Design and operation of dense-medium cyclone plants for the recovery of diamonds in Africa*

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SYNOPSIS

A full and detailed description is given of the dense-medium cyclone plants used in Africa for the recovery of diamonds. The criteria used in plant design are discussed with reference to type and size of separator and to the associated screening and medium-recovery circuits.

The use of automatic controls and instrumentation in the operation of the plants is discussed, with examples from present practice.

Characteristics of the various types of media used are given, and the effects of changes in the quality and size of the medium are noted.

A break-down and comparison of the operating costs of various working plants are given.

SAMEVATTING

Daar word 'n volledige en uitvoerige beskrywing gegee van die digtemediumsikloonaanlegginge wat in Afrika vir die herwinning van diamante gebruik word. Die maatstawwe wat by die aanlegontwerp toegepas word, word bespreek met verwysing na die keuse van die soort en grootte van die skeier en die geassosieerde sif- en medium-herwinningsbane.

Die gebruik van outomatiese kontroles en instrumentasie in die bedryf van die aanlegginge word bespreek met voorbeelde uit die hedendaagse praktyk.

Daar word kenmerke vir die verskillende soorte media wat gebruik word, gegee en die uitwerking van veranderinge in die gehalte en grootte van die medium word aangegee.

Daar word ook 'n ontleding en vergelyking van die bedryfskoste van verskillende werkende aanlegginge gegee.

INTRODUCTION

For nearly a century, the diamond pan has been the basis of diamond-recovery plants. Long experience has shown that close control of diamond-pan operation is difficult, even with the most skilled and conscientious operators. Diamond losses, particularly when the finer sizes of ground are treated, can be considerable.

Given adequate feed preparation, heavy-medium processes can be controlled automatically; they can handle wide fluctuations in feed conditions and consistently give virtually complete recovery of free diamonds in the feed. Heavy-medium plants are more expensive to run than pan plants, but, where the potential losses can justify this extra operating cost, they are more attractive than diamond pans.

A heavy medium was first used in diamond processing at Premier Mine in 1946 in the form of heavy-medium cones, which were introduced to treat the coarser, plus 3 mm feed material[1]. The success of these cone installations led to experiments in heavy-medium cyclone operation for the recovery of the smaller diamonds down to the lowest size at which diamond recovery is usually attempted—½ to 1 mm.

At that time, the early 1950s, most heavy-medium cyclone plants used magnetite media, and so it was that a magnetite system was installed in 1955 to recover diamonds from the minus 6 mm ground at Williamson Diamond Mine in Tanzania. An almost identical plant was installed at Bakwanga, in what is now Zaire, in 1959. As described below, these plants used small, high-angle cyclones.

Following these successful installations, work was carried out in 1961 at Premier Mine with a small, narrow-angle cyclone using a ferrosilicon medium. This was followed in 1963 by the installation of a 525 mm rubber-lined 20° cyclone using 100 D ground ferrosilicon. This cyclone was subsequently replaced by a 600 mm cyclone and a 750 mm cyclone for test purposes, and the plant was finally operated with a 600 mm rubber-lined 20° cyclone.

A 600 mm DSM (Dutch State Mines) heavy-medium cyclone was installed to treat the fine material at the No. 4 plant of the Consolidated Diamond Mines of South West Africa Limited in 1965. In the same year, a 450 mm rubber-lined cyclone was installed to reconcentrate the fine material at Finsch. A 450 mm rubber-lined cyclone plant was installed on the De Beers mine at Dreyers Pan in Namaqualand during 1966 to treat the whole gravel size range from minus 20 mm to 2 mm. Standard DSM 350 mm heavy-medium plants were built at Kimberley in 1968 for reconcentration. All these installations had pump-fed cyclones.

Gravity-fed 600 mm heavy-medium cyclones were introduced with the construction of the No. 1 plant at Consolidated Diamond Mines in South West Africa in 1968 for treating all the feed in the size range minus 20 mm plus 2 mm.

The success of the gravity-fed system was such that it was followed by similar installations at the No. 4 plant at Consolidated Diamond Mines in 1969, the Koffiefontein (Orange Free State) plant in 1971, the Orapa (Botswana) plant in 1971, and at the Kleinzee (Namaqualand) plant in 1972.

Four pump-fed 600 mm cyclones were successfully installed at Premier Mine in 1970 to take the place of jigs in the retreatment section. It was necessary to use a pump-fed system to fit the plant into the existing building.

Details of some of these heavy-medium cyclone plants are given in

*Based on a paper by I. R. M Chaston that was presented at the International Mineral Processing Congress, London, in 1973.

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Tables I and II. Table I lists the operating conditions in the major cyclone plants used for the recovery of diamonds. Tables II and III list the equipment installed in these plants under the headings that are used in the following discussion.

Heavy-medium cyclones now represent the major primary concentrating process used in diamond recovery, and all the diamond plants at present being planned are being designed round this system.

DESIGN OF A HEAVY-MEDIUM CYCLONE PLANT

At first sight, the separation of diamonds of specific gravity 3,5 from a gangue that mostly has a specific gravity of less than 2,7 does not seem to present any great problem. The gap between the two is wide in terms of many separations that involve heavy media in the coalfields. Separations in which the difference is only 0,1 specific gravity units are referred to in the literature[2–4].

However, in those operations the emphasis is not on complete recovery, whereas, because of the very high value of the individual diamonds, it is usually necessary to plan for a total recovery of diamonds. Paradoxically, the value of the ground as mined is often extremely low because of the very small number of diamonds in the ground. The Premier Diamond Mine, source of the Cullinan and many other famous diamonds, extracts ore from underground that has an average diamond content worth less than ore containing 0,2 per cent copper. It is therefore also necessary to operate the diamond concentration processes as cheaply as possible.

A typical flowsheet for a heavy-medium cyclone is shown in Fig. 1.

A. Preparation of Feed

Great emphasis is usually placed on the need for careful feed preparation, and in all the diamond plants considerable trouble is taken to remove fines and water from the feed to the heavy-medium cyclones. If fines are allowed to enter the medium in excessive quantities, they can accumulate in the circuit until it becomes difficult to maintain the density. The increase in viscosity resulting from excessive contamination by fines will lead to an increase in the power drawn by the medium pumps, and may also affect the separation achieved by the cyclone. Some authorities believe that the viscosity of the medium has little effect on cyclone operation, but a recent incident at the Koffiefontein Mine indicated that a fall-off in cyclone performance could be partly attributed to high viscosity caused by contamination of the medium by fines.

The build-up of contamination is related to the effectiveness of the medium-cleaning circuit. If all the medium were cleaned every time it passed through the cyclone, there would be little need to remove fines from the feed. However, this would involve increasing the cleaning circuit more than threefold to handle the extra volume of pulp, and the extra cost of the extended medium-cleaning circuit would need to be balanced against the cost of the feed-preparation installation. At present, the balance of capital and operating costs is thought to favour careful feed preparation, except when the feed contains a large amount of slowly disintegrating clay.

A more important objective of feed preparation is to reduce the water content of the feed to a constant low figure. Uneven drainage in surge bins ahead of the cyclones can result in wide variations in the moisture content of the feed. The effect of free water in the feed to the cyclone is to dilute the medium and so reduce its effective density. A fluctuating moisture content in the feed can result in undesirable variations in the density of separation. To overcome this bin-drainage effect, the final feeders are now fitted with dewatering wedge-wire panels.

B. Method of Feeding

As mentioned above, the feed to the early cyclone plants was added to the medium in a pump sump, and the mixture was pumped through the cyclones. Fine material is easily introduced in the medium flow but, with coarser material, the rafting of flat, light particles in the feed sump and feed surging present problems. These problems have been overcome by gravity feeding the heavy-medium cyclones, A constant head is maintained in a feed-mixing box above the cyclone, and a prepared feed is then added to the mixing box and gravitates into the cyclone. In this gravity-fed system, only the finely divided particles of the medium have to be pumped. Ferrosilicon particles are extremely abrasive and can make short work of ordinary unprotected steel pumps and piping. Rubber-lined pumps are, however, easily damaged by stray steelwork, welding rods, bolts, etc., and, when damaged, can cause catastrophic failure of the heavy-medium system by choking the cyclone inlets, spigots, etc., with large pieces of detached rubber. Ni-hard cast-iron pumps are therefore preferred on many of the recent diamond plants. The extra cost of spares for the pump is covered by the reduced risk of sudden and expensive failure.

A further advantage of the gravity-fed plant is that the pressure drop across the cyclone is kept constant by the constant head (on the assumption that the density of the medium is constant) and is not dependent upon pump efficiency, which may change as a result of wear or other factors. A disadvantage is the additional height required, resulting in increased capital costs.

The optimum value of head required for any application is a matter for conjecture. Extensive testwork by the DSM established an optimum of $9D$ for coal separation, where D is the diameter of the cyclone; for a 600 mm cyclone, the required head would therefore be 5,4 m. However, it was believed that greater heads (and hence pressures) would be required for high-density separations, and all gravity-fed cyclone plants within De Beers have been constructed with a head of 8 m. Recent testwork at the Diamond Research Laboratory, however, has shown that, at least for ores from the Consolidated Diamond Mines, a head as low as 5,1 m gives a satisfactory separation; indeed, the quality of separation was marginally improved. Clearly, the feed pressure should not be so low as to cause the vortex inside the cyclone to collapse, but it may be that excess-

TABLE I

OPERATING DETAILS OF SOME OF THE MAJOR DIAMOND HEAVY-MEDIUM CYCLONE PLANTS

Mine	Year installed	Feed to cyclones t/h	Feed pressure or head	Feed size range mm	Specific gravity of medium			Type of medium	Conc. ratio	Medium use g/t	Diamond recovery %
					Feed	Spigot	Overflow				
Williamson's	1955	155	Pump 290 kPa	−6+1	2,05	2,8	2,0	80% Mag. 20% FeSi	1:475	1600	97
Premier Mine, No. 9 unit	1964	160-200	Pump 250 kPa	−6+3	2,30	2,57	2,14	65 D FeSi	1:250	330	97
Dreyers Pan	1966	21	Pump 110 kPa	−20+2	2,3	2,9	2,03	100 D FeSi	1:50	600	99
CDM*, No. 1 Plant	1968	80	Gravity 8,0m	−25+2	2,76	3,0	2,7	100 D FeSi	1:65	450	99
CDM*, No. 4 Plant	1969	360	Gravity 8,0m	−25+2	2,72	3,0	2,6	100 D FeSi	1:50	400	99
Premier Mine, Retreatment Plant	1970	340	Pump 210 kPa	−8+1,8	2,62	2,95	2,56	65 D FeSi	1:125	350	98
Orapa	1971	350	Gravity 8,0m	−25+1,6	2,55	2,80	2,4	100 D FeSi	1:100	350	98
Koffiefontein	1971	560	Gravity 8,0m	−30+0,5	2,71	2,82	2,66	100 D FeSi	1:300	700	98
Kleinzee	1972	250	Gravity 8,0m	−25+2	2,68	2,96	2,60	100 D FeSi	1:75	420	99

*Consolidated Diamond Mines

TABLE II

DETAILS OF EQUIPMENT FOR SOME MAJOR HEAVY-MEDIUM CYCLONE DIAMOND PLANTS

Mine	A Preparation of feed	B Method of feeding	C Cyclones	G Density control
Williamson's	Four 0,9 m sieve bends, 1 mm aperture Four 1,8 × 3,9 m a.c. step-deck screens, 1 × 6 mm mesh	Two 8/6 Warman pumps	Six 300 mm nickel-hard Inlet: 75 × 28 mm Vortex: 110 mm dia. Spigot: 35 mm dia. Cone angle: 60°	Manual
Premier Mine, No. 9 Unit	One D/D 1,5 × 4,3 m a.c. low-head screen Top deck: 8 × 32 mm mesh Bottom deck: 3 mm square mesh	One 8/6 Warman pump with stand-by	One 600 mm Inlet: 280 × 55 mm Vortex: 230 mm dia. Spigot: 110 mm dia. Cone angle: 20° One standby cyclone	Manual
Dreyers Pan	Feed milled and screened at 2 mm	One 6/4 Warman pump	One 450 mm rubber-lined steel Inlet: 75 × 75 mm Vortex: 150 mm dia. Spigot: 50 mm dia. Cone angle: 20°	Manual
Consolidated Diamond Mines, No. 1 Plant	One 1,5 × 4,9 m a.c. low-head screen, 1,5 × 7 mm mesh	Gravity	One 600 mm nickel-hard Inlet: 110 × 110 mm Vortex: 250 mm dia. Spigot: 180 mm dia. Cone angle: 20° One standby cyclone	Ramsay magnetic coil
Consolidated Diamond Mines, No. 4 Plant	Feed milled and screened at 2 mm	Gravity	Four 600 mm nickel-hard Inlet: 110 × 110 mm Vortex: 250 mm dia. Spigot: 180 mm dia. Cone angle: 20°	Ramsay magnetic coil
Premier Mine, Retreatment Plant	Four D/D 1,5 × 4,3 m Vibrex screens Top deck: 5 × 45 mm Bottom deck: 1,7 × 30 mm	Four 8/6 Warman pumps	Four 600 mm nickel-hard Inlet: 110 × 110 mm Vortex: 250 mm dia. Spigot: 150 mm dia. Cone angle: 20°	Ramsay magnetic coil
Orapa	Five 1,9 × 4,9 m a.c. low-head screens, 1,6 × 4 mm mesh	Gravity	Four 600 mm nickel-hard Inlet: 110 × 110 mm Vortex: 250 mm dia. Spigot: 180 mm dia. Cone angle: 20°	Ramsay magnetic coil
Koffiefontein	Five D/D 1,9 × 6 m Ripflo screens Top deck: 12 mm mesh Bottom deck: 3 mm mesh	Gravity	Seven 600 mm nickel-hard Inlet: 110 × 110 mm Vortex: 250 mm dia. Spigot: 130 mm dia. Cone angle: 20°	Ramsay magnetic coil
Kleinzee	Two 1,9 × 4,9 m a.c. Ripflo screens, 2,0 × 5 mm mesh	Gravity	Three 600 mm nickel-hard Inlet: 110 × 110 mm Vortex: 250 mm dia. Spigot: 180 mm dia. Cone angle: 20°	Ramsay magnetic coil

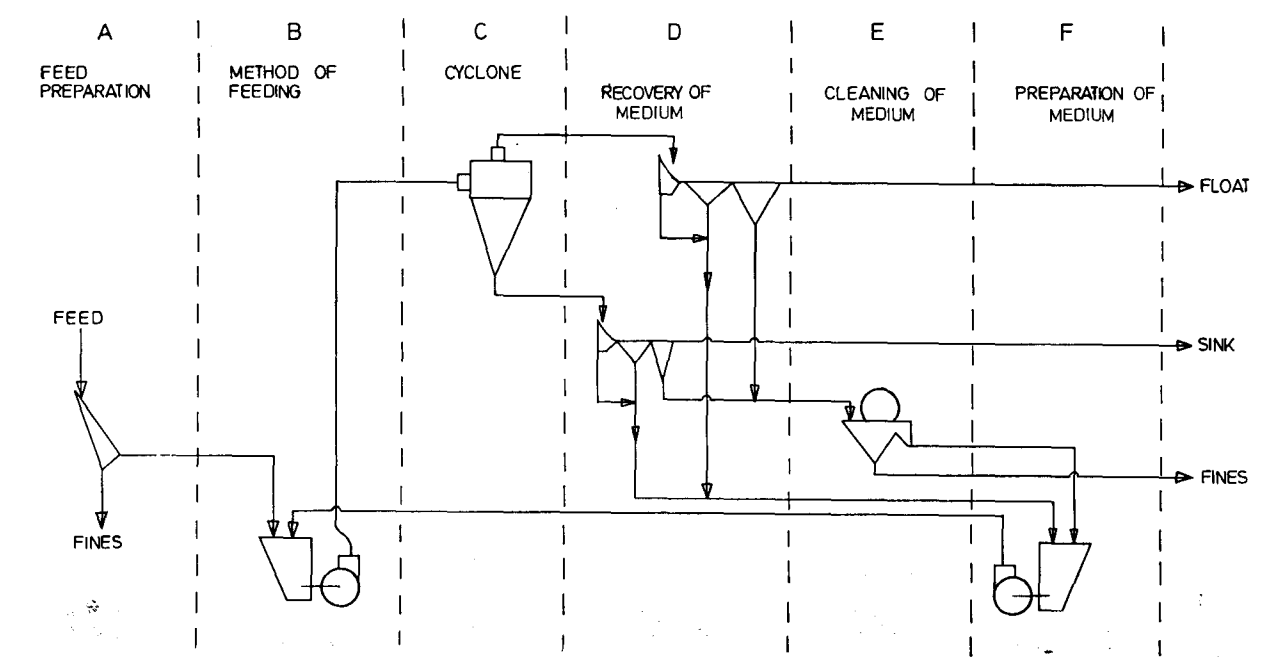

Fig. 1—Typical flowsheet for a heavy-medium cyclone

TABLE III

DETAILS OF EQUIPMENT FOR THE TREATMENT OF MEDIA ON SOME MAJOR HEAVY-MEDIUM CYCLONE DIAMOND PLANTS

Mine	D Recovery of medium	E Cleaning of medium	F Preparation of medium
Williamson's	Two duplex 0,9 sieve bends, 1 mm aperture Two 1,8 × 3,9 a.c. step-deck float screens, 1 × 6 mm mesh One 0,6 × 3,0 m a.c. step-deck sink screens, 1 × 6 mm mesh	Two-stage drum magnetic separators Two: 0,75 m dia. × 1,5 m Two: 0,75 m dia. × 1,5 m	One thickener unit, 4,9 m dia. × 1,8 m One 75 mm Dorrco pump
Premier Mine, No. 9 Unit	One 0,9 m float sieve bend, 0,8 mm aperture One 1,9 × 4,9 m a.c. low-head float screen, 1,0 mm wedge wire One 1,9 × 4,9 a.c. low-head float screen standby One 0,6 × 3,0 m a.c. low-head sink screen, 0,5 × 4,5 mm mesh	Two-stage drum magnetic separators Two: 0,9 m dia. × 1,9 m Eriez	Medium thickened by decantation from the feed sump Floor drainage pumped to magnetic separator
Dreyers Pan	One 0,9 m sieve bend, 2,0 mm aperture One 1,5 × 3,0 m a.c. low-head split screen: 1,2 m for float 0,3 m for sink 2,5 mm aperture	One-stage drum magnetic separator One: 0,75 medium × 1,2 m Rapid	Spiral densifier, 0,6 m dia.
Consolidated Diamond Mine, No. 1 Plant	One 1,5 m wedge wire drainage panel, 2 mm aperture One 1,9 × 4,9 m a.c. low-head float screen, 1,5 × 7 mm mesh One 0,6 × 4,9 m a.c. low-head sink screen, 1,5 × 7 mm mesh	Two-stage drum magnetic separators Two: 0,9 m dia. × 1,9 m Eriez	Spiral densifier, 1,7 m dia.
Consolidated Diamond Mines, No. 4 Plant	Four 1,5 m sieve bends, 2 mm aperture Four 1,9 × 4,9 m a.c. low-head float screens, 1,5 × 7 mm mesh Two 0,6 × 4,9 m a.c. low-head sink screens, 1,5 × 7 mm mesh	Two-stage drum magnetic separators Four: 0,9 m dia. × 1,9 m Eriez	Spiral densifier, 1,7 m dia.
Premier Mine, Retreatment Plant	Eight D/D 1,5 × 4,3 m a.c. low-head float screens Top deck: 5 × 45 mm mesh Bottom deck: 0,7 × 30 mm mesh Four 0,5 m sieve bends, 1,2 mm aperture Four 0,6 × 3 m Aerovibe sink screens, 1 × 5 mm mesh	Two-stage drum magnetic separators Eight: 0,9 m dia. × 1,9 m Eriez	Four cyclones, 200 mm dia.
Orapa	Four 1,5 m sieve bends, 2 mm aperture Four 1,9 × 4,9 m a.c. low-head float screens, 1,6 × 4 mm mesh Two 0,6 × 4,9 m a.c. low-head sink screens, 1,6 × 4 mm mesh	Two-stage drum magnetic separators Four: 0,9 m dia. × 1,9 m Sala	Spiral densifier, 1,7 m dia.
Koffiefontein	Seven D/D 1,9 × 6 m Eliptex float screens Top deck: 12 mm mesh Bottom deck: 0,5 × 4,5 mm mesh Seven 0,9 × 3,7 m a.c. low-head sink screens, 0,5 × 4,5 mm mesh	Two-stage drum magnetic separators Fourteen: 0,9 m dia. × 1,9 m Sala	Seven cyclones, 200 mm dia.
Kleinzee	Three 1,5 m sieve bends, 2 mm aperture Three 1,9 × 4,9 m a.c. low-head float screens, 2,0 × 5 mm mesh One 0,6 × 4,9 m a.c. low-head sink screen, 2,0 × 5 mm mesh	Two-stage drum magnetic separators Two: 0,9 m dia. × 1,9 m Sala	Spiral densifier, 1,8 m dia.

ively large heads are also detrimental, possibly owing to turbulence effects. It seems, therefore, that the DSM estimate of 9D may also be applicable to diamond separations.

The problem of light particles floating in the feed-mixing chamber is avoided by use of the DSM Stamicarbon design of feed box, which creates a suction condition in the feed section and effectively draws all the feed material down into the cyclone feed pipe.

The Orapa Mine is an open-cast operation starting literally at grass roots. In addition to grass roots, there are many tough bush roots that penetrate deep into the ground in search of moisture. On the start-up of the plant, these long roots in the feed were dragged through the screens by the gravel and caused choking of the cyclone feed inlets. Once in the cyclone, these roots tended to be pinned in the outer dense layer and to appear in the concentrate. This caused choking in the concentrate chutes and in the reconcentrating system. These chokes had to be cleared by hand and led to some diamond theft. To eliminate these roots, which had a density of about 1,5, the feed-mixing boxes were quickly redesigned in the form of inverted settling pyramids with continuous overflow. These effectively separated the roots before they were drawn into the cyclone, and the settling-box overflow, which had a density of 1,9, together with the roots and some light particles, was safely fed onto the cyclone tailing-product screen for immediate disposal of the roots and for recovery of the medium.

This shape-factor effect, by which some of the light particles that are flat or elongated can be entrapped with the heavy fraction in the heavy-medium cyclone, has been encountered with feed containing shell fragments in coastal operations and shale slabs inland. These light flats cause problems in the subsequent treatment of the diamond concentrates, both on the grease belts and in the X-ray separators. The effect seems to be related to the cyclone cone angle and is worse with 20° cyclones than with 40° cyclones.

The ratio of medium to ore fed to the cyclone is important. Obviously, it is necessary to prevent crowding and interference with free movement of particles in the brief time that they are in the cyclone and the actual separation is taking place. To use an excessive quantity of medium is, however, wasteful of power, and requires extra screening and cleaning capacity. For normal ore separation, the DSM designers have found that the pulp of the medium should be at least three to four times the quantity of ore. However, over 99 per cent of the feed has to be rejected as float in diamond separations, and it has been found that a low ratio of medium to ore leads to excessive sink fractions and to unstable operations. It is necessary to use a medium-to-ore ratio of between 5 and 7 to achieve this high degree of concentration and total diamond recovery with a clean separation.

For a gravity-fed cyclone, the ratio of medium to ore is controlled entirely by the feeding rate of ore to the mixing box. Recent testwork on the 600 mm cyclone plant at the Diamond Research Laboratory using ore from Consolidated Diamond Mines, has shown that excellent separations can be achieved at feed rates up to 135 t/h with a medium flow of approximately 220 m^3/h (800 gal/min), a medium-to-ore ratio of 4,4 to 1; feed rates of more than 160 t/h were also maintained for long periods (a medium-to-ore ratio of 3,7 to 1), and, although the quality of the separation was not assessed accurately, observation suggested that the separation was not impaired. At these feed rates, large product screens are required to give a good recovery of medium.

C. Type of Cyclone

The Williamson cyclones, using a magnetite-base medium, are 300 mm in diameter, have a wide cone angle (60°), and are operated at fairly high pressure (290 kPa). As discussed later, it has been found that high-angle cyclones can reject coarse, heavy particles larger than 6 mm, and so this type of cyclone is not suitable for coarse feed.

The bulk of the diamond operations now use standard DSM-design heavy-medium cyclones with 20° cones. There is a limited application for 40° cones in reconcentration, but testwork has shown that these cyclones, too, can reject heavy particles larger than 18 mm.

The cyclones are nearly all constructed of Ni-hard cast iron. Rubber-lined cyclones are probably cheaper to maintain, but, as with rubber-lined pumps, the lining has an unfortunate tendency to tear off in patches as it becomes worn or damaged. Unless immediately noticed, the pieces of rubber can interfere catastrophically with the separation in the cyclone and can cause serious losses. Wear on the metal cyclones causes no more than a gradual deterioration in performance, and periodic planned inspections are then sufficient to determine at what point the cyclone parts should be replaced.

Worn vortex finders are particularly dangerous since even a small hole in the vortex finder has been found to result in significant diamond losses.

The testwork at Premier Mine with their No. 9 unit encompassed a variety of cyclone designs ranging from a 20° cyclone of 525 mm diameter with an inlet of 270 mm by 70 mm, to a cyclone of 750 mm diameter with an inlet of 420 mm by 45 mm. The final cyclone used is a 600 mm 20° rubber-lined cyclone with an inlet of 280 mm by 55 mm, a vortex finder of 230 mm diameter, and a spigot of 110 mm diameter. This cyclone is fed with upwards of 150 t of feed per hour and with 8200 litres of medium per minute. It is evident that many designs of heavy-medium cyclone perform adequately.

The choice of cyclone size is not a decision that can be based on feed tonnage alone. If the feed contains large particles, the cyclone chosen will need to have an inlet large enough to prevent choking. It has been found that standard DSM cyclones of 350 mm diameter can accept feed material up to 20 mm without choking, and have even operated successfully with feeds up to 25 mm with only occasional blockage.

Apart from particle size, the choice of cyclone size may be governed by the associated pumping or screening equipment. Thus it has been found

that screening of the product and recovery of the medium from a 600 mm cyclone can be achieved satisfactorily on a standard 1,8 m by 4,9 m low-head screen.

The use of cyclones of larger capacity would then require either multiple product screens or larger product screens. To split the feed to multiple screens would result in a loss of head-room and would require more floor area. Larger screens have, to date, not been found as reliable as those used at present.

Until the recent testwork at the Diamond Research Laboratory, the capacity of the standard range of DSM heavy-medium cyclones for the treatment of diamonds from gravel was taken to be as follows:

	Cyclone diameter mm	*Feed capacity* t/h
14 inch	350	0- 25
16 inch	400	25- 50
20 inch	500	50- 75
24 inch	600	75-100

However, it seems probable that, for each type of plant and for each type of feed condition, there will be one particular design that will have particular advantages in achieving an accurate split at minimum cost. The Diamond Research Laboratory is at present undertaking research on a full-scale test rig to permit the development of optimum designs for particular conditions.

D. Recovery of Medium

After the separation in the cyclone, it is usual to recover as much of the medium as possible by drainage. This medium is promptly recycled. If the feed has been effectively prepared, there is little chance of fine, light solids accumulating in the recycling material. However, if fines do enter the medium circuit, a controlled amount of this recycled medium must be bled off and fed to the medium-cleaning circuit.

Many plants do not have this bleed facility, and rely on the inefficiency of the medium-drainage section to push a sufficient quantity of contaminated medium onto the washing screen and so keep the contamination of the medium within acceptable limits. However, existing evidence is that the major loss of medium is from the medium-cleaning circuit. It would therefore seem sensible to keep to a minimum the quantity of medium being fed to the magnetic separators by having an efficient medium-drainage section and controlling the quantity of medium to the cleaning circuit to the minimum required for efficient operation.

Usual practice on diamond plants is to have a sieve bend before the product screens to provide preliminary drainage of media, and then to use the first quarter of the product screen to complete the drainage. Williamson Mine has found that a double-stage sieve bend is most effective in draining the medium from the float product, and they then use the total-product screen for washing. The double sieve bend requires an extra 4 ft of head-room between the cyclones and the screen. This may present a problem in gravity-fed cyclones, where head-room is usually at a premium, but should not be difficult when pump-fed cyclone plants are being designed. The authors' view is that a double-stage sieve bend, combined with a drainage section on the screen, would pay in terms of reduced consumption of the medium when the feed preparation has been effective.

E. Cleaning of Medium

The dilute medium from the wash sections of the product screens and the bleed, if any, from the dense-medium circuit are cleaned by being passed through drum magnetic separators.

Losses of medium from the magnetic separator form a major part of the total loss from the system where adequate screen washing area has been supplied for the cyclone products. General experience suggests that some three-quarters of the total physical loss of the medium, as opposed to loss in chemical solution, can be attributed to the magnetic separators. The finer particles of the medium are more likely to be lost from the separators, both for mechanical reasons and because of their magnetic properties, and this results in a constant depletion of fine medium from the circuit, which is not usually balanced sufficiently by the continuous degradation of the remaining medium by pumping and attrition. For this reason, the medium in the cyclone circuit is nearly always found to be coarser than the fresh medium added to the circuit. In extreme cases, this loss of fines has contributed to a significant drop in the efficiency of the cyclone. However, a serious loss can usually be detected through an increase in the differential in specific gravity between the overflow and underflow medium.

Electro-magnetic separators were used at Williamson, but these have been superceded in the later plants by a modern type of improved permanent-magnet drum separators employing ceramic magnets[5].

These magnetic separators are usually fed concurrently, two in series, with the second machine scavenging the magnetics from the tailings of the first machine, although some designers have suggested the use of the two separators in parallel, thus reducing the load to each separator.

Drum speed is held at around 28 m/min at the surface of the drum, since this corresponds to the manufacturers' recommendations. Whether this is the optimum speed for all solid loadings is doubtful, and experiments are being carried out to determine whether there is any reduction in losses of medium if the second separator is run more slowly than the first.

In the earlier plants, the feed to the magnetic separators was pumped to the machine header box, which distributed the feed across the full width of the magnet. The design feed rate was about 1500 l/min per metre of separator width for the usual 0,9m-diameter drum separators. It was found that pump surging led to fluctuations in the flow rate of the magnetic separators, and that this led to increased loss of magnetics.

Recent plants have been fitted with a header cone, to which the dilute medium is pumped. The cone overflow is led to flood boxes over the float screens prior to the water sprays. The steady flow of cone underflow is led to the magnetic separators. Because of the settling action in the cones, very little

medium overflows the cones and is returned to the circuit.

F. Preparation of Medium

Once the medium has been recovered and cleaned, it is necessary to return enough over-dense medium to absorb the free moisture content of the feed and to permit final adjustment of the density of the feed medium by addition of a variable amount of water.

At the early Williamson plant, this preparation of the medium was carried out by a small 16 ft-diameter thickener. The underflow from the thickener was withdrawn by a Dorrco duplex diaphragm pump. The density was controlled by adjustment of the variable stroke of the diaphragm pump to give the required feed density as measured by manual samples. Thickener overflow was returned as wash water on the product screens. To assist in the thickener operation, the feed to the thickener was passed through a magnetizing coil to help the magnetite particles to flocculate. This system has been found clumsy to operate, and any build-up of fines in the circuit can lead to great difficulties in obtaining sufficient density in the thickener underflow.

With the introduction of the denser ferrosilicon medium, two methods of densification have developed.

One, 'settlement densification', uses a spiral classifier to accept the magnetic fractions from the magnetic separators. The ferrosilicon settles in the classifier and is raked up at high density for return to the dense-medium pump sump. The classifier overflow feeds back to the dilute-medium sump, and returns to the magnetic separators. With the spiral raised, all the medium in the circuit can be stored in the classifier, and this prevents the medium from settling out in the sumps during close-downs.

It can be very difficult to reagitate media that have been allowed to settle out in sumps. Corrosion of the ferrosilicon in the sump can cause it to form agglomerates large enough to be lost from the circuit with the cyclone products when the plant is restarted. However, a medium that has settled out in a spiral classifier can be gradually returned to the circuit in a dispersed form by gentle lowering of the spiral onto the settled material.

The evolution of bubbles of hydrogen as a result of the corrosion process is a common sight in both spiral densifiers and sumps during shut-down. Recent laboratory and plant work at the Diamond Research Laboratory[6] has established that the regular addition of a powdered mixture of sodium nitrite and borax to the circuit, in the approximate proportions of 0,3 to 0,5 kg of each reagent per tonne of ferrosilicon in circuit per day (for a closed circuit), causes corrosion to cease almost entirely. A dramatic reduction in hydrogen evolution was observed during the test of this inhibitor on the full-scale cyclone pilot plant at the Diamond Research Laboratory, and it was found that the ferrosilicon could be allowed to stand in the storage sump for over two weeks without any serious difficulty being encountered on start-up after this period. A full test of the inhibitor is to be carried out at Consolidated Diamond Mines shortly.

The second system is 'cyclonic densification'. Here, part of the medium is pumped at high pressure through small cyclones. The densified underflow fraction is fed to the dense-medium sump, and the overflow is fed to the dilute-medium sump and through the magnetic separators. This system gives a more compact plant of lower capital cost.

With cyclone densifiers, the quantity of medium in the circuit is generally less than an equivalent spiral densifier plant. As a result, the circuit is more sensitive to sudden changes in feed conditions and therefore requires a higher standard of operating attention. There is also no alternative to storing the medium in the pump sumps during shut-down.

G. Plant Control

Density

Initially, heavy-medium cyclone plants were controlled by the operators, who measured the density of the media manually.

The basis of automatic density control is the production of an over-dense medium to which water is added in response to measurements from a density-determining device, either on the pipe that feeds the medium to the mixing tank above the cyclone or on the pipe that feeds the mixed feed and medium into the cyclone.

Two tried and reliable methods have been developed for this density measurement.

The first is a radiation attenuation system. This employs a radio-active source on one side of the pipe and a detecting system on the opposite side of the pipe that determines the degree of radiation passing through the pipe and its contents. This type measures all the solids in the pipe (ferrosilicon, slime, and ore) and will, at a given setting, react to dilute the medium if there is an increase in slime content of the circulating medium, or if there is an increase in quantity of feed. When viscosity is not a problem, this dilution will reduce the density of separation and may be undesirable. Where viscosity problems exist because of inadequate feed preparation or breakdown of the feed in the cyclone, this device will ensure that the system fails to safety and that increasing viscosity will not lead to loss of diamonds.

The second system uses wire coils round the pipe. Magnetic material passing through the coil generates a current indicative of the quantity of magnetic material present. Because of the variation in magnetic properties, this second system cannot be used satisfactorily for mixtures of magnetite and ferrosilicon, or for flows of mixed ore and medium where the ore contains an appreciable proportion of magnetic material.

The capital costs of both these systems are of the same order — approximately R4000 per installation.

The simple differential-pressure devices used for the measurement of medium density in coal preparation have not found favour in diamond plants.

Viscosity

At present, no automatic means of measuring or controlling the viscosities of media are in use on heavy-medium cyclone plants. Several devices based on measuring the force required to rotate drums

or vanes in the medium have been proposed, but none has gained acceptance.

Efficiency

All the more recent diamond plants have been designed with an integral tailing-sampling unit that treats a continuous sample cut from the tailings screens.

Typically, a cut of 1 to 3 per cent is made of the tailing stream, and this is treated in a separate small heavy-medium cyclone installation. By observation of the quantity of heavy mineral recovered by the test plant, the operator of the main cyclone plant can quickly detect any defect in the operation. Daily recovery of diamonds from the concentrate of the test cyclone gives a continuous figure for the operating efficiency of the main cyclone plant.

A statistical-significance technique has recently been introduced that allows the operator to determine whether the number of diamonds recovered by the test plant can simply be attributed to normal process fluctuation or is indicative of a significant drop in the efficiency of the main plant[7].

It is accepted that the use of a heavy-medium cyclone test plant to check the efficiency of another heavy-medium cyclone plant is not ideal, since any basic inefficiency of the system will be duplicated. Past alternatives have, however, presented cumbersome problems in operation and certain security hazards. Consideration is now being given to the use of X-ray separators for this policing operation, but this, in turn, presents certain operating problems because of the vibration and humidity associated with most large-scale treatment plants.

In some plants a continuous check is kept of the operating efficiency of the cyclone plant by the circulation of radio-active isotopes of diamond density, which are made by the irradiation of particles fabricated from aluminium and cobalt powder. These isotopes are detected by scintillators next to the concentrate product stream, which operate hydraulic deflectors to return the portion of the concentrate containing the isotope back to the feed. The isotope then circulates continuously through the system and triggers a counter that records the number of trips. A scintillator on the tailings belt detects any isotope lost from the system, and sounds a hooter to alert the plant staff to the plant failure. The artificial isotope particles gradually wear away in the system, and are eventually lost through the screens.

An alternative type of isotope that has been used consists of an actual diamond with a hole drilled in it. This hole is plugged by a piece of radio-active cobalt wire.

Pressure

All heavy-medium cyclones are fitted with pressure gauges to indicate the feed pressure, but few of these operate reliably for any period of time. In theory, these gauges could be used to deduce pulp densities on gravity-fed cyclones and to indicate pump wear on pump-fed cyclones, but in practice the usual type of pressure gauge cannot be expected to provide reliable information for more than a short period.

However, experience on the pilot plant of the Diamond Research Laboratory has shown that, if the narrow-bore pipe feeding the gauge diaphragm is extended vertically by about 20 cm, the solids in the static pulp present in the pipe tend to settle rapidly, preventing blockage of the pipe and damage to the diaphragm. One standard coil-spring gauge has now operated successfully on this plant for some weeks.

Good correlation has been obtained on this plant between the reading of actual pressure and the theoretical pressure to be expected from a consideration of the constant head and the pulp density. This suggests that accurate pressure measurement could be used as a method for estimating the density of the medium.

Analyses of the Product

The use of analyses of product density and Tromp curves is almost the only aspect of heavy-medium plant operation that is well covered in the literature[2–4,8]. Criteria derived from these curves, such as the 'split point density' or $s.g._{50}$ and the 'probable error' or *Ep*, are very useful in the determination of optimum operating conditions, but, in diamond concentration, where complete recovery is aimed for, it is the shape of the upper and lower tail end of the Tromp curve that is of major importance. A sharp upper cut-off will indicate the likelihood of complete diamond recovery, and a sharp lower cut-off will ensure that a relatively large quantity of light material will not accompany the small percentage of heavy mineral usually present. The standard *Ep* limits of 75 per cent and 25 per cent cannot always be guaranteed to reveal the tail shapes of the Tromp curves, and may not be sufficient for the comparison between different diamond heavy-medium separators.

The importance of this tail shape of the separation curves has been commented upon by Krijgsman[3] and Dreissen[2], but no simple method of defining these tail shapes has yet been advanced.

Plans are well advanced for the introduction of a specially manufactured plastic material, colour-coded in a range of accurately known densities, that can be added in particulate form to a cyclone feed, recovered from the products, sorted by hand, and counted or weighed, thus providing a rapid method of estimating the Tromp curve of the separation; present methods of heavy-liquid analysis at high densities are messy and time-consuming.

Magnetite

The early Williamson cyclone plant[8] used a ground Swedish magnetite, which was substantially minus 65 mesh. It was found that the magnetite wore down in the circuit and that the optimum grading of new medium added to the circuit was 40 per cent coarser than 200 mesh.

This resulted in a circulating medium that was only 30 per cent coarser than 200 mesh. A finer medium was found to increase the viscosity of the medium circuit and to give a poorer separation, while a coarser medium classified too much in the cyclone and created unstable separating conditions. With a feed density of 1,9, the spigot density was 2,7 and the overflow density 1,88. Feed pressure was 330 kPa, ore-to-medium ratio 1:7, percentage concentrate 0,44 per cent, and medium consumption 700 g of magnetite per tonne of cyclone feed.

This two-cyclone plant treated 47 t/h. It was later increased to a four-cyclone plant treating 100 t/h. The feed pressure was dropped to 280 kPa and the ore-to-medium ratio reduced to 1:5. With a feed density of 2,05, the percentage concentrate fell to 0,3 per cent and the loss of medium increased to 900 g/t.

Density analyses of the products from the cyclones gave irregular Tromp curves. This suggested that an improvement in separation with a reduced percentage concentrate could be expected from an increase in the feed density. With magnetite alone, tests showed that a higher feed density gave an increased viscosity, which led to an increased retention time of diamond tracers and a loss of tracers of up to 5 per cent to the cyclone overflow.

Mixture of Magnetite and Ferrosilicon

Tests were then carried out at Williamson's with mixtures of Knapsack atomized ferrosilicon and magnetite. These pulps showed a rapid fall in viscosity when the percentage of ferrosilicon was above 20 per cent for mixtures of magnetite and normal fine-grade ferrosilicon and also with cyclone 60 grade atomized ferrosilicon.

Mixtures of magnetite and milled ferrosilicon showed the same fall only with ferrosilicon contents of over 40 per cent. One unexpected result of using the low viscosity mixtures was that large diamond tracers (2 carats) were lost to the cyclone overflow. Scintillometers grouped round the test cyclone indicated that the tracers were appearing at the outer shell before being lost. Smaller tracers were rarely lost with feeds of low viscosity. This suggests that the loss of the larger tracers was not due to any turbulence in the high-angle high-pressure cyclones.

A similar effect has been noted in large-angle desliming hydrocyclones, where large stones are held in the cyclone or are rejected with the overflow but do not come out of the spigot. It is suggested that this happens when the thickness of the downward-spiralling wall flow is appreciably less than the diameter of the particle at some part of the cyclone wall, i.e. the large particle projects through the zero flow envelope into the inner rising-spiral flowstream. Under these circumstances the large particles may easily be held up in the cyclone, or even pulled into the vortex flow and discharged with the overflow.

At Williamson's the effect was ascribed[8] to the large particles ricocheting off the inner wall and was avoided by limiting the percentage of ferrosilicon in the feed to 20 per cent of the magnetite. The pulp density of the feed was increased to 2,15, and the total cyclone capacity, six cyclones operating, was increased to 155 t/h. The percentage concentrate was reduced to 0,2 per cent.

One result of mixing ferrosilicon with magnetite was an increased consumption of medium. This was probably due to the abrasive nature of the hard ferrosilicon, which rapidly grinds away the softer magnetite. The fact that ferrosilicon is an effective grinding medium should not be overlooked. One of the early advantages ascribed to gravity-fed heavy-medium cyclones over pump-fed heavy-medium cyclones was the reduced pump wear that would result through not having to pump abrasive ore particles. However, it would seem that for kimberlite the reverse may be true.

Ferrosilicon

Ferrosilicon is now used by all the diamond plants in Southern Africa. Because of the nature of the separation required, the use of the more expensive grades of atomized ferrosilicon cannot normally be justified, and most of the cyclone plants operate on the finer grades of milled ferrosilicon. The manufacturers' specifications for the various grades available in South Africa are given elsewhere[9].

Previous operating experience has suggested that any given grade (size distribution) of ferrosilicon would cut at a fixed specific gravity regardless of the specific gravity of the medium or the feed pressure. However, recent tests at the Diamond Research Laboratory on a 600 mm cyclone indicated that relatively wide variations in $s.g._{50}$ can be achieved by varying the specific gravity of the medium — typically variations of 2,4 to 3,0 in the specific gravity of the medium produced variations of 2,9 to 3,35 in the $s.g._{50}$ over a narrow range of ore characteristics. Small changes in the size distribution of the medium were also found to affect the quality of the separation significantly. However, no direct relationship was found between the $s.g._{50}$ and the specific gravity of the underflow medium, as suggested in the literature[10], since the specific gravity of the underflow medium was found to vary only slightly with specific gravity of the feed for a given grade of ferrosilicon.

The sharpness of the split achieved has been found to be influenced by the grade of milled ferrosilicon used, being higher for the finer ferrosilicon, particularly in the finer sizes of ore. In some diamond applications, however, the proportion of feed ore of middlings density is small, and it is not necessary to strive for the sharpest possible split. It is then possible to operate the cyclone with a low feed density, so as to reduce the probability of diamond loss without increasing the amount of concentrate unduly. Under a given set of operating conditions, this also leads to a reduction in the amount of ferrosilicon in the cleaning circuit, and hence to lower ferrosilicon losses.

Corrosion of the milled ferrosilicon can lead to high losses, and massive corrosion can be initiated, even at a pulp pH as high as 10, by a variety of causes that as yet are not well understood. However, as noted earlier, the introduction of a promising corrosion inhibitor may succeed in reducing corrosion significantly.

Some losses of ferrosilicon can occur if new medium is added to the circuit without pre-wetting, the unwetted ferrosilicon being carried out as a film on the products of the separation; a separate circulatory pump and sump have been found useful to pre-wet the added ferrosilicon. Laboratory tests have suggested that atomized ferrosilicon is considerably less prone to this loss than milled ferrosilicon.

Costs

Although the subject of costs must be paramount in the consciousness of all practising engineers, it is possibly the most difficult area in which to obtain exact and com-

parable figures, not only from one operation to another, but even from month to month within one given operation. The most detailed computerized system still relies on the fallible individual for the conscientious logging of time spent on different sectors by maintenance and engineering personnel. The cost of spare parts may or may not include transport costs, storage costs, and stores overheads. Amortization allowances are usually included in power costs, but not in water-supply costs or in general plant costs. The cost of replacing major equipment may be included as it arises, or may be carried in an accumulating suspense or contingency account. To the despair of the engineer, accounting seems to be much more of an art than a science, and its findings must be applied with considerable circumspection. The figures in Table IV must then be viewed in the light of the above. The basic data have been supplied in good faith by the mines concerned but may not be strictly comparable between mines. The authors have arranged the data in roughly similar areas and have reduced the figures to cost per tonne of units of feed to the cyclone operation concerned. The tonnages are generally corrected for moisture content. The figures for screening, pump parts, and cyclone parts refer solely to the cost of replacement parts and, together with the cost of ferrosilicon, represent the most accurately costed areas.

Despite all the above reservations, Table IV shows remarkably close agreement between the operating costs of the various plants. The slightly higher cost of spare parts at Consolidated Diamond Mines can be related to the corrosive effect of the sea water used in this plant, while the higher use of medium at Koffiefontein may be due to the lack of storage facilities in the circuit as discussed above. The higher power costs relate to the mines that generate their own power, while the lower figures are from mines that use cheaper power from the national grid.

A reasonable conclusion from these figures is that the operating cost of fairly large heavy-medium cyclone plants in the diamond field is about 15 to 20 cents per tonne of feed to the heavy-medium cyclone.

Capital Cost

The capital cost of heavy-medium plants is increasing rapidly with inflation, but at the time of writing it is estimated that the budget price of a heavy-medium cyclone plant with feed preparation is of the order of R150 000 per 100 t/h of cyclone capacity.

CONCLUSIONS

Heavy-medium cyclones are now widely used in the diamond industry, and it is hoped that the figures given in this paper will enable other sections of the minerals industry to assess the economic worth of this technique. As a primary gravity-separation system, it cannot rival the low cost of, say, the jigs used for the recovery of tin. However, the heavy-medium cyclone is capable of making a much more complete separation of minerals that have only a small difference in specific gravity than can a jigging process, and it is capable of handling a coarser feed.

This aspect of the technique makes it an ideal primary separator for the removal of clean, light gangue from partially liberated heavy minerals, with a consequent reduction in the amount of ground to be treated by further expensive grinding and flotation methods. Heavy-medium cyclones are already being successfully used for primary concentration in the recovery of uranium, tin, fluorspar, coal, and iron ore in South Africa, and of tungsten in Portugal. The expansion of the unselective open-cast mining of low-grade orebodies makes it seem likely that there will be a growing field of application for heavy-medium cyclones in the mineral-processing industry.

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TABLE IV

OPERATING COST OF HEAVY-MEDIUM CYCLONE PLANTS IN SOUTH AFRICAN CENTS PER TONNE OF FEED TO THE CYCLONE

	No. 4 Plant C.D.M. c/t	Premier Retreatment c/t	Koffiefontein c/t	Orapa c/t	Williamson's c/t
Labour and supervision	1,1	2,5	2,0	1,9	1,3
Screening	1,6	1,5	1,4	1,9	
Medium	3,4	2,8	6,8	5,4	5,3
Cyclone parts	0,4	0,2	0,1	0,1	
Pump parts	0,8	0,5	0,2	0,4	
Maintenance	1,6	2,7	1,5	2,6	2,6
Power and water	4,0	3,8	3,5	6,6	6,2
Overheads and sundries	2,3	2,8	2,1	1,5	1,5
TOTAL	15,2	16,8	17,6	20,4	16,9
Tonnes per hour to heavy-medium cyclones	360	340	560	350	155

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DISCUSSION OF THE ABOVE PAPER

In introducing the above paper, Mr Chaston mentioned that it was based on a paper that he had presented to the International Mineral Processing Congress in London in 1973. However, as a result of the recent work of his co-author, Mr Napier-Munn, several additions had been made to the original paper. For example, this work had led to a re-appraisal of the optimum head required for gravity-fed cyclones. It now appeared that a head of only 5 m was required to operate standard 600 mm cyclones and that, on the type of gravel treated at Consolidated Diamond Mines, the quality of separation was marginally improved at this lower head. The consequent saving in conveyor length and structural steel in future plant designs would be very considerable. The work also indicated that higher feed rates of up to 160 tonnes per hour per cyclone of this type of gravel could be handled by the standard 600 mm cyclone without any appreciable effect on the quality of the separation.

The development of the mixture of sodium nitrite and borax as a corrosion inhibitor could be of great interest to many operators who had problems during hot-weather shut-downs with caking and gassing of corroding media.

The costs given in the paper were applicable to 1972 and had risen considerably since then. The average operating cost of a dense-medium cyclone plant on the diamond mines could now be reckoned to lie in the range 20 to 25 cents per tonne treated, rather than the 15 to 20 cents given in the paper, and the capital cost of recent plant had been of the order of R200 000 to R250 000 per 100 tonnes per hour of cyclone capacity.

Mr Chaston wished that he had as much faith in the high efficiency of magnetic separators as had been indicated by Dr Beeton in his contribution (pp. 115-116). If this was so, then it would seem possible, as he had suggested in the paper, to extend dense-medium cyclone operation down in size to below the 0,5 mm that was the present limit imposed by the difficulty and expense of fine screening, and also to eliminate the expense of careful feed preparation. If the feed was cycloned to remove the bulk of the slime, it could be mixed with recycled ferrosilicon and passed through the cyclone. The products could then be treated directly by magnetic separators for the recovery of medium without screening or, at most, the coarser material that might interfere with the operation of the magnetic separator could be removed. Although the expense in magnetic-separation equipment might be high, the operating cost of magnetic separators was very low and such a plant could be extremely compact. The major consideration would be the very high recovery efficiency required of the magnetic separators. At present, the authors' experience suggested that the ferrosilicon loss from the magnetic separators at present in use would make such a system impractical, but it would not seem impossible to hope that, with improved magnetic separators, such a system would be operable.

The table on page 133, which shows an analysis of the products of a cyclone separation of a uranium ore, is of considerable interest.

It can be seen that most of the ground is in the density range 2,6 to 2,65. Nevertheless, after separation in the cyclone, the sink product in this very narrow density range assayed three times the float product in the same density range. It seems probable that this was due to some fortuitous shape factor that causes the uranium-rich material to collect in the sink. Such an effect would not have shown up in a preliminary density analysis of the feed material.

Mr Chaston closed his introduction by emphasizing the worth of the gravity-concentration process as a cheap method of primary concentration for the increasingly low-grade orebodies of today and the future, and hoped that more research students would continue the excellent investigational work carried out by Professor Richards at the end of the last century into the science of gravity concentration. This had been largely overlooked in the rush of research work into the new science of flotation, which had developed in the early part of the century. It was now time to direct some of this energy into the development of improved methods of gravity concentration, since this permitted a concentration to be made at a coarse size before the great expense in cost and energy that was involved in fine grinding was incurred.

R. J. ADAMSON*

The paper is a comprehensive description of past and current practice, and it is therefore difficult for me to offer a contribution on normal lines—such as filling in gaps or elaborating on methods currently employed or pending—the latter particularly as I have not been in close touch with dense-medium separation for the last five years. However, it has been said, and I think justifiably, that the history of a science is in fact the science itself. By providing a history of heavy-medium separation as applied to diamond recovery, the authors have rendered a valuable addition to its general application in mineral-dressing techniques.

There is, however, one emendation and one explanation that I wish to add to their presentation. Firstly I must correct an impression conveyed by them that dense-medium processes were introduced to displace washing pans in the treatment of diamondiferous ore. Up to the last World War, methods of diamond recovery in Southern Africa were more or less evenly divided between pans and jigs. At Kimberley, at Jagersfontein, and on the alluvial diggings, the concentration of diamond ore depended on washing pans but, at Premier Mine, at the State Alluvial Diggings in Namaqualand,

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and in South West Africa, pans had not been successful and primary concentration was effected by jigs. At Premier Mine, so-called 'pulsion jigs' displaced pans from 1909 onwards, and, in Namaqualand and South West Africa, both Plietz and Schiechel jigs held sway until 1950[1].

When heavy-medium separation —also then termed 'high D' and later 'sink and float'—was invented by Wuensch and his collaborators at Eagle Picher for the beneficiation of iron ore, the process depended on either galena or iron pyrites as the medium, with flotation the means of medium recovery. Subsequently, Henry Wade and his staff at Minnesota University developed a medium of 15 per cent ferrosilicon, which could be recovered and cleaned by magnetic separators. The higher density of ferrosilicon (close to 7) greatly extended the scope of heavy-medium separation, as a separating density of 2,8 to 3,0 could be sustained with a low viscosity in the medium.

As a result, great interest was aroused in mineral-dressing circles by this new process, and soon a slogan appeared propagating the adoption of heavy-medium separation, claiming that 'whatever jigs can do, sink and float can do better'.

It was at this stage of heavy-medium separation that we in the Anglo American Corporation were studying the best means of treatment for the re-opening of Premier Mine, which had ceased operations in 1932. As it appeared possible that heavy-medium separation would offer an improvement on the previous jigging plant, a pilot plant of 100 tons per hour capacity was erected in 1947, using ferrosilicon imported from the U.S.A. Following successful results, the main plant of 13 000 tons per day capacity was commissioned in 1950[1]. It was not only the sole heavy-medium separation plant in Africa, but tonnage-wise was the largest in the world. The 100 tons per hour pilot plant was then transferred to Consolidated Diamond Mines in South West Africa, where it proved an excellent production unit, replacing the jigging plant and meeting demands for extended output from 1951 onwards. In both cases no difficulties were experienced regarding patent rights and royalties—the latter, being reasonable, were readily paid.

It would seem anomalous, therefore, that, after heavy-medium separation by means of cones had been pioneered by diamond plants in South Africa in the late forties, hydrocyclone separation units, using either magnetite or ferrosilicon as a medium, were not in operation in South Africa until 1961. The authors mention the installation of hydrocyclones during 1955 in Tanzania and in 1959 at Bakwanga. Presumably these installations were not handicapped as we were in South Africa and South West Africa by the imposition of uneconomic royalties by the holders of the patent rights for the use of hydrocyclones as concentrators employing magnetite or ferrosilicon media. The unrealistic royalty demands—particularly in application to the smallest and least valuable constituents of the diamondiferous ores—delayed the use of hydrocyclones at Premier Mine until 1961, the year in which patent rights were expiring. This resulted in the installation of hydrocyclones with ferrosilicon media in the re-treatment plant commissioned in 1962 to recover industrial diamonds from the tailings dump.

From that stage onwards, as the authors have clearly demonstrated, marked advances in the application of dense-medium cyclones have been made in diamond recovery over all size ranges.

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R. J. MACGREGOR* and C. B. PARKER*

Much published information is available to permit the precise design of 'classifying' cyclones for any particular application, but to date there has been a paucity of published data on the design, and even application, of the cyclone as a heavy-medium separator. Most design criteria and the effects of the type of medium used remain purely empirical. It is hoped that the publication of Messrs Chaston's and Napier-Munn's paper will provoke wider international interest, and will lead to a general dissemination of the information already available so that needless duplication of research work is prevented.

It is interesting to compare the concentration ratios for the various plants as reflected in Table I. Dreyers Pan, Consolidated Diamond Mines, and Kleinzee, all treat alluvial gravels and give the lowest concentration ratios. Better ratios are achieved when only kimberlite is treated. Is this effect solely due to the lower ratio of heavy mineral content in kimberlite (generally, less than 0,2 per cent mass has a specific gravity of more than 3,0), or is the separation affected by inherent slime generated in the medium circuits of the latter?

Feed preparation is correctly shown to be an economic consideration balanced against the amount of medium to be cleaned per cycle. At the Premier Mine Retreatment Plant, the quality of the water used in circuit was found to have a significant effect on separation over a period of time. The spray water and make-up circuits consist entirely of reclaimed water containing 8 to 12 per cent suspended solids, which are all in the minus 200 mesh size range and mainly colloidal in nature. Possibly owing to the decreased screening efficiency, a build-up of slime in the medium circuit can be measured. This in effect displaces the equivalent amount of medium being recycled, i.e., the ratio of medium to ore (as mentioned in section B of the paper) gradually decreases and results in a sharp drop in efficiency of separation, visible as a sudden increase in spigot product with entrainment of lighter float particles. This effect is minimized in practice by the 'bleeding off' of medium to the magnetic cleaning circuit during 'slack' periods to restore the ratio.

It is felt that this unbalance of the medium-to-ore ratio by entrained slimes is the main reason for an upset in separation efficiency, rather than the increased viscosity of the medium due to the slime. High shear rates in pump and

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cyclone tend to overcome the effects of increased viscosity.

Experience with the earlier pump-fed plants emphasized the necessity of maintaining a constant head for efficient separations. Only slight variations, or rather fluctuations, in medium level in the pump sump were sufficient to reject radio-active tracers to tailings.

Particle shape has been mentioned as resulting in the entrainment of flat, light particles in the spigot product. In this regard it may be worth mentioning a problem encountered with the Premier No. 9 cyclone unit treating old dump tailings, in which layers of ash and particles of unconsumed coal are often found.

Like the grass roots of Orapa, a considerable amount of coal reported with the final concentrates, fouling the grease surfaces in the final recovery process and leading to mechanical loss of diamonds. Because it was not a gravity-fed unit, there was no easy solution as at Orapa. A measure of success (but not a complete solution) was achieved by altering the geometry of the inlet to the cyclone, which at the time was a semi-ribbon feed flush with the top of the inlet chamber. Lowering the top of the inlet below the top of the inlet chamber and using a wider and shorter inlet aperture with substantially the same inlet area appeared to have the desired effect on the separation by minimizing the amount of coal entrained in the spigot product.

Further investigation on these lines may be profitable. In this regard, also worthy of mention may be the wear pattern of the vortex finders in the Premier retreatment nickel-hard cyclones, which are now routinely rotated by 90° or 180° to extend their useful life. Wear shortens the effective length of the vortex finder by as much as 20 to 25 per cent before a decrease in diamond recovery efficiency is noted.

The most effective use of a heavy-medium cyclone in older established diamond plants, where jigs are part of the concentration circuit, is as a secondary concentrator treating the very dilute jig concentrate. Under these circumstances, the reconcentrating heavy-medium cyclone may make a spigot product of 10 per cent or upwards, i.e., a concentration ratio of 1:10. Slight variations in day-to-day efficiency are of no import if the float product from the cyclone is recycled to the jig feed.

AUTHORS' REPLY

Messrs MacGregor and Parker are to be thanked for their addition to the information on the operation of the heavy-medium cyclones at Premier Mine. A sudden change in rheological properties of the medium may present a very real danger to efficient separation. Recent work at the Diamond Research Laboratory suggests that, under high shear forces, ferrosilicon suspensions form a dilatent mixture where viscosity increases under shear. This could lead to some very odd effects in the central regions of high shear in the cyclone. The effect of a pseudo-plastic slime on the dilatent ferro-silicon mixture is being investigated at the Diamond Research Laboratory.

The reason for the lower concentration ratios in the treatment of clean gravels as compared with the treatment of kimberlites is solely related to the percentage of heavy minerals, which is higher in the gravels than in kimberlite.

Products from a heavy-medium cyclone treating a uranium ore

Density range	Float			Sink		
	Mass % of feed	U_3O_8 kg/t	U_3O_8 %	Mass % of feed	U_3O_8 kg/t	% of feed
−2,6	2	0,03	—	—	—	—
−2,65+2,6	55	0,06	17	19	0,20	19
−2,7 +2,65	13	0,27	17	4	0,48	10
−2,9 +2,7	—	—	—	4	1,00	20
+2,9	—	—	—	3	1,20	17
	70	0,10	34	30	0,44	66

Electrochemistry Conference

The Fourth Australian Electrochemistry Conference will be held at The Flinders University of South Australia, Adelaide, from 16th to 20th February, 1976. The central theme will be 'Electrochemistry for a Future Society', and the sessions will emphasize electrochemical contributions in the following areas:

Energy Conversion and Storage
Materials Science and Corrosion
Utilization of Natural Resources
Environmental Sciences
Waste Treatment and Recycling
Bio-electrochemistry.

Other fields of electrochemistry will be included in a general session.

Papers are now invited on the above specific topics and for the general session. The final submission date for titles is 1st August, 1975, and for abstracts is 1st October, 1975.

The Conference Secretary is Dr T. Biegler, CSIRO, Division of Mineral Chemistry, P.O. Box 124, Port Melbourne, Victoria 3207, Australia.