Flotation at Goedehoop Colliery

by S.N. Opperman, D. Nebbe, and D. Power*

Synopsis

Testwork at Goedehoop Colliery showed that fine coal, essentially –150 microns can be successfully beneficiated using froth flotation. Both conventional and column flotation were tested. It was found that the traditional stirred tank type of flotation machines used in conventional flotation produced the best recovery of fine coal. After extensive testwork it was decided to develop a flotation machine on Goedehoop Colliery that would combine stirred tank and quiescent column technology. It was thought that this design would give the best combination of recovery and selectivity. The Multicell was developed and is producing results acceptable for Witbank coal flotation.

Keywords: Multicell, Witbank coal flotation, froth, stirred tank, quiescent column.

Introduction

Goedehoop Colliery is situated in South Africa's Mpumalanga Province about 150 km east of Johannesburg. The coal mined forms part of the Witbank Coalfields, and the majority of this is mined from underground operations. Initial testwork on flotation dating back to the 1980s showed that Witbank fine coal was very difficult to float due to the nature of the surface properties. In those days MIBC was used as a frother and power paraffin as a collector. Testwork using the above-mentioned reagents was not very successful, and yields were generally low. It was decided that recovering ultra-fine coal by means of flotation was not financially justifiable.

With new developments in flotation technology and especially flotation reagents it was decided to test flotation again at Goedehoop. Different reagents were used this time with the following improved properties. A collector consisting mainly of hydrocarbons with additions of mono and dihydric alcohols, ethers and ethoxylates. This improves utilization and absorption of higher molecular weight fractions and also collecting properties. A frother consisting mainly of polypropylene glycol ether with additions of monohydric alcohols also improves utilization, absorption of higher molecular weight fractions and collecting properties.

Initial testwork was completed making use of a Wemco mechanical test cell. The reagents used proved to be more efficient and promising yields were obtained. The froth produced was found to be very stable and caused problems in downstream operations i.e. froth on top of thickeners. The frother's chemical composition was altered by shortening the length of the carbon chains which resulted in a less stable froth. It was subsequently decided to test column flotation at Goedehoop. The Jameson Cell was tested but the performance was poor.

With the quiescent nature of column technology, and with the mixing and high power input of mechanical cells in mind, a cell was designed at Goedehoop that combines these two features in one. The cell was named after the combination of technology and is today known as the Multicell. The Multicell design was very successful and is still used at Goedehoop.

Testwork philosophy

Initial flotation testwork at Goedehoop Colliery was aimed at determining flotation characteristics. It was thus decided to test flotation on a conventional test cell because this technology is known and used extensively with good effect throughout the minerals industry. This testwork was also aimed at serving as the basis of comparison for all future testwork. After this testwork was successful it was decided to investigate different flotation machines to enable the mine to choose the most profitable and mineral specific flotation machine on the market. This decision drew the mine's attention to column flotation which in essence is easier to operate, cheaper to run and has a smaller footprint.

---

* *Goedehoop Colliery, Anglo Coal, South Africa.*

Summary of flotation testwork

Wemco test cell

Testwork involved a 6 m3/hr unit with four rotors. The unit proved that Goedehoop coal slimes can be successfully upgraded by means of flotation. Results indicated that ash yields in the order of 80 per cent could be achieved with reagent consumption of 4 kg/ton and 1 kg/ton for the collector and frother respectively. Although the testwork showed very promising results it is important to note that the Wemco test cell achieved the recoveries through a double stage flotation.

Jameson test cell

Testwork involved a 1 m3/hr unit with single stage recovery abilities. Maximum yields of 60 per cent could be achieved using similar reagent dosing rates as for the Wemco test cell. The Jameson could never match the 80 per cent yields achieved with the Wemco without dosing excessive amounts of reagents. Feed density and feed volume were found to be the two most important variables affecting the performance of the Jameson. High feed volume through the cell, resulted in lower yields due to a lower power-to-volume ratio, and increased turbulence inside the separating vessel. Below 2 per cent solids in the feed the Jameson cell produced higher yields due to an increased power-to-solids ratio. It was also apparent that the Jameson was more efficient on the smaller size fractions, generally smaller than 100 microns. It was concluded that the Jameson cell does not provide enough mixing power through its orifice plate at the top of the downcomer in order to utilize the frother completely. The low yields at comparative reagent dosing rates made the Jameson an economically non-viable option for fine coal beneficiation at Goedehoop.

Development of the Multicell

Throughout the testwork on characterizing flotation at Goedehoop it was found that high mixing energy is required to achieve acceptable recoveries and optimal use of reagents. High energy mixing if applied in the right way produces very small bubbles, increasing the bubble–solid contact area. This allows a higher carrying capacity in the cell related to an increase in the probability of bubble–solids collisions. Because of the high intensity mixing regime and smaller bubbles, the probability of bubble–solid and solid–reagent contact is increased and lower dosing rates are required to achieve comparative recoveries as for a low intensity big bubbles regime. Column cells generally have no impeller mechanisms and flow in the column is very quiescent compared to the turbulent mixing in mechanical cells. Jameson cells do not make use of large tanks normally associated with columns but rather use mixing power through an orifice plate and the hold up of bubbles in the downcomer as they try to rise while being pushed downwards, eventually emerging at the bottom and discharged into a tank. It was found that the mixing power through the orifice plate in the downcomer of a Jameson cell was just not enough to achieve the recoveries expected on the Goedehoop fine coal.

These findings initiated a flotation design, which would combine the high intensity mixing of mechanical cells with the quiescent nature of column cells.

The Multicell was developed in three stages:

- A 1 m3/hr cell which produced extremely good results. The success of this cell gave the confidence to proceed with a scale-up version
- The 1 m3/hr was scaled up to a 100 m3/hr unit, which also did very well

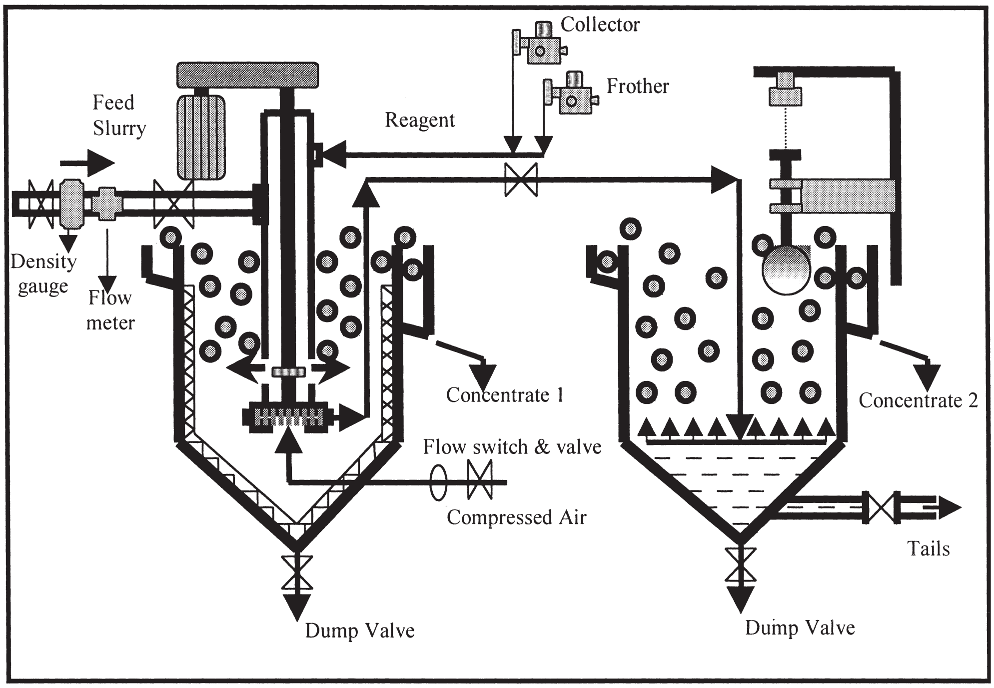

Figure 1—Multicell schematic

- ➤ Thirdly it was decided to scale-up to a production size unit which could treat 250 m³/hr. This scale-up was also successful.

A South African patent was granted to Anglo Coal for the Multicell in the year 2000. Because of the in-house development of the Multicell, it was erected at reduced cost.

Multicell design and operation

A schematic layout of the Multicell is shown in Figure 1. Feed slurry is introduced into the chamber of a vertical spindle pump with its suction hole positioned at the bottom. Flotation reagents are dosed with pumps into the top of the chamber. The reagents are mixed with the slurry by perforated paddles attached further down the pump shaft. Compressed air is blown into the suction of the pump at a controlled flowrate. Some of this air escapes out the pump alongside the shaft and gets sheared by the perforated paddles attached to the shaft. The slurry-air mixture exits the chamber through four perforated windows at the bottom of the pump shaft. This forms the first part of flotation in the Multicell and may be considered similar to the mixing and bubble generation zone within the more traditional stirred tank design. Remaining coal and discard flow downward where it gets sucked in by the pump at the bottom of the tank. Inside the pump the air stream is sheared into very small bubbles. As a result the high intensity mixing increases the probability of bubble–solid and solid–reagent contact. The mixture of air coal and discard are pumped over to the second tank through a flow distributor. In this tank coal captured in the froth is allowed to separate from gangue material. This tank allows for an absolute quiescent zone, ensuring no product is dislodged to tails and no mechanical entrainment of tailings is observed within the product. This second part of the flotation may be compared with stable zones established within column cells. As a result of these optimum conditions a high recovery with a very clean product is achieved.

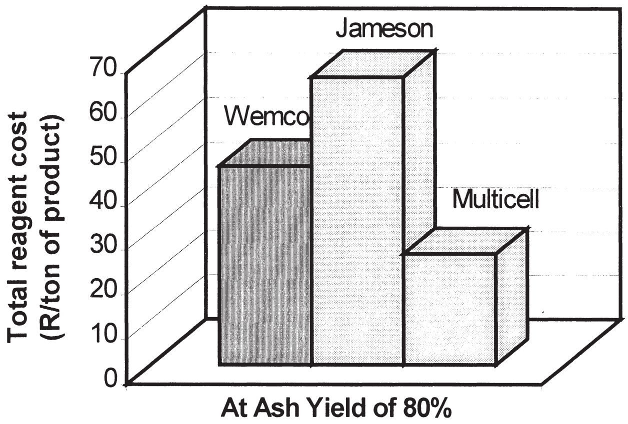

Figure 2—Reagent cost comparison

The level in both tanks is controlled using an ultrasonic probe, which measures the froth-liquid interface from a floating ball with an extended arm and plate attached to it. The ultrasonic head gives constant feedback to a valve positioner, which in return reacts to the level measured. Tailings exit at the bottom of the second tank through the level control valve.

Reagent dosing is controlled automatically from a mass flow reading, which is obtained from a density gauge and flow meter.

Multicell performance

The operational performance indicators of the Multicell are given in Table I.

Table I

Performance indicators for Wemco, Jameson and Multicell

Machine Type Plant arrangements		Wemco 1 test cell	Jameson 1 test cell	Multicell 1 production cell
Date		01/97—12/97 Average	01/98—12/98 Average	06/99—12/2000 Average
Feed solids	%	3.1	4.50	5.5
Product solids	%	9.4	11.0	14.2
Tailing solids	%	0.9	3.1	1.9
Feed ash	%	17.2	17.0	17.6
Product ash	%	9.8	8.0	8.5
Tailing ash	%	49.3	23	45.0
Product recovery	%	81.26	40.0	75.07
Combustible recovery to product	%	88.53	44.34	83.36
Flotation efficiency index	η_{wf}%	42.23	25.51	47.10
Reagent consumption	kg/t	6.3	5.9	3.0
Capacity: pulp	m³/hr	6.2	1.38	250.0
Capacity: dry solids	t/hr	0.19	0.06	13.0
Unit capacity: pulp	m³/h/m³	17.71	19.53	9.62
Unit capacity: dry solids	t/h/m³	0.54	0.85	0.5
Power consumption				
• Pulp	KWh/m³	0.87	-	0.24
• Dry coal	KWh/t	5.7	-	4.6

Combustible material recovery to product is given by the equation:

$$E_1 = 100 \times \frac{r_c(100 - A_c)}{100(100 - A_f)} \quad [1]$$

Where r_c = clean coal recovery, A_c = clean coal ash, and A_f = feed ash.

Non-combustible material recovery to product is given by the equation:

$$E_2 = 100 \times \frac{r_c A_c}{100 A_f} \quad [2]$$

According to Lianqing and Dai Wei the flotation efficiency index is given by:

$$\eta_{wf} = E_1 - E_2 \quad [3]$$

From the performance indicators it is evident that the overall performance of the Multicell is better than the other two machines. When evaluating the performance on the basis of product solids and quality, the indices for the Multicell are excellent. The Multicell maintains a high product quality at a high yield without using excessive amounts of reagents. This is of utmost importance for Goedehoop because of the relative high cost of flotation compared to Dense Medium Separation (D.M.S.) process costs for the larger fractions of coal. The reagent and power consumption for the Multicell make it the cheapest machine out of the three to run. This can been seen in Figure 2 where the reagent cost is compared at an ash yield of 80 per cent.

The unit capacity of the Multicell is low compared to the other two machines. It is believed that this can still be improved by reducing the length of the tanks without affecting the yield and quality of the product. The high intensity mixing and quiescent separating zones present in the cell will allow it to run with reduced residence time.

Froth handling and dewatering

After flotation the froth is broken down mechanically and then pumped with a specially designed froth pump into a mixing box where it is mixed with spiral product. From the mixing box the slurry mixture is gravity fed into a screen-bowl centrifuge and dewatered.

Testwork indicated that 90 per cent of the feed solids can be recovered at a 21 per cent surface moisture when feeding the screen-bowl at a 75 per cent spiral / 25 per cent flotation ratio. The coarser spiral product fraction is required to recover the ultra fine fraction because it acts as a filter bed.

It was found that the recovery in the screen-bowl started dropping dramatically as the flotation material increased above 50 per cent in the feedstock. This also resulted in surface moisture going up to 22 per cent. Most of the losses occurred through the screen section of the machine and therefore it was decided to test a solid-bowl centrifuge.

The solid-bowl test unit improved recovery of the ultra-fine material but at high surface moisture (with the exception of a 100 per cent spiral feedstock). A comparison between the screen-bowl and solid-bowl is shown in Table II.

The increased recovery of solids and increase in surface moisture prompted the modification of a full-scale screen-bowl to a hybrid solid-bowl. The hybrid solid-bowl has a much shorter screen section when compared to a conventional screen-bowl. This screen section will allow for extra dewatering at the discharge end of the machine through the short screening section and it is expected that solids losses will be significantly less than with the conventional screen-bowl machines.

The increase in moisture of the spiral product due to the addition of flotation product will decrease the gross as received (k.cal./kg.) value of the final product. At the present moment this decrease in value is not observed because the flotation plant is not run continually and is only used for test purposes. Full-scale flotation plants will only be installed once dewatering circuits have been finalized. Investigation into moisture reduction on the coarser coal products in order to eliminate the effect on final product value is currently being carried out.

Conclusions

When reviewing all the work done to recover ultra-fine coal with flotation it is evident that Witbank coal is difficult to float. A lot of mixing energy is required to ensure bubble-solid contact. The surface properties of Witbank coal are such that it requires a substantial amount of reagents to enhance the hydrophobic nature of coal. The work done by chemical

Table II

Performance comparison between screen-bowl and solid-bowl centrifuge

Percentage flotation product in feed	Surface Moisture %		Recovery %	
	Screen-bowl	Solid-bowl	Screen-bowl	Solid-bowl
0	14.47	7.92	91.92	99.95
25	16.55	22.47	90.17	98.64
50	21.31	24.66	82.90	99.75
75	21.96	29.26	32.31	96.65
100	33.01	38.42	7.64	97.61

companies to improve flotation reagents for Witbank fine coal has been successful.

Testwork done using mechanical (stirred tank) flotation proved to be more successful than column flotation. Column flotation proved to be more efficient on the smaller size fractions generally smaller than 100 microns while mechanical cells proved efficient over the entire size range. The development of the Multicell was successful and more of these will probably be installed at Goedehoop as soon as dewatering circuits for the ultra fine coal have been optimized. Because the Multicell utilizes its energy input into forming micro-bubbles the probability of bubble–solid contact is increased due to the increased number of bubbles. The high energy mixing also allows for very good aeration uniformity and good dispersion of reagents. The quiescent separating zone in the Multicell allows for better selectivity. Because of its simple structure, ease of manufacture, low capital cost, low maintenance requirements, lower reagent consumption and high product recovery the Multicell will be used to recover ultra fines at Goedehoop.

Flotation of ultra-fine coal remains expensive due to the cost of reagents. The cost to dewater the fines recovered needs to be minimized. This limits the available options. A lot of work has been done on screen-bowl and solid-bowl centrifuges and it is believed that this might be the solution.

Acknowledgements

The authors would like to express their sincere gratitude to everybody who contributed to the flotation testwork done at Goedehoop Colliery.

References

1. LIANQING, M. and DAI WEI, W. Development and application of type XPM-16 and XFM jet flotation cells. *Proceedings XIII International Coal Preparation Congress, Brisbane, Australia.* Partridge, A.C., Partridge, I.R. (ed.). Australia. The Australian Coal Preparation Society, 1998. Volume II, pp. 737–745. ◆

Tech transfer success from flotation research*

Two flotation tools developed at the JKMRC through the P9 project are making their way into industry both for practical trouble-shooting and for longer-term plant optimization uses.

The tools emanate from Barun Gorain's PhD Research conducted in the early to mid-1990s at the JKMRC when he looked for devices to characterize flotation cells in terms of their hydrodynamic status.

From this work came a Superficial Gas Velocity probe—also known as the Jg probe—and an Air Hold Up device.

Used in conjunction with the University of Cape Town's Bubble Size Analyser, the tools have proved an invaluable aid in the development of flotation models for the simulator JKSimFloat, along with day to day plant trouble-shooting and optimization.

The instruments' current 'custodian', JKTech engineering consultant Dan Alexander said the devices had gradually become portable, reliable, and user-friendly through a series of design modifications stemming back to Barun Gorain's work almost a decade ago.

Dan said there had been a surge of interest in these devices over the past few months: 'While the instruments are used separately, the measurements are usually made together to achieve the best results'.

The devices are designed to get hydrodynamic information inside the slurry phase of flotation, and are best used in large cells of greater than 8 m^3 up to 200 m^3.

'The instruments have been specifically designed for plants rather than laboratory-scale work,' Dan said.

Superficial gas velocity—or Jg—is the average velocity of bubbles rising within the pulp phase in a flotation cell. Information from the Jg probe can help metallurgists better define the characteristics of the flotation circuit.

The Air Hold Up device measures the quantity of air inside the flotation cell. This information can help metallurgists to diagnose the performance of individual cells.

The instruments are packaged with a training component whereby JKTech metallurgical engineering consultants instruct metallurgists at the processing plant on their use.

Dan said plant metallurgists usually take the opportunity to use the instruments during the training phase to 'trouble shoot' around the plant, thereby receiving immediate benefits for their operation.

On return visits, Dan then takes plant metallurgists through incremental training steps towards using the instruments for overall plant optimization.

'This is a good example of technology transfer in action, where the results from research from the P9 project have been translated to commercial enterprise through JKTech Pty Ltd.'

Currently through the P9 project the JKMRC is working together with Professor Jim Finch and the McGill University Mineral Processing Research Group to further develop the Jg probe and the Air Hold up device for on-line use in industrial flotation plants.

For more information about the Jg probe and the Air Hold Up device, contact Dan Alexander on +61 7 3365 5984, email: d.alexander@jktech.com.au ◆

---

* *Contact: JKMRC Communications Coordinator, David Goeldner, Tel: +61 7 3365 5848, email: d.goeldner@uq.edu.au*