An approach to confidently predicting jigging performance

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Synopsis

Bateman Minerals & Metals supplies the APIC Technologies, which include the under-bed air-pulsed APIC jig and related technologies such as the JigScan controller and advanced mathematical models of the jig process. Bateman have developed a methodology for predicting process performance for jigs from simplified testing and modelling, based on batch equipment matched to industrial designs.

Batch tests conducted on laboratory-scale air-pulsed jigs can process small batches of material, such as those obtained from drill core samples. The novelty comes from using an advanced jig process model, ASTRAD, to link the results of batch and continuous jigs.

The batch jig presented as a novelty in this paper has been designed to be hydraulically equivalent to the full-scale APIC jig, allowing the generation of equivalent pulse shapes and using JigScan controller. Lump and fine ferrous ore material have been separated in this unit and any feed >1 mm can be tested and extracted.

The global test procedure and further modelling focus on the stratification of material, with emphasis on key aspects such as pulse shape, feed characteristics and residence time. The splitting of rejects from concentrates is itself more difficult to reproduce in batch jigging; however, the ASTRAD model includes a separation imperfection module, and the APIC Technologies have extraction systems adapted to each type of material.

Air-pulsed batch jigs are available in several locations and are relocatable. They have been used to treat samples from Australia, South Africa and India as part of studies into ore processing using jigs. Each test layer is available for various physical testing procedures (density and chemical analyses). Test work is performed on a case by case basis, and analysed using an advanced model—now available over the Internet.

Some fundamentals of air-pulsed jigging are recapped along with some of the features of APIC jigs. The process of designing a 'hydraulically equivalent' batch jig test is then described. Some results from jigging tests are presented plus the results of the ASTRAD advanced jig model, which was first developed at the JKMRC with ferrous ores and coal and is now being supported and further developed and utilized by Bateman.

Background and history

The jigging of ferrous ore to produce higher-grade products has been practised for many decades. The reasons for choosing jigging before other processes might include one or more of the following:

- ➤ A relatively easy separation
- ➤ A beneficial trade-off between operating cost and reduced yield relative to dense medium processes
- ➤ The ability to treat ores requiring cut densities higher than an SG of 4.0
- ➤ Physical characteristics of the ore that make heavy medium separation unsuitable (for example, unacceptable media loss in macroscopic pores).

There is at present a drive towards the use of air-pulsed jigs for the beneficiation of ferrous ores. This is because air-pulsed jigs are capable of generating the large pulse amplitudes required to fluidize a deep bed of heavy ore—particularly lump iron or manganese ore.

Description of air-pulsed jigs

Detailed descriptions of the features of the various air-pulsed jig designs can be obtained from vendors. However, the fundamental principle of air-pulsed jigging is the injection of low-pressure air (<1 bar) into a chamber with an open base, to accelerate the water column through the bed of material being jigged. There are two ways in which this principle is implemented (see Figure 1). Either the air pocket runs across the width of the jig below the screen deck, or it is located to one side of the jig bed. The first implementation is known as an 'under-bed pulsated' jig and the second as a 'side pulsated' or Baum jig.

Two questions are often asked:

- ➤ Why use air instead of some mechanical actuator? and
- ➤ Why use large volumes of blower air instead of compressed air or hydraulics?

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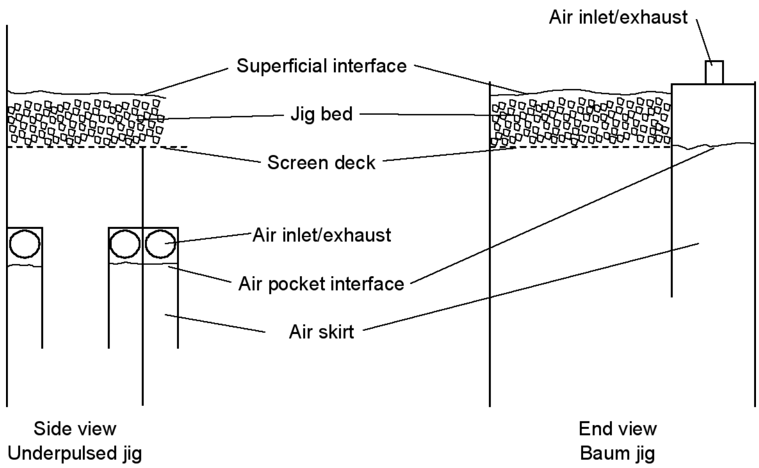

Figure 1—Sections through two types of air-pulsed jig

The answer to the first is simply that the instantaneous power required to accelerate the water column up to the required velocity is very high over a short period. A blower supplying air to a receiver operates continuously at a reasonable average power draw. The answer to the second is that for a given power requirement, a blower is easier to maintain than a compressor or a hydraulic pack.

Challenges

The challenge for mining companies wishing to use jigging to beneficiate their ore is that the iron ore density distribution extends significantly beyond an SG of 4, which is the current limit of heavy liquid separations. This makes it impossible to meaningfully predict the performance of jigs using partition curves and density distributions generated by heavy liquids. In addition, porous or odd-shaped particles behave very differently in heavy liquids and in jigs. The indicative performance of a particular ore is therefore hard to predict from such information.

An obvious answer is to subject the sample to jigging. This is, however, less simple than it might first appear. Two major jig parameters affect the result of a jigging test. They are: the shape of the pulse, and the period of time over which the sample is pulsed.

'Pulse shape' is a broad term used to describe many things; to mention a few:

- The amplitude of the pulse
- The frequency of the pulse
- The 'sharpness' of the pulse—typically referring to the acceleration of the water column at the beginning of the pulse or its deviation from a sinusoidal shape.

'Period of time' refers to the residence time of the ore in the jig bed. With the pulse shape set correctly for optimum stratification rate, it is still necessary to provide enough residence time (jig width, depth, length) to ensure the difficult material (fine and near gravity materials) has time to migrate to the expected layer in the bed.

It has been found that changing the pulse shape affects the rate of separation and the quality of the separation. Usually rate and quality changes work against each other and a successful commercial jig uses a pulse shape that gives an acceptable separation in an economically feasible residence time.

A next challenge for the producer is therefore to select with confidence a jig technology that is properly sized and offers the adequate pulse shape to ensure maximum performance and flexibility. The user of existing jig(s) may want to check or predict performance changes when feed varies or when it is intended to blend ores.

The challenge for the technology provider is to take data from laboratory tests and predict the performance of continuous jigs. The potential for getting the air-pulsed jig design wrong is large where 'generic' jigs, such as mechanical jigs, are used to perform the test work. Allowing too long or too short a residence time, or a poor pulse shape, has negative implications. By way of illustration, the range of residence times (determined by ease of ore separation) operated in existing iron ore jigs varies by a factor of two.

The equipment utilized (what type of batch jig to use?), the interpretation of the batch test results (the various layer densities and assays) and the concept itself of using batch jigging, can create uncertainty that does not help to predict confidently jig performances.

The innovative solutions to jig performance prediction

ASTRAD, detailed jig modelling and analysis

A solution is to use the ASTRAD model to simulate the stratification in a continuous jig bed. ASTRAD is described in detail elsewhere[1,2].

The dynamic separation in a continuous jig differs in various respects from the separation in a batch jig. The most obvious is that top layers in a continuous jig travel from the feed end to the overflow weir very rapidly. The residence times of light particles are therefore very short relative to the average residence time. Conversely, the lower layers travel very slowly, which gives them a much longer residence time than the average.

To account for this behaviour using data from a batch jig requires a rigorous modelling approach. Such an approach was developed at the JKMRC in a study for an Australian client. The model is known as the ASTRAD (Advanced Stratification Transport Rate And Diffusion) model. Bateman is funding the continued development of this model and has established the construction of the proper equipment and the procedures to use this model. ASTRAD is implemented in an Excel interface in a form accessible to Bateman clients through an Internet link to the ASTRAD server.

ASTRAD is a mathematical model for predicting both the rate of stratification and ultimate separation of ores by density and size in a jig. It is a practical method of combining empirical results with simplified physical separation principles. It provides a robust and rapid calculation framework for interpreting, mass balancing, extrapolating and scaling jig test work data from small laboratory batch jigs through to pilot plant tests and even full-scale industrial jigs.

Numerous defined parameters describing the feed ore and residence time (jig dimensions) are taken into account by the model equations. The forces acting on particles in the jig bed (see Figure 2) are summarized by the two main variable parameters in ASTRAD: a mobility coefficient, and a diffusion coefficient.

An entire series of stratification tests for a known feed washability over the complete range of residence times in the jig can usually be summarized with just these two variable parameters. These parameters are determined either by test work or from historically similar washability data and allow the calculation of the following results:

- Partition curves (split to product as a function of density)
- Grade/recovery curves (provided the density grade relationship is known)
- Jig capacity as a function of the above curves and jig dimensions
- What if scenarios—what if the feed rate increases by 10%? what if the ore quality degrades by 5%? etc.

One of the main features of ASTRAD is the ability to determine improvements in jig yield as a function of jig size and feed rate, which permits an economically optimum jig size to be selected. It can also determine the range of yields achievable over an orebody, which has a variable but known washability (density distribution), including ore blends. ASTRAD is used in the testing and design process for jigs as illustrated in Figure 3.

The key factors in determining the jig capacity for a given ore are therefore:

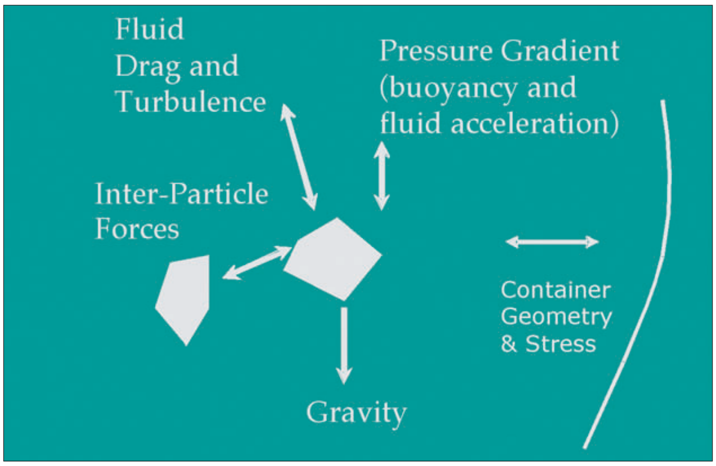

Figure 2—The various forces affecting stratification in a jig bed

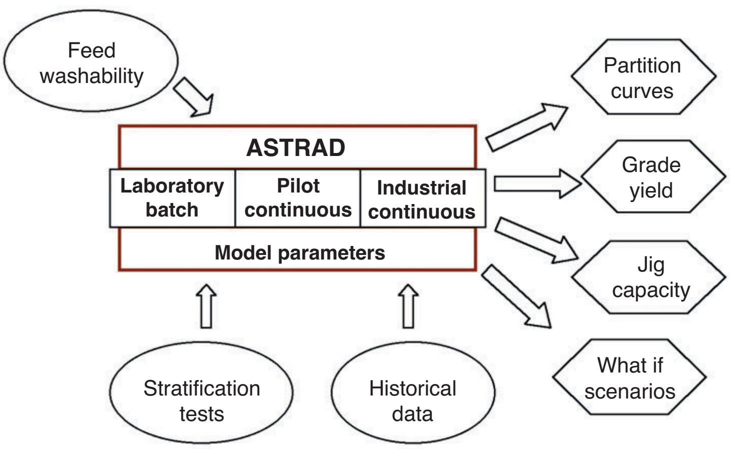

Figure 3—The context in which ASTRAD is used to predict jig performance

- Residence time of particles in the jig (a function of feed rate and jig dimensions)
- The density (and size) range of the product and reject components of the feed
- The separation and remixing rate determined by the jig pulse.

The design size of the jig is chosen to best match the residence time in the jig with that required for the material in the bed to approach equilibrium (maximum separation). The operation point of the jig pulse is set to maximize the separation rate while minimizing the turbulent remixing effects. An example of this calculation is shown below in Figure 4.

The ASTRAD model has now been tested and used on materials over a wide range of densities, from coal to iron ore, in size ranges from 0.5 mm to 100 mm, with more data being added daily; the limit on ASTRAD is usually determined by the availability of adequate washability data.

The Figure 5 illustrates the good fit between ASTRAD prediction, model being informed with coal washability, and the pilot test which was run and interpreted layer by layer.

The Apic batch jig

The innovative solution in terms of hardware that has been adopted by Bateman is to build a jig that is hydraulically equivalent to a commercial air-pulsed jig. Put simply, a jig that would be scaled down in all respects would give a pulse that is scaled down in all respects. What is required is a body shape in which, compared to a commercial unit:

- The two air-liquid interfaces (above the bed and in the air skirt) are the same vertical displacement from each other
- The path length of the water from one interface to the other is the same
- The relative area of the water path as a function of the path length is the same.

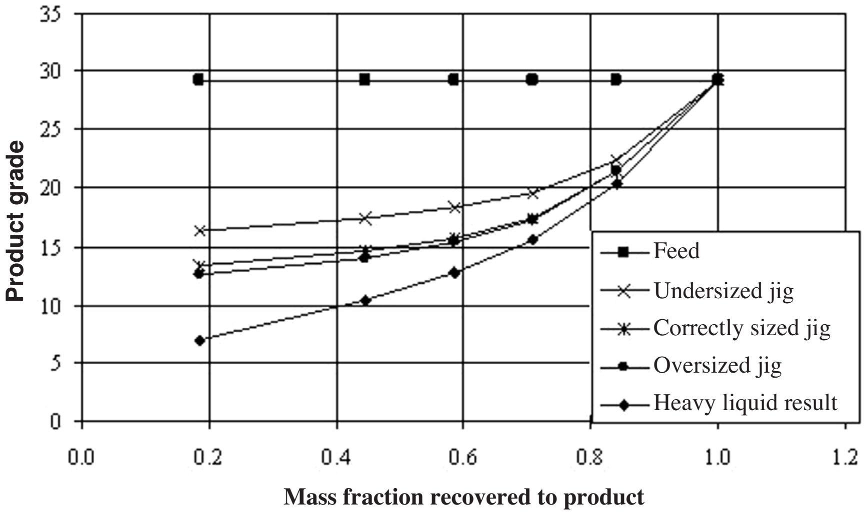

Figure 4—An example of ASTRAD predictions used to simulate jigs

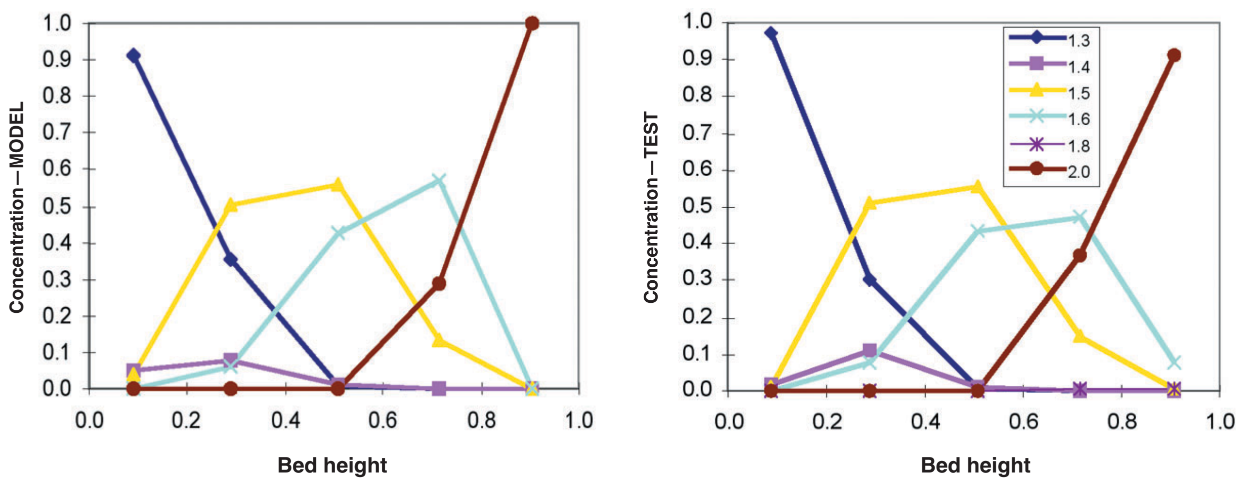

Figure 5—Comparison in stratification, ASTRAD prediction versus real test, jigging coal

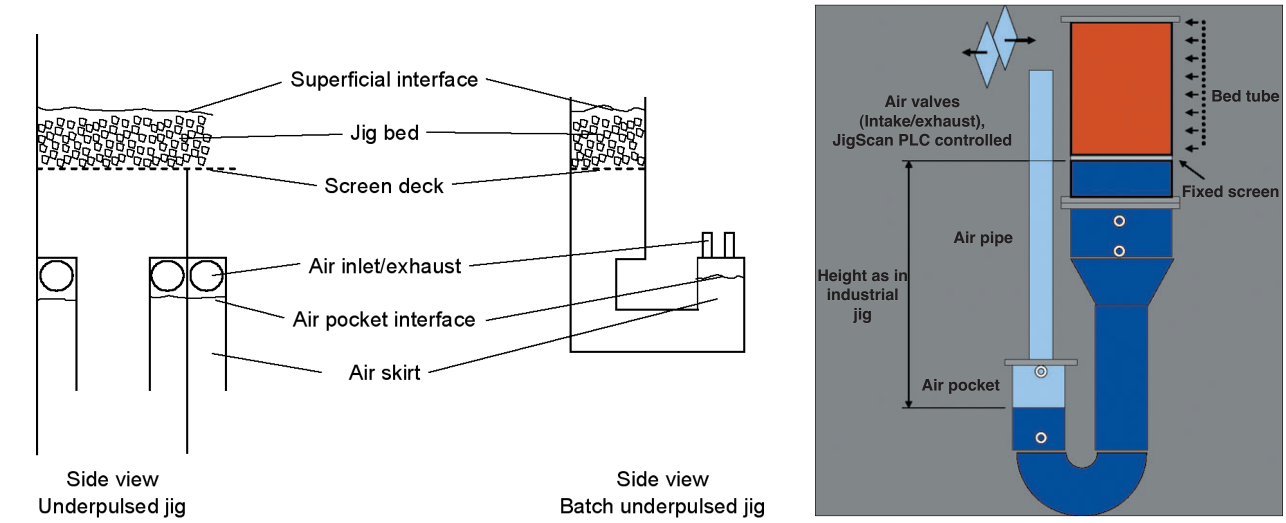

Figure 6—The batch Apic under-bed pulsed jig and its analogy with the Apic jig

In addition, the air piping into the air skirt zone must be of similar area ratio to the commercial unit and the air pressure used must be the same. The principles of these scaling criteria are shown in Figure 6.

The Apic J-TUB batch jigs ('J-Tube Under Bed' pulsed batch jig)

Two sizes of sample are typically presented for jigging—small sighter test samples and larger bulk samples requiring separation prior to further test work. The J-TUB jig is sized to treat small samples and so larger samples require multiple batches to be treated and combined. The jig has a bed diameter of about 300 mm and can treat lump ore beds up to 400 mm deep, giving a bulk batch volume of 30 litres, although volumes of around 22 to 25 litres are preferable. This makes it ideal for treating crushed bore core samples.

The first J-TUB was built in 2002 and commissioned with fine iron ore from SA. In 2004 a second J-TUB jig was built and used to conduct test work on an Australian ore. This later test work was principally required to generate physical samples of concentrate for chemical analysis. Layers were extracted from some timed tests as per the ASTRAD methodology, but were found to have an unusual density distribution. This was later found to be a result of a porous fraction that reported to middlings but was of high grade and could be included in the product. In 2006 tests are being run using the J-TUB jig for iron ore, with the notable addition of the JigScan controller as on Bateman industrial jigs, to control and stabilize the pulse to the desired shape and level.

The desired output from a batch jig test is a series of layers of material, from the top to the bottom of the jig. The extraction of these layers—particularly with lump iron ore—can be laborious and slow. The method that is used with the Bateman batch Apic jig is to extract the material by means of a vacuum extractor.

The layers so generated, can be used to calculate an approximate grade-recovery curve for the ore being tested, but other more sophisticated techniques are available and under continuous development at Bateman.

Required inputs for ASTRAD utilization in batch tests

As with any model, the output is only as good as the input. For the ASTRAD model the following inputs are required:

- Size by density distribution of the feed
- Chemical analyses of each size by density fraction
- Bulk measured data from a series of timed batch tests (densities and assays).

For item 1, it is possible to use heavy liquid analysis but, given the amount of material in ferrous ores above a density of 4, it is preferable to perform individual particle analyses.

Note that recent work has demonstrated in specific cases that feed density distribution could be back calculated by ASTRAD from a series of batch tests at different residence times. This is opposed to the common procedure using 'infinite residence time' which will always under predict the sharpness of the float and sinks curve, even with the best possible pulse. It may well be possible to use ASTRAD with confidence where there are only a few float and sinks data available to represent the entire curve.

In the present method, batch tests are conducted for various durations (standard procedure adapted to each case). After each test, the bed is extracted in layers and each layer is screened. The bulk density of each sample is determined (usually by weighing in air and water), and assays may also be determined. This data is then used to fit the ASTRAD model parameters which define the response of the jig with a particular pulse shape to the ore type. Simulations can then be run using only these model parameters for estimating changes in product due to changes in feed washability and residence time.

As said previously, it is preferable to use a batch jig whose pulsing characteristics would be close to a real jig in order to feed the model with data of an existing jig as relevant as possible. ASTRAD model parameters may be scaled to the new pulse characteristics based on historical data but it will always be more uncertain than scaling between jigs with similar pulse characteristics.

Results from ASTRAD simulation, calibrated by batch tests on iron ores

Figures 7 and 8 shows the fit between the calibrated ASTRAD model, and real stratification data for different residence times in a batch jig (MDS) and an APIC pilot jig used in batch mode.

The laboratory batch tests were performed with 80 to 100 kg of iron ores of coarse and fine fractions, at four different residence times to determine the migration of particles from layer to layer with time as a function of their density. Another series of batch tests was performed in a full scale pilot jig, with the feed material homogeneously distributed in the bed by hand. The bed was then jigged for selected residence times in order to collect data from batch tests run under real operating conditions in term of pulse shape, upward water flow, screen deck aperture, etc.

The results are presented on a graph in Figures 7 and 8, as the predicted versus measured density in the jig bed. Each point on the graph is a measured density for a size fraction (here, -8 mm) from one of the various layers at different heights in the batch unit for various periods of separation time. The ASTRAD model summarizes the entire range of tests with just two parameters. Of course many more graphs result from the model showing variation of density and size distribution in the jig bed with bed depth and residence time.

The imperfection of the fit translates into maximum deviations of about 5% at layers' densities of 4.0 and about 3.5% at layers' densities of 3.0.

Results from ASTRAD simulation, calibrated by pilot tests on iron ores

The next tests were performed in a continuous Apic jig. Figure 8 shows the ASTRAD model fitted to layer data from a crash stop of a fines (-3 mm) test where layer densities were measured over the height of the bed and along the length of the jig.

The continuous test provides similar pulse characteristics to a large industrial jig, and the pilot jig consumes about 10 ton/hour of iron ore, fines, smalls and lumpy, then at various capacities to generate data, here also with various residence times.

The fit shows maximum deviations of 3.5% to about 6% at layers' densities of 4.0/4.5 and of about 5% at lower densities. This indicates that the ASTRAD simulation predicts the density in the various layers as accurately in continuous as in batch mode. Moreover, this demonstrates that this testing and modelling method can predict accurately which density (or grade) profile to expect in a jig bed, which leads to direct calculation of the stratification and jigging efficiency as a function of jig capacity and ore washability.

Other utilizations of ASTRAD simulation, calibrated by batch or pilot tests

The above obvious first application is to select pilot test characteristics (size fraction, capacity, jig dimensions, etc.) based on simple batch tests. Of course, preliminary batch tests would also have confirmed the said material was 'jig-able'.

Once the ASTRAD model is calibrated with test data, tremendous possibilities exist to understand the consequences of jig capacity and feed changes on the rate and quality of the product. These studies can extrapolate significantly from the feed quality actually used in the underlying batch tests, and to jigs of widely varying capacity.

Many case studies can be considered when engineering a jigging plant, as illustrated in Figure 9. A study using ASTRAD was conducted where it was found that by building 25% extra capacity into the jig body beyond initial design capacity, these jigs will typically outperform by approximately

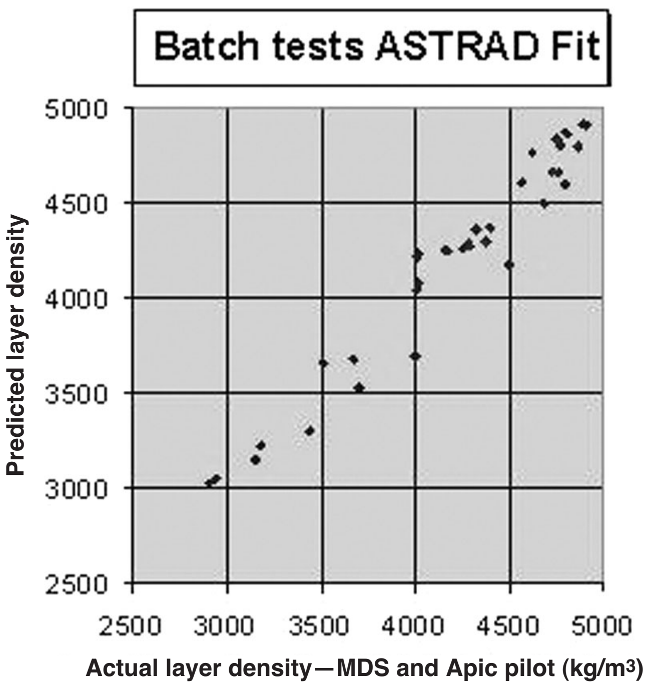

Figure 7—Fit between ASTRAD predicted layers' density and actual batch test's density

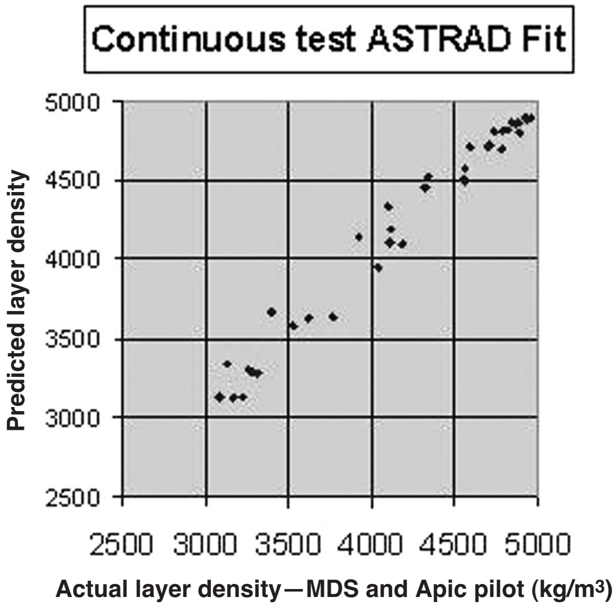

Figure 8—Fit between ASTRAD predicted layer's density and actual pilot test's density

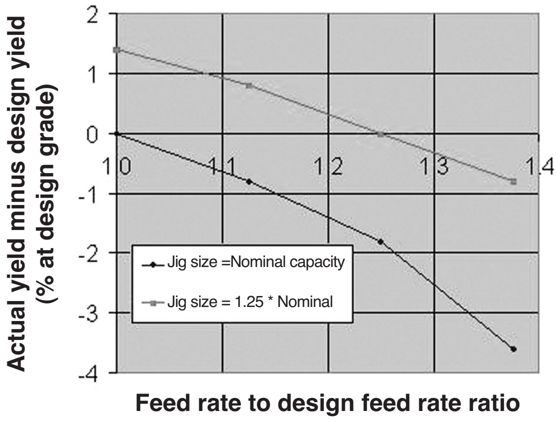

Figure 9—Yield loss versus feed rate for different sized jigs' density

1.5% the absolute yield at target grade and design feed rate. Further, when fed at 25% above design feed rate (performance drop was then quantified), the gap between the two designs increased to about 2% yield, with of course the more robust response for the conservative design.

These values although non-negligible were 'typical' figures and showed that jigs were fairly well sized at first. Such study can take place before costly pilot tests are envisaged.

It also allows the study of the influence of feed characteristics and throughput of an already operating jig plant. Calibration of the model takes place first, from either batch jig data or from the actual industrial jig. The feed parameters and the residence time in the model can be varied at will to make predictions of how the jig performance will change under different scenarios of feed rate and quality.

An immediate application is to predict jig efficiencies with feed blends. This can be done at plant design stage or in an existing plant, where the operator wishes to prepare his production in anticipation of processing feeds different from the usual.

One of the most exciting applications is the possibility to use the ASTRAD model and the bulk layer properties measured from timed batch jig tests, as pointed out earlier, to calculate the equivalent float and sinks analysis for the feed material; this is the 'feed that the model requires in order to correctly predict the timed batch results', including the ultimate test that varies from float/sink data by inefficiencies in the jigging process. The excellent fit between the ASTRAD model and actual stratification would then provide a significant opportunity to reliably estimate float and sinks data from simple jig batch tests. Recent work indicated that this should be possible, leaving the subject for a further study.

References

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2. Jonkers, A., Lyman G.J., and Loveday G.K., Advances in modelling of stratification in jigs, *XIII International Coal preparation Congress*, 1998, Paper G2, vol. 1, pp. 266-276, Brisbane, Australia. ◆