International Fertilizer Industry Association

IFA Technical Conference

Johannesburg, South Africa
30 September-4 October 1996

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Date of Receipt: 15 May 1996

IMPROVED REACTOR CONTROL AND INCREASED FILTRATION CAPACITY BY UPGRADING FILTRATION EQUIPMENT IN A PHOSPHORIC ACID PLANT

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RESUME

Le résumé de cette communication est le suivant :

1. *Présentation de la situation existante dans une unité d'acide phosphorique Prayon au dihydrate de 1200 t/j P_2O_5 démarrée en 1976 et fonctionnant avec 2 filtres Bird-Prayon mod. 30615.*

2. *Définition des objectifs :*
   - *Amélioration des conditions de fonctionnement des deux filtres suite à une sévère corrosion observée sur les cellules de filtration ;*
   - *Augmentation de la productivité des 2 filtres grâce au remplacement des cellules existantes ;*
   - *Amélioration du contrôle des solides dans la cuve d'attaque grâce à un meilleur contrôle de l'acide de recyclage.*

3. *Description de l'amélioration des filtres.*

4. *Description des mesures faites sur un vieux fond en pente et sur une nouvelle cellule brevetée à drainage rapide.*

5. *Résultats et conclusions.*

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1. INTRODUCTION

Indian Ocean Fertilizer operates a Prayon design Di-hydrate Phosphoric Acid Plant in Richards Bay, South Africa. This plant was designed in 1974 and commissioned in 1976. By 1991 the plant had been in operation for fifteen years and it became necessary to do major repairs to the filters.

ORIGINAL DESIGN OF THE PLANT

The plant is a Mark III design Prayon reaction and filtration system followed by forced circulation vacuum evaporation concentration units. The nameplate capacity of the plant was 1 200 ton P_2O_5 per day and the plant was designed to process 80 BPL Foskor rock.

REACTOR DESIGN

The reaction tank is a rectangular concrete tank with eight compartments and has a volume of 2 000 m^3. The reaction tank overflows to a series of three maturation tank with a total volume of 1 000 m^3. The reactor slurry is pumped from the third maturation tank to the filters. The reactor is relatively large and the specific reaction volume at nameplate capacity is 1,67 m^3/ton P_2O_5 per day for reaction with an additional maturation volume of 0,83 m^3/ton P_2O_5 per day.

FILTRATION SECTION DESIGN

Phosphoric acid is separated from the gypsum crystals through filtration on two identical model 30.165 Bird-Prayon tilting pan filters. Each filter had thirty filter cells and an active filtration area of 171,15 m^2. The filter cells were designed with sloped bottoms and a drainage channel down the middle of the pan. The plant was designed to process Foskor rock which is igneous and produce needle type crystals. The filtration area was therefore unusually large at 342,30 m^2 active filtration area to produce 1 200 ton P_2O_5 per day (3,5 ton P_2O_5 per day/m^2 active area). The filter cells were originally constructed in 316L stainless steel.

2. SITUATION BEFORE UPGRADING THE FILTERS

By 1993, when the new filter cells were ordered, the existing filters had been in operation for seventeen years. The filters were in poor mechanical condition, equipment availability was low and normal maintenance and repair became uneconomical.

PHYSICAL CONDITION OF THE FILTERS

The filter cells were severely corroded causing vacuum leaks and it was necessary to stop frequently in order to repair leaks. The structural beams of the filter cells had lost up to 40% of original wall thickness through uniform corrosion. Stress corrosion was also evident on the structural beams resulting in less than 50% effective wall thickness. This weakening in the structure of the cells caused sagging of up to 2 cm over the length of the cell between the two support bearings.

PROCESS PERFORMANCE BEFORE UPGRADING OCCURRED

The plant was operated with two different rock types as feed material. One of rock types was Togo 79/80 BPL sedimentary material and the other Foskor 80 BPL of igneous origin. The two types of rock behave significantly different and are therefore discussed separately.

Because of the condition of the filter it was not possible to achieve some of the parameters as specified in the design. The most important of which was the control over product acid recycled to the reactor. The retention of acid inside the filter cells determined the quantity of product acid recycled with second filtrate to the reactor. The control valve for bleeding product acid into the recycle was permanently closed and the operator therefore had no control over the solid content of the reactor slurry.

PERFORMANCE WHEN OPERATING WITH 80 BPL FOSKOR ROCK

The original design specified a reaction slurry solids content of 22% v/v while the actual result was only 18% v/v. The significance of this becomes apparent when comparing the mass balance for the same production rate but under the two different solids content conditions. (See Table 1).

The increased quantity of product acid to be filtered resulted in a reduction of product acid concentration from the design specification of 26,5% P_2O_5 to approximately 25% P_2O_5.

Filtration capacity was however maintained at a level higher than design. This was achieved by using a crystal habit modifier to improve crystal shape and filterability. The maximum sustainable filtration rate achieved was 4,39 ton P_2O_5 per day/m^2 active area (design = 3,5).

Table 1
Process Performance with Foskor Rock before Upgrading of the Filter (Relative to Design)

Performance Parameter	Design Value	Actual Performance
Reactor slurry solids content (volume %)	22	18
Relative filter feed volume for the same production rate	1	1,22
Relative quantity of product acid to be separated for the same production rate	1	1,285
Filter acid concentration	26,5% P_2O_5	25% P_2O_5
Relative concentration capacity required (same production rate)	1	1,12

PERFORMANCE WHEN OPERATING WITH 79/80 BPL TOGO ROCK

The plant was not designed for operation with Togo rock and the deviation from recommended design conditions were even higher. Different operators suggest that the reaction slurry solids content should be

30% by volume (and sometimes even higher) while the actual result achieved during Togo operation was only 20%. The relative mass balance comparison for Togo operation is given in Table 2.

The actual filtration capacity (5 ton P_2O_5 per day/m^2 active area) was significantly lower than values reported in the literature. Filter product acid concentration was also significantly lower than reported values. (See Table 2).

Table 2
Process Performance with Togo Rock before Upgrading of the Filter
(Relative To Recommended Values)

Performance Parameter	Recommended Value	Actual Performance
Reactor slurry solids content (volume %)	30	20
Relative filter feed volume for the same production rate	1	1,5
Relative quantity of product acid to be separated for the same production rate	1	1,67
Filter acid concentration	30% P_2O_5	28% P_2O_5
Relative concentration capacity required (same production rate)	1	1,16

3. OBJECTIVES OF THE FILTER UPGRADING PROJECT

The main objectives with replacement of the old filter cells were to reduce total maintenance cost and improve equipment reliability. Replacement also presented the opportunity to upgrade technology for improved process performance.

MAINTENANCE COST AND EQUIPMENT RELIABILITY

The new fast drain cells were constructed of the material Cronifer 1925 h Mo for higher corrosion resistance. The selection of this material was estimated to be the most economic choice for the specific application.

The filter cells were also constructed with an improved cloth fastening system for faster and more effective changing of cloths.

IMPROVED PROCESS PERFORMANCE

Improved drainage of the new cells would improve separation of filtrates and result in improved recycle control and reduced losses of final filtrate to gypsum disposal.

At the same time it was also possible to increase filtration area with the benefit of increased filtration capacity and reduced water soluble P_2O_5 losses.

4. DESCRIPTION OF THE FILTER UPGRADE

4.1. DESCRIPTION OF THE EXISTING FILTRATION EQUIPMENT

4.1.1 A central aspiration distributor allows to preseparate the filtrates and the air thanks to a preseparation chamber located inside the distribution channel: the distribution rotating crown being equipped with a synthetic wear ring ensuring the tightness between the rotative and static parts.

4.1.2 30 filtration cells designed with two slopes bottom, one perforated cloth support and one lateral cloth. All cells in 316L are corroded and present some air leaks (see Figure N° 1).
Each cell is also equipped with a tilt arm having 3 cell rollers; 2 of them being necessary to tilt the cell and the third one ensuring a permanent horizontal position of the cell thanks to an adjustable stop system in contact with the rotating car frame (see Picture N° 1).

4.1.3 One slurry feed box ensuring the distribution of slurries into the filtration cells.

4.1.4 Two cake wash boxes distributing the wash liquors over the cake.

4.1.5 A rotative car frame supporting the cells and the stainless steel splash guards normally preventing acidic spillages on outer parts in carbon steel, but no more effective, this explains the high corrosion state observed on the car frame.

4.1.6 One set of car frame centring and supporting rollers.

4.1.7 One stationary outside frame work supporting:

- the cell inverting track;
- the spray and fume hood;
- the safety guard panels.

4.1.8 Other technical data of the existing filtration equipment:

- total filtering surface	:	202,68 SQM
- total useful filtering surface	:	171,15 SQM
- number of cells	:	30
- number of vacuum circuit	:	1
- installed power of the motor ensuring the drive of the filter	:	25 KW
- installed power and capacity of the cloth wash pump	:	4 KW
- installed power and capacity of the cake discharge blower	:	1,1 KW
- cake discharge and cell cloth wash	:	in two separate hoppers.

4.2. DESCRIPTION OF THE FILTRATION EQUIPMENT AFTER THE FILTER UPGRADING

4.2.1 The central aspiration distributor has been equipped with an ultra high molecular weight polyurethane ring fixed on the stationary part; the new arrangement of partitions allowed to win 1,3% filtration surface. A stainless steel wear plate has been fitted on the upper rotating crown. An adjustable cloudy port movable thanks to an external lever was installed (see Picture n° 2).

4.2.2 The 2 filters have been equipped with new patented cells, called « fast drain » due to their 3 slopes bottom allowing to increase drastically the slope of the final central filtrates draining channel (see Figure N° 2). Each cell has been designed in order to offer 15,5% additional surface if compared to an original cell. Moreover, each new cell was perfectly interchangeable with old ones which allowed to equip the 2 filters according to the manufacturer delivery schedule spread on +/- 1 year time.
After technical discussion with IOF maintenance people, it was decided to realize the cloth filtering system according to an original IOF idea allowing to decrease the cloth change time.
After several exercises, one man can make a cloth change within 15 min (see Pictures Nos 3, 4 and 5).

4.2.3 A second feed box has been installed in order to still fill the cells with slurry in the filtration zone (with cells under vacuum).
The purpose was to increase the filter feed capacity (see Picture N° 6).

4.2.4 The 2 cake wash troughs have not been modified.

4.2.5 A new car frame with a removable wear plate in contact with support rollers has been erected.

4.2.6 Each filter has been equipped with a low acceleration inverting track allowing to reduce forces on the tilt arm rollers and to increase the rotation speed of the filter. The two filters are running regularly at 2 Min 30 Sec per revolution.

4.2.7 Technical data of the 2 filters after the upgrading :

- total filtering surface	233,49 SQM (+ 15,2%)
- total useful filtration surface	199,44 SQM (+ 16,5% = 15,2 + 1,3)
- possible useful filtration surface in wet discharge (cake discharge and cloth washing in one single hopper)	204,1 SQM
- other characteristics	unchanged

5. RESEARCH OF THE POTENTIAL ADDITIONAL CAPACITY INCREASE

5.1 MEASUREMENT OF THE FILTRATE WEIGHT FLOWING INSIDE THE FILTER HOSES CONNECTING THE CELLS AND THE CENTRAL DISTRIBUTOR

In order to find the additional capacity increase, it was decided to measure the weight of the filtrates flowing through the hoses of :

- one existing original cell having a 2 slopes bottom + one central inclined draining channel.
- one new patented fast drain cell having a 3 slopes bottom + one central, more inclined draining channel covering partly the cell length.

For this purpose, we installed a weight gauge under 2 consecutive hoses and connect the output to a recorder (see Picture N° 7).

Two other pressure gauges were fitted on the hose flanges in order to measure the vacuum applied in each cell. After the filter was started in production and reached equilibrium working conditions, the recorder printed the diagram showed on Figure N° 3.

Figure N° 4 is showing the 2 diagrams computed with a same time and weight origins.

It can be seen that the total filtration cycle can be reduced with the new fast drain cell by the 3 time savings coming from the 3 filtrate flows coming after the slurry feed and the 2 cake wash.

As the filtration capacity of a filter equals the following formulae:

$$Q = KS\sqrt{\frac{\Delta P}{Tc}}$$

where K is a filtration factor depending from the product to be filtered.
S is the surface of the original filter cell.
P is the vacuum existing inside the cell.
Tc is the total filtration cycle time.

If the filtration time Tc can be reduced by T1, T2, T3 when using the new cell, then we may consider that the additional potential filtration capacity is given by the following ratio:

$$\sqrt{\frac{Tc}{Tc - (T1 + T2 + T3)}}$$

In the tests made, T1 + T2 + T3 have been measured on the diagram. They reached 32,5% of the filtration time Tc.

It can also be seen that thanks to the faster drain effect of the new cell, the cake wash feeds could be moved in an opposite direction of the filter rotation.

In that case, 2 other time savings, M1 and M2 can be added to T1, T2, T3; the total reached 36% of Tc.

So, after adjustment of the cake wash troughs, the final potential additional filtration capacity found was :

$$\sqrt{\frac{Tc}{0{,}64\ Tc}} = \underline{1{,}25 \text{ or } 25\%}$$

As the fast drain cell surface was 15,2% superior to the existing cell, this means that the fast drain effect on the additional potential filtration capacity equals 9,8%.

6. RESULTS ACHIEVED

The replacement of the filter cells combined with the replacement of the filter frames, inverting tracks and the sealing mechanism of the central distributor resulted in the desired reliability of the filters. The time required for changing of filter cloths were also reduced from approximately 60 minutes to 15 minutes per cloth.

The improved reactor and filter control and increased filtration capacity will now be discussed in more detail.

IMPROVED REACTOR AND FILTER CONTROL

Improved separation of filtrates made it possible to gain control over and reduce the quantity of product acid recycled to the reactor. Reactor slurry solids content could thus be increased and kept stable and the mean reaction retention time was increased significantly for the same production rate.

PERFORMANCE WHEN OPERATING WITH 80 BPL FOSKOR ROCK (AFTER UPGRADING)

Reactor slurry solids content is now being controlled at 24% v/v compared to the design specification of 22%. The influence of the change on the mass balance and reaction retention time is indicated in Table 3.

Table 3
Process Performance with Foskor Rock After Upgrading of the Filter (Relative to Design)

Performance Parameter	Design Value	Actual Performance After Upgrading	Actual Performance Before Upgrading
Reactor slurry solids content (volume %)	22%	24%	18%
Relative filter feed volume for the same production rate	1	0,92	1,22
Relative quantity of product acid to be separated for the same production rate	1	0,89	1,285
Mean reaction retention time (relative to design)	1	1,09	0,82
Filter acid concentration	26,5% P_2O_5	26,5% P_2O_5	25% P_2O_5
Relative concentration capacity required (same production rate)	1	1	1,12

FILTRATION CAPACITY WHEN OPERATING WITH 80 BPL FOSKOR ROCK (RELATIVE TO PERFORMANCE BEFORE UPGRADING OF THE FILTER)

From Table 3 it can be seen that the upgrading reduced the quantity of product acid to be separated from the gypsum crystals by 31%, reduced the feed of slurry to the filter by 25% and increased the mean reaction retention time by 33%. The new filter cells have 15,2% larger filtration area and the measurements done indicated that fast draining of the cells contributed an additional filtration capacity of 9,8%.

In an attempt to determine the cumulative result of the mentioned improvements, one filter was operated alone to determine the maximum production rate per filter. The maximum sustainable rate was 67% higher (6,32 ton P_2O_5 per day/m^2 active area) than the maximum achievable rate before optimization and upgrading of the filter and was limited by the capacity of the filter feed, wash water and filtrate pumps and not by filtration capacity.

PERFORMANCE WHEN OPERATING WITH 79/80 BPL TOGO ROCK (AFTER UPGRADING)

It has been demonstrated that it is now possible to control the reactor slurry solids content at 27% v/v when processing 79/80 BPL Togo rock. The potential benefits from operating at this condition are illustrated in Table 4 in which the mass balance and reaction retention is compared with operating conditions before upgrading of the filter. It is now also possible to achieve the recommended operating conditions but production is limited by other units and there is currently nothing to be gained by operating at the higher conditions.

Table 4
Process Performance with Togo Rock after Upgrading of the Filter
(Relative to Recommended Operating Conditions)

Performance Parameter	Recommended Value	Actual Performance After Upgrading	Actual Performance Before Upgrading
Reactor slurry solids content (volume %)	30%	27%	20%
Relative filter feed volume for the same production rate	1	1,1	1,5
Relative quantity of product acid to be separated for the same production rate	1	1,16	1,67
Mean reaction retention time (relative to recommended value)	1	0,9	0,67
Filter acid concentration	30% P_2O_5	29% P_2O_5	28% P_2O_5
Relative concentration capacity required (same production rate)	1	1,08	1,16

FILTRATION CAPACITY WHEN OPERATING WITH 79/80 BPL TOGO ROCK (RELATIVE TO PERFORMANCE BEFORE UPGRADING OF THE FILTER)

The results from Table 4 indicate the following:

- Quantity of product acid to be separated from the gypsum crystals was reduced by 31%.
- Slurry feed to the filter was reduced by 27%.
- The mean reaction retention time was increased by 34%.

Other benefits from the new filter cells:

- 15,2% larger filtration area
- 9,8% additional capacity through improved drainage.

Similar tests done with Togo rock to determine the cumulative benefit from the upgrading indicated an increase of 50% in filter capacity (6,55 ton P_2O_5 per day/m^2 active area). The filtration capacity achieved was again limited by pump capacity and was still low compared to values reported by other operators. This presents the potential to find other options to fully utilize filtration equipment.

7. CONCLUSIONS

The filtration area and therefore filtration capacity of a new or existing Prayon Tilting Pan Filter can be increased successfully through changing the design of only the filter cells. The exact magnitude of the increase will depend on the specific design and was 15,2% for the application at Indian Ocean Fertilizer.

A direct increase in filtration capacity can be gained from the faster drainage achieved in the new design filter cell. For the application at Indian Ocean Fertilizer, measurements indicated that this benefit is equivalent to an increase of 9,8% in filtration.

It is also possible to increase filter capacity by changing the layout of filtrate separation partitions. At Indian Ocean Fertilizer this increase was 1,3%.

The fast drain feature of the new design cell improves the separation of filtrates which can result in significant benefits if the quantity of product acid recycled is too high and can not be controlled.

FIGURE 1 - FILTRATION CELL WITH 2 SLOPES BOTTOM

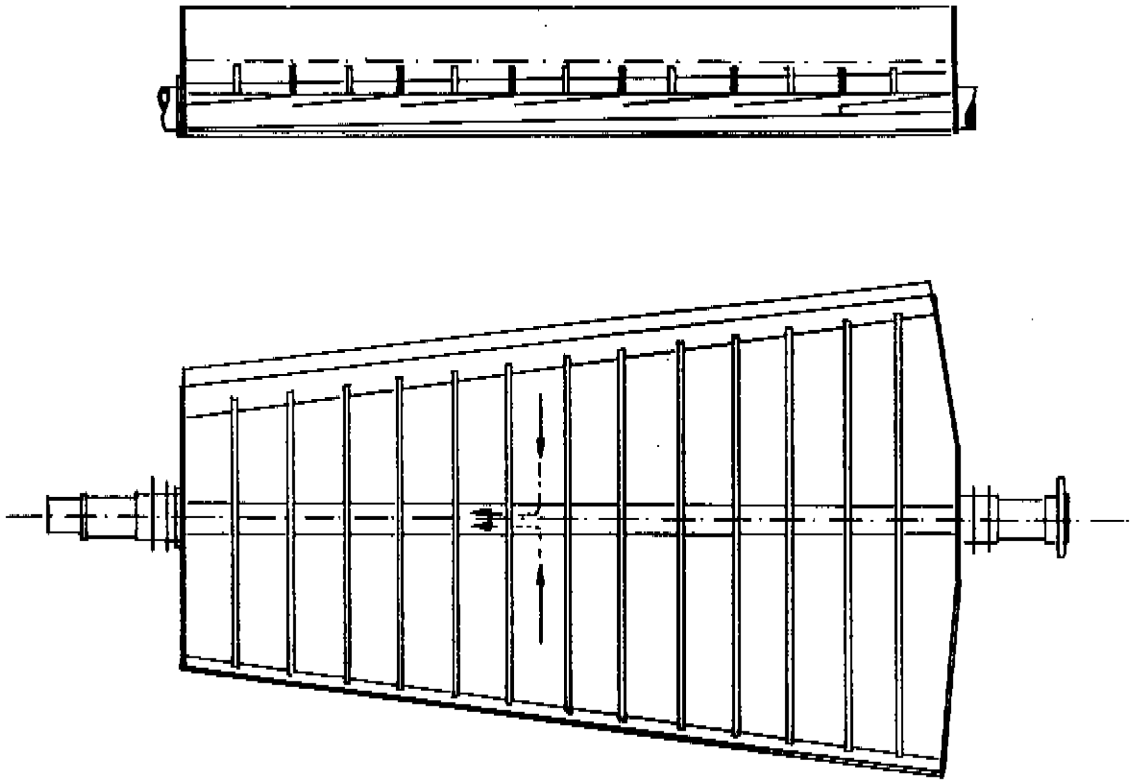


FIGURE 2 - PATENTED FAST DRAIN CELL WITH A 3 SLOPES BOTTOM

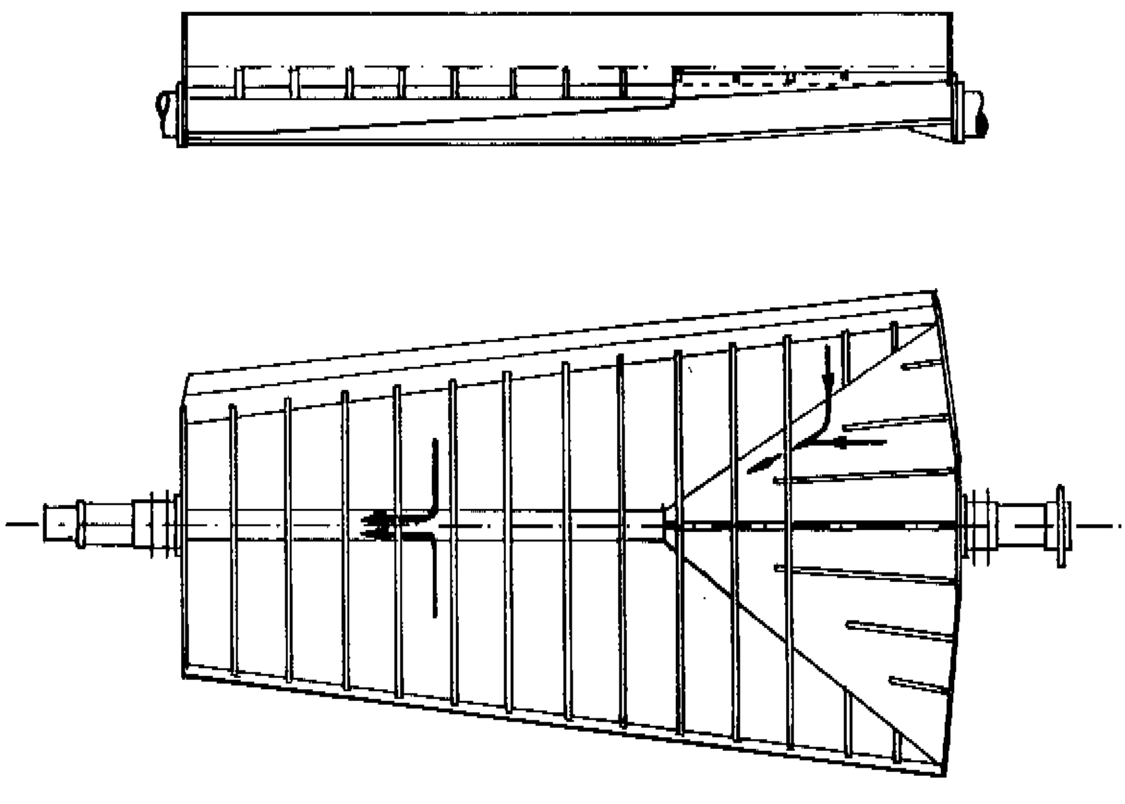


FIGURE 3

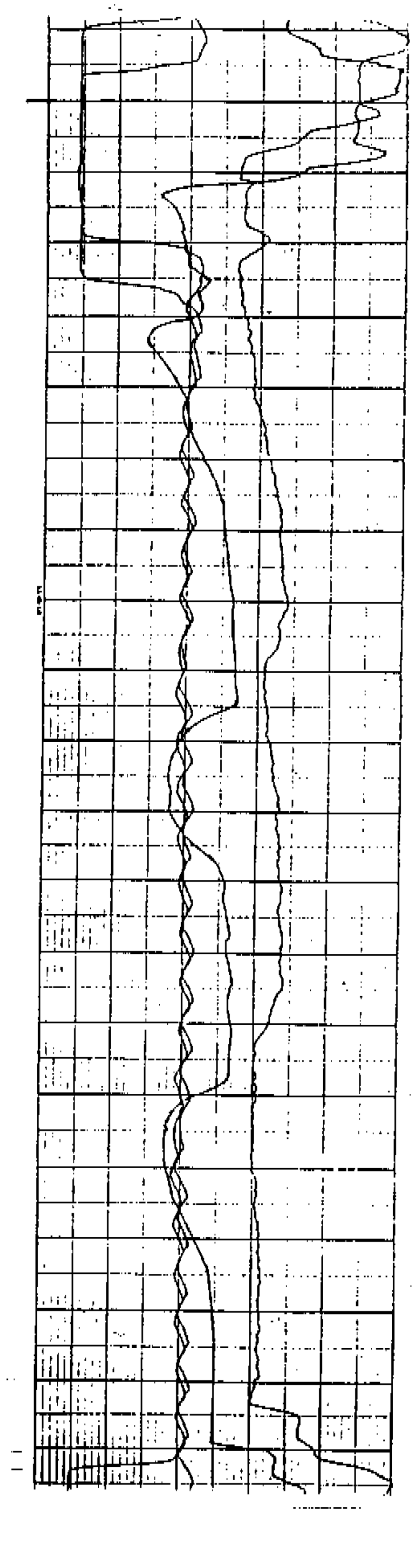
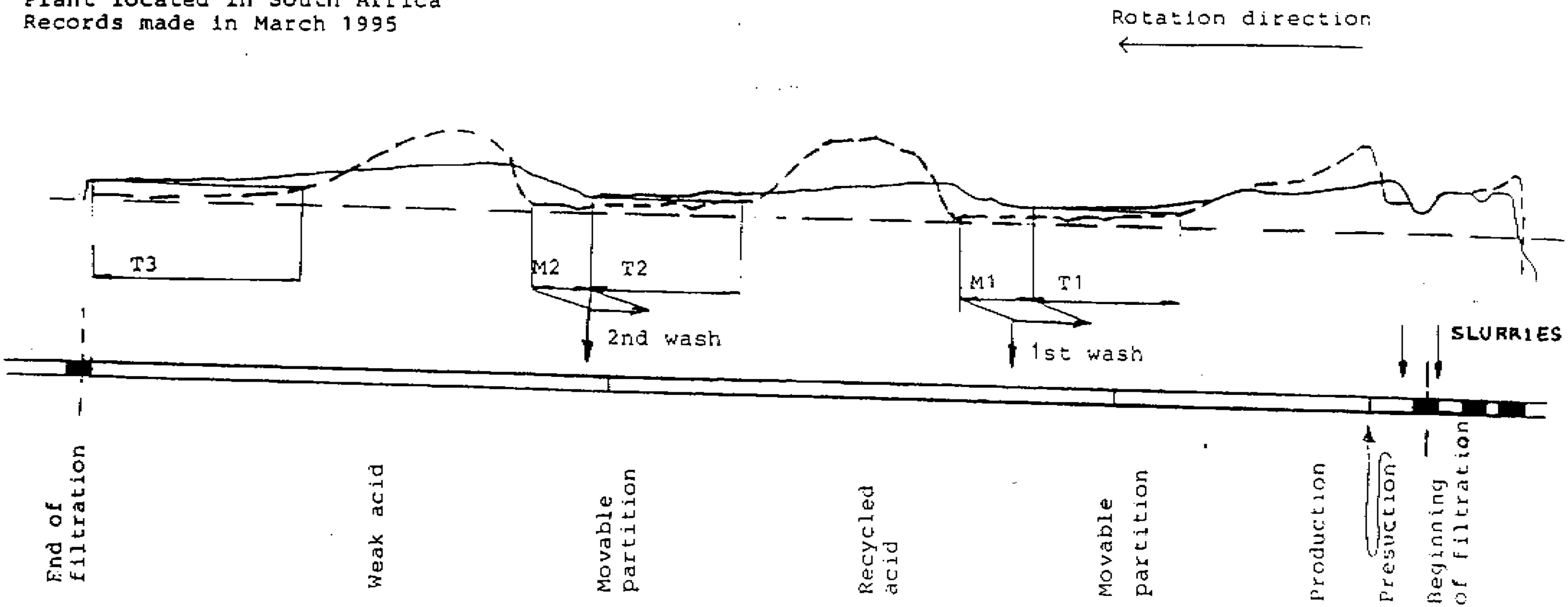


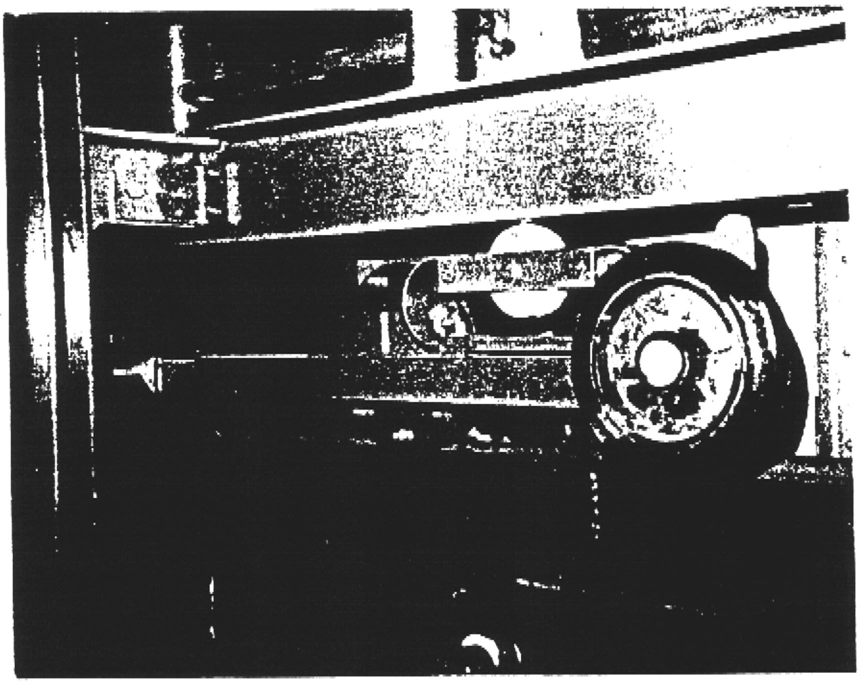
FIG. N° 4 : CELL FILTRATES FLOW DIAGRAMS RECORDED ON A BIRD-PRAYON FILTER MOD. 30-165

Filter speed : 200 sec per rev
Capacity : 744 T P2O5/D
Plant located in South Africa
Records made in March 1995

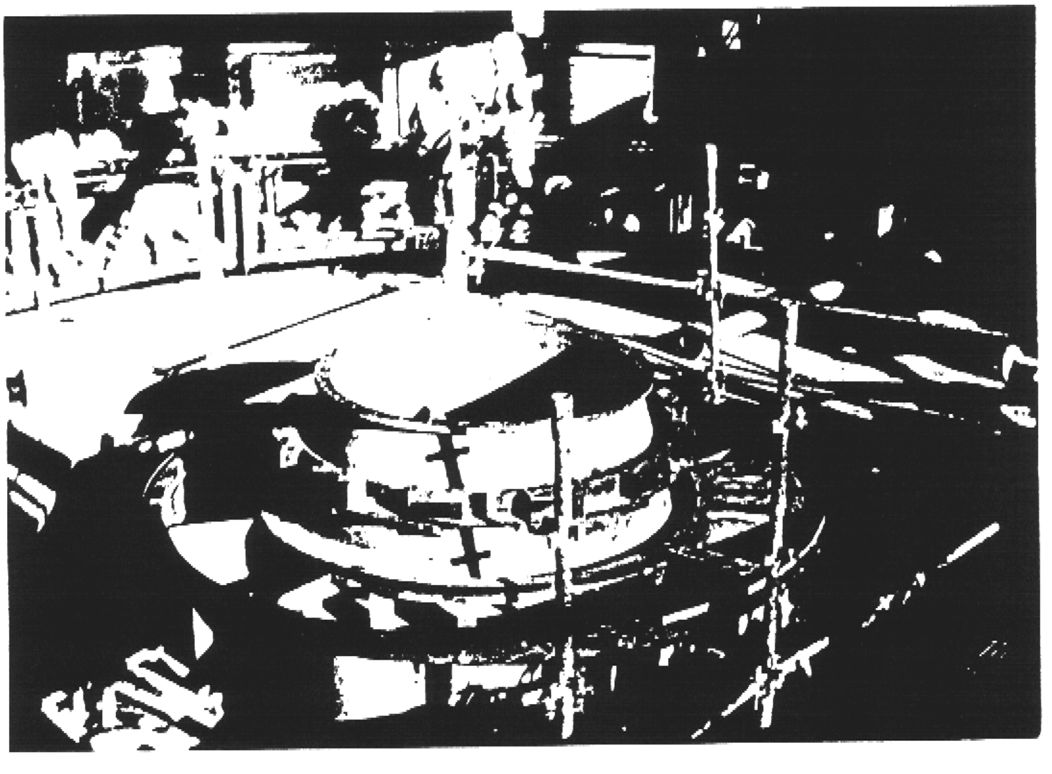


————	2 slopes existing cell (6,756 SQM).
— — — —	New patented fast drain cell with 15,5% additional surface.
Tc	Actual filtration cycle time (171 sec).
T1+T2+T3	Time savings due to the additional surface and faster drainage.
M1+M2	Time savings due to the move of cake wash boxes thanks to additional surface and faster drainage.

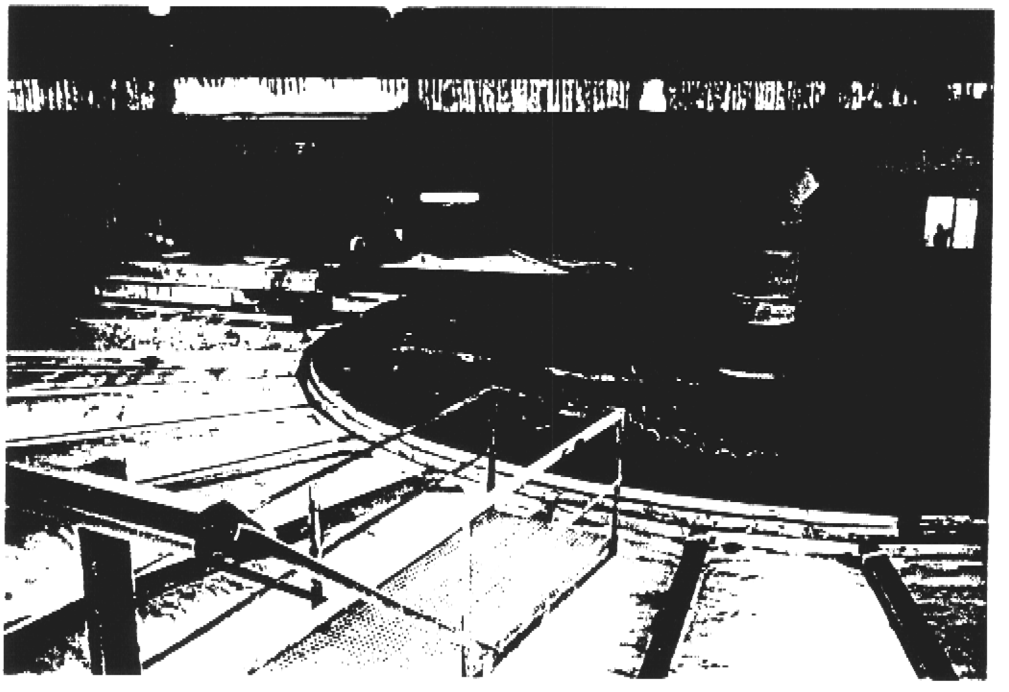
PICTURE N°1



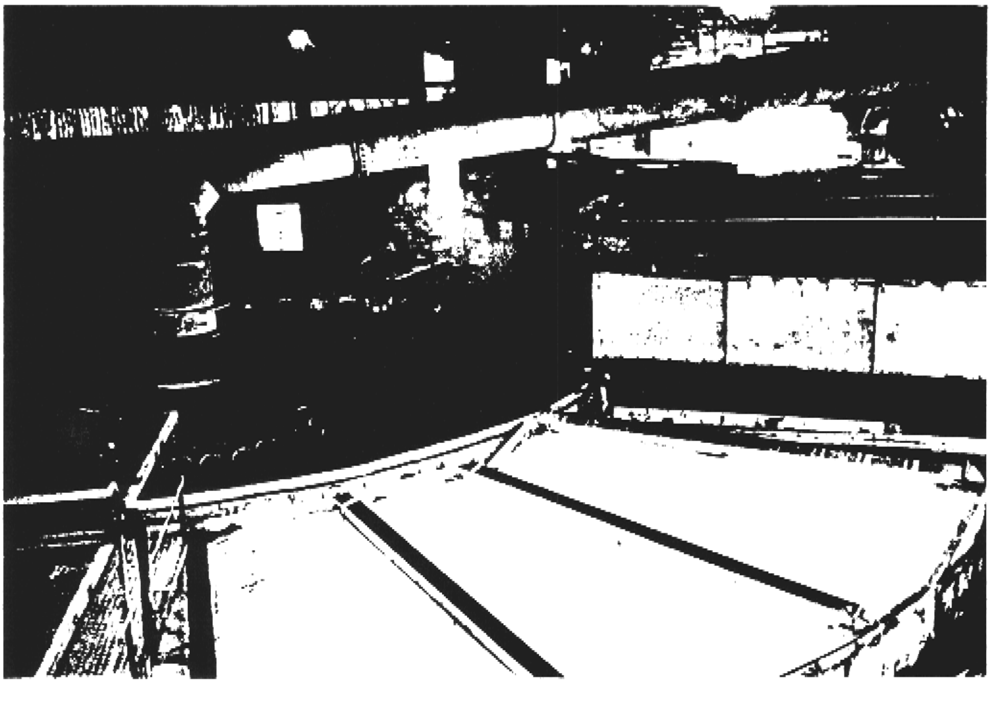
PICTURE N° 2

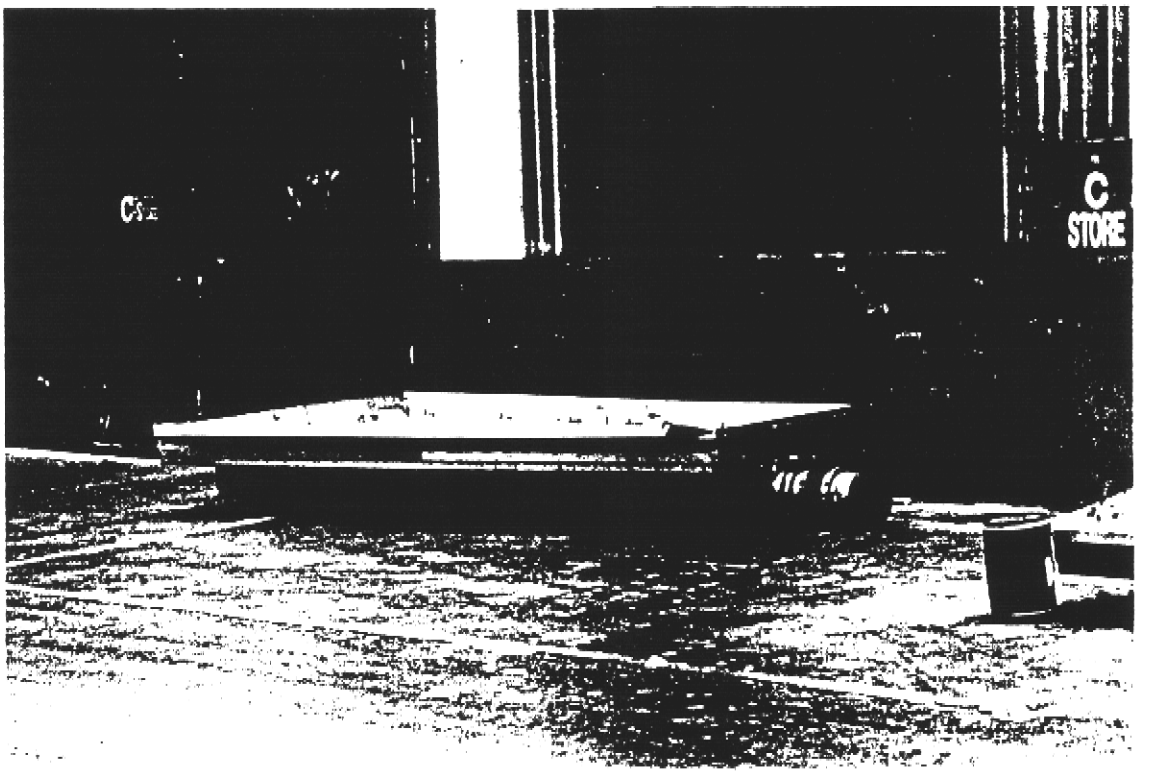


PICTURE N°3

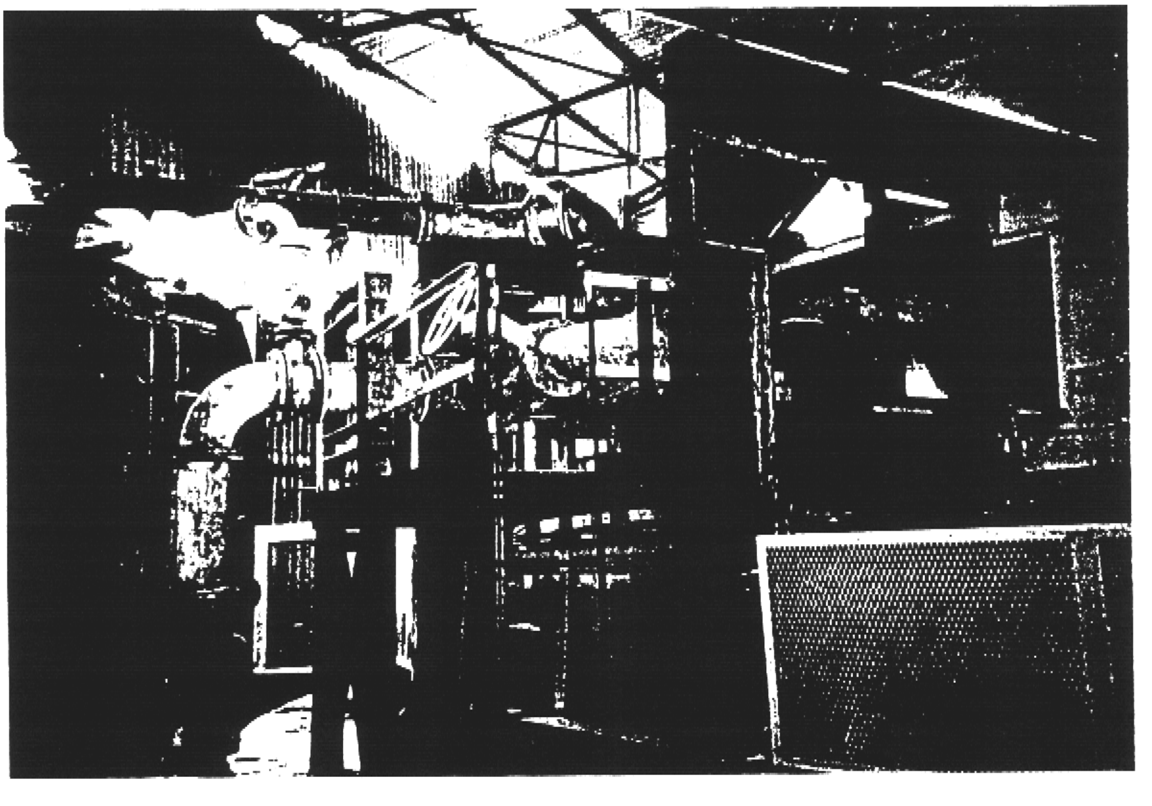


PICTURE N° 4





PICTURE N° 6



PICTURE N° 7