Novel basket design for fine coal centrifuges

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Synopsis

This paper summarizes the results from a project aimed at adapting scroll centrifuges for application to the dewatering of flotation concentrates. The main impetus for the project was to reduce the high cost and footprint size of the technology currently used to dewater fine coal. The technical challenge was to enhance solids capture by incorporating a laser-cut screen into the design of the basket.

The project has shown that a pilot-scale scroll centrifuge can be used to dewater froth concentrate. A number of different basket designs were tested, the best results being achieved with a basket comprising a laser-cut screen of aperture 70 µm. The best result on a sample of untreated flotation concentrate, which was taken from the open trough flotation cells at a coal preparation plant (CPP) in NSW was a solids recovery of 82 wt% at a product moisture of 24.3 wt%. By comparison the best product achieved with a conventional wedge wire basket was a similar moisture content but solids recovery was only 64 wt%. This could only be achieved after the feed had been artificially thickened.

Conditioning of the centrifuge feed with polymer flocculants led to an increase in recovery up to 88 wt% with a moisture content of ca 25 wt%. It is thought that optimizing additive selection and conditioning parameters, as well as screen aperture and open area, could improve performance still further.

The results were obtained using centrifuging conditions (centrifugal force, feed solids, feed rate) in the pilot-scale machine which should be possible to translate into conventional designs of commercial scale machines, without downgrading solids throughputs. However only with full-scale trials will it be possible to establish this assertion with certainty.

Introduction

The reduction of moisture levels in export coals has been an enduring priority for the Australian coal industry[1]. High moisture can lead to high transport costs, technical problems during conveying, handling and storage, lost sales opportunities and moisture penalties. The problem is particularly acute for fine (< 0.5 mm) coal, where product moisture values are typically between 20 and 25 wt%. Up to half of the moisture within the total coal product can be within the fines fraction.

The vacuum belt filter is relatively expensive, but it is still the preferred technology for dewatering fine coal within the Australian coal industry. Extra costs are incurred due to the large footprint of the machine, which often requires an extension to the plant or even an extra building in which to house it. Despite these limitations, belt filters have many fine qualities to which any new fines dewatering technology will have to aspire, in particular their reliability, ability to accommodate changing feed sizes, ease of control and low maintenance.

CSIRO has been investigating ways of adapting scroll centrifuges[2] for dewatering froth concentrates. Like the vacuum belt filter, the scroll centrifuge, which is widely used in Australian coal preparation plants for dewatering spiral product, is a machine that is reliable and easy to control. The only maintenance required is in changing baskets and bearings. The scroll centrifuge has a much lower capital cost than the vacuum belt filter and is much more compact. It can thus easily be incorporated into the design of an existing plant and does not require its own building.

However the scroll centrifuge's ability to capture the finest size ranges (-0.1+0 mm) is poor. Thus, in order to replace the vacuum belt filter, it is important to improve the ability of the scroll centrifuge to capture fine particles, and having captured them, to establish what operating conditions are required in order to dewater them effectively. This is the issue that a recent project funded by the Australian Coal Association Research Program has been addressing by devising new designs of centrifuge baskets[3,4]. The results of this work are summarized in this paper.

Method of approach

The problem of particle retention on scroll centrifuges is thought to be controlled by the rate of formation of the particulate bed on the centrifuge basket. With the first few layers of particles in place, the problem of particle retention should go away, since the bed itself would be acting as the filtering medium. The

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bed formation rate is dictated primarily by the feed solids concentration. With spiral products the typical feed solids would be ca 45 wt% but for froth concentrates, the feed solids is much lower, usually between 20 and 30 wt%.

The critical region for particle retention is where the feed slurry first encounters the basket (i.e. at the top) and this was thought to be the region where bed formation had to be promoted if the scroll centrifuge was to be capable of capturing fines. Thus, the concept was formulated to make this part of the basket look more like a filter cloth, which is extremely efficient at retaining the finest particles. It was decided that the top third of the basket should incorporate a mesh, and that mesh size would be one of the crucial parameters to investigate. The most prospective screen material was thought to be a laser cut screen manufactured by ActionLaser Pty Ltd. These materials are widely used in the manufacture of centrifuge baskets in the sugar industry, but it is thought that their application to coal had never been attempted before.

The approach adopted was to test the concept initially in a batch, bench-scale centrifuge and then transfer the results to a continuous pilot scale machine.

Materials

All of the work was conducted on flotation concentrate from a mine in New South Wales. The ultimate and proximate analyses were determined on one batch of material and are shown in Table I. The results of quadruplicate size analyses using a Microtrac laser size analyser are shown in Figure 1.

Table I

Analytical details of the coal

	Air Dried Basis	Dry Ash Free Basis
Fixed Carbon (wt%)	66.5	73.0
Moisture (wt%)	0.8	-
Ash (wt%)	8.1	-
Volatiles (wt%)	24.6	27.0
Carbon (wt%)	80.1	87.9
Hydrogen (wt%)	4.63	5.08
Nitrogen (wt%)	1.6	1.76
Total Sulphur (wt%)	0.43	-
Density (kg/m^3)	1360	-

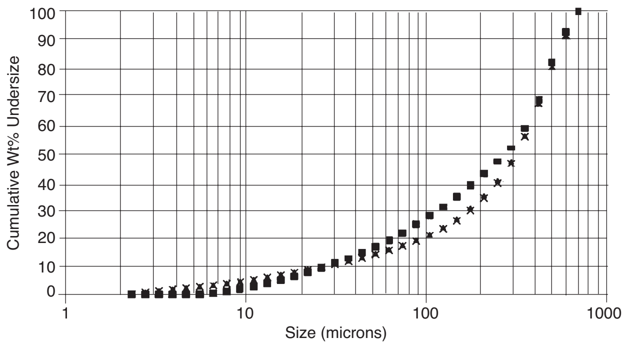

Figure 1—Size analysis of feeds used for the bench-scale tests

Bench scale experimental procedure

A batch, bench-scale centrifuge, fitted with a swing arm attachment that allowed four cylindrical containers to be spun simultaneously, was used for the testwork. These containers were each fitted with a screen supported on a perforated steel plate in the base. The screen functioned as the dewatering medium. Laser-cut screens with the same parameters as the materials used in the construction of the pilot-scale baskets were used. Threaded cups were attached to the containers under the filter medium in order to catch the centrate.

A representative sample of feed slurry was poured into the centrifuge cups, which were then immediately placed in the centrifuge and spun for the required time at the appropriate spin speed. All tests were performed in duplicate and the results presented are average values. Repeated tests were rarely more than 0.5 wt% moisture apart, as measured by overnight drying in an oven at 105°C. Across the entire suite of tests cake thickness was rarely outside the range 19.5 ± 1.0 mm, and solids recovery was always above 98.4 wt%.

The spin time quoted for each test includes the time required for the centrifuge to reach the set speed. Thus the time spent at the set spin speed was somewhat shorter than the test duration. The braking time was not included in the quoted test duration.

The centrifugal force (Z) was calculated from the spin speed n, the radius of the centrifuge r and angular velocity ω is the angular velocity using Equation [1].

$$Z = \frac{r\omega^2}{g} = \frac{r}{g}\left(\frac{2\pi n}{60}\right)^2 \qquad [1]$$

The test in no way attempted to simulate the action of a continuous scroll centrifuge, in which the particle bed is churned up as it is transported down the basket by the scroll. Rather, the purpose of this work was to establish what centrifugal force was needed to dewater a sample of flotation concentrate.

Bench scale results

Four series of tests were undertaken to determine the effect on dewatering behaviour of centrifugal force between values of 100 and 1000 g, which covered (and exceeded) the range of spin speeds of conventional scroll centrifuges. Centrifuging time was varied between 5 s (the approximate residence time of material on the basket of a commercial centrifuge and 900s (after which equilibrium moisture was being approached). The tests were all performed using a sample of laser cut screen (aperture 70 μm) as the dewatering medium.

The results (Figure 2) show the expected profiles of decreasing product moisture with increasing force. The proportional benefits of increasing force from 100 to 500 g are much greater than increasing force from 500 to 1000 g, irrespective of centrifuging time

After 5 s at 100 g, product moisture had dropped from the feed moisture of ca 40 wt%, down to 26.9 wt%. After 5 s at 1000 g, product moisture had dropped to 15.6 wt%, which is significantly lower than would be expected from a vacuum filter.

The lowest moisture value of 8.3 wt% was achieved at 1000 g and a spin time of 900 s. Although the conditions of this experiment could not be reproduced in practice, the data are nevertheless useful, in that they indicate that the only barrier to generating extremely dry flotation concentrates is the kinetics of the dewatering. The bench-scale information suggested two important conclusions:

➤ Under conditions thought to provide a reasonable simulation of scroll centrifuge performance, it was clearly possible to dewater froth concentrate to moisture levels comparable or even below what might be expected from a vacuum filter

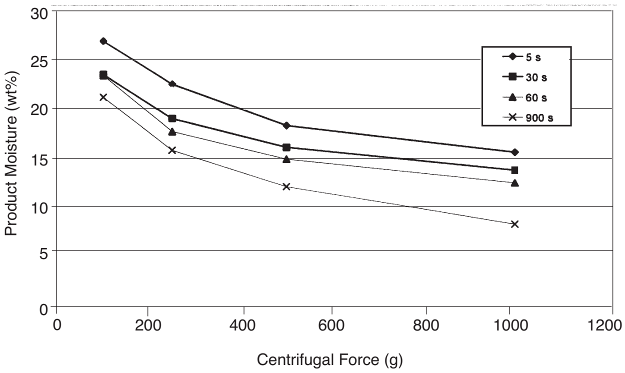

Figure 2—Effect of centrifugal force on product moisture

- In order to attain the required moisture values in the pilot scale tests it would be necessary to investigate values of centrifugal force between 200 and 500 g.

Based on the above results, the concept of using a scroll centrifuge to dewater froth concentrate seemed viable assuming that high solids recovery could be achieved.

Pilot scale—equipment

The pilot scale machine was a scaled-down version of a vertically mounted scroll centrifuge. The basket was a truncated cone with dimensions of 8.5 cm (upper diameter), 19.1 cm (lower diameter) and 14.6 cm (sloping height) and a basket angle to the vertical of 21°.

Feed was delivered to the top of the centrifuge via a Mono pump. In contrast to a full-scale centrifuge, the pilot scale machine did not have a chute distribution zone, nor did the basket have a solid anti-wear zone at the top where the feed impinges on it. Four baskets were used in this study:

- Basket #1 – 100 % wedge wire of nominal aperture 250 μm to act as the baseline. The actual aperture was determined to be 238 μm and the open area was 15.2%.
- Basket #2 – the lower two-thirds comprised wedge wire of nominal aperture 250 μm and the upper third comprised laser cut screen containing slots of aperture 290 μm. The open area of the wedge wire was determined to be 13.8%, with an average aperture of 248 μm. The laser cut screen was 0.3 mm thick, had an open area of 10% and was manufactured from hard-chrome plated 304 stainless steel.
- Basket #3 – the same as Basket 2, but with a 70 μm aperture laser cut screen
- Basket #4 – 100% laser cut screen of aperture 70 μm.

A simple recycle circuit was used to feed the centrifuge as shown in Figure 3.

Pilot scale centrifuge—operating procedure

The first step of each run involved charging of the feed into the centrifuge sump. The sump agitator was started as soon as it was covered with the slurry, in order to minimize the chances of particles settling and blocking the outlet valve or pump. The following procedure was used to start up and operate the rig, once conditioning (if used) of the feed slurry was complete.

- The centrifuge was switched on and its rotation speed adjusted using the variable speed controller to the required value between 114 and 603 g.
- The Mono pump speed controller was adjusted to the required feed flow rate (between 0.5 and 4 m^3/h) and the pump was started.
- Immediately on starting the pump, the centrate discharge line was removed from the sump so that the water filling the lines could be run to waste. When the centrate turned black (which usually took ca 10 s) the centrate line was returned to the sump.
- Assuming by this stage that the centrifuge and pump were running smoothly, the sampling procedure was initiated at once. This was permissible since the residence time of the coal in the centrifuge was only a few seconds, thus the time required to come to steady state was very short. At the end of sampling the next set of conditions was dialled up on the basket and/or pump speed controllers and the next run was initiated without a break.
- Three sets of conditions were investigated before the sump contents were run to waste. The system was flushed out ready for the next test sequence.

Each test, covering a single set of run conditions, lasted between 15 and 20 minutes. Multiple samples of product, centrate and feed were taken during each run for moisture assay by oven drying and size analysis by laser size analyser.

Reproducibility of pilot scale tests

Duplicate tests on twelve runs were performed at different times during the programme to establish the reproducibility of the test procedure. The tests were all performed with Basket #4 and covered a range of values of centrifugal force (114 to 456 g), feed flow rate (0.75 to 1.8 m^3/h) and feed solids (25 to 51 wt%).

Figure 4 compares the moisture content results from two sets of results. Also included for each data point is an error bar equivalent to ± 1 wt% moisture, which was considered acceptable for establishing the overall objective of the project i.e. does the concept of applying laser-cut screen basket designs have merit? All of the data points except two fell within or close to the acceptable error limits of the median line.

Figure 5 compares the solids recovery from the two sets of results. As in Figure 4, an error bar, this time equivalent to ± 2 wt% recovery, has been included, the selection of this value also reflecting the error considered acceptable for establishing the overall objective. The solids recovery results in Figure 5 show considerably more variation than the moisture data in Figure 4, with five of the 12 data points straying considerably from the median line. The worst variation was a difference of 8 wt% recovery (i.e. between 82

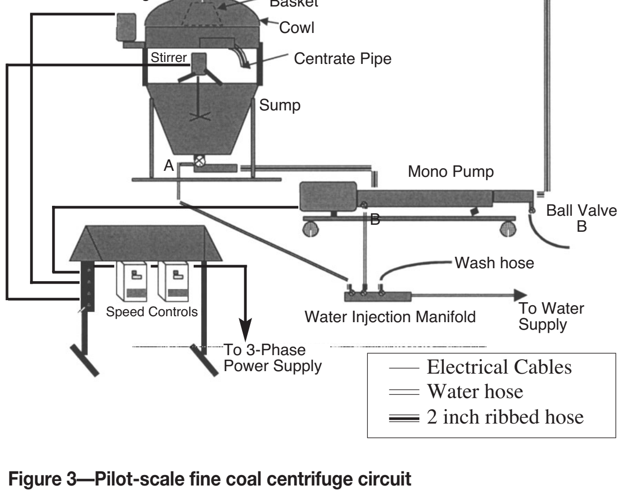

Figure 3—Pilot-scale fine coal centrifuge circuit

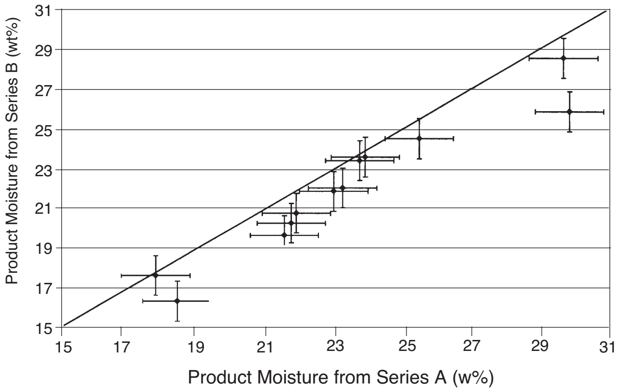

Figure 4—Comparison of product moisture from duplicate runs

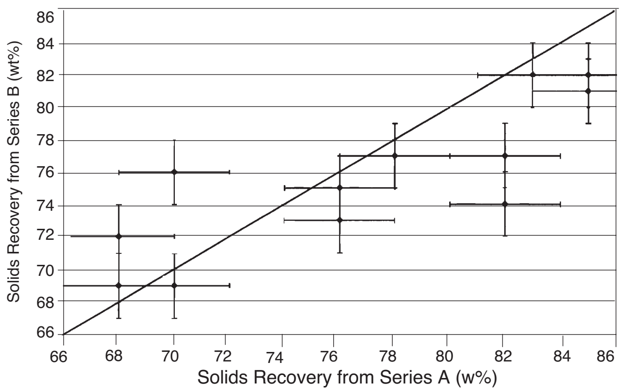

Figure 5—Comparison of solids recoveries from duplicate runs

and 74 wt%) between two repeat runs.

The reasons for this behaviour are not thought to be due to any innate uncontrollability of the centrifuge itself but was related to control of the feed solids, which in some pairs of repeats also varied quite considerably. For good consistent results it was necessary to control feed solids to within ± 2 wt%. When this occurred, product moisture and solids recovery were invariably within the required limits.

Basket comparison at pilot scale

A series of scoping runs was performed with each of the four baskets to assess their effect on centrifuge performance when dewatering froth concentrate. These runs varied feed flow rate between 1 and 4 m^3/h, centrifugal force between 114 and 456 g, and feed solids between 15 and 46 wt%. The results of the best run performed with each basket are summarized in Table II.

The results for Baskets # 1, 2 and 3 were all obtained at the highest value of feed solids tested which led to maximum recovery and at the highest value of centrifugal force tested which led to minimum moisture. As was expected, the wedge wire basket (#1) gave the lowest recovery (64 wt%). Incorporating the laser-cut screen collar with an aperture of 300 μm led to a small increase in recovery to 67 wt% (Basket #2) although moisture increased from 23.9 to 29.9 wt%. Reducing the laser-cut screen aperture from 300 to 70 μm led to a substantial increase in recovery from 67 to 79 wt%, whilst moisture remained unchanged at ca 30 wt%. However the best result of all was obtained with the basket constructed solely out of 70 μm laser cut screen. Recovery was slightly increased from Basket #3 from 79 to 82 wt%, but product moisture at 24.3 wt% was lower by almost 8 wt%. All this was achieved by Basket #4 at a centrifugal force of only 256 g and a feed solids of 34.9 wt%, compared with values of 456 g and 45–46 wt% for the other baskets. At this stage of the scoping programme the higher centrifugal force had not been tested on Basket #4, but it was clearly giving superior dewatering.

The reasons for the trends in solids recovery are reasonably clear. The presence of the laser-cut screen reduced the tendency of the solids to report to the centrate as was postulated prior to the start of the project. The finer the screen the less the solids loss. With the all-screen basket (#4) recovery was at its highest, suggesting perhaps that some solids in Baskets #2 and 3 were being lost from the wedge wire section.

Microtrac size analyses on the centrates are shown in Figure 6. The centrates captured by Baskets #3 and 4 which both contain the 70 μm screen were very similar with 90–95 wt% passing 100 μm. The fact that particles above 70 μm were present probably reflects the elongated slot shape of the aperture in the laser cut screen allowing particles longer than 70 μm in one dimension to pass through. These particles would then appear as a larger size in the Microtrac, which determines size based on an equivalent sphere diameter for the longest dimension.

The centrate from Basket #2 with the 300 μm screen was, as might be expected considerably coarser than with the finer baskets. Approximately 90 wt% was below 300 μm, again in line with expectation, with 50 wt% less than 100 μm. The centrate from the wedge wire basket (#1) was almost identical in size distribution to that from Basket #2, probably reflecting the closeness in basket aperture size.

The dewatering performance of Basket #4 was most encouraging and merited more systematic investigation, the results of which are described in the next section.

Pilot scale results with Basket #4

Effect of centrifugal force

The effect of centrifugal force on product moisture is shown in Figure 7 for three series of runs undertaken at feed flow rates of 1.0, 1.5 and 2.0 m^3/h. The average feed solids for the three series was 29.5 wt%, typical of flotation concentrate from conventional cells. The standard deviation of the variation in feed solids was a little high at 3.1 wt%.

As expected, increasing centrifugal force led to drier products with moisture falling from ca 28 wt% at 114 g to 17.3 wt% at 456 g. There was no correlation between centrifugal force and product recovery, as would have been expected. *A priori*, simply spinning a centrifuge basket at a faster rate would not be expected to affect its efficiency at capturing particles. All variations in recovery that were seen were due to batch-to-batch changes in feed solids.

Effect of feed rate

Figure 8 shows that increasing feed rate between 0.75 and

Table II

Results of the best runs with Baskets #1–4

Test #	Basket #	Centrifugal Force (g)	Feed Rate (m^3/h)	Feed Solids (wt%)	Moisture (wt%)	Recovery (wt%)
23	1	456	2.0	45.5	23.9	64
27	2	456	2.0	45.7	29.9	67
24	3	456	2.0	45.1	30.2	79
61	4	256	2.0	34.9	24.3	82

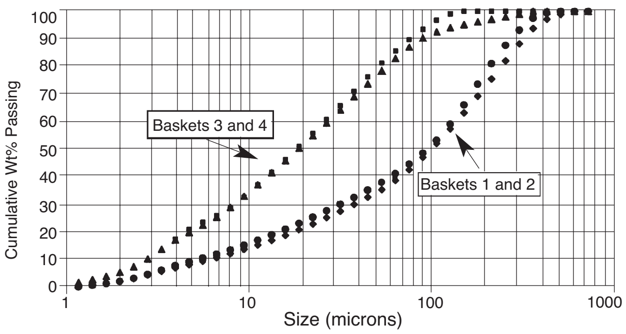

Figure 6—Comparison of centrate size distributions from Baskets #1–4

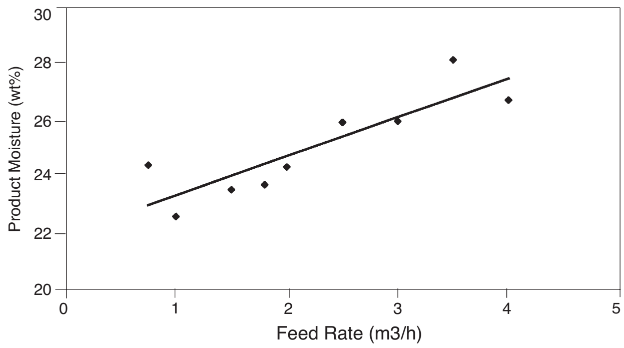

Figure 8—Effect of feed rate on product moisture

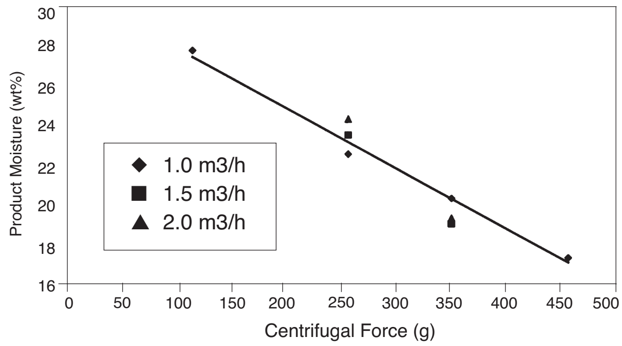

Figure 7—Effect of centrifugal force on product moisture

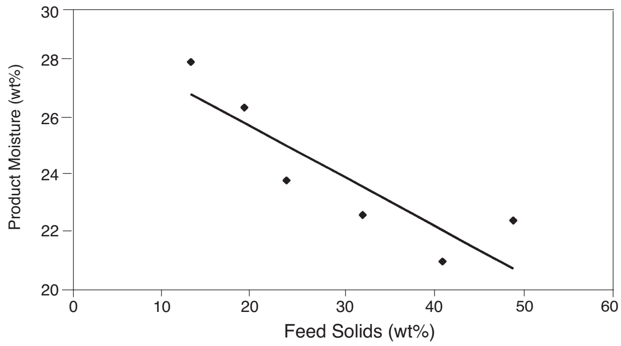

Figure 9—Effect of feed solids on product moisture

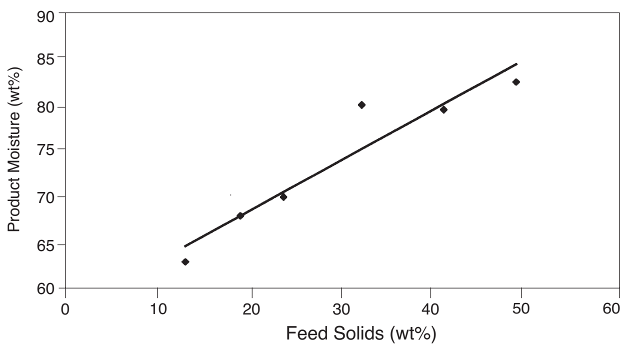

Figure 10—Effect of feed solids on solids recovery

4 m^3/h, at a centrifugal force of 256 g and feed solids of 32.1 wt%, brought about a steady, not far off linear increase in product moisture. There was an increase in moisture of ca 2 wt% for every 1 m^3/h increase in feed rate. This trend was not surprising. Since the differential rotation speed between the scroll and the basket is fixed, the retention time of coal within the dewatering zone of the basket would also be fixed. Hence increasing feed rate would lead to an increase in the effective thickness of the bed, although the bed would be churned up as it is conveyed down the basket by the scroll. In addition the higher feed rate increases the hydraulic load on the centrifuge which would also be expected to lead to wetter products. The fact that the increase in moisture with feed rate was linear is probably only an artefact of the range of conditions over which the data were obtained.

There was no relationship between solids recovery and feed rate.

Effect of feed solids

Figures 9 and 10 show the effect of changing feed solids content on product moisture and solids recovery in a series of tests performed at a spin speed equivalent to 256 g and a feed rate of 1 m^3/h. Both graphs show trends that were in line with expectation. As feed solids increased from 13 up to 41 wt% product moisture fell from 28.0 down to 21.0 wt% in an approximately linear fashion. This trend reflects the reduced amount of water that had to be removed per tonne of solids allowing more rapid cake formation and hence allowing more time for cake desaturation to occur. Increasing feed solids up to 50 wt% led to a slight increase in product moisture from 21.0 up to 22.4 wt%. This may have been due to experimental error. Alternatively it might have been caused by the viscosity of the feed becoming so high that the rate of fluid flow within the cake formation zone of the centrifuge actually decreased with a consequent decrease in the rate of cake formation.

Effect of polymer flocculant addition

The losses of particles into the centrate were occurring primarily because ultrafines were able to pass through the screen before the cake had formed. Thus the final series of tests was undertaken in the presence of a polymer flocculant, in an attempt to aggregate the particles and enhance the rate of cake formation. Both effects might be expected to enhance solids recovery and dewatering kinetics, as happens when flocculants are added prior to vacuum filtration. However there is one major difference between the scroll centrifuge and the vacuum filter, which might affect the performance of the flocculant. Although very difficult to quantify, the shear suffered by the flocs in the cake formation zone of the centrifuge would be far higher than in a vacuum filter. Hence the strength of the flocs and their ability to survive intact would be crucial to whether the addition of a polymer had any effect at all. Preliminary tests indicated that Magnafloc 1011 (supplied by CIBA Speciality Chemical Pty Ltd) would be a suitable polymer but the choice was not optimized.

A series of tests was undertaken in which centrifugal force and feed rate were varied as in previous testwork. The feed solids throughout this series had a mean value of 29.4 wt%, with a standard deviation of 2.3 wt%, which was considered reasonable enough when trying to compare solids recovery from one test to the next. Care was needed in interpreting the data since, as noted previously, changes in feed solids could potentially mask any changes in recovery due to the polymer addition.

The effect of floc dose on solids recovery was examined at a spin speed equivalent to 256 g, and a flow rate of 2 m^3/h. The data are shown in Figure 11. There was a trend of increasing recovery with floc dose with the highest recovery of 88 wt% achieved at a dose of 50 g/tonne. There was a marked improvement on recovery achieved in the absence of polymer.

There was no significant effect of flocculant dose on product moisture with all values being 25 ± 1 wt%. This was despite the increase in recovery with presumably more fines being included into the product. It is possible that the presence of the flocculant brought about an increase in cake permeability thereby increasing dewatering rate, but at the moment this remains speculative.

More work is needed but the effect of polymer flocculant on centrifuge performance was encouraging, especially so given the non-optimized nature of the ways in which the flocculant was selected and conditioned with the feed slurry.

Discussion

The primary objective of the work described in this paper was to develop a new design of basket in order to improve the solids capture of a scroll centrifuge and to show that the design had merit when applied to the dewatering of froth concentrate at the pilot-scale. It is felt that this was achieved. Recoveries up to 88 wt% were demonstrated at a product moisture of ca 25 wt% in the presence of flocculant at a centrifugal force of 256 g. Optimization of conditions should achieve further improvements.

In order to place these results in context, a comparison was made of centrifuge performance with one of the full-scale vacuum belt filters at the plant. The plant filter data were derived from assaying a series of 23 grab samples taken during the course of the pilot scale testwork. It would have been preferable to run a series of pilot-scale filter tests but this was outside the scope of the project. The mean moisture from the filter was 21.9 wt%, with a standard deviation of 1.8 wt%, at a throughput of ca 600 kg/m^2/h. These numbers are reasonably typical for a belt filter. Based on filtrate analyses, the solids recovery by the filter was 96 wt%. Thus the filter was performing slightly better than the centrifuge, but, as mentioned above, with further optimization it should be feasible to close the gap between the centrifuge and the filter.

The work conducted within this project is thought to be novel. Mesh screen baskets have been used before in scroll centrifuges, before wedge wire was adopted, but not laser cut screens and not when applied to flotation concentrate of size down to zero. The laser cut screen is thought to be of crucial importance to the overall objective. In order for the concept to be translated eventually into commercial reality, it is vital that the screen be sufficiently robust and wear resistant, giving at least the same and preferably better life as wedge wire. This is the subject of ongoing investigations. It was reassuring that after the pilot scale work there had been no significant change in the aperture of the laser cut screen in Basket 4, although the tests were of short duration, in comparison to what will be encountered in a commercial machine.

The results obtained to date suggest that a centrifugal force of somewhere between 250 and 600 g is needed in order to obtain sufficient dewatering of the cake and a sufficient rate in order for the application of a scroll centrifuge to froth concentrate to be viable. The necessity for these speeds is dictated by the capillary forces retaining the moisture in the fine coal filter cake, which need a certain g force in order to overcome them.

Conclusions

- The concept of using a scroll centrifuge to dewater froth concentrate by incorporating a laser-cut screen in place of wedge wire in the centrifuge basket has been demonstrated at pilot scale.
- The best dewatering results were achieved with a basket constructed entirely from laser-cut screen. In the absence of additives the best results gave a solids recovery of 82 wt% at a product moisture of 24.3 wt%, compared to a product of similar moisture but at a solids recovery of only 64 wt% with a wedge wire basket of aperture 250 μm
- Incorporation of a polymer flocculant to aggregate the particles, led to increases in recovery up to 88 wt% at a product moisture of ca 25 wt%.
- Examination of the basket at the end of the testwork programme indicated that the basket had undergone no significant wear, with the slot width remaining constant.
- The next stage of the work will involve demonstrating that the laser cut screen has sufficient wear resistance to be suitable for commercial application, and relating the performance of the pilot scale centrifuge to a full-scale unit.

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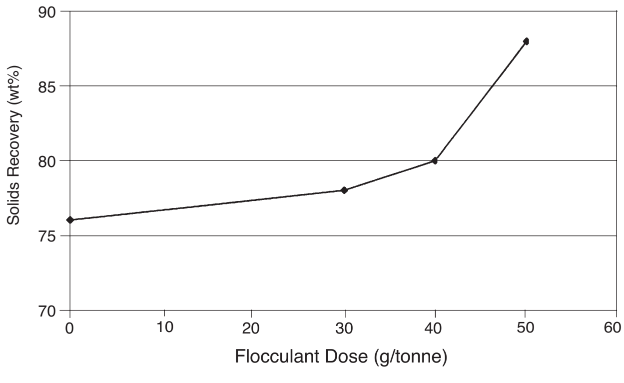

Figure 11—Effect of flocculant dose on solids recovery