type of analysis serves as a proxy for the product coal, so the projects CHPP product types determine the type and number of analysis undertaken.
- Float-sink and froth flotation analysis:
  - samples are processed put through density cells (~1.25–2.00 SG)
  - samples are processed through froth flotation cells (time/reagent released)
  - float/sink/tailing material analysed for fractional per cent of mass (yield) and ash.
- Detailed product composite analysis:

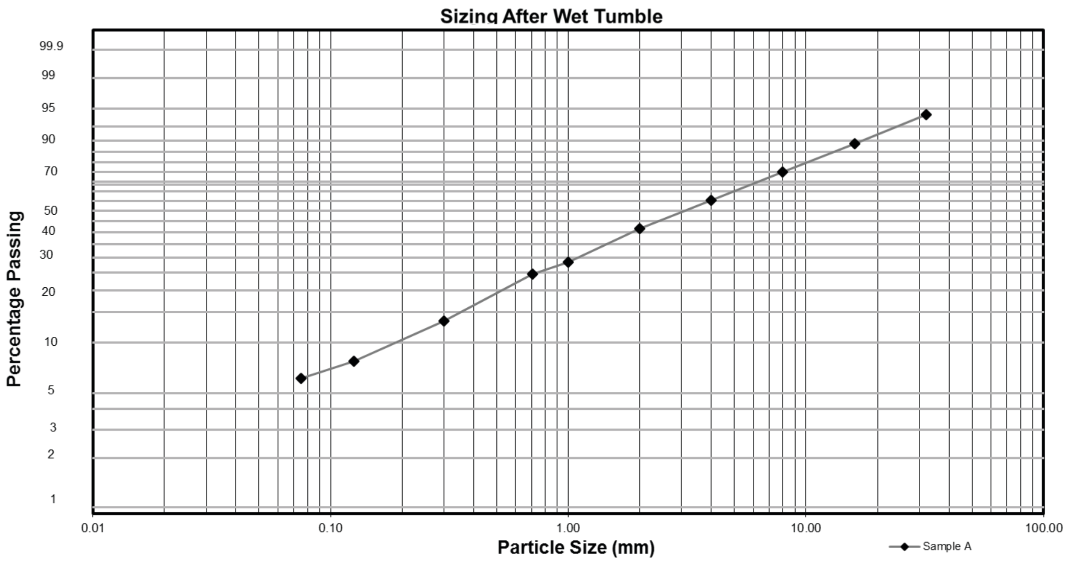

FIG 1 – Example of a Rosin-Rammler graph.

- Different size fractions are added together to make up the target product (eg 9.5 per cent ash) and the resultant sample has various physical and chemical analysis undertaken. Note: more detailed product coal tests (coking indices etc) are conducted at this stage.

Figure 2 details an example of a borecore analysis program, including the washability analysis.

The sizes employed, float cell densities and analysis undertaken differ from project to project. These differences are attributed to the different coals being analysed, CHPP configurations and product types.

The float sink (Figure 3a) results from this analysis are plotted graphically as a series of washability curves for interrogation. These represent the percentage of material floating (or sinking) calculated on a cumulative basis, plotted against the percentage non-combustible (ash) content of that cumulative material. Similarly, the samples cumulative float percentages can be plotted against the relative density of the liquid in which it was tested (Figure 3b). These type of plots are useful in determining the cumulative theoretical yield of the coal seam; at different ash; or density; cut points.

From these graphs, theoretical yields of the coal seam can be estimated. For example (from Figure 3a) a target of a 9.5 per cent

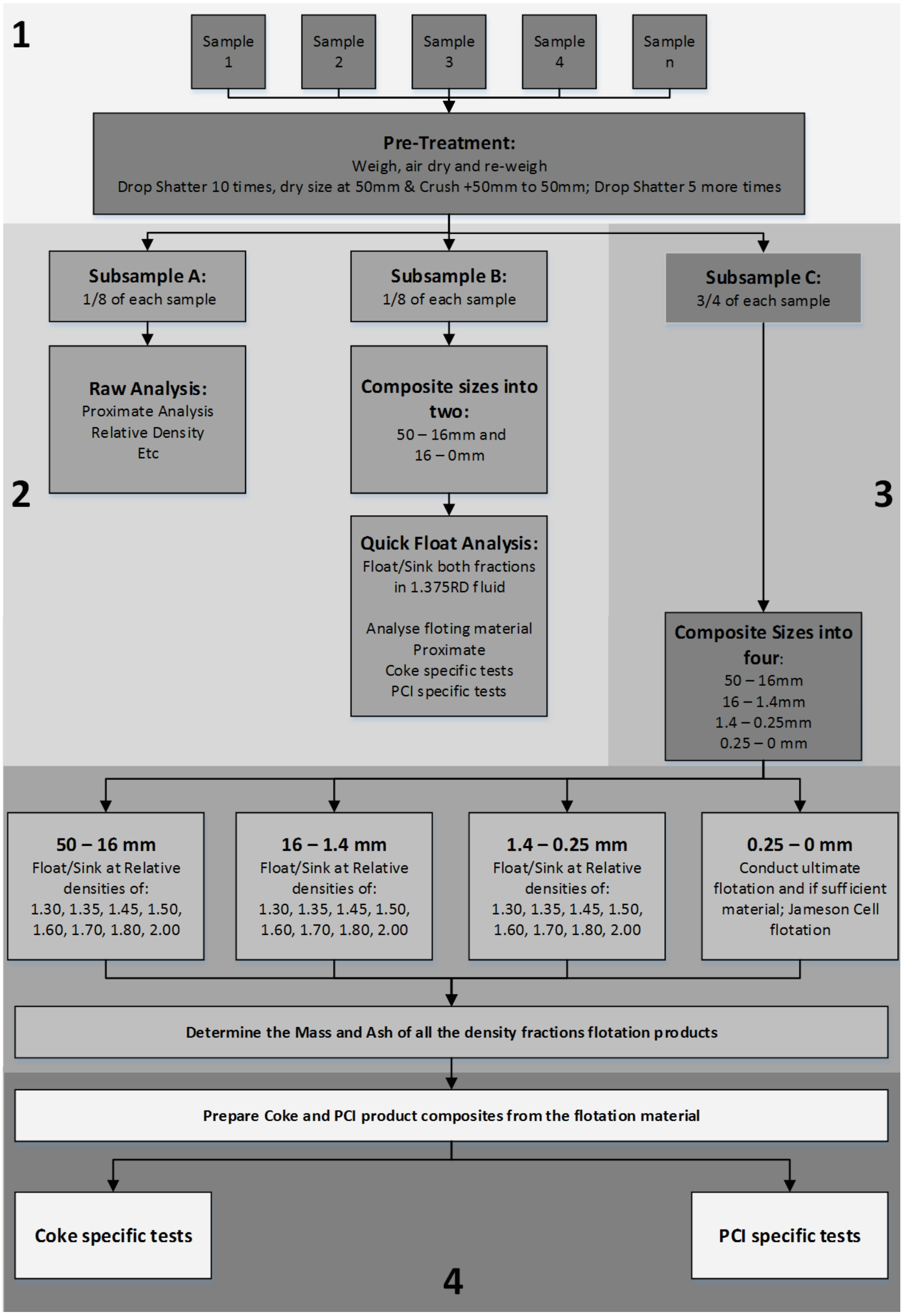

FIG 2 – Coal quality analysis flow chart. Section 1 details the pretreatment steps; Section 2 details the raw and quick floatation analysis methods; Section 3 details the float sink (washability) analysis section; Section 4 details the product composite (or the indicative product) preparation and analysis.

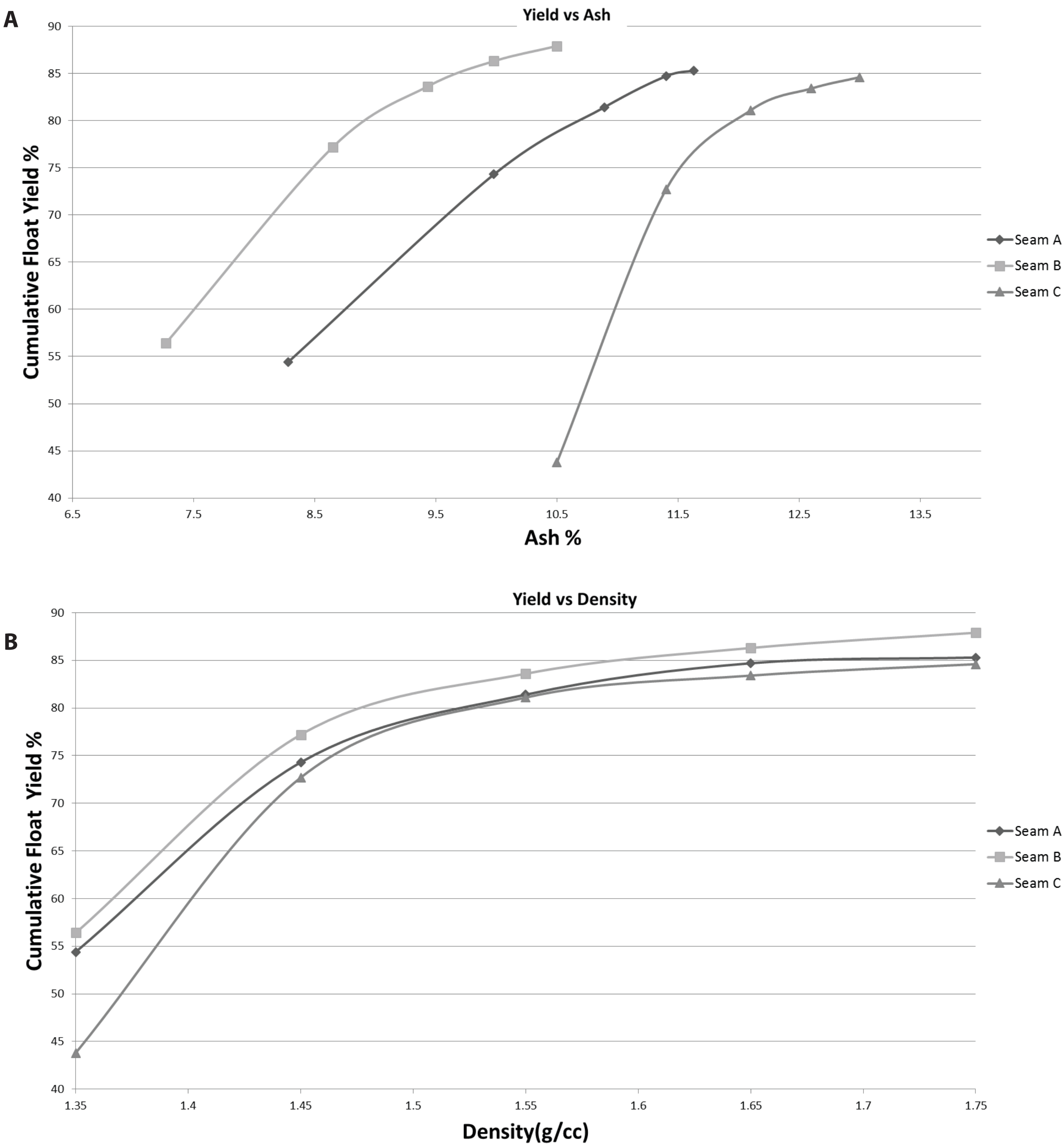

FIG 3 – (A) Example of a cumulative float yield versus density washability graph. Coal Seams A–C have different resultant yields at the same density cut points; (B) example of a cumulate float yield versus cumulative ash washability graph. Note that Coal Seams A–C have vastly different washability curves.

ash product will beneficiate; 85 per cent Seam B; 67 per cent Seam A; and 0 per cent Seam C. This data is vital for the CHPP to optimise yields – especially when blending multiple seams together to produce a standard ash target product.

The yields generated from this process are theoretical in that they do not account for dilution (from the roof or floor material surrounding a coal seam) or for the individual preparation plant components efficiencies. As these are theoretical yields, care has to be taken when forecasting from these values as they can over or underestimate the actual achievable CHPP product yields. To overcome this, the process engineers at each of BHP Coal's operating CHPP utilise Limn® models to optimise the operating conditions. Limn® models account for efficiencies in each of the processing circuits and enable the estimation of both user input and dynamic optimisation scenarios to maximise CHPP performance.

The current best practice in BHP Coal is to modify the mine site CHPP Limn® model to accept the borecore washability data, and run scenarios to produce ash and Yield data for modelling purposes. This paper will discuss an example of how adopting the Limn® model has been successful in influencing how coal seams are washed to optimise both yield and revenue at the Poitrel mine site.

Poitrel mine site

The Poitrel open cut mine is located approximately 65 km south-east of Moranbah, 175 km from Mackay by road and 170 km by rail south-west from the Hay Point Port Facility.

The mine is owned and operated by BHP Mitsui Coal Pty Limited (BMC).

The Bowen Basin is part of a connected group of Permo-Triassic basins in eastern Australia that includes the Sydney and Gunnedah Basins. The basins axis orientation is NNW-SSE roughly parallel to the Palaeozoic continental margin.

Tectonically, the Bowen Basin can be divided into NNW-SSE trending platforms or shelves separated by sedimentary troughs. The units from west to east are the Springsure Shelf, Denison Trough, Collinsville Shelf/Comet Platform, Taroom Trough, Connors and Auburn Arches (interrupted by the Gogango Overfolded Zone) and the Marlborough Trough.

Development of the basin in the Early Permian was in the form of half grabens which subsequently became areas of regional crustal sag. Variations in depositional patterns and deformation styles that occur along strike suggest the possibility of NE-trending deep-seated crustal transfer faults referred to as transfer corridor by Hammond (1987).

The basin has experienced extensional and compressional events oriented NE–SW.

Structurally the Poitrel deposit lies on the western boundary of the deformed Nebo Synclinorium, in a shallow synclinal structure between the Isaac and New Chum thrust faults. To the east (of the New Chum fault) the seams are repeated in the Mavis Downs and Daunia deposits. To the west (of the Isaac fault) and the north the seams are repeated in the Wotonga and Morambah deposits.

Further to the west is the structurally simple Collinsville Shelf.

The economic seams at the Poitrel mine site are contained in the Late Permian Rangal Coal Measures formation that is approximately 100 m thick. The Rangal Coal Measures Formation is underlain by the Fort Cooper Coal Measures and overlain by the Late Permian to Early Triassic Rewan Group.

The coal seams at Poitrel were originally explored around 1966 by Thiess Peabody Mitsui Pty Ltd. Initial development and operation of the mine commenced in April 2006. Poitrel currently produces ~4.5 Mt of export quality metallurgical; Coking and PCI; products each year.

The Leichhardt and the upper portion of the Vermont Seam of the Rangal Coal Measures form the principal economic coal resources in the Poitrel area.

POITREL PRODUCTS AND UTILISING WASHABILITY DATA TO PREDICT PERFORMANCE

As briefly discussed, Poitrel produces two main metallurgical products; a mid-volatile coking coal and PCI coal. The CHPP utilised at Poitrel is set-up to beneficiate the different coals mined primarily by particle size differences. For a dual product CHPP configuration, the coke product is produced from the 16–0 mm coal size fractions, and the PCI produced from the 50–16 mm coal size fractions. This is not always the case though, as some of the coal seams present at the Poitrel deposit are of higher quality than others. Because of this, the CHPP is also able to be configured to produce a 50–0 mm coking or PCI product. The schematic in Figure 4 details these range of CHPP configurations.

The coal quality of the seams that are being fed into the CHPP at any one time ultimately determines the resultant configuration utilised. The produced coke and PCI products have vastly different parameter ranges, but to simplify for this paper, coking products at Poitrel have a lower ash target; between 8.2–8.7 per cent and PCI products range between

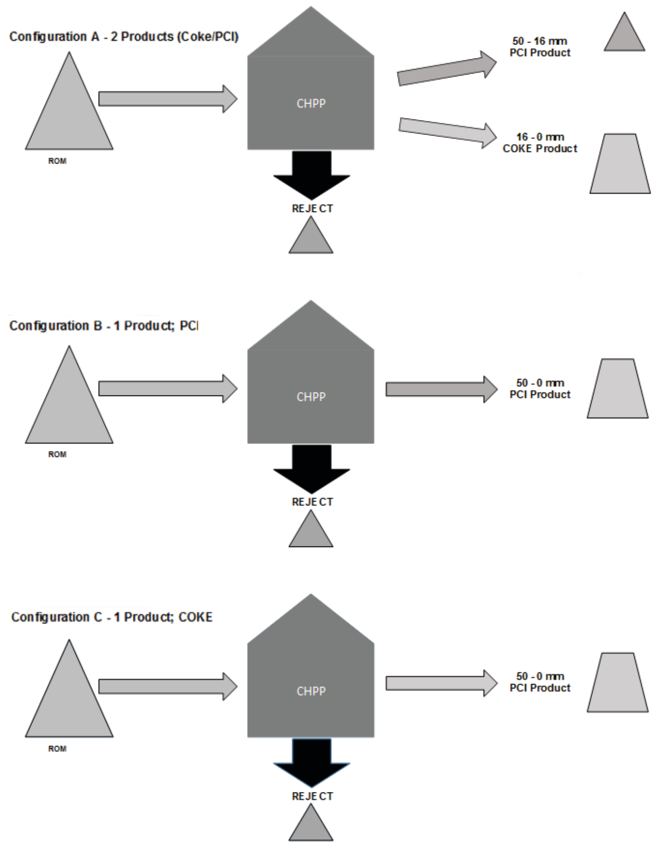

FIG 4 – Schematic of the different CHPP beneficiation settings. Configuration A – Two product split; Configuration B – coke only product; Configuration C – PCI only product.

9.3–9.5 per cent. Table 1 details the products produced from the different seams at Poitrel.

The decision point as to which of the configurations is used depends upon the coal seam being mined and what products are required to be shipped at the port. It is, therefore, critical for the Mine Geologist and Metallurgists to work together to estimate and forecast the washability characteristics of the coal seams.

Methods to model washability data

Prior to Limn® models being adapted to accept borecore data, various software packages had been employed to determine both theoretical yield and ash at the different density cut points, or theoretical yield at various target ash scenarios (depending upon desired product). These techniques are flawed as they add the different sizing's data (yield/

TABLE 1

The range of coke and PCI products produced at the Poitrel Mine site.

Coal seam	Product	Size (mm)	CHPP product ash (%)
Seam A	coke	16–0	8.2
Seam A	PCI	50–16	9.5
Seam A	coke	50–0	8.3
Seam A	PCI	50–0	9.5
Seam B, Seam C	coke	50–0	8.7
Seam B, Seam C	PCI	50–0	9.3

CHPP – coal handling preparation plant. Note: there have been times when urgent shipping requirements mean the CHPP is configured to meet product requirements, regardless of the coal source.

ash) together post simulation. This technique will always underestimate the actual achievable yield because of the *constant incremental quality* principal. This concept, which has long been recognised in coal preparation (Mayer, 1950; Dell, 1956; Abbott, 1982; Rayner, 1987), states that the clean coal yield for parallel operations is highest when all circuits are operated at the same incremental ash (quality) (Luttrell *et al*, 2009). The following discusses the merits of the constant incremental quality principal on real data.

Yield at target ash examples – with/without the use of the incremental quality principal

Figure 5 shows an example whereby the sizing properties of Seam A are such that 30 per cent will beneficiate to a *Coarse* fraction; having a size range between 50–16 mm; and the resultant 70 per cent splitting into a *Fine* size fraction. Figure 6a displays the resultant washability curves for these *Coarse* and *Fine* fractions. The different coal quality characteristics of each of these two size fractions result in the *Fine* proportion achieving higher yields at the same target ash values than the *Coarse*. In this instance at an 8.5 per cent target, the *Coarse* fraction achieves 80 per cent recovery, and the *Fine* fraction achieves 88 per cent recovery. These results and the calculations displayed in Table 2a show that using this method, at an 8.5 per cent ash target ash product, Seam A will have a theoretical yield of 85 per cent.

The summing of the results at the same target ash technique has been used to estimate theoretical yields in the coal industry in the past. In the following example, the *constant incremental quality* principal will show that a higher yield from Seam A is achievable. The theory states that if the *Coarse* fraction's target ash is increased to a higher value and the *Fine* fraction's target ash is decreased by an *incremental* amount (proportional to the increase in the *Coarse*), then more coal can be beneficiated. Figure 6b and Table 2b diagrammatically explains this relationship further (King, 1999).

In this instance, the *Coarse* fractions ash target is increased to 9.6 per cent, which results in an increased yield of 92 per cent. By incrementally decreasing the *Fine* target ash, so that the resultant weight averaged ash (weighting based on the proportion of final product) will still equal the target of 8.5 per cent. Although the yield of the *Fine* fraction has decreased to 86 per cent, the overall product yield, shown in Table 2b is now 88 per cent (3 per cent higher).

This principle is the basis for how the Limn® model processes the raw washability data. As well as this, however, the Limn® model also includes individual component separation efficiencies.

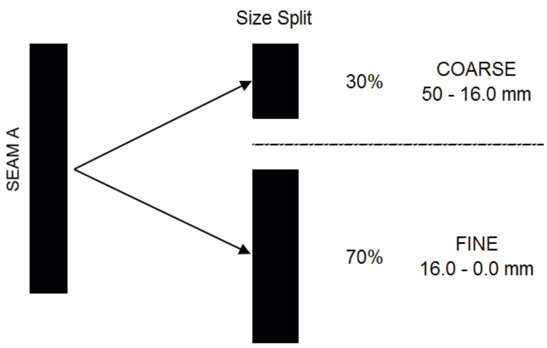

FIG 5 – Example of the percentage sizing split of a coal seam A.

The Limn® model

Limn® (which originates from the Latin word for illuminate) is a spreadsheet add-on that contains information on each component of a CHPP. The user can easily customise the Limn® model to match the configuration of an active or simulation CHPP. Once each CHPP component is added in sequential order, the Limn® model simulates how a coal feed will beneficiate through the set design. Limn® models are robust in that the user can add, or remove different components to test design configurations or possible modifications.

As discussed previously, coals separate into different size fractions and the effectiveness of the various coal cleaning processes on these different size ranges ultimately influences CHPP design. Figure 7 display's the different recovery efficiency relationships between the various coal particle sizes and different recovery equipment. Because of these limitations, a CHPP may incorporate as many as four parallel process circuits to effectively treat the various size particles (Osborne, 1988).

By creating a simple flow sheet within the Limn® model, the user can visually display how a coal feed will progress through different circuits. Once the flow sheet is set-up, the efficiencies of each component can be adjusted to reflect actual performance.

Process Engineers use their site-specific Limn® models to:

- predict how coal feeds will perform
- monitor the performance of individual components
- apply quality assurance/quality control (QA/QC) to the overall CHPP process.

Once the efficiencies for each of the CHPP components are established, the Limn® model can simulate how a coal feed will beneficiate. As discussed previously the Limn® model uses the principal of incremental quality to add the parallel circuits yield and ash values together to achieve the target end product specification.

The data that feeds into a Limn® model that the process engineer's use comes from a bulk sample gathered from the CHPP coal feed stockpile. These are collected monthly and have sizing and float sink analysis undertaken. These results are fed into the Limn® model, and the output is compared to the CHPP actual product qualities. This quality control process enables the metallurgist to validate and *Fine*-tune the Limn® models component efficiencies.

Lastly, for the Mine Geologist to be able to utilise a process engineers' mine site particular CHPP Limn® model, the data input component has to be modified to be able to accept borecore data.

BENEFITS OF THE LIMN® MODELLED DATA AT POITREL

By utilising the Limn® model, the multiple product scenarios detailed in Table 1 have been simulated. By understanding the differences between each of these scenarios, the Mine Geologist and Metallurgist's can optimise the CHPP set-up. The highest beneficiation yield alone does not always dictate the produced product. As Poitrel produces two main types of Coal products; PCI and coke; the price differential between these products can drastically affect the amount of revenue. During the last few years, the coal industry has been in a changing lower price environment. Because of this, the price difference between the higher quality (higher priced) coke products and the lower quality (lower priced) PCI products has also been variable (Figure 8).

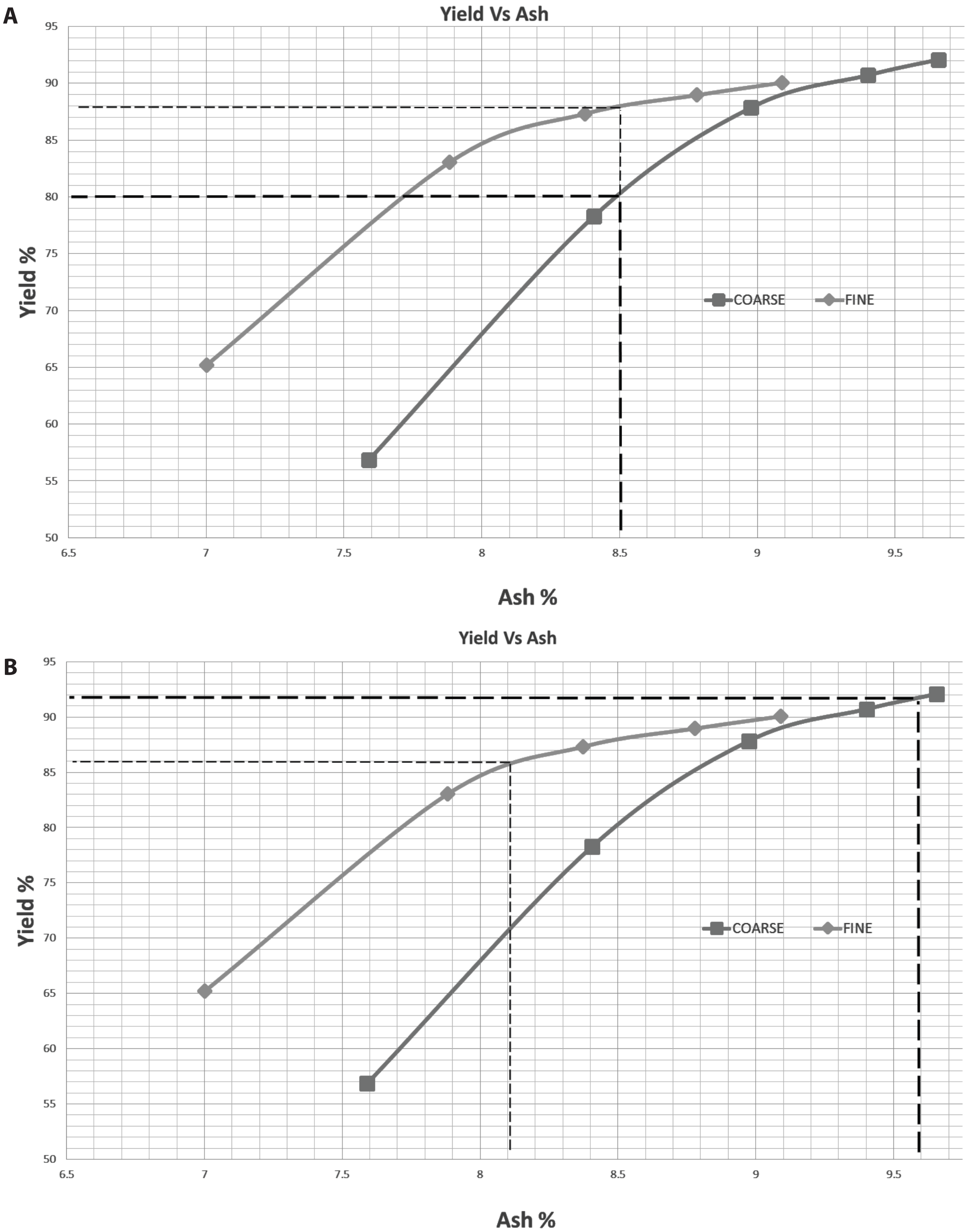

FIG 6 – (A) Cumulative yield versus cumulative ash of the *Coarse/Fine* components of Seam A. At a target of 8.5 per cent ash; *Coarse* = 80 per cent yield; *Fine* = 88 per cent yield; (B) cumulative yield versus cumulative ash of the *Coarse/Fine* components of Seam A. Instance, using the incremental quality theory; *Coarse* has a yield of 92 per cent @ 9.6 per cent ash; *Fine* has a yield of 86 per cent @ 8.1 per cent ash.

Because of the price differential between the two products over time, the past decision point or trade-off of producing a lower CHPP yielding coke product versus a higher CHPP yielding PCI product has been challenging for the geologist/ process engineers to determine. However, by using the various Limn® modelled CHPP yield and ash values, the geologists/ process engineers have been able to visually determine what the optimal product to produce is at any one time. The following Figure 9 displays an example of how the generated products are decided upon when the different resultant potential product grade and price are known.

In this example, 100 000 t of coal are fed into the CHPP. From the Limn® modelled yield data, if the CHPP splits the feed coal to produce a PCI and coke product, the combined return (yield) will be 67 per cent (48 per cent coke, 19 per cent PCI). Whereas if the product were washed to produce a full seam PCI product, the yield would be 81 per cent. If viewing this data alone, the fact that 81 per cent beneficiates for a full

TABLE 2

Resultant recovery of Seam A when (A) the same target ash used; and (B) when the constant incremental quality principal is used.

(A) Same target ash results			
Fraction	**% of Seam A**	**% Recovery**	**Resultant % recovery of Seam A**
Coarse	30	80	24
Fine	70	88	61
Resultant recovery of Seam A			*85%*

(B) Constant incremental quality					
Fraction	**% of Seam A**	**Target ash %**	**Yield % at target ash**	**Resultant % recovery of Seam A**	**Weight averaged resultant product ash %**
Coarse	30	9.6	92	28	**8.55**
Fine	70	8.1	86	60	
Resultant recovery of Seam A				*88%*	

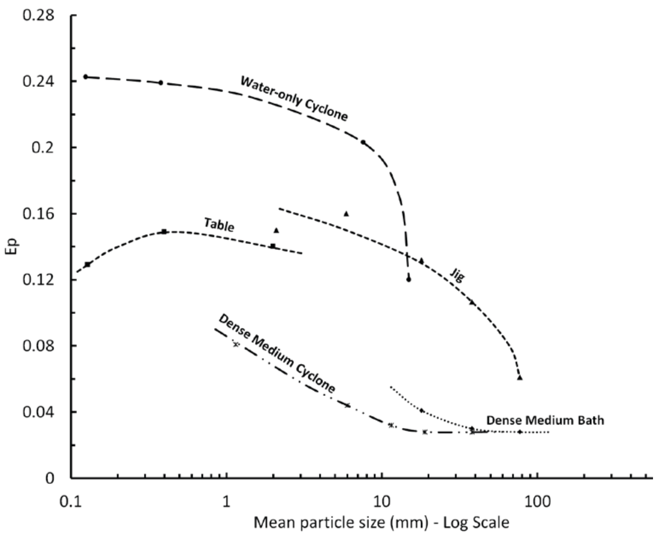

FIG 7 – Approximate operating efficiencies of coal cleaning equipment (Osborne, 1988).

seam PCI, against 67 per cent for coke means the PCI would be the preferred option. However, as the coke product achieves a higher price; $110/tonne versus $75/tonne; more revenue for the mine can be realised through splitting into two products. Conversely, if the price of coke is $95 and PCI $75 (Figure 8 – early October 2014) then producing only a PCI product will generate a higher revenue for the mine than splitting into two.

By understanding the range of potential products that the different coal seams can produce at any one time, process engineers and mine geologists work together to determine the optimal possible product or range of products. By working together, this enables a greater compliance to plan as both teams understand why and how it is important to produce the highest value adding coal products at any one time for the mine site.

Because the geologists and process engineers understand the potential range of coal products from any one area, problematic (lower yielding or higher ash) areas can more effectively be scheduled. That way the forward-looking CHPP wash plan can be tailored to wash these in times when product inventories are higher, thereby lowering the risk of contaminating the higher quality products.

As well as the increased throughput, by knowing where the lower or higher quality coals are within the upcoming mining schedule, the process engineers can set-up the CHPP and feed stockpile blending plans more efficiently beforehand to maximise the coal product recoveries.

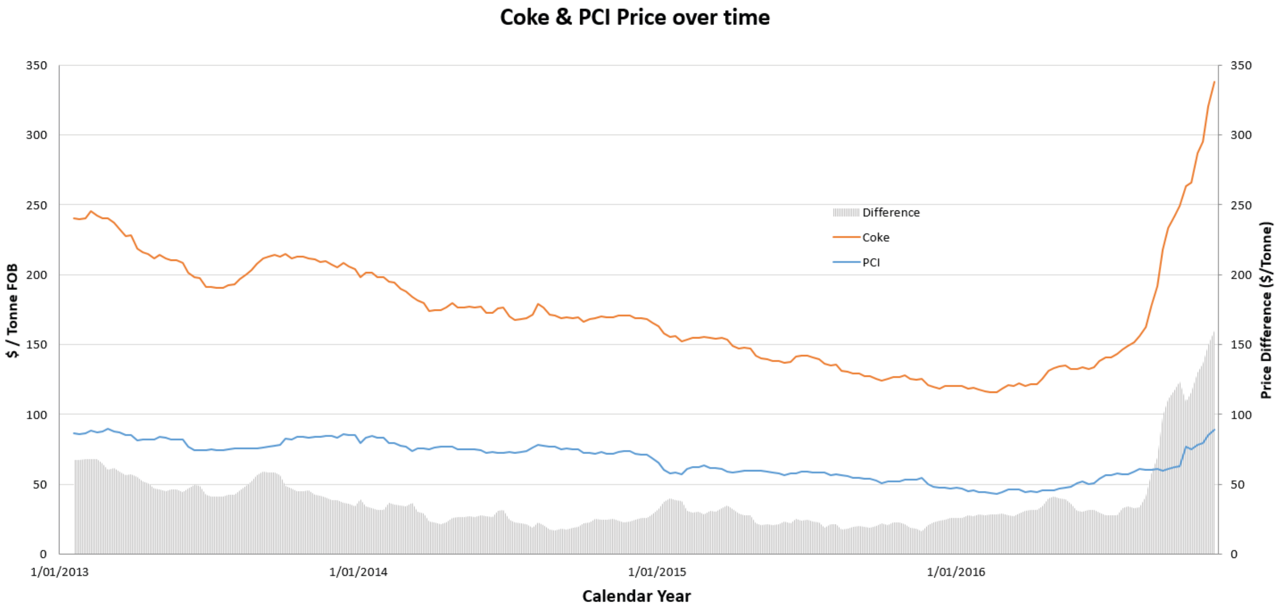

FIG 8 – Price of coke, PCI and their difference over time. Data sourced from Thomson Reuters via S&P Global Market Intelligence.

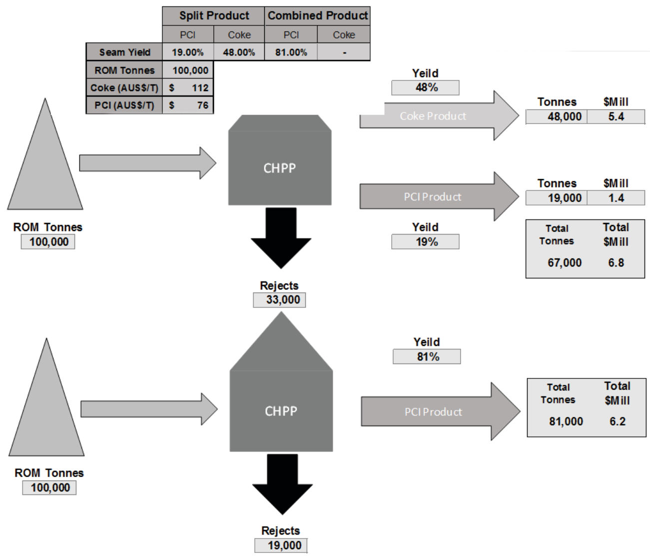

FIG 9 – Product designation decision tree.

CONCLUSION

By using the constant incremental quality principle in estimation techniques via the utilisation of a Limn® model, the following benefits have been realised:

- more accurate way to predict CHPP beneficiation (yield)
- by running different scenarios (options) geologists/process engineers can predict how different products or product mixes will beneficiate through the CHPP
- by incorporation of basic cost information, geologists/process engineers can maximise revenue for the mine site.

As well as this, by working together, the geologist and process engineers can understand how different coal feeds can be beneficiated through the CHPP at any one time. From this, the optimal feed blends and CHPP configurations settings to achieve the highest yield or revenue (or both) for the mine site can be scheduled.

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