Plant practice in the flotation of phosphate

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SYNOPSIS

This paper highlights modern practices in ore-treatment plants, with particular reference to the flotation of P_2O_5 at the plants of the Phosphate Development Corporation (Foskor) at Phalaborwa in the northern Transvaal. The following aspects are covered: design criteria, equipment and personnel, production standards and control, cost control, maintenance, and process development.

SAMEVATTING

Hierdie referaat bring die moderne praktyke in ertsbehandelingsaanlegginge na vore met spesiale verwysing na die flottasie van P_2O_5 by die aanlegginge van die Fosfaat-ontginningskorporasie (Foskor) te Phalaborwa in Noord-Transvaal. Die volgende aspekte word gedek: ontwerpmaatstawwe, toerusting en personeel, produksiestandaarde en -beheer, kostebeheer, onderhoud en prosesontwikkeling.

The extraction of minerals in the present climate of ever-increasing prices of labour, equipment, spares, and chemicals can become very costly if the operations are not managed effectively. To be competitive in price and quality on local and overseas markets, producers of minerals must build competitive plants, develop cheaper extraction processes, minimize the use of expensive chemicals, especially those derived from oil, and manage their plants professionally. This paper highlights modern plant practices, illustrating them by reference to the flotation plants of the Phosphate Development Corporation (Foskor) at Phalaborwa.

The subject of plant practice in phosphate-flotation covers such a wide area that it would be impossible for a short paper to deal with all the factors involved. This paper therefore covers only the following aspects: the design criteria for a flotation plant, the equipment used and personnel employed, suitable reagents, production standards and control, cost control, maintenance, and process development.

Phosphate Flotation Plant

A general flowsheet for a P_2O_5-enrichment plant is given in Fig. 1, which shows the position of the P_2O_5-flotation plant in the general configuration. A specific flowsheet for such a flotation plant is shown in Fig. 2.

The mass balance of the flowsheet shown in Fig. 2 is given in Table I.

The operating results related to the mass balance of Table I were as follows:

Solids feed, t/h 140

Pulp density of feed 1,498

Reagent dosage rates, ml/min

NaOH (20%)	=	3 300
Waterglass (20%)	=	18 000
Fatty acid	=	650
P.G.E.*	=	180

Results	P_2O_5 in feed	12,4%	P_2O_5 in tailings	4,7%
	P_2O_5 in conct.	36,5%	Recovery	70,9%

*Nonyl phenol tetraglycolether.

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Design Criteria

The following points are important in the design of a flotation plant.

(*a*) *Volume of Flotation Cells Required to Float 1 t/h Ore*

This volume is the basis for the design of a flotation plant, and differs for different types of ore and for different types and sizes of flotation cell.

The flotation of apatite ore at Foskor involves three types of feed: pyroxenite, foskorite, and copper tailings (also referred to as PMC tailings, being tailings from the copper-recovery operation at Palabora Mining Company).

For the pyroxenite, the following results have been obtained over the years.

Flotation cell: Denver, 1,416 m^3

Annual tonnage: 20 300 t/m^3 (of cell), or 28 800 t per cell

Flotation cell: Wemco–Fagergren, 8,496 m^3

Annual tonnage: 28 600 t/m^3 (of cell), or 242 700 t per cell

Table II illustrates the difference between the type of ore and the required flotation-cell capacity. The tonnages are fixed for a specific fineness and pulp density of feed.

(*b*) *Fineness of Flotation Feed*

The fineness of grind is optimized for every type of apatite ore to be floated, as shown in Table III.

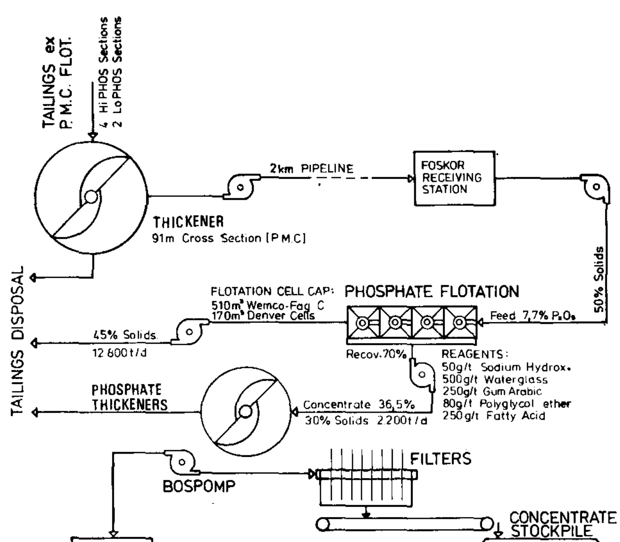

Fig. 1—Flowsheet for the treatment of copper tailings from Phalabora Mining Company (PMC)

TABLE I

MASS BALANCE OF FLOWSHEET SHOWN IN FIG. 1

Sample/Stream	P_2O_5 %	Pulp density	Solids %	Sieve analysis −65M	Sieve analysis 65–35M	Sieve analysis +35M	P_2O_5, % −65M	P_2O_5, % 65–35M	P_2O_5, % +35M	Solids flow t/h
Feed	12,9	1,498	47,2	60,0	27,4	12,7	13,9	12,7	8,8	140
Ro feed	18,5	1,362	37	68,3	24,1	7,7	17,8	23,1	12,5	357
Ro tails	11,4	1,282	43	63,7	24,8	11,5	10,3	14,8	9,0	199
Ro conct.	28,7	1,383	46,8	81,0	17,6	1,3	26,4	39,4	38,8	158
Sc tails	4,9	1,203	24,5	53,5	30,8	15,8	3,5	6,4	6,8	112
Sc conct.	20,6	1,234	27,7	82,7	16,0	1,4	17,5	35,3	39,1	89
Cl tails	26,9	1,301	33,5	80,0	18,6	1,5	24,2	38,8	39,3	129
Final conct.	36,8			82,6	16,3	1,2	35,8	41,3	40,9	29
Overall recovery						71,4	82,5	58,6	27,6	
Ro recovery						64,4	69,3	56,8	35,3	
Sc recovery						84,6	83,6	69,5	30,1	
Cl/ReCl recovery						24,0	26,8	20,6	22,4	

Ro average retention time, 7,2 min
Sc average retention time, 9,9 min
Cl/ReCl retention time, 8,7 min

(*c*) *Configuration of Cells*

Depending on the floatability, fineness of ore, concentrate grade, and P_2O_5 recovery, an optimum configuration of rougher, scavenger, cleaner, and recleaner cells must be arrived at.

(*d*) *Circulating Load*

The circulating load determines the required capacity of the pumps in a plant.

(*e*) *Rotation Speeds of Rotors in Cells*

The optimum tip speed of the rotors depends on the rotation speed of the rotors:

Pyroxenite ore 300 r/min
PMC tailings 350 r/min.

(*f*) *Materials of Construction for Cell Parts*

The material of construction must be selected to suit the erosion properties of the ore, the fineness of the grind, and the pH value of the flotation material.

(*g*) *Flow Velocities in Pipelines*

The flow velocities are determined by the relative density of the pulp and solids to be pumped. In the flotation of P_2O_5 the velocities vary between 2 and 3 m/s.

Although there are other aspects to be considered in the design of a flotation plant, the most important ones have been given here. Others include the following:

(i) a mill circuit capacity to provide a certain throughput at a given size distribution (very coarse and very fine material give poor recoveries);
(ii) a flotation capacity to give at least the minimum retention time required for a certain recovery;
(iii) a flotation circuit that will produce the required grade of concentrate while being as simple as possible, and flexible so that it can adapt to changing types of ore and grades of feed;
(iv) an accurate and stable dosage system for reagents;
(v) an accurate monitoring system to measure how much goes in and how much comes out, and so ensure accurate metallurgical control; and
(vi) standby pumps and lines to ensure a minimum of downtime.

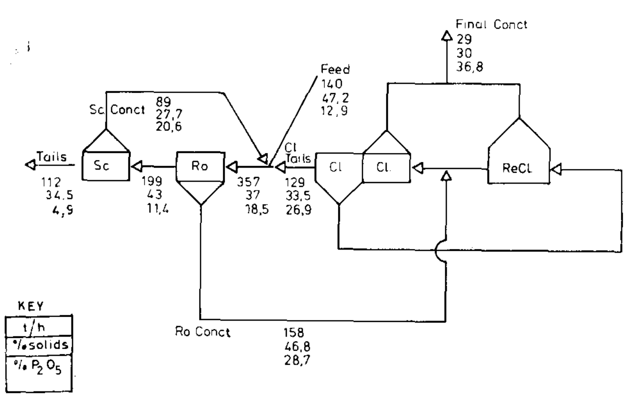

Fig. 2—Flowsheet for the flotation of copper tailings from Phalabora Mining Company (PMC)

TABLE II

THROUGHPUT OF ORE PER ANNUM

Feed	Denver 1,416 m^3 cell t/m^3	Denver 1,416 m^3 cell t per cell	Wemco–Fagergren 8,496 m^3 cell t/m^3	Wemco–Fagergren 8,496 m^3 cell t per cell
Pyroxenite	17 500	24 700	24 000	203 900
Foskorite	10 700	15 200	17 900	152 000
PMC tailings	12 000	17 000	14 300	121 700

TABLE III

TYPICAL SIZE GRADING OF FLOTATION FEED

Particle size μm	Pyroxenite %	Foskorite %	PMC tailings
+ 35	14,5	12,8	2,1
+ 65	17,8	13,4	6,8
+100	14,0	11,4	10,7
+200	13,1	13,7	20,9
+270	7,4	11,0	14,7
−270	17,4	23,5	25,3

Equipment for a P_2O_5 Flotation Plant

The following equipment is required.

(*a*) *Milling Circuit*

(i) 2,7 m by 4,1 m rod mills

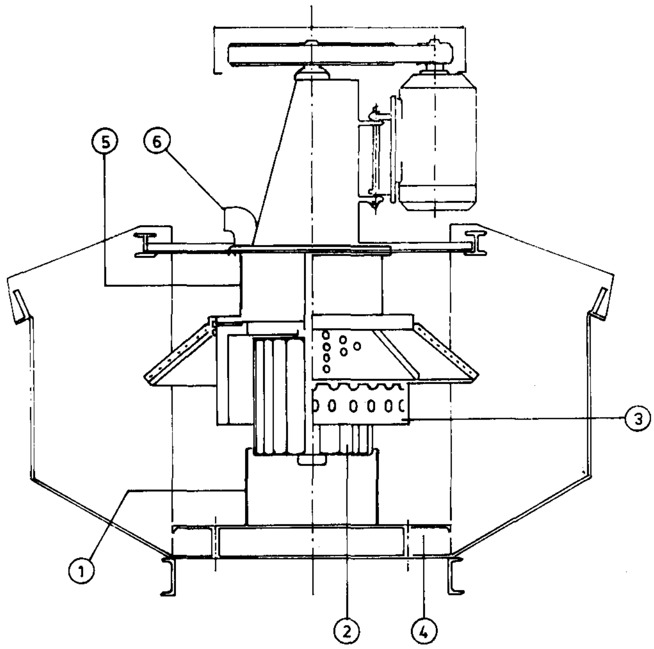

Fig. 3—A typical 8,496m³ flotation cell
1. Draught tube
2. Rotor
3. Dispenser
4. False bottom
5. Standpipe
6. Air inlet

(ii) 10 by 10 in Hydroseal horizontal centrifugal pump
(iii) MSRL cyclones
(iv) MSRL piping.

(b) *Flotation Plant*
(i) Mild-steel rubber-lined piping (P.V.C. piping)
(ii) Mild-steel rubber-lined conditioners
(iii) Flotation cells.

In the selection of a flotation machine, the machine should offer maximum economy in terms of capital, installation, and operating costs, commensurate with a high metallurgical efficiency in regard to concentrate grade and recovery. It was with these considerations in mind that Foskor installed the larger, 8,496 m³ machines. These machines are self-aerating units and are mounted in an open trough type of tank (Fig. 3). The principal parts of the mechanism are the moulded-rubber star-shaped rotor and the stationary rubber disperser that surrounds it.

The following example is given as a practical illustration of the advantage of these large cells. For the treatment at Foskor of 10 Mt of foskorite per annum, or 1150 t/h, the following would be required for an ore relative density of 3,0, a feed slurry of 43 per cent solids or a pulp density of 1,420, and a retention time of 24 min:

$$\frac{1150 \times 24}{0{,}43 \times 1{,}420 \times 60} = 753 \text{ m}^3$$ flotation capacity. Table IV gives comparative data for a plant of this capacity using flotation cells of two sizes. (It is assumed that the performances of small and large cells are equal.)

Fig. 4 illustrates the cost factor per cubic metre of cell capacity. It is apparent that the installed power will also result in reduced capital spending, and, owing to the fewer cells installed, the size of the building can be considerably smaller.

(iv) Recycle pumps, tailing pumps, and sumps

Hydroseal or Centriseal horizontal pumps are used at Foskor, and are fed from conical pump-sumps to de-aerate the slurry. A froth factor of up to 100 per cent must be allowed for in the calculation of pump requirements.

(v) Sampling points

Adequate sampling points with automatic samplers must be installed.

Personnel Employed

A typical organizational chart for an ore-treatment plant is given in Fig. 5. The responsibilities of the officials mentioned are as follows:

1 Metallurgist is in charge of 6 flotation plants
1 Shift Foreman is in charge of 6 flotation plants
1 Plant Operator is in charge of 2 flotation plants
1 Plant Attendant is in charge of all the pumps in one flotation plant

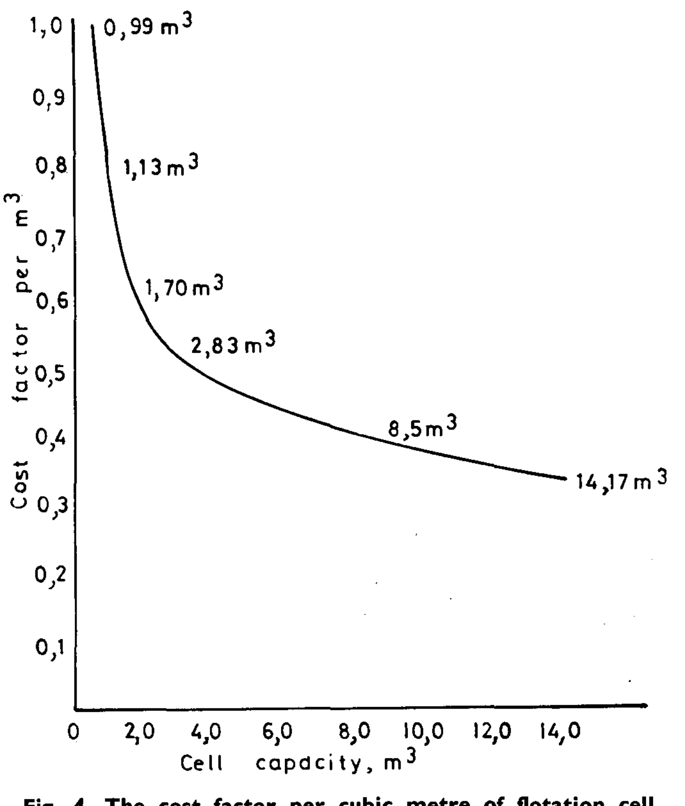

Fig. 4—The cost factor per cubic metre of flotation cell capacity

TABLE IV

A COMPARISON BETWEEN FLOTATION CELLS OF TWO SIZES

Cell volume m³	Number of cells	Cost factor per m³	Total installed power, kW
1,416	531	1,00	3 980
8,496*	88	0,40	2 404

*In practice, this means 5 rows of 16 cells each compared with 22 rows of 24 1,416 m³ cells each.

1 Plant Attendant is in charge of all the cells in one flotation plant

1 Plant Attendant is in charge of reagent dosing in one flotation plant.

All the superintendents and metallurgists are graduates (B.Sc. or B.Sc.(Eng.)), and very often also have M.B.A. or M.B.L. degrees. Special investigations on the plant are undertaken by the Metallurgical Services Department. All the control samples are analysed by a central shift laboratory, and all the research and development work is undertaken by the Research and Development Laboratory.

For comparison purposes, the total manhours required to produce 1 ton of P_2O_5 concentrate is 0,06, and the manhours required to treat 1 ton of ore is 0,009.

Reagents Used

Different reagents are used for the three types of feed at Foskor.

(*a*) *Pyroxenite*

(i) Distilled tall oil fatty acid

The fatty acid used is derived from tall oil and/or vegetable oils, and consists of unsaturated and saturated acids. The fatty acid acts as a collector for apatite, as well as possessing certain frothing characteristics. The typical consumption rate is 200 g per ton of ore.

(ii) Petroleum sulphonate

This is an alkyl aryl petroleum sulphonate with about 80 per cent active ingredients, $R\text{-}SO_3H$, which acts as a froth modifier. The typical consumption is 160 g per ton of ore.

(*b*) *Foskorite*

Foskorite consists of the following by mass:

Apatite	15 to 30%
Calcite/dolomite	10 to 50%
Olivine/serpentine	10 to 25%
Magnetite	10 to 30%
Mica	0 to 10%
Others	Less than 5%

The reagents used are as follows.

(i) Waterglass, $SiO_2 : Na_2O$ 2 : 1

This sodium silicate acts as a dispersant, and serves to depress the iron silicates, diopside, and olivine. The typical consumption rate is 800 g per ton of ore.

(ii) Fatty acid

This is the same as the fatty acid used in the flotation of pyroxenite. The consumption runs at about 250 g per ton of ore.

(iii) Caustic soda

Caustic soda serves as a pH-regulator and surface cleaner, and, together with waterglass, as a water softener. The consumption rate is variable since it is used only in the flotation of weathered ore.

(iv) P.G.E.

A non-ionic surfactant and emulsifier, P.G.E. is manufactured as a condensation product of nonyl phenol and ethylene oxide. P.G.E. acts as a froth modifier, and depresses calcite and iron minerals. The typical consumption rate is 100 g per ton of ore.

(*c*) *PMC tailings*

(i) Waterglass

This is the same as the waterglass used in the flotation

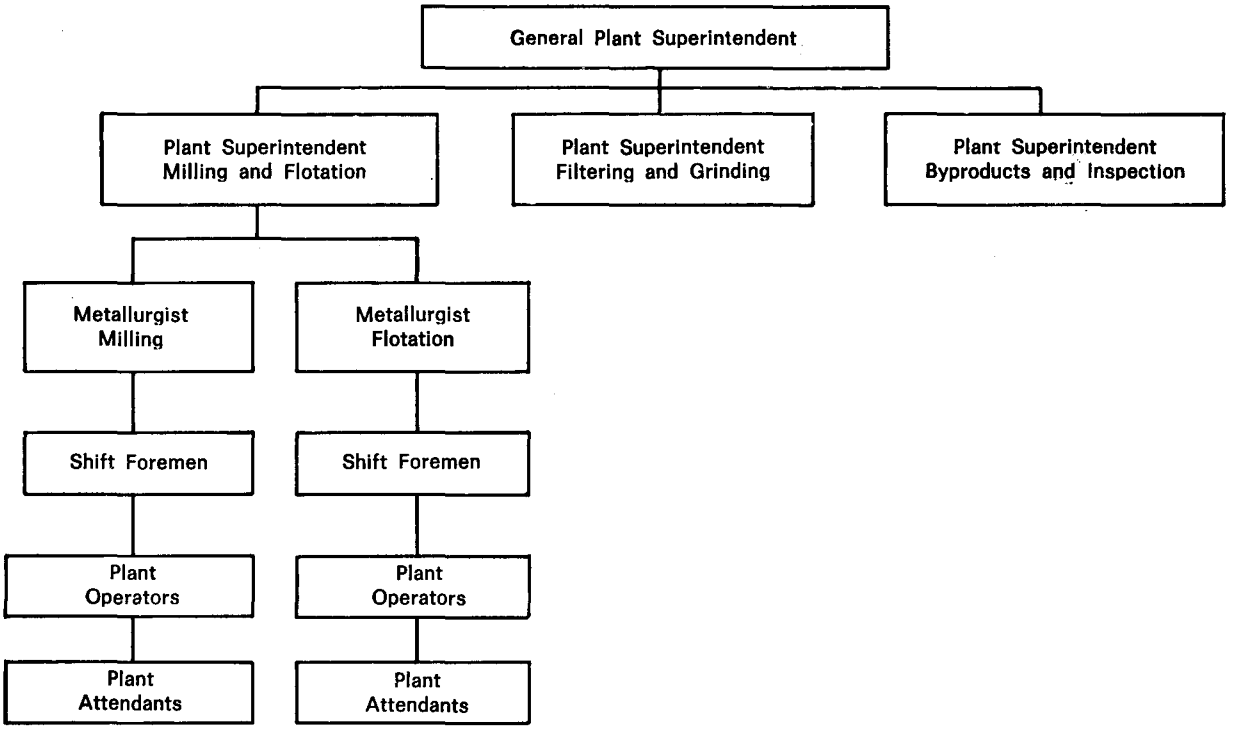

Fig. 5—Organizational chart of an ore-treatment plant

of foskorite. The consumption is about 500 g per ton of feed.

(ii) Gum arabic

Gum arabic is a polysaccharide, consisting mainly of glucuronic acid, galactose, arabinose, and rhamnose. It serves as a depressant for calcite by rendering it hydrophilic, and thus preventing it from entering and stabilizing the froth. The results of work conducted at the National Institute for Metallurgy (NIM) and at Foskor have shown that the non-selective flotation conditions experienced in the flotation of PMC tailings by conventional means are due to the nature of the water in the PMC tailings. Precipitates formed by the interaction between the collector ions and the metal ions present in this water (magnesium and calcium) can act as non-selective collectors, presumably by coating the various particles. It is believed that gum arabic, by its strong dispersant action, removes these coatings of metal oleate from the particles of ore and thereby restores selectivity to the flotation system. The consumption is about 250 g per ton of feed.

(iii) Caustic soda

This is the same as that used for the flotation of foskorite. The consumption runs at about 100 g per ton of feed.

(iv) Fatty acid

This is the same as that used for the flotation of pyroxenite. The consumption is about 350 g per ton of feed.

(v) P.G.E.

This is the same as that used for the flotation of foskorite. The consumption is about 130 g per ton of feed.

Production Control and Reporting

High productivity in a plant means the optimum utilization of money (capital), machines (plant equipment), and men (personnel). One must never look at any of these on its own but always as a system, which must be in balance. Some of the practical aspects in a P_2O_5 flotation plant are briefly outlined below.

(*a*) *Running Time of Equipment*

As equipment costs in a flotation plant are very high, one must always try to run a plant for 95 per cent or more of the available time in a month. This figure allows 3 per cent of the available time for scheduled stoppages (inspections and scheduled maintenance) and 2 per cent for breakdowns. The plant should have standby pumps and lines. The relevant figures must be reported daily and summarized monthly on a daily cumulative basis as shown in Table V. The production and maintenance staff should discuss these figures every day, and should take necessary action. The same applies to the flotation plant.

(*b*) *Condition of Equipment in the Flotation Plant*

The daily performance results (Table VI) should be reconciled to the condition of the cell parts. The cost of replacing a worn cell part is minimal compared with a decrease of 5 per cent in recovery in the cell. If the cells are in good condition and the recovery is less, one knows that this must be due to the reagents or the type of ore.

TABLE V

RUNNING TIME OF EQUIPMENT

Mill no.	Amount milled t	Downtime, h					Rods load	Remarks
		Sched. maint.	Breakdown	Ore shortage	Other	Total		
1	1 600	—	—	—	—	Nil	—	
2	1 650	—	0,25	—	—	0,25	—	Oil pump tripped
3	1 650	—	—	—	—	Nil	—	
4	1 650	—	—	—	—	Nil	—	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
24	1 500	2	—	—	—	2,0	10	Scheduled inspection

TABLE VI

DAILY PERFORMANCE RESULTS

Plant	Bank no.	Parts replaced		Last inspection		Performance		Down-time h	Remarks
		Date	Type	Date	Condition	Date	Recovery %		
A	1	16/01/78	P	05/04/78	A	15/5/78	82	0	
	2	02/12/78	P	10/05/78	B	,,	79	3	Cell inspection
	3	17/11/77	P	17/11/77	A	,,	87	0	
	4	02/12/77	D	13/11/77	B	,,	70	0	
B	5	08/11/77	S	07/03/78	B	15/5/78	63	0	
	6	29/06/77	S	07/03/78	B	,,	55	0	Parts replaced 17/5/78
C	7	01/07/77	S	07/03/78	B	,,	50	0	Parts replaced 24/5/78
	8	07/04/78	R+S	07/04/78	A	,,	65	1	V-belts broken

Condition A Good
B Fair
C Bad, must be replaced

Parts S Steel
R Rubber
P Polyurethane
D Denvathane

If one does not know the condition of the cell parts, one is flying blind.

(c) *Water Balance and Consumption*

As water and effluent are one of South Africa's biggest problems, one has to know the daily consumption of fresh and reclaimed water. At Foskor, where 60 000 t of fresh ore is floated per day, the average consumption is 130 Ml of water per day, of which only 30 Ml is fresh river water. Money spent on the reclamation of water is money saved on the treatment of effluent.

(d) *Consumption of Energy*

The typical consumption of energy on a P_2O_5 flotation plant is as follows:

Grinding plant	50 kW.h per ton of final concentrate
Flotation plant	21 kW.h per ton of final concentrate
Tailings plant	14 kW.h per ton of final concentrate
Services	0,24 litre of diesel oil per ton of final concentrate
	0,12 litre of diesel oil per ton of final concentrate
	0,14 litre of oil per ton of final concentrate

TABLE VII

PRODUCTION RESULTS FOR 25/05/78

(i) *Flotation Feed*

Ore	Grind +35 µm, %		Grind −65 µm, %	
	Actual	Standard	Actual	Standard
Foskorite	9,9	13	66,9	70
Pyroxenite	18,9	18	53,2	50

(ii) *Flotation Plant Performance*

Plant	P_2O_5, % Conct.		P_2O_5, % Feed		P_2O_5, % Tailings	P_2O_5, % Recovery		Feed t		Conct. produced t	
	Act	Std	Act	Std		Act	Std	Act	Std	Act	Std
A	37,0	36,5	9,5	7,5	1,87	84,6	70	4 708	5 000	1 023	720
B	36,3	36,5	7,1	7,5	3,08	61,9	75	6 696	6 500	810	1 000
C	37,0	36,5	9,5	7,5	2,63	77,9	70	4 708	5 000	944	720
D	36,9	36,5	9,5	7,5	2,81	76,2	70	14 124	15 000	2 772	2 300
F	36,3	36,5	11,5	11,5	3,18	79,3	65	13 146	15 000	3 291	3 070
Total										8 840	7 810

(iii) *Final Production*

Production according to analyses	=	8 840 t
Physical production (weighed)	=	8 620 t
∴ Loss	=	220 t 2,5%

(iv) *Analysis of Loss (Reconciliation)*

Source of loss	Reason for loss	Calculated loss t of 36,5% P_2O_5	Action taken
1. Flotation feed pumps			
2. Feed thickeners			
3. A-plant feed pumps			
4. B-plant feed pumps			
5. C-plant feed pumps			
6. D-plant feed pumps			
7. F-plant feed pumps	Power failure	100	Taken up with Electrical Engineer
8. A-plant middlings pumps			
9. B-plant middlings pumps			
10. C-plant middlings pumps			
11. D-plant middlings pumps			
12. F-plant middlings pumps	Power failure	80	
13. Concentrate thickener overflow	Solids in overflow	30	Thickeners overloaded
Total		210	

(e) Production Reporting

Production results must be reported daily and compared with set standards, and the variances must be reported daily. A typical daily production report is given in Table VII.

The reconciliation shown in Table VII is very important for effective production control. An example of a daily laboratory report is given in Table VIII.

Cost and Budgetary Control

A budget is drawn up at the beginning of each financial year, and, at the end of each month, the actual costs are compared with the budgeted costs and the variances are explained in detail.

Of the total direct costs of the final P_2O_5 concentrate, the flotation costs account for about 27 per cent. The total flotation costs are made up as follows:

Labour	2%
Reagents	87%
Power	4%
Maintenance	4%
Others	3%

It is apparent that the costs of the reagents must be strictly controlled if the flotation costs are to be controlled. The best way to do this is to control all the reagents both by the shift and by the day. A typical reagent control sheet is given in Table IX. All the dosage rates must be reconciled daily with the actual consumption from the main reagent storage tanks (via dip readings).

TABLE VIII

AVERAGE ANALYSES FOR 24 HOURS, 25/05/78

Source	Analysis, %				
	P_2O_5	Fe	MgO	H_2O	CO_2
PMC Tailings	10,1	2,1*			
Conct. A	36,7				
Tails A	2,4				
Conct. C	37,0				
Tails C	4,4				
Conct. D	36,2	0,17*	1,44*		
Tails D	4,4				
Pyroxenite B (24 h)	8,4*			2,5	1,6*
Feed B	8,3				
Conct. B	36,9	0,29*	1,35*		
Tails B	2,8				
Foskorite F	11,2	3,6			10,5*
Conct. F	36,4	0,33*	1,95*		
Tails F	3,5				
Final tails	4,2				
Filter belts 51					
151	36,6			10,3	
152	36,6			10,2	
271	36,1			11,4	
272	35,6			11,0	

*Analysis of composite, relative density of composite 3,00

Maintenance

A good scheduled maintenance system is imperative for a flotation plant. Without it, one has continuous plant breakdowns and, with every unplanned stoppage, one loses material (cell tanks' drain) and costly reagents. Maintenance schedules should be completed on a routine basis by the production staff, and the completed forms should be sent to the maintenance personnel for action.

All pumps and other moving equipment should be serviced after the prescribed number of operating hours, the frequency being determined by computer as based on previous breakdown history. So that all the planned maintenance work, annual shutdowns, and scheduled stoppages can be co-ordinated, weekly meetings are held between the operating and maintenance staffs. Official minutes are kept of these meetings, and responsibilities are indicated for each job as well as the expected dates of completion.

Process Development

If a mine is to be kept alive and economic, continual attention must be paid to process development, which includes the following in the case of Foskor.

(a) Better Milling Processes

Alternative (or improved) milling and classification processes to yield higher throughput, better flotation products, lower costs per ton milled, etc. Examples include two-stage hydrocyclones to improve the sharpness of cut, the Hukki-classifier to reduce the circulating fines and thus improve the throughput, and alternative mill-liner materials to reduce the cost per ton milled.

(b) Better Reagents

Reagents are an important cost item, and development is conducted towards cheaper suppliers of the reagents used (e.g., P.G.E.), partnerships for the local manufacture of reagents (e.g., fatty acid), different types of reagents (e.g., gum arabic), similar but cheaper types of reagents (e.g., 38X instead of T.E.B.), and reagents with higher selectivity or recovery.

(c) Better Flotation Processes

The development of better flotation processes has involved testwork on the reduction of magnesium in the concentrate produced, the development of flotation models with a view to the implementation of a feed-forward control system (a very ambitious project that is

TABLE IX

REAGENT CONTROL SHEET FOR D PLANT ON 26/05/78

(Feed 16 886 t)

Reagent	Waterglass	Caustic soda	Gum arabic	Fatty acid	P.G.E.	Pet. sulph.
Total consumption, ml/min	99 914	9 646	34 000	10 657	3 505	6 400
Dosage, ml/min	33 750	9 646	35 000	4 408	1 683	
Dosage, g/t	432	123	217	342	143	
Dosage, std	500	100	250	350	130	