Plant practice in the flotation of phosphate


SYNOPSIS

This paper highlights modern practices in ore-treatment plants, with particular reference to the flotation of P₂O₅ 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 praktolie in ursbehandelingsaanlegginge na vore met spesiale verwysing na die vlotwerk van P₂O₅ by die aanlegginge van die Foskor-ontginingskorporsias (Foskor) te Phalaborwa in Noord-Transvaal. Die volgende aspekte word gedek: ontwerpmaatstawwe, toerusting en personeel, produksiestandaarde en -beheer, kostebeheer, onderhoud en prosentontwikkeling.

The extraction of minerals in the present climate of ever-increasing prices of labour, equipment, spaces, 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 P₂O₅-enrichment plant is given in Fig. 1, which shows the position of the P₂O₅-flotation plant in the general configuration. A specific flowsheet for such a flotation plant is shown in Fig. 2.

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

Solids feed, t/h 140
Pulp density of feed, g/l 1,498
Reagent dosage rates, ml/min
NaOH (20%) = 3 300
Waterglass (20%) = 18 000
Fatty acid = 650
P.G.E. = 180

Results P₂O₅ in feed, % 12.4%
P₂O₅ in tailings, % 4.7%
Recovery, % 70.9%

*Nonyl phenol tetraglycolether.

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, foscokite, 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 m²
Annual tonnage: 20 300 t/m² (of cell), or 28 800 t per cell

Flotation cell: Wembo–Fagergren, 8,496 m²
Annual tonnage: 28 900 t/m² (of cell), or 342 700 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.
TABLE I

<table>
<thead>
<tr>
<th>Sample/Stream</th>
<th>P₂O₅, %</th>
<th>Pulp density</th>
<th>Solids, %</th>
<th>Sieve analysis</th>
<th>P₂O₅, %</th>
<th>Solids flow, t/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>12.9</td>
<td>1,498</td>
<td>47.2</td>
<td>60.9 27.4 12.7</td>
<td>13.0 27.4</td>
<td>8.8</td>
</tr>
<tr>
<td>Ro feed</td>
<td>18.5</td>
<td>1,362</td>
<td>37</td>
<td>68.3 24.1 7.7</td>
<td>17.8 23.1</td>
<td>12.5</td>
</tr>
<tr>
<td>Ro tails</td>
<td>11.4</td>
<td>1,282</td>
<td>43</td>
<td>63.7 24.8 11.5</td>
<td>10.3 14.8</td>
<td>9.0</td>
</tr>
<tr>
<td>Ro conc.</td>
<td>28.7</td>
<td>1,383</td>
<td>46.8</td>
<td>81.0 17.6 1.3</td>
<td>26.4 39.4</td>
<td>38.8</td>
</tr>
<tr>
<td>Sc tails</td>
<td>4.9</td>
<td>1,203</td>
<td>24.6</td>
<td>33.5 30.8 15.8</td>
<td>3.6 6.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Sc conc.</td>
<td>20.6</td>
<td>1,234</td>
<td>27.7</td>
<td>82.7 16.0 1.4</td>
<td>17.5 35.3</td>
<td>39.1</td>
</tr>
<tr>
<td>Ci tails</td>
<td>26.9</td>
<td>1,301</td>
<td>33.5</td>
<td>80.0 18.6 1.5</td>
<td>24.2 38.5</td>
<td>39.3</td>
</tr>
<tr>
<td>Final conc.</td>
<td>36.8</td>
<td></td>
<td></td>
<td>82.6 16.3 1.2</td>
<td>35.8 41.3</td>
<td>40.9</td>
</tr>
</tbody>
</table>

Overall recovery: 71.4%
Ro recovery: 64.4%
Sc recovery: 84.6%
Cl/Reel recovery: 24.0%

(c) Configuration of Cells
Depending on the floatability, fineness of ore, concentrate grade, and P₂O₅ recovery, an optimum configuration of rougher, scavenger, cleaner, and reclaimer 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 P₂O₅, 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.

Equipment for a P₂O₅ Flotation Plant
The following equipment is required.

(a) Milling Circuit
(i) 2.7 m by 4.1 m rod mills
(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:

\[
\frac{1150 \times 24}{0.43 \times 1,420 \times 60} = 753 \text{ m}^3 \text{ flotation capacity. Table IV gives comparative data for a plant of this capacity using flotation cells of two sizes. (It is assumed that the performances of small and large cells are equal.)}
\]

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 deaerate 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
2 Shift Foreman is in charge of 6 flotation plants
3 Plant Operator is in charge of 2 flotation plants
4 Plant Attendant is in charge of all the pumps in one flotation plant

TABLE IV
A COMPARISON BETWEEN FLATATION CELLS OF TWO SIZES

<table>
<thead>
<tr>
<th>Cell volume m³</th>
<th>Number of cells</th>
<th>Cost factor per m³</th>
<th>Total installed power, kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,416</td>
<td>531</td>
<td>1.00</td>
<td>3,980</td>
</tr>
<tr>
<td>8,496*</td>
<td>88</td>
<td>0.40</td>
<td>2,404</td>
</tr>
</tbody>
</table>

*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, $R\cdot SO_3\cdot H$, 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, $SiO_2 : Na_2O \cdot 2 : 1$

   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 calcium 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.
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 olate 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**

<table>
<thead>
<tr>
<th>Mill no.</th>
<th>Amount milled t</th>
<th>Downtime, h</th>
<th>Rods load</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sched. maint.</td>
<td>Breakdown</td>
<td>Ore shortage</td>
<td>Other</td>
</tr>
<tr>
<td>1</td>
<td>1 600</td>
<td>0,25</td>
<td>Nil</td>
<td>0,25</td>
</tr>
<tr>
<td>2</td>
<td>1 650</td>
<td></td>
<td>Nil</td>
<td>0,25</td>
</tr>
<tr>
<td>3</td>
<td>1 650</td>
<td></td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>4</td>
<td>1 650</td>
<td></td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>24</td>
<td>1 500</td>
<td>2</td>
<td>Nil</td>
<td>2,0</td>
</tr>
</tbody>
</table>

### TABLE VI
**Daily Performance Results**

<table>
<thead>
<tr>
<th>Plant</th>
<th>Bank no.</th>
<th>Parts replaced</th>
<th>Last inspection</th>
<th>Performance</th>
<th>Down-time h</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>16/01/78</td>
<td>P</td>
<td>06/04/78</td>
<td>A</td>
<td>15/5/78</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>02/12/78</td>
<td>P</td>
<td>10/05/78</td>
<td>B</td>
<td>..</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>17/11/77</td>
<td>P</td>
<td>17/11/77</td>
<td>A</td>
<td>..</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>02/12/77</td>
<td>D</td>
<td>13/11/77</td>
<td>B</td>
<td>..</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>08/11/77</td>
<td>S</td>
<td>07/03/78</td>
<td>B</td>
<td>15/5/78</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>29/06/77</td>
<td>S</td>
<td>07/03/78</td>
<td>B</td>
<td>..</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>01/07/77</td>
<td>S</td>
<td>07/03/78</td>
<td>B</td>
<td>..</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>07/04/78</td>
<td>R+S</td>
<td>07/04/78</td>
<td>A</td>
<td>..</td>
</tr>
</tbody>
</table>

Condition:
- A: Good
- B: Fair
- C: Bad, must be replaced

Parts:
- S: Steel
- R: Rubber
- P: Polyurethane
- D: Donathane

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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 P₂O₅ flotation plant is as follows:

<table>
<thead>
<tr>
<th>Plant</th>
<th>Feed Consumption (kW.h) per ton of final concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding plant</td>
<td>50</td>
</tr>
<tr>
<td>Flotation plant</td>
<td>21</td>
</tr>
<tr>
<td>Tailings plant</td>
<td>14</td>
</tr>
<tr>
<td>Services</td>
<td>0,24 litre of diesel oil per ton of final concentrate</td>
</tr>
<tr>
<td></td>
<td>0,12 litre of diesel oil per ton of final concentrate</td>
</tr>
<tr>
<td></td>
<td>0,14 litre of oil per ton of final concentrate</td>
</tr>
</tbody>
</table>

TABLE VII

PRODUCTION RESULTS FOR 25/05/78

(i) Flotation Feed

<table>
<thead>
<tr>
<th>Ore</th>
<th>Grind +35 μm, %</th>
<th>Grind -65 μm, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Standard</td>
</tr>
<tr>
<td>Foskorite</td>
<td>9,9</td>
<td>13</td>
</tr>
<tr>
<td>Pyroxenite</td>
<td>18,9</td>
<td>18</td>
</tr>
</tbody>
</table>

(ii) Flotation Plant Performance

<table>
<thead>
<tr>
<th>Plant</th>
<th>P₂O₅ %</th>
<th>Feed</th>
<th>Tailings</th>
<th>Recovery</th>
<th>Feed</th>
<th>Conct. produced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Act</td>
<td>Std</td>
<td>Act</td>
<td>Std</td>
<td>Act</td>
<td>Std</td>
</tr>
<tr>
<td>A</td>
<td>37,0</td>
<td>36,5</td>
<td>9,5</td>
<td>7,5</td>
<td>1,87</td>
<td>84,6</td>
</tr>
<tr>
<td>B</td>
<td>36,3</td>
<td>36,5</td>
<td>7,1</td>
<td>7,5</td>
<td>3,08</td>
<td>61,9</td>
</tr>
<tr>
<td>C</td>
<td>37,0</td>
<td>36,5</td>
<td>9,5</td>
<td>7,5</td>
<td>2,63</td>
<td>77,9</td>
</tr>
<tr>
<td>D</td>
<td>36,9</td>
<td>36,5</td>
<td>9,5</td>
<td>7,5</td>
<td>2,81</td>
<td>76,2</td>
</tr>
<tr>
<td>F</td>
<td>36,3</td>
<td>35,5</td>
<td>11,5</td>
<td>11,5</td>
<td>3,18</td>
<td>76,3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th>Source of loss</th>
<th>Reason for loss</th>
<th>Calculated loss t of 36.5% P₂O₅</th>
<th>Action taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flotation feed pumps</td>
<td>Power failure</td>
<td>100</td>
<td>Taken up with Electrical Engineer</td>
</tr>
<tr>
<td>2. Feed thickeners</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. A-plant feed pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. B-plant feed pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. C-plant feed pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. D-plant feed pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. F-plant feed pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. A-plant middlings pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. B-plant middlings pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. C-plant middlings pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. D-plant middlings pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. F-plant middlings pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Concentrate thickeners overflow</td>
<td>Power failure</td>
<td>80</td>
<td>Thickness overloaded</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>210</td>
<td></td>
</tr>
</tbody>
</table>

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(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 percent. The total flotation costs are made up as follows:

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>2%</td>
</tr>
<tr>
<td>Reagents</td>
<td>87%</td>
</tr>
<tr>
<td>Power</td>
<td>4%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4%</td>
</tr>
<tr>
<td>Others</td>
<td>3%</td>
</tr>
</tbody>
</table>

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).

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...