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The management of carbon in a high-tonnage CIP operation

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SYNOPSIS

The paper describes each of the stages in a carbon-in-pulp (CIP) or carbon-in-leach (CIL) plant, and details the steps that can be taken to achieve effective carbon management by referring to practices at the Daggafontein CIP plant. This approach was adopted because of the difficulty in summarizing current carbon management in the many varying operations in South Africa, Daggafontein being chosen as a high-tonnage dedicated well-run plant of recent design. Because of the major role played by the consumption of carbon in the operating costs of CIP and CIL plants, an attempt is made to develop a series of indexes based on quality parameters and price that can be used as a guide in the selection of carbon.

SAMEVATTING

Die referaat beskryf elke stadium in 'n koolstof-in-pulp (KIP) of koolstof-in-loogaanleg (KIL) en verstrek besonderhede van die stappe wat gedoen kan word om effektiewe koolstofbestuur daar te stel deur verwysing na praktyke by die Daggafontein-KIP-aanleg. Hierdie benadering is gevolg vanweë die probleem om 'n opsomming van die huidige koolstofbestuur in die baie uiteenlopende werksaamhede in Suid-Afrika te gee. Daggafontein is gekies as 'n toegewyde goedgeorganiseerde aanleg met 'n moderne ontwerp wat 'n hoë tonnemaat gebruik. Vanweë die belangrike rol wat die koolstofverbruik in die bedryfskoste van KIP- en KIL-aanlegte speel, word daar 'n poging aangewend om op grond van die gehalteparameters en prys 'n reeks indekse op te stel wat as leidraard by die keuse van koolstof gebruik kan word.

INTRODUCTION

With the rapid development of carbon technology in South Africa over the past decade, culminating in some 30 larger and 30 smaller carbon-in-pulp (CIP) operations, a system of carbon management akin to trial and error has grown up in the industry. Many of the first-generation circuits were beset, and still are, with major engineering problems, making effective carbon management difficult. Owing to the integral relationship between the many unit operations in such circuits, effective carbon management relies on the optimum performance of all the unit operations. Carbon management is concerned not only with the physical aspects of carbon handling and housekeeping but also with the metallurgical performance of each unit operation.

It is not the purpose in this paper to accentuate poor plant practice; the intention is rather to generate a better understanding of the attributes related to effective carbon management. Because of the very different plant designs and scales of operation, as well as differences in the types of material currently being treated in South Africa, any general overview of current carbon management is difficult to summarize. The intention is therefore to illustrate by way of example the management of carbon in a high-tonnage dedicated well-run operation of recent design. The Daggafontein CIP plant, managed by the East Rand Gold & Uranium Company (ERGO), was selected for this purpose.

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DESCRIPTION OF DAGGAFONTEIN PROCESS

Background

Two important technological advances during the past 25 years were key factors in the conception of the Daggafontein project.

Firstly, the concept of large-scale dump retreatment and the technology needed to transport over large distances, treat, and dispose of enormous tonnages of slimes were pioneered and established by the ERGO operation. This has enabled large, low-grade, slimes-dam retreatment operations to be a viable proposition. The second key factor has been the development of the CIP and carbon-in-leach (CIL) gold-recovery processes, which were vital to the Daggafontein project since the very low gold grades and low sulphide sulphur content of the feedstock makes treatment of the dams uneconomic by the conventional ERGO route.

These new technologies and the increase in gold price experienced in the late 1970s and early 1980s led to the formation of a joint venture between ERGO and East Daggafontein Mines to provide reserves and to fund, design, and construct a plant to re-treat 1 Mt of material per month. Some 286 Mt will be treated by the Daggafontein plant, which was constructed at a cost of approximately R150 million. The management of the project was conducted by Anglo American Corporation utilizing ERGO metallurgical and engineering staff to provide specialist technical know-how and experience. The plant operates as a division of ERGO, falling under the direct control of the ERGO management.

Process Details

Each of two parallel streams (Fig. 1), referred to as the North and South Streams, has a nominal capacity of

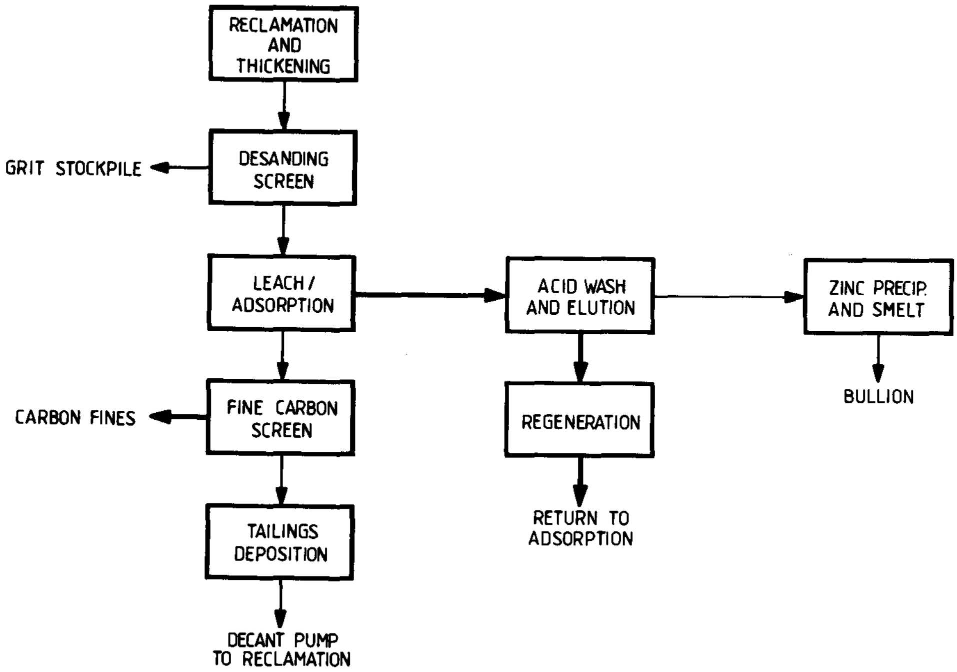

Fig. 1—Simplified flowsheet of one of the streams at Daggafontein

500 kt per month. Each slimes-treatment stream consists of a pre-leach thickener, a desanding and CIP/CIL stream, and a fine-carbon recovery section; the residue-disposal facility is common to both streams.

The carbon treatment consists of a hot acid wash followed by the elution procedure developed by the Anglo American Research Laboratory (AARL). Three identical parallel streams have been provided, giving a full stand-by facility. The eluted carbon is regenerated in a rotary kiln.

Gold is recovered from the eluate by zinc precipitation. The zinc–gold slime is acid-washed, filtered, and despatched to ERGO Division for calcining and smelting.

Reclamation of Slimes

During the projected life of the Daggafontein Division Plant, slimes dams from distances of up to 15 km away will be reclaimed hydraulically and pumped into the central plant for treatment.

The monitoring technique to be employed is similar to that developed at ERGO. High-pressure water (2 MPa) is pumped from the central plant to the two reclamation sites, where remotely operated monitor guns are utilized to slurry the dam material. The reclaimed pulp gravitates through a system of earth launders to a pump station located at the lowest point on the perimeter of the dam. The elevation of the inlet to the pump station is calculated so that all the material will gravitate to a single such station.

At the pump station, the slurry passes over two Vibramech 6,4 m by 2,4 m vibrating screens for the removal of oversize tramp material (plus 2 mm), which might otherwise damage the pump and pipeline. Envirotech rubber-lined D-frame pumps transfer the material to the plant.

Pre-leach Thickening

The density of the material reclaimed from the dam sites tends to fluctuate, with pulp density ranging from 1,35 to 1,55 under normal conditions. Two 137 m peripheral-drive thickeners ensure that the CIL section of the plant is presented with material of a steady density and flowrate.

Slurry from the dams is received, via a distribution box, into a mixing tank, where dilution water is added to produce a thickener-feed pulp with a density of 1,28. Lime is added to the mixing tank for primary pH modification.

The thickener overflow is recycled as dilution water for the feed slurry, with the excess supplementing the monitor water supply. D-frame pumps located in a ventilated chamber beneath the thickeners are used to transfer thickened material to the desanding section. The a.c. variable-speed underflow drives can be controlled for the measurement of either volumetric flow or density. A facility to bypass the thickeners and feed reclaimed slurry direct into the desanding area has been incorporated.

Preparation of Feed (Desanding)

AAC/Delkor linear screens were selected for the removal of tramp material from the feed to CIP. Four 20 m^2 units are used (two per stream).

Oversize material from the linear screens is removed by a water wash, and gravitates via launders to a sump from where it is pumped to dewatering screens. The screen underflow returns to supplement the launder flow, the excess being used as a pre-wash on the linear screens. The screen oversize is collected in a storage bin and trucked to a stockpile.

Screened pulp is transferred to two 'desanding' tanks (i.e. the first two units of each stream in the main tank farm). The tanks, 12 m in diameter by 12 m high, are agitated using Prochem agitators, each absorbing 62 kW. A facility for the measured and controlled addition of air, lime, and calcium cyanide is provided in each tank.

The second-stage tank incorporates a screened outlet and the facility to purge any accumulated grit back to the linear screens. NKM mechanically swept screens with a cut size of 0,50 mm are used.

Incorporated into the design of this section is a calibration facility for all the main slurry mass-flow installations.

Adsorption

Each adsorption train comprises six tanks, 12 m in diameter by 12 m high, each fitted with Prochem agitators absorbing 32 kW. Each adsorption tank is fitted with two NKM screens of 1,6 m diameter by 2,0 m high. Sala recessed-impeller vertical-spindle pumps are used to transfer the carbon, the piping arrangement being such that low pumping heads are maintained to keep the pump-impeller speeds to a minimum.

The carbon concentration in the tanks is 18 g/l. However, the plant design allows for carbon concentrations of 15 to 30 g/l.

Recovery of Fine Carbon

The fine-carbon screening and carbon scavenging from the residue pulp employs 20 m^2 linear screens in a manner similar to that in the desanding process. The washed oversize material is pumped to a three-product screen for the separation of water, fine carbon, and re-usable carbon. The re-usable carbon is fed into the seventh adsorption tank of the North Stream, while the carbon fines are collected for further treatment. A screening installation for adsorption-area spillage is incorporated in this section of the plant, recovering carbon before returning the spillage to the circuit.

Disposal of Residues

The residue from the Daggafontein CIL plant is pumped to a tailings dam, situated some 7 km away, by up to eight Envirotech D-frame 300 by 300 pumps. The 500 ha dam is constructed by the use of cyclones in a fashion similar to that employed at ERGO.

Acid Washing/Elution

The loaded carbon is washed and elutriated for the removal of slimes and woodchips before passing to a measuring hopper. A measured volume of carbon (12,5 t) is transferred to the acid-washing column, where it is treated with 3 per cent hydrochloric acid at 60°C. The acid-washing columns are constructed of carbon steel lined with Volco Durit D3. The candle screens and fittings within the column are of Hastelloy C276.

After neutralization, the carbon is transferred to the elution column, where gold is eluted by the AARL method using soft water at temperatures of up to 140°C. The elution columns and fittings are made of 316L stainless steel.

Heat to the process is derived from the combustion of Sasol gas. Three Wanson Thermopac 2000B units are used to heat a thermic oil-ring main, which feeds the shell-and-tube heat-exchangers. Prior to its regeneration, the eluted carbon is transported under water, through pressurization of the elution columns, to storage bins.

Three identical parallel streams have been provided, giving a full standby facility.

Regeneration

The carbon is regenerated in equipment that has been standardized with the ERGO CIL plant and supplied by Wellman Engineering Africa.

Rotary-vane feeders and dewatering screws transfer the carbon from the storage bins into rotary pre-dryers. The carbon is dried to a moisture content of between 5 and 10 per cent by burner off-gases from the gas-fired regeneration kilns. Supplementary heat is provided by hot-gas generators. The regeneration kilns provide a carbon temperature of about 700°C for 20 minutes before cooling and quenching. The retorts of the regeneration kilns are fabricated from 321 stainless steel and are reinforced on the areas of maximum bending.

Incinerators have been provided in order to destroy noxious fumes produced during regeneration. (The Daggafontein plant is located adjacent to a residential area.)

Recovery of Gold

Eluate is received in an agitated storage tank prior to sampling and transfer to a precipitation-feed tank. A mixture of zinc dust and filter aid is added as a slurry to three precipitation reactors. The precipitated slurry is dewatered using filter presses before acid treatment and refiltering.

Monitoring and Control

A network of eight PLCs controls the process and transmits data to the CYGNUS supervisory system. The system not only allows for operator interface with the process, but provides an extensive data-logging and manipulation facility.

BULK DELIVERIES OF CARBON

Perhaps the most important aspect of effective carbon management relates to the selection and quality of carbon entering a plant. Although this is the most important aspect of carbon management, it is the most neglected and least understood in the entire industry. In many operations, little or no effective quality control is applied to bulk deliveries on a routine basis, primarily because of the costs involved and the inability at the present time of relating such control data to plant operation. This unhappy circumstance places too much reliance on the carbon supplier and provides no long-term solution to the quality upgrading of the carbon used in the industry.

While this situation may persist in many carbon-based operations, the quality of carbons currently being marketed in South Africa continues to improve. Undoubtedly, a better understanding of the qualities required by the industry is being developed. Specification limits with regard to the size, shape, and hardness of suitable coconut-based products are being formulated. Unfortunately, the selection of the carbon activity required remains a debatable issue and requires further study. A recent pilot-plant trial conducted by Mintek in which carbons of different activity were compared illustrated that carbon activity is a most important consideration.

Carbon as delivered to Daggafontein is stored in separate demarcated areas to facilitate the separation of delivery batches. One bag of carbon is removed from each delivered batch and introduced to the make-up system. A representative sample of the entire bag is obtained via a sample cutter, which is an integral part of the make-up system. The sample thus obtained is further riffled into four equal representative samples.

At the Daggafontein laboratories, the sample is subjected to a size analysis in accordance with the specifications laid down by AARL. The analysis is then used as a check on the d_{50} and the percentage fines less than 1,19 mm. The sample is also subjected to activity testing. Any carbon not within specification can thus be traced to its delivery batch. Suppliers are then asked to check the results obtained by repeating the tests on one of the remaining three samples. An independent laboratory is approached to resolve any discrepancies.

The quality-control programme will later be expanded to include an accurate measurement of the mass and moisture content of newly delivered carbon. Shape factor and hardness are checked (on stored batches of carbon) only when the carbon consumption on the plant has been excessive.

The practice followed at Daggafontein is certainly to be recommended, although not enough emphasis is placed on the shape and hardness of bulk deliveries. While the activity of the carbon in the circuit can be controlled in the regeneration circuit, the physical shape and hardness of virgin carbons can only deteriorate with use. Therefore, more attention should be paid to the selection and sampling of bulk deliveries. (Great variations in both hardness and shape have been experienced in the industry owing primarily to poor quality control on bulk deliveries.)

PREPARATION AND MAKE-UP OF CARBON

Extended attrition studies carried out by McArthur[1] at AARL on numerous samples of carbon indicated an initial rate of carbon attrition some 5 to 8 times greater than the rate measured after extended attrition times (5 to 10 days). This initial rate of carbon attrition was invariably accompanied by a reduction in the gold-adsorption activity of the residual carbon due to the loss of a small, low-density, soft but highly active component originally present in the commercial product.

The soft, highly active carbon referred to would soon be lost in any contacting circuit, resulting not only in an initially high attritional loss, but also in a considerable gold loss, particularly in high-grade circuits, where much of this material would have a rapid co-current movement in the adsorption circuit and would be lost to the tailings residue. These findings confirm the view that any make-up carbon entering the adsorption circuit should first be conditioned mechanically. The removal of soft flaky material, besides improving the metallurgical efficiency, would improve the performance and maintenance of the interstage screens.

The presence of this soft, highly active carbon in bulk deliveries should also be considered in any selection of carbons. After light attrition scrubbing, which resulted in a mass loss of only 1 to 2 per cent, McArthur[1] showed that some samples suffered a decrease of 33 per cent in original kinetic activity. Likewise, loading capacities were shown to decrease by as much as 20 per cent.

The carbon stockpiles at Daggafontein are operated on a first-in first-out basis. The fresh-carbon storage vessel is maintained at a constant level to hold approximately 40 t of virgin carbon. (This is equivalent to the inventory of two adsorption tanks.)

The make-up with fresh carbon is controlled by the monthly usage of carbon on the plant. The carbon requirements are calculated back to a daily average, and this predetermined amount is blow-cased to the adsorption section every day. Currently, it works out to be approximately one bag of carbon per stream per day.

Virgin carbon is loaded into a pretreatment vessel, where it is subjected to mechanical agitation in water at an approximate 5:1 volumetric ratio (water:carbon) for 5 minutes. This process removes friable particles and wets the carbon.

The carbon is then pumped, with the addition of dilution water, over a vibrating screen, where the oversize product passes to the fresh-carbon storage tank. Here, fresh carbon is stored under water before being added to the adsorption circuit. The screen undersize (minus 1 mm) gravitates to the waste-water sump before being pumped to the dirty-water section for further clarification.

Attritional losses in the above carbon-preparation circuit at Daggafontein are estimated to be between 3 and 5 per cent of the total carbon loss. This estimate is significantly greater than the attritional losses measured on carbon samples at AARL, where mass losses of 2 to 3 per cent after a 5-day test procedure are commonly reported. Such discrepancies further emphasize the need for the sampling of bulk deliveries.

TRANSPORTATION OF CARBON

This aspect of carbon management relates particularly to the selection of the carbon-handling equipment commonly used in CIP circuits in order to minimize carbon losses and to prevent corrosion of the equipment. Granular activated carbon is an extremely abrasive material, as well as being highly corrosive towards mild steel owing to its anodic properties. The transportation of carbon slurries in pipelines is also affected by such characteristics as linear flow velocities, water-to-carbon ratios, and the width of pipe radius bends. In this paper, the emphasis is placed on the actual transportation equipment.

Details of Equipment

Blow-case

The blow-case uses compressed air or pressurized water applied in a specially designed pressure vessel to move the carbon slurry (Fig. 2a). Carbon and water are slurried in the feed tank located above the pressure vessel. The slurry falls into the pressure vessel, and the feeding valve is closed. Air or water pressure is applied and moves the slurry out through the discharge pipe. At the end of the transfer, the valve in the air/water line is closed and the vessel is vented/drained before starting a new cycle. The cycle is completely automated and controlled by timers.

At the beginning of the transfer, the concentration of the slurry is very high, and its moisture content could be close to 50 per cent (wet basis); thereafter, the excess water should dilute the slurry and, in a properly designed system, flush the pipelines at the end of the transfer. The required motive pressure for the air/water in most cases is a minimum of 1 bar above the static head from the blow-case to the discharge point.

This system of transportation has found considerable success in carbon plants because it has no moving parts,

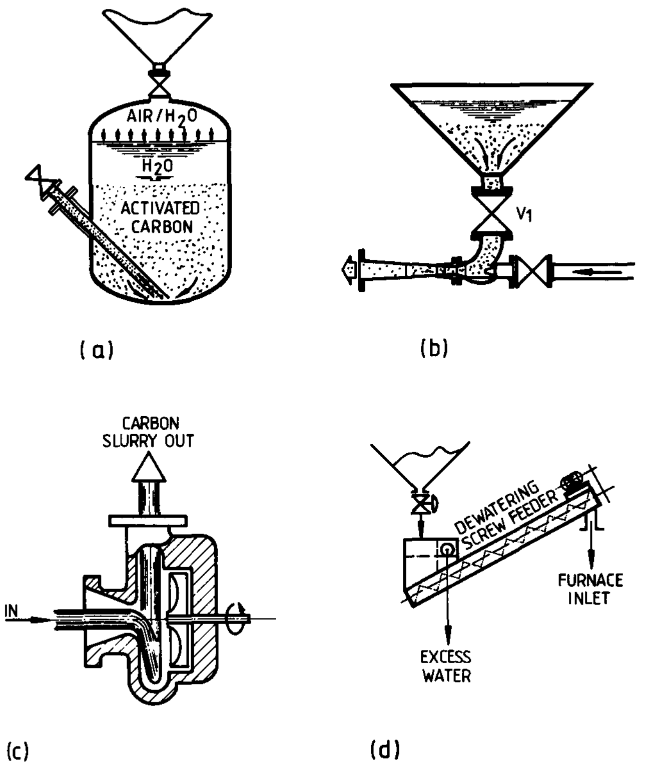

Fig. 2—The equipment used for the transportation of carbon
a. Blow-case
b. Eductor
c. Recessed-impeller pump
d. Inclined screw feeder

its maintenance is low (only required on instruments), it is not limited by the discharge head, and it is subject to few erosion or corrosion problems.

Eductor

Water-jet eductors for granular materials are similar to those installed in steam vacuum units (Fig. 2b). A suction effect is created by the pushing of water at high velocity in a venturi installed in the body of the eductor. The discharge of carbon from the feed hopper is controlled by the feed valve and the flow of water through the venturi. Water eductors have been used successfully in situations where motive water can be used in large quantity and is ready to be recycled; they are easy to operate, and replace, require minimum maintenance, and are of low initial cost.

Their disadvantages can be listed as follows.

- They are subject to corrosion and erosion. The life of an eductor in continuous service has varied from one month to one year, depending on the duty.
- They require large volumes of motive water at elevated pressure (as a function of the discharge head).
- Their efficiency drops off rapidly if the discharge head is located at more than 10 m of water column.
- They use very diluted carbon slurry (below 0,10) and therefore have a low delivery rate.
- They easily become blocked by gravel, trash, or any extraneous foreign material.

Centrifugal Pump

Many types of pumps have been tried for the transportation of carbon in slurries. The most successful pump has been the recessed-impeller pump because it maintains a maximum clearance for the passage of carbon granules (Fig. 2c). The speed of the pump should not exceed 1000 r/min. This avoids excessive wear of the pump and minimizes degradation of the granules. A rubber-lined impeller is recommended to improve the pump's resistance to abrasion.

The major disadvantages of recessed-impeller pumps are as follows.

- Their efficiency is very low—the discharge head is limited to 15 m of water column.
- They experience corrosion and erosion problems (of the impeller and casing).
- The dilution water to the pump must be controlled very carefully to avoid any feed overload.
- The density of the carbon slurry is very low owing to the water dilution needed for the correct operation of the pump. The rate of carbon delivery is therefore as low as with a water eductor.

The operating characteristics of the recessed-impeller pump vary considerably from one make of pump to another, and it is therefore wise for the design criteria to be checked before purchase. In continuous service operation, e.g. under a quench tank, this type of equipment has given full satisfaction in many carbon-reactivation plants, the life of a pump having been reported as one to two years.

Continuous Dewatering Screw Feeder

Continuous dewatering screws (Fig. 2d) used to feed carbon to regeneration kilns have proved to be the most satisfactory equipment for reducing the water content to at least 50 per cent on a wet basis. The inclined screw conveyor, which is fitted with a box-like back end, is fairly insensitive to fluctuation in the feed-storage bin up to the limits of its design capacity.

This equipment is relatively inexpensive, and is very reliable in providing continuous dewatering at low maintenance costs. The feedrate to the reactivation furnace is not controlled by the screw itself, but by a timer-operated valve; therefore, it provides very accurate control. In addition to its dewatering function, this equipment serves as a water-sealing device and eliminates the need for a rotary air-lock valve.

Carbon-transportation Equipment at Daggafontein

Based on pilot-plant testwork at ERGO, and with the assistance of Chemviron Engineering, the following carbon-transportation systems were adopted for Daggafontein:

(a) *Interstage pumping*. Sala STGVA vertical-spindle pumps fitted with all-metal impellers were selected. For interstage pumping with static heads of up to 15 m and 10 to 60 g carbon per litre in the slurry, this pump gave the best performance (based on the lowest amount of carbon abrasion).

(b) *Carbon-in-water pumping*. The Morris 3HS10 recessed-impeller pump gave the best performance. The unit must be operated with a water-to-carbon ratio of from 7:1 to 10:1 to minimize carbon attrition (such pumps are used in the quench tanks for fresh-carbon make-up).

(c) *Blow-cases.* 1 m^3 blow-cases (1 m^3 carbon capacity) were utilized for heads above 15 m and to minimize the dilution of the slurry circuits (fresh and regenerated carbon).
(d) *Eductors.* These were not considered for Daggafontein because of their performance at the ERGO CIP plant, where they were tried for discharging quench-tank carbon. They were found to block easily, resulting in frequent downtime for removal and cleaning operations. These downtime periods affected the kiln throughput and, because of this, the eductors were removed from service.

Transport-water Circuit

Owing to the often involved water circuits in many major gold-metallurgical complexes, the containment and re-use of carbon-transport water is most essential. This involves significant savings in water, and such transport waters usually contain both granular and carbon fines that may seriously affect other gold-recovery circuits, e.g. conventional filter plants and milling circuits. Such carbon may also contain significant gold values arising from plant spillages or from circuits transporting loaded carbon.

During the initial design phase for Daggafontein, the one area that was doubtful was the dirty-water purification plant. Visits to several plants showed that this was a 'grey' area from the viewpoint of design, and none could boast a very good system. Although the design of the dirty-water plant at Daggafontein was based on the best available information, the plant, shortly after being commissioned, underwent several changes. These included re-routing of the piping and replacement of a sieve bend with a Velmet rotary-drum screen.

The flow from the acid-wash and elution overflow tanks, regeneration spillage, eluted-carbon storage overflow, and fresh and regenerated carbon make-up spillage is all routed to the fresh-carbon pretreatment tank. This allows all the carbon-bearing water to be screened over the fresh-carbon pretreatment screen (1 mm slotted aperture) before being routed to the waste-water sump. The plus 1 mm usable carbon is then blow-cased back to adsorption. Underflows from the regenerated-carbon screen are also routed to the waste-water sump. All the products of the waste-water sump are pumped over the rotary-drum screen (0,3 mm aperture), where intermediate carbon is separated from the water. This carbon product is stockpiled, and the water in the dirty-water storage tank is used for blow-casing and column transportation, and for maintaining the levels in the carbon-storage vessels. (All the carbon is stored under water.) A side-stream continuous operation removes some of the carbon fines by means of a plate-and-frame pressure filter. The quality of the dirty water is difficult to ascertain, but no detrimental effects have been observed on the plant.

ADSORPTION CIRCUIT

Both the carbon concentration, and the rate and mode of carbon transfer in the adsorption circuit play significant roles in the metallurgical efficiency and bullion lock-up of a plant. Simulation studies have indicated[2,3] the use of an even distribution of carbon in circuits where no leaching takes place, and have suggested[3] the use of higher carbon concentrations in the later contacting stages in circuits where leaching is still in progress, i.e. CIL-type circuits. In the case of carbon transfer, this latter study[3] also indicated the use of a sequential mode of carbon transfer, in which carbon is first transferred to elution and then proceeds in logical sequence through the contacting circuit before finally adding regenerated carbon to the last contacting stage. (The study also indicated the improved performance obtained in a carousel-type of operation, i.e. 100 per cent carbon transfer.)

Carbon management in the adsorption circuit is essentially related to the control and movement of the carbon inventory in the contacting circuit in order to effect the most cost-effective metallurgical efficiency. As the overall profitability of a CIP plant is affected by a vast number of variables, many of which are constrained by the plant design and throughput, the emphasis in the present paper relates more particularly to the physical movement and control of the carbon inventory.

The distribution of the carbon inventory in the adsorption circuit is currently monitored by the taking of dip samples through the contacting stages. This is generally performed manually once or twice per shift, but as infrequently as once daily in some circuits. Sampling usually involves the taking of a grab sample of 1 to 2 litres from 1 to 2 m below the pulp surface before volumetrically measuring the washed carbon.

While this method may be adequate in circuits in which the carbon distribution is 'reasonably' uniform because of efficient mixing and mass transfer, unreliable results are often obtained in circuits in which poor mixing is evident. The taking of a 1-litre grab sample from a 2 by 10^6-litre contacting stage at ERGO is a good example. In such circuits, the taking of larger and/or more frequent samples may be required. The development of a reliable 'plant-proof' on-line monitor would appear to be justified in many circuits.

Preparation of Feed

One of the most crucial factors in CIL and CIP adsorption systems is to ensure that no near-size material becomes entrained in the carbon circuit. Coarse material (consisting typically of wood fibre, calcium sulphate, coal–ash–clinker, and quartz grits), unless removed prior to adsorption, will accumulate in the circuit and have a number of detrimental effects. The following are a few examples:

- reduced interstage-screen throughput and increased wear on the screen surfaces
- increased elution costs per yield as the carbon treated becomes steadily diluted with near-size tramp material
- reduced efficiency in both the elution and the adsorption circuits
- more frequent descaling of the regeneration kiln.

At Daggafontein, the feed to the desanding section arises from the underflow from the preleach thickeners or, in the event of bypassing of the thickener, directly from the reclamation pump stations. The material is discharged into a distribution box–launder system before gravitating to four 20 m^2 AAC/Delkor linear screens. The oversize (plus 0,5 mm) is removed via a water wash. The underflow passes to a main sump before being pumped to the first of two desanding tanks.

The desanding tanks have two main functions. The first tank is utilized for pH-conditioning of the pulp in preparation for leaching (pH 10 to 10,5) and for pre-leaching oxidation by the sparging of air into the pulp. The second desanding tank also utilizes air sparging, but its main purpose is to act as a screening vessel with the ability to purge back over the linear screens. Thus, any material that was not removed by the linear screen and has become trapped in the second desanding vessel by the NKM interstage screens can be purged back over the linear screens. The aperture of the NKM screens in the desanding tanks is 0,5 mm (the adsorption being kept between 0,65 and 0,85 mm).

Spillage from the desanding-tank overflow is kept separate from the adsorption spillage, and is returned to the front of the desanding circuit (i.e. to the desanding linear screens).

Interstage Screening

Interstage screening is the most critical of all the unit processes in a CIP or CIL plant. Inefficient screening results in the co-current movement of carbon, and even small leakages of carbon can result in large increases in soluble loss and gold lock-up.

The NKM interstage screens designed and used by the Daggafontein operation are undoubtedly a major breakthrough in high-tonnage screening. They satisfy the four main criteria of an effective screen: reliable and effective performance, high unit capacities, robust construction, and cost effectiveness.

The NKM screen (Fig. 3) consists of three main components:

- the mounting frame, pulp chamber, and outlet valve,
- the central drive unit and agitator arrangement, and
- the replaceable wedge-wire screen section.

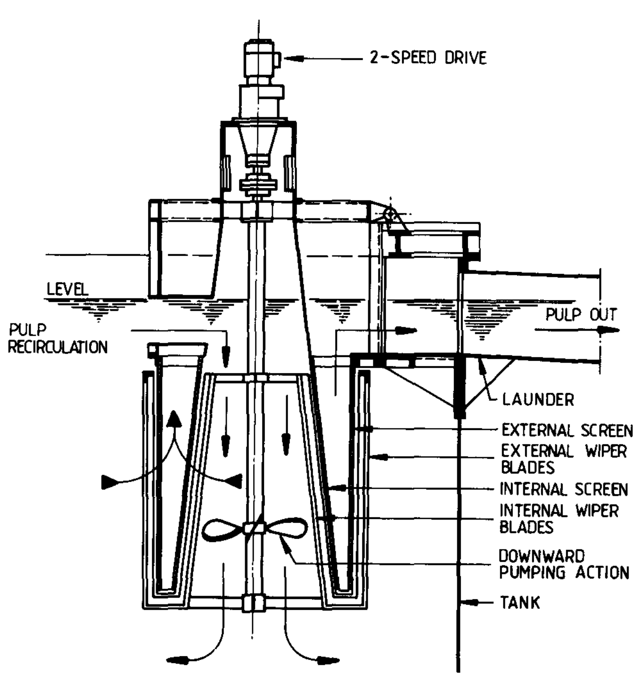

Fig. 3—A diagrammatic representation of the modified Anglo American NKM interstage screen

Regular checking of interstage screens for blinding and/or excessive aperture wear is an important control measure if steep carbon profiles are to be maintained.

The interstage screens at Daggafontein are fitted with type 430 stainless-steel wedge-wire screens. The desanding-tank screens have a nominal aperture of 0,5 mm, which wears to 0,65 mm within approximately 2½ months. The adsorption screens have an aperture of 0,65 mm, which is allowed to wear to 0,85 mm (in about 8 months) before the screens are removed from service. Desanding screens, on reaching an aperture of 0,65 mm, are moved to the adsorption circuit.

Monitoring exercises have established that each interstage screen must be removed for cleaning approximately every 10 days. The unit cleaning time has been reduced from 4 hours to 15 minutes, simply by the use of high-pressure water cleaning instead of manual wire brushing. After a screen has been cleaned, the aperture is checked by use of a magnified optical measuring device. Sealing gaskets are replaced on the screen unit each time that the unit is cleaned. This reduces the possibility of carbon escaping through the interstage-screen seal on the transfer launder to the downstream adsorption tank.

Apart from arranging regular screen maintenance, the production personnel check for interstage-screen leakage twice per shift. This is done using a test sieve of 0,8 mm aperture. Interstage-screen leakage detectors developed by Mintek were used originally, but their unreliability and high maintenance costs led to the resumption of manual checking.

Control of Carbon Inventory and Sampling

All interstage carbon-transfer pumps at Daggafontein can be started independently from the control room, and each pump can be allocated a variable running time that, as shown by experience, allows for good control of the carbon movement and the maintenance of carbon profiles.

The carbon in the last contacting stage (before the carbon is transferred to the acid wash) is normally kept at a slightly higher concentration than the rest of the adsorption tanks (22 g/l as opposed to 18 g/l). Carbon is first moved into the acid-wash/elution circuit from this vessel before the rest of the tank farm profiles are corrected. This circumvents the dilution of loaded carbon into the elution circuit from the second adsorption vessel. Regenerated carbon is blow-cased continually into the last adsorption tank as and when this carbon arises. Fresh carbon is added only on the dayshift.

Accurate carbon sampling depends on the homogeneous dispersion of carbon in the slurry, which is totally dependent on the mixing system used. The adsorption vessels at Daggafontein are fitted with Prochem single-impeller agitators, and the last adsorption tank is fitted with sampling points down the side of the tank. Samples were initially taken from these points to give an indication of the carbon concentration throughout the height of the tank. Long sampling devices were also made up and the top of the tank was sampled at different places, ranging in depth from 1 to 2 m. All the samples taken were found to be very similar in terms of carbon concentration. However, it was ascertained that the most representative samples are taken 1 m below the slurry surface. To fur-

TABLE I
GOLD-LOADING PROFILES AT DAGGAFONTEIN FOR THE PERIOD APRIL TO SEPTEMBER 1990

Monthly average	Loading profile, g/t											
	North tank farm						South tank farm					
	N3	N4	N5	N6	N7	N8	S3	S4	S5	S6	S7	S8
April	456	243	191	105	46	26	462	323	174	94	67	32
May	459	371	233	131	72	40	456	291	152	73	46	55
June	465	313	173	113	67	35	432	272	165	106	50	27
July	482	276	138	92	55	39	340	192	125	88	80	35
August	439	301	171	101	73	52	439	250	148	80	53	42
September	412	266	176	117	79	51	396	268	161	111	79	56
6-monthly average	452	295	180	110	65	41	421	266	154	92	63	41

ther improve the sampling of carbon concentration, stainless-steel sampling devices were made up for each adsorption vessel, and these are permanently chained in place. Samples are taken every 4 hours on a routine basis, and these samples are kept and composited over a 24-hour period for analysis.

The average gold-loading profiles for the period April to September 1990 from the North and South tank farms at Daggafontein are given in Table I, where the relatively steep and consistent profiles in both circuits can be noted. The low gold loadings in the final contacting stages (41 g/t), producing soluble gold losses of about 0,005 g/t, are also highly commendable. These data are an excellent example of effective carbon-inventory control and efficient carbon elution in a low-grade dump-treatment operation.

ELUTION CIRCUIT

Owing to equilibrium rather than kinetic restraints, soluble losses in the adsorption circuit are largely dependent on efficient gold elution. Since gold loadings of less than 100 g/t are required to contain a gold soluble loss of 0,01 g/t in the final stage[3], eluted carbon containing less than 50 g/t gold would be required since considerable back-mixing takes place in the contacting circuit. While this statement may not apply to all CIP circuits, it does emphasize the important role played by the elution circuit. A survey of 19 elution circuits indicated that, in many of the circuits reviewed, eluted carbon containing in excess of 50 g/t gold was being returned to its respective adsorption circuit. While it is perhaps difficult to relate the soluble losses incurred in these circuits to any single process variable, inefficient gold elution is likely to be a major cause. Furthermore, as the rates of carbon movement are largely defined by soluble gold losses incurred in the adsorption circuit, inefficient gold elution will increase the rates of carbon movement and so lower the gold loadings, thus increasing the elution and regeneration costs as well as increasing the carbon losses.

Because of the batch nature of the elution process and the importance of attaining efficient gold elution, the representative sampling of both loaded and eluted carbons is a prerequisite in the effective metallurgical control of an elution circuit.

The transfer of loaded carbon from the tank farm to the acid-wash building at Daggafontein takes approximately 4 to 5 hours. The sampling is performed manually by the taking of an hourly cut sample from the entire width of the loaded-carbon screen. Samples of acid-washed and eluted carbon are taken manually during the transfer of carbon from the acid-wash column to the elution column and from the elution column to the eluted-carbon storage respectively. These samples are also composite samples, taken every 10 minutes during a transfer (a transfer takes approximately 60 minutes).

Initially, all the carbon sampling was automated, the loaded-carbon samples being taken via a sample cutter, and the acid-washed and eluted-carbon samples via high-pressure poppet samplers installed in the respective transfer lines. All the sampling equipment had a common failure, which required high maintenance to prevent sample leakage. Maintenance costs, operational problems, and continual clean up of carbon spillage resulted in a change to manual sampling.

Manual carbon sampling during a transfer operation commences only 5 minutes after the start of the respective transfer. Testwork has established that the small quantity of carbon lying below the internal column candle distributors has a high gold value. Throughout the rest of the column, the acid-washed and eluted grades are fairly consistent. The 5-minute delay before commencing carbon sampling ensures that this material does not adversely bias the respective assay values.

Each batch of carbon is sampled and analysed for gold before and after acid washing, elution, and regeneration. The regenerated carbon is also tested for activity by use of the ACIX method developed by National Chemical Products. Composite samples are collected over a week from all the points for activity testing.

Monthly composited samples of loaded, acid-washed, eluted, and regenerated carbon are tested for gold, calcium, copper, nickel, iron, silicon, and zinc. Typical loadings are given in Table II, which shows that acid washing removes 60 to 70 per cent of the calcium, that only minor amounts of base metals are removed by acid washing, and that 80 to 90 per cent of the copper and nickel are removed during elution.

Eluted-carbon grades at Daggafontein are usually below 20 g/t (the year's average being 16 g/t), with a corresponding elution efficiency of above 95 per cent.

TABLE II
COMPOSITION OF CIRCUIT CARBONS AT DAGGAFONTEIN FOR THE PERIOD APRIL TO AUGUST 1988

Element	Carbon composition, g/t					
	Loaded carbon		Acid-washed carbon		Eluted carbon	
	North	South	North	South	North	South
Ca	18 117	20 456	6 541	13 530	4 944	6 261
Ni	15 545	15 637	12 792	13 499	1 070	643
Cu	548	988	497	953	93	62
Fe	1 096	1 390	1 020	1 374	858	843
Si	4 314	6 258	3 457	4 462	2 346	3 266

REGENERATION CIRCUIT

As the quantity of fresh make-up carbon entering the adsorption circuit seldom exceeds 5 per cent of the total carbon feed, it is obvious that both the activity and the hardness of the circuit carbon are largely defined by the conditions used for its regeneration. These conditions, in turn, will influence the metallurgical efficiency of the adsorption circuit. The basic function of carbon management in this regard is to define such conditions and to maintain the quality of this circuit carbon.

From a survey of 19 large CIP operations (Table III), it became apparent that carbon regeneration temperatures in the range 600 to 750°C are in common use. The methods used for carbon-quality control in these circuits invariably included various methods of kinetic activity testing, which were carried out by the metallurgical staff, the mine assay laboratories, or carbon suppliers. Only in a few circuits were such parameters as volatile content, loading capacities, iodine numbers, and carbon hardness monitored as a means of maintaining carbon quality.

Carbon quality is perhaps the single most important aspect in any carbon-based operation. Little attention is focused on carbon hardness primarily because of the costs associated with such testing and the difficulty in relating the results to plant performance. While the common practice of monitoring only carbon activity may be a practical means of effecting quality control when low regenerating temperatures (600 to 700°C) are used, higher regenerating temperatures and/or longer residence times call for a consideration of the carbon hardness.

The effect of acid washing as a means of maintaining carbon hardness should also be emphasized. As calcium, magnesium, and iron are well known catalytic oxidants for the water–gas reaction, acid washing prior to thermal regeneration allows the use of high regenerating temperatures, resulting in more efficient carbon regeneration without the sacrifice of physical hardness. Thermogravimetric evidence supporting this conclusion is illustrated in Fig 4.

TABLE III
CARBON REGENERATION AT VARIOUS CARBON-BASED PLANTS

Circuit	Pre-acid wash (Yes/No)	Pre-drying (Yes/No)	Kiln type	Regeneration conditions: Carbon temp. °C	Regeneration conditions: Approx. residence time at temp. min
Ergo	Yes	Yes	Rotary	730	40
Simmergo	No	No	Rotary	650	15
Daggafontein	Yes	Yes	Rotary	700	20
New Brand	Yes	No	Rotary	600–650	NA
Brand Calcine	Yes	No	Rotary	660–730	NA
City Deep	Yes	Yes	Rintoul	700	30
Crown Mines	Yes	Yes	Rintoul	700–750	90
Crown Mines	Yes	No	Rotary	750	
Harmony		Yes	Rintoul	700	60
Western Areas	No	No	Rotary	600 – 650	
Doornkop	No	No	Rotary	720	10
Grootvlei	Yes	No	Rotary	650	
Beatrix	No	Yes	Rotary	600	
St. Helena	No	No	Rotary	710	
Kinross	No		Rotary	590 – 610	
Af. Lease	Yes	No	Rotary	600	3 – 5
VR No. 8	No	No	Rotary	600	10
VR No. 9	No	No	Rotary	400	10
WDL No. 1	Yes	Yes	Rintoul		
WDL No. 3	Yes	Yes	Rintoul	650	30

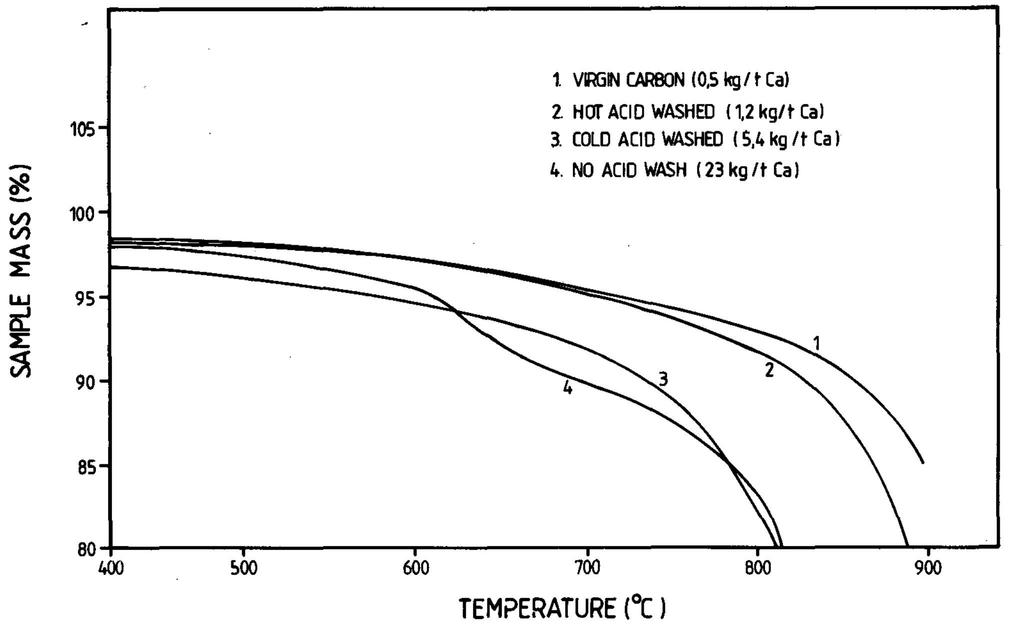

Fig. 4—Thermogravimetric analysis of eluted carbon originating from a CIP plant

The beneficial effects of acid washing before, rather than after, regeneration on the quality of the carbon taken from Vaal Reefs No. 8 CIP plant was demonstrated by McArthur[4] (Table IV). The relatively high mass and attritional losses incurred when acid washing followed regenerating at 750 to 850°C should be noted. Likewise, the decrease in loading capacity following extended carbon attrition would suggest localized surface activity that is readily lost by attrition.

Acid washing of carbon is a recognized form of chemical regeneration that may well diminish the frequency of thermal regeneration in many instances. Carefully monitored carbon-in-pulp pilot operations at AARL indicated that non-regenerated carbon can be re-used at least five to six times with little fall-off in carbon activity when a hot acid wash (90°C) is followed by AARL elution. Acid washing of carbon following gold elution is not advisable since severe chloride corrosion in the furnace may ensue.

Practice at Daggafontein

Indirect gas-fired rotary kilns are used at Daggafontein for regeneration. Two kilns are employed (one per carbon stream) at a carbon throughput of approximately 520 kg/h in each kiln. Many methods of checking and controlling throughput and carbon temperature in the kiln were tried, and the following was found to be the most practical.

Carbon is discharged from the regeneration kiln into a quench tank, from where it is pumped by recessed-impeller Morris pumps over 1 mm vibrating screens before being stored in a pachuca. As the quench-tank pumps remove carbon faster than the kiln discharges, the quench tanks are usually empty of carbon, and an impeller device (bindicator) has therefore been installed in the quench tank at a predetermined height. If the quench-tank pumps are stopped, carbon builds up in the quench tank and, when it reaches the bindicator, a torque alarm is sounded. Using the time from pump stop to alarm, the operator calculates the carbon throughput of the respec-

TABLE IV
THE EFFECT OF ACID WASHING ON CARBON QUALITY

Test parameters measured	Regeneration temperature (30 min contact time + steam) 750°C	800°C	850°C
Mass loss, %			
Acid wash before regeneration	0,36	3,15	3,25
Acid wash after regeneration	0,73	3,14	6,23
Attrition resistance, %*			
Acid wash before regeneration	0,9	1,0	1,7
Acid wash after regeneration	1,8	1,4	2,6
Kinetic activity†, %			
Acid wash before regeneration	52 (43)	53 (48)	56 (56)
Acid wash after regeneration	51 (50)	51 (53)	56 (56)
Carbon capacity for gold†, kg/t			
Acid wash before regeneration	20 (18)	20 (18)	19 (19)
Acid wash after regeneration	24 (17)	24 (17)	24 (17)

* Attrition was measured after 5 days by use of the standard AARL procedure

† Kinetic activity and carbon capacity were measured, by use of AARL procedures, both before and (after) extended attrition

tive kiln. This method allows on-line throughput measurement without the handling of carbon, and requires only a stopwatch and a pump stop and start. Any deviations are immediately corrected by adjustment of the feed to the kiln. Measurements are carried out every 4 hours.

The zone temperatures in the kiln are controlled automatically, and the controllers, linked with accurate kiln feedrates, allow for the desired carbon regeneration temperature to be maintained. To further supplement the system, operators have been trained to determine the correct carbon colour for normal operating conditions.

Any surges in the carbon flow prior to regeneration will require bypassing of the kilns, since the carbon fed to the kilns is regenerated under the required conditions, thus observing the policy 'rather regenerate some of the carbon well, than all of the carbon badly'.

Measurement of Kinetic Activity

Owing to the variable activity of virgin carbons[1], the common practice of relating the activity of plant carbon to that of virgin carbon entails the use of an unnecessary variable and is thus most difficult to justify. As the measurement of kinetic activity is a purely empirical function, carbon activity in the regeneration circuit may be more effectively controlled by the use of kinetic activity only. Furthermore, as the activity of virgin carbon is reduced considerably by mechanical attrition, any attempt to regenerate circuit carbon to 100 per cent of virgin activity will result in an unnecessary loss in carbon hardness due to over-activation.

The kinetic activity of circuit carbon at Daggafontein is maintained above 50 per cent by use of the ACIX testing procedure. This level of carbon activity has been found to adequately maintain an adsorption efficiency of 98 per cent in the contacting circuit.

CONSUMPTION OF CARBON

The consumption of carbon, which varies considerably in various operations (Table V), constitutes a very significant operating cost. At a consumption of 60 g/t and a carbon price of R7 per kilogram, a direct reagent cost of R0,42 per tonne is incurred. This, of course, does not reflect the contained gold that is lost with this degraded carbon. If this carbon had a gold content of 100 g/t, a further loss in revenue of R0,18 per tonne treated would be incurred. This emphasizes the importance of effective carbon selection and management.

Owing to the difficulties associated with the monitoring of carbon losses, quantitative data on the carbon losses in the unit operations of CIP plants are sadly lacking. In a serious attempt at rationalizing these carbon losses, Sorensen[5] reviewed 18 large CIP operations and found carbon losses ranging from 23 to 263 g/t, with an average loss of 69 ± 59 g/t. A further simulated study[6] of a plant treating 100 kt per month and having a carbon consumption of 55 g/t indicated the following breakdown in carbon consumption: mixing 48,2 per cent, pumping 0,7 per cent, Kambalda mechanically swept screens 5,1 per cent, regeneration 41,7 per cent, quenching 2,7 per cent, elution 0,9 per cent, and acid washing 0,7 per cent. This assessment would indicate that about 50 per cent of the carbon is lost in the adsorption circuit via mechanical attrition, while about 40 per cent is lost via oxidation in the regeneration circuit.

Apart from demonstrating a linear relationship between carbon inventory and ore treatment rate, the studies mentioned were not able to identify any single process variable that had a significant influence on the consumption of carbon. The sampling techniques currently in use appear to be unable to adequately quantify the carbon inventory in the adsorption circuit. Moreover, this circumstance could result in an unaccounted gold loss or gain on an annual basis of as much as 180 kg in some circuits.

Quantification of the areas of carbon losses at Daggafontein has been very difficult. The poor reproducibility of sampling campaigns has highlighted the difficulties, but the loss appears to be approximately 3 to 5 per cent during the make-up sequence, during which fresh carbon is agitated under water and screened at 1 mm before being fed to the adsorption section. The remaining carbon losses appear to be equally split between the adsorption and the regeneration sections.

SELECTION OF CARBON

As stated earlier in this review, perhaps the most important aspect of effective carbon management relates to the selection of suitable carbon for a particular operation. Although the empirical test procedures generally used in the evaluation of carbons are difficult to relate to plant operation, test results do provide considerable information on the physical and chemical characteristics of carbons, thus affording some selection criteria. These tests, besides being relatively costly (about R1500 per carbon sample at AARL), are used only in the ranking

TABLE V
CARBON CONSUMPTIONS IN VARIOUS CIP OPERATIONS*

Circuit	Consumption, g/t	Carbon	Circuit	Consumption, g/t	Carbon
Ergo	45	YAO + 205C	New Brand Mod. 1	31	G210
Simmergo	76	YAO	New Brand Mod. 2	24	G209
Daggafontein	32	YAO + ANK10	New Brand Mod. 3	45	YAO
City Deep	47	ANK11	Brand calcine	46	G210
Crown	80	TN5	Grootvlei	45 – 60	ANK11
Harmony	54	GRC22 + ANK11	Beatrix	80	TN5
Western Areas	26	ANK11	St. Helena	60	TN5
Doornkop	28	ANK11	Kinross	90 – 150	TN5
Vaal Reefs No. 8	39	ANK11	WDL No. 1	48	G210 + GRC22
Vaal Reefs No. 9	43	ANK11 + NORIT	Af. Lease	85	G210

* 6-month survey ending December 1988

of tendered samples in terms of each parameter tested (hardness, shape, activity, particle size, etc.) since no simple means of carbon evaluation has generally been accepted. Because of this difficulty, much of the test results are not used effectively, while in some instances inferior products may be purchased.

Here, an attempt is made to 'weight' and to normalize the various chemical and physical parameters that are used in the adjudication of tendered samples, together with the 'weighting' of the commercial price of the commodity, so as to rationalize the selection of carbons on the basis of technical and commercial considerations. Data using the proposed specifications[1] for the 18 samples tendered to AARL in July 1988 are used to illustrate this weighting exercise.

The four principal parameters related to carbon evaluation (viz attrition hardness, shape, loading capacity, and kinetic response) can be normalized and 'weighted' according to a point-count index totalling 100 points, where the sum of the four weighted factors also totals 100 points. Each parameter can thus be defined (depending on the selected weighting factors) within specification limits as follows, x being used to represent the specification limit:

(a) Shape Index =

$$\frac{x - \text{shape factor}}{x - \text{optimum shape factor}} \times \text{weighting factor}$$

The specification limit used was 10 per cent, while an optimum shape factor of 0 per cent was selected.

(b) Attrition Index =

$$\frac{x - \text{attrition resistance}}{x - \text{optimum attrition resistance}} \times \text{weighting factor}$$

The specification limit used was 3,0 per cent, while the optimum attrition resistance was adjudged to be 2,0 per cent.

(c) Capacity Index =

$$\frac{K \text{ value} - x}{\text{Optimum } K \text{ value} - x} \times \text{weighting factor}$$

The specification limit used was 15 kg of gold per tonne of carbon, while an optimum K value of 19 kg of gold per tonne of carbon was selected.

(d) Kinetic Index =

$$\frac{R \text{ value} - x}{\text{Optimum } R \text{ value} - x} \times \text{weighting factor}$$

The specification limit of 50 per cent was used, while an optimum R value of 62 per cent was selected.

It should be noted that, as can be seen from the above 100 point-count index, penalty points are incurred where carbon samples fail to meet certain specification limits.

As the moisture, solubles, and fines (less than 1,2 mm contents) of tendered samples must also be considered in any carbon evaluation, these values expressed in percentage terms can be conveniently subtracted from the evaluation index, which can then be expressed as follows:

Evaluation Index = Shape Index + Attrition Index + Capacity Index + Kinetic Index − % moisture and solubles content − % fines content.

Each carbon can be 'weighted' in terms of price according to the following:

$$\text{Price Index} = \frac{PH - PS}{PH - PL} \times \text{weighting factor,}$$

where PH = highest carbon price
PL = lowest carbon price
PS = sample carbon price.

Having thus normalized and 'weighted' the physical and chemical parameters of the carbon samples using an Evaluation Index, one can add the Price Index to give a Final Index, which can be used to evaluate carbon samples, i.e.

Final Index = Evaluation Index + Price Index.

In the evaluation of the 18 tendered carbon samples according to the proposed specifications, the following weighting factors were assumed:

Shape factor	25
Attrition hardness	25
Loading capacity	25
Kinetic response	25
Total	100.

When the normalized test data presented in Table VI are evaluated according to the procedure outlined, the following findings are of significance.

(1) A reasonably good correlation exists between the kinetic index and the CTC activity of samples from each major supplier; this correlation is not as marked in terms of carbon capacity.
(2) The samples supplied by A have generally a high fines content and poor shape characteristics.
(3) The samples supplied by B have excellent capacity characteristics and good shape factors.
(4) The samples supplied by C have excellent attrition resistance.
(5) All E's samples have a low fines content and good shape characteristics.
(6) The excellent Evaluation Index of the C3 carbon and the consistent quality of the B carbons are noteworthy.
(7) A good correlation exists between the Evaluation Index and the CTC activity and price (see below) in the case of the A, C, D, and E samples.

In the present investigation, a price 'weighting' factor of 50 was assumed, which can be equated to a maximum of 33⅓ per cent of the Final Index. From the normalized data incorporating the Price Index (Table VII) several further comments arise.

(i) But for the B and C samples, no significant changes in carbon ranking are evident from a comparison of the Evaluation Index (Table VI) with the Final Index.
(ii) A good correlation exists between the Price Index and the CTC activity of samples from each major supplier.

TABLE VI
CARBON EVALUATION BASED ON NORMALIZED LABORATORY TEST DATA

Sample identification*	Shape Index	Attrition Index	Capacity Index	Kinetic Index	Moisture and solubles	Fines content	Evaluation Index	Ranking no.
A1	−11,3	17,5	6,3	−2,1	1,5	3,9	5,0	15
A2	−20,3	−5,0	6,3	0	2,8	6,7	−28,5	18
A3	− 6,3	10,0	12,5	22,9	9,5	4,6	25,0	12
A4	− 4,3	0	12,5	18,8	1,9	4,3	20,8	13
A5	− 8,8	10,0	25,0	22,9	3,3	3,2	42,6	5
B1	14,8	15,0	25,0	0	2,3	0,6	51,9	2
B2	18,5	0	18,8	6,3	1,8	0,4	41,4	6
B3	14,5	7,5	18,8	12,5	2,9	1,1	49,3	3
C1	4,0	20,0	6,3	−8,3	2,4	3,3	16,3	14
C2	7,5	17,5	6,3	6,3	1,2	3,3	33,1	11
C3	12,5	22,5	12,5	25,0	1,2	1,0	70,3	1
D1	− 0,8	−10,0	12,5	0	5,2	1,7	− 5,2	17
D2	12,8	0	12,5	12,5	3,2	0,2	34,4	8
D3	7,5	− 5,0	12,5	22,9	3,6	0,4	33,9	10
E1	14,3	5,0	−6,3	−6,3	3,5	0,1	3,1	16
E2	14,8	12,5	0	12,5	5,5	0	34,3	9
E3	19,0	7,5	6,3	16,7	4,9	0	44,6	4
F1	− 0,8	17,5	25,0	0	3,1	1,3	37,3	7

* Samples listed in order of increasing CTC activity for each major supplier

TABLE VII
FINAL CARBON SELECTION USING CURRENT WEIGHTED COMMODITY PRICES

Sample identification	Evaluation Index (total 100)	Price Index (total 50)	Final Index	Final ranking
A1	5,0	46,5	51,5	14
A2	−28,5	43,2	14,7	18
A3	25,0	36,8	61,8	9
A4	20,8	31,7	52,5	13
A5	42,6	26,4	69,0	5
B1	51,9	19,2	71,1	3
B2	41,4	12,1	53,5	11
B3	49,3	0	49,3	15
C1	16,3	50,0	66,3	7
C2	33,1	38,5	71,6	2
C3	70,3	23,3	93,6	1
D1	5,2	28,8	23,6	17
D2	34,4	23,3	57,7	10
D3	33,9	18,8	52,7	12
E1	3,1	37,6	40,7	16
E2	34,3	31,3	65,6	8
E3	44,6	22,6	67,2	6
F1	37,3	33,4	70,7	4

Although the various parameters were weighted arbitrarily, the procedure illustrates a selection method that is based only on technical and commercial considerations. The development of a computer-based software package that could readily adjust these weighting factors would be a logical step in further aiding effective carbon selection.

As can be seen, this selection exercise was carried out on samples of carbon submitted for tendering purposes, which may not be representative of the quality of bulk deliveries. To obviate such an eventuality, it is recommended that samples for evaluation should be taken from bulk deliveries in any serious selection campaign. Furthermore, the sampling of bulk deliveries as an on-going exercise would be the most effective means of improving the quality of carbon as supplied to the industry.

Because carbon represents such a significant cost, the weighting of the price of the commercial product needs careful consideration. Thus, the use of a good-quality product with good hardness and shape characteristics at R8 per kilogram incurring a consumption of 30 g/t (i.e. R0,24 per tonne treated) is more cost-effective than the use of a softer product priced at R4 per kilogram that results in a consumption of 100 g/t (i.e. R0,40 per tonne treated). Needless to say, this does not take into account the gold lost using the inferior product.

Owing to the presence of soft, highly active material in most commercial products[1], some form of attrition scrubbing prior to the monitoring of carbon activity is strongly recommended in any selection campaign. As this soft material is readily lost in the contacting circuit, this procedure more closely simulates the activity of carbon when in actual use.

CONCLUSIONS

Running a dedicated high-tonnage operation handling large quantities of carbon, Daggafontein has demonstrated that, with effective carbon management, the consumption of carbon can be maintained at a cost-effective level in a CIP type of operation. The latest results at Daggafontein indicate a carbon consumption of 26 g per tonne treated. Notwithstanding the excellent carbon management practised at Daggafontein, several improvements can still be made and warrant further emphasis when related to the industry in general.

(1) While the use of 8 by 16 mesh carbons (with a d_{50} of 1,6 to 1,8 mm) are currently in general use in South Africa, the advent of wedge-wire mechanically swept screens perhaps requires a slightly coarser carbon (with a d_{50} of 1,8 to 2,0 mm).
(2) The use of wedge-wire interstage screens immediately places more emphasis on carbon shape. Purchasing specifications related to carbon shape require further consideration since some bulk deliveries have been shown to contain a high amount of flaky material.
(3) Further attention to carbon selection based on the sampling of bulk deliveries is urgently needed in order to upgrade the quality of carbon used in the industry.
(4) Finally, a carbon consumption of 10 g per tonne treated may yet be attainable.

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Mining tax*

'If anyone is smiling after a mixed Budget, he must surely be a mine manager', says Ernst & Young tax partner Ken Walton, who explains as follows.

For the first time in many years, the mining industry will be a major beneficiary of the Budget proposals. The relief comes at the right time for the gold-mining industry in particular, which is suffering from a depressed gold price coupled with rising production costs.

The industry will now benefit from the uniform lower formula for gold-mining tax and the further phasing out of the surcharge for other mines, the halving of the import surcharge on capital goods, the granting of a full VAT input credit for capital goods, and an input credit for all mining stores.

Mining Income Tax

The Government expects to collect, in aggregate, 20 per cent less tax from the gold mines in the current year, although this is largely as a result of lower profits. The reduction of the maximum theoretical marginal rate to 57,95 per cent will cost the Government about R15 million.

The loss of revenue from other mines will be in the region of R34 million as a result of the reduction in the basic rate and the surcharge. The maximum marginal rate for those mines is now 50,88 per cent.

Import Surcharge

Mines that consciously decided to switch the emphasis to mechanical mining were badly affected when the Government suddenly introduced the import surcharge. Much of the sophisticated equipment had been imported.

The further reduction of the import surcharge on capital goods from 10 to 5 per cent will therefore be welcomed with the anticipation that it will be removed altogether before long.

Paradoxically, the yield from the import surcharge is expected to rise by almost 4 per cent to R2,165 million in the current year, in spite of the reduction of the rate on capital and intermediate goods.

Valued Added Tax: Capital Goods

The most welcome news of all is that mines will be able to claim a full credit for the input tax paid on capital purchases. It was expected that the credit would be phased in over a period of five years, which would have complicated accounting for VAT.

Suppliers of capital equipment to the mines are concerned that sales in the next six months will decline since mines are unlikely to want to pay 13 per cent GST. A purchase after 30th September, 1991, would effectively cost 12 per cent less. It is, however, possible to structure the purchase to satisfy both the buyer and the seller and at the same time gain the maximum tax advantages.

Valued Added Tax: Mining Stores

Mines should not forget the other major advantage that VAT has over GST. GST exemptions for the industry are essentially limited to purchases of safety equipment, explosives, and certain repair and maintenance services. It has been estimated that these exemptions represent less than 20 per cent of working costs. When VAT starts, a full credit will be available for all mining stores.

The result is that gold mines and exporting mines will receive a significant VAT refund each month from the Receiver.

It is hardly surprising that the mining industry is well pleased with the Budget.

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