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# DESIGN OF THE JAMAICA BAUXITE INSTITUTE BAYER PROCESS PILOT PLANT*

Prepared by

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## 1. INTRODUCTION

The Bayer Process Pilot Plant sited at the Jamaica Bauxite Institute, and funded jointly by the United Nations Financial System for Science and Technology for Development and the Government of Jamaica, was completed in August 1984. In concept, the pilot plant was designed in order to be able to:

(i) Evaluate the processing characteristics of a wide range of bauxite ores, and thereby to identify their attendant processing problems, both technical and economic.

(ii) Provide facilities for carrying out process research studies on all of the operations involved in the Bayer Process.

(iii) Provide facilities for use in training programmes for bauxite industry personnel.

(iv) Assist other developing countries in developing their own ore resources.

Since the Bayer Process is a fairly typical hydrometallurgical operation it was envisaged that it may also be possible for the plant to investigate the processing behaviour of non-bauxite ores, as appropriate, with suitable process modification.

A major consideration in pilot plant design was the provision of a high degree of flexibility of operation. In particular it should have the capability of operation under boehmite conditions, in addition to gibbsite conditions, and also under either the batch or continuous mode of operation. Budgetary allocations constrained the size of the plant both in terms of equipment size andd hence throughput, and also in terms of building space to house the pilot plant.

The work reported in this paper relates to the basic design of the pilot plant covering process description, plant throughput considerations, process flowsheet, heat and mass balances, comments on equipment specifications, instrumentation, provision of services and plant layout.

## 2. PROCESS DESCRIPTION

The pilot plant was conceptualized as a typical Bayer process operation, except that calcination facilities to deal with the full output of alumina hydrate would be initially excluded. However, facilities for the calcination of small quantities of alumina hydrate produced in the plant were to be provided in the Process Laboratory.

The processing areas identified as necessary for the pilot plant operation, and incorporated into the plant were as follows:

(a) Grinding and slurrying
(b) Predesilication
(c) Digestion
(d) Decanting and Mud Washing
(e) Pregnant Liquor Filtration
(f) Precipitation and Hydrate Filtration
(g) Evaporation

The process block and line diagram incorporating all the operations involved in the process is shown in Figure 1.

An important feature of the plant is the provision of ample holding tank capacity at appropriate points in the processing system. This feature was incorporated in order to allow for ease of batch operation, and also to allow for operation of individual processing areas in isolation from the rest of the process, if appropriate.

## 3. PLANT THROUGHPUT

The three critical operations in the process, on which the production of high grade alumina hydrate depends, are:

(i) Digestion
(ii) Mud separation
(iii) Precipitation

The approach taken in the design of these areas was to purchase suitable available equipment packages for digestion and mud separation, and then design sufficient precipitation capacity into the system to handle the capacities of these packages.

A suitable digestion package comprising three 100 litre autoclaves, followed by a tube reactor and three flash vessels, was identified and purchased. A diaphragm pump was also purchased to allow for continuous operation of this area. This system was assessed to be suitable for operation under either gibbsite or boehmite operating conditions.

When operating the digestion area in the batch mode, cycling all three autoclaves at a residence time of 30 minutes, the overall throughput was estimated to be ~150 litres $h^{-1}$. This figure is also consistent with the effective operation of one autoclave in the continuous mode. When operating continuously, the other two autoclaves would be used to heat the slurry up to the reaction temperature.

An appropriate decanting and mud separation package comprising three 450 litre settling vessels was purchased, one vessel to be used as the decanting vessel and the other two for mud washing. The capacity of this system was assessed as being compatible with that of the digestion system.

The plant design was therefore based on a slurry throughput of 150 litres $h^{-1}$ through the digestion system, under normal operating conditions.

## 4. PROCESS FLOWSHEET

For convenience the process flow sheet was broken up into seven processing areas identified in Section 2:

**Area No. 1 - Bauxite Grinding and Slurrying**

The purpose of this area is to take raw bauxite and test tank liquor and to produce a slurry of these constituents. A ball/rod mill reduces the bauxite to a size suitable for predesilication and digestion. The process flow sheet for this area is shown in Figure 2.

**Area No. 2 - Predesilication and Slurry Holding**

The predesilication reaction is carried out in two vessels prior to transfer to two large digester feed holding tanks. The process flow sheet for this area is shown in Figure 3.

**Area No. 3 - Digestion, Blow-off and Storage**

The slurry is heated by blow-off steam before being fed to the reaction system. The reactor effluent is then flashed before storage in the blow-off tanks. The process flow sheet for this area is shown in Figure 4.

**Area No. 4 - Red Mud Settling and Washing**

The red mud is settled from the liquor in the first vessel, the decanter, and then subjected to a countercurrent two stage wash in the other vessels. Facilities for flocculant addition to the three vessels are provided, the process flow sheet being shown in Figure 5.

**Area No. 5 - Pregnant Liquor Filtration**

The pregnant liquor is filtered in a plate and frame press prior to precipitation. Facilities for precoating the filter cloth are provided, together with liquor storage capacity both before and after filtration, as shown in the process flow sheet in Figure 6.

**Area No. 6 - Precipitation and Hydrate Filtration**

Precipitation is carried out in three tanks utilizing a batch mode of operation. The pregnant liquor is cooled to the appropriate temperature for precipitation by recirculation through a heat exchanger. Once the precipitation process is complete the alumina hydrate crystals are separated from the liquor and washed in a two pan, batch operated vacuum filter. The process flow sheet for this area is shown in Figure 7.

**Area No. 7 - Evaporation and Liquor Storage**

The spent liquor from the hydrate filter is concentrated in a rising film evaporator system before being stored ready for reuse in the process. Synthetic aluminate liquor tanks and caustic make up tanks are also provided. The process flow sheet for this area is shown in Figure 8.

## 5. MASS AND HEAT BALANCES

### 5.1 Mass Balance

For design purposes a detailed mass balance was carried out, assuming a continuous mode of operation on an overall basis. Any mass balance for such a plant will depend on the raw material specification of the bauxite to be processed. The design mass balance was for a low grade bauxite, this being chosen as a potential worst case situation. The bauxite analysis used in the calculations is shown in Table 1.

A number of assumptions were made in the mass balance, the main ones being:

| | |
|---|---|
| Test tank liquor - caustic composition | - 250 gms $l^{-1}$ $Na_2CO_3$ equivalent |
| A/C ratio | - 0.32 wt. basis |
| $P_2O_5$ content | - 0.11 gms $l^{-1}$ $P_2O_5$ |
| Lime addition | - 2.37 gms CaO per gm $P_2O_5$ |
| Soda loss per unit silica | - 1.1 wt. basis |
| Predesilication circuit solids concentration | - 35% by wt. |
| Digestion - Reactor throughput | - 150 l $h^{-1}$ |
| Extraction efficiency | - 98% |
| A/C target ratio | - 0.65 wt. basis |
| Decanter/Mud Washing - Dilution liquor recycle | - 20% feed to blow-off tank |
| Caustic concentrations - Decanter | - 190 gms $l^{-1}$ |
| - Washer No 2 | - 40 gms $l^{-1}$ |
| A/C ratios - Decanter overflow | - 0.64 |
| Mud to mud pond | - 0.45 |
| Underflows | - 200 to 250 gms $l^{-1}$ |
| Precipitation/Hydrate Washing - Hydrate density | - 2.42 kg $l^{-1}$ |
| Hydrate Wash water | - 1 kg water per kg hydrate |

The complete mass balance is shown in Table 2, the stream numbers being identified in Figure 1. It should be noted that precipitation, hydrate filtration and possibly evaporation will not be operated on a continuous basis. The flow rates are merely quoted in continuous flow form for convenience.

It should be stressed that these mass balance calculations were carried out for a specific low grade bauxite. The same calculation method could be used for any analysis and therefore used to form the basis of determining anticipated pilot plant flows before any run. In addition, any of the assumptions used may be modified on the basis of modified data.

### 5.2 Heat Balance

Heat balance calculations were determined from operation to operation, starting from the test tank liquor line and working through all the processing operations, using the mass balance as the basis. The major reasons for carrying out the heat balance were:

(i) To determine the heat flows at each part of the system
(ii) To calculate the steam requirements for the jacketed vessels, heat exchangers and wash water tanks
(iii) To identify the basic conditions for the design of the various heat exchangers in the plant

The estimated steam requirements are shown in Table 3 which must be used in conjunction with Figure 1 to identify the stream numbers.

## 6. EQUIPMENT SPECIFICATIONS

### 6.1 Grinding and Slurrying

The ball/rod mill was purchased directly from the manufacturer's list of standard equipment and has a quoted capacity of ∿75 kg $h^{-1}$. This is more than twice the anticipated throughput under continuous operation. This will allow for a certain amount of flexibility in operation, and should thus be able to operate at the design rate with materials that are difficult to grind. The Trommel screen at the outlet of the mill is interchangeable so that the process cut raw material particle size specification may be modified according to requirement.

The mill slurry tank and the slurry transfer tank are simple 200 litre capacity stirred tanks to collect mill oversize and mill product size bauxite respectively in slurry form in preparation for transfer back to the mill or to the predesilication circuit,as appropriate.

### 6.2 Predesilication and Slurry Holding

Two steam jacketed 500 litre capacity stirred tanks are provided for desilication with a total holding time of ∿22 hours under conditions of continuous operation as identified in the mass balance. Use of 1 tank only and/or operation at reduced depths will provide flexibility in the operation of the predesilication system.

Two large 2500 litre capacity steam jacketed, agitated holding tanks store the slurry prior to digestion. They were sized to store more than three times the hold up of the Decanter/Mud washing circuit. This allows for the satisfactory operation of the Decanter/Mud washing circuit under equilibrium conditions for a length of time suitable for system evaluation.

## 6.3 Digestion

The digestion system is a manufacturers package, consisting of three 100 litre stirred autoclaves, followed by a tube reactor and three flash vessels. Also incorporated into the package are three shell and tube heat exchangers for preheating the slurry feed, utilising steam from the flash vessels. A diaphragm pump was added in order to allow for continuous operation. The autoclaves are heated electrically and are designed to operate under conditions as severe as required for processing boehmitic ores. The system can be operated in a batch mode cycling the three autoclaves ,or in a continuous mode whereby one or two of the autoclaves are used for heating the slurry feed up to the required temperature, with the third autoclave carrying out the bulk of the reaction. Two 750 litre capacity stirred steam jacketed vessels collect digestion product after flashing, and mix dilution liquor prior to feeding to the Decanter/Mud washing circuit.

The equipment package as designed allows for a wide flexibility in investigation.

## 6.4 Decanting and Mud Washing

Three settling tanks, each of 450 litres capacity form the basis of this system. The performance of this area will depend considerably on the properties of the mud generated, operating temperature, the amount and type of flocculant used and the quantity of wash water. The use of flocculant and wash water, and settling conditions are variables which can be controlled and investigated in the system. Sufficient feed tank capacity is allowed for running the system for 24 hours without operating the mill/predesilication circuit. Wash water is heated by steam sparging in a 175 litre lagged tank.

The underflow from the second washer is pumped to the red mud pond, located some distance away from the pilot plant building. The pond is suitably lined to prevent seepage and is of sufficient capacity such that red mud removal will only be at infrequent intervals. Settled liquid can be pumped back to the pilot plant as and when necessary.

## 6.5 Pregnant Liquor Filtration

This area consists of a proprietry plate and frame filter press with 750 litre capacity stirred steam jacketed feed and filtrate tanks. Facilities for filter precoat addition are provided together with filtrate recycle when needed. A plate andd frame press is in concept a batch filtration device. However the amount of filtration area provided is such that it is anticipated that, under normal decanter operation, cleaning would only be necessary every few months. The system may thus be considered to be effectively continuous.

## 6.6 Precipitation and Hydrate Washing

The precipitation system was designed to operate in the batch mode with a residence time of 36 hours, this to include filling and emptying. On this basis, three precipitation vessels, each of capacity 2150 litres, were deemed to be suitable from mass balance considerations. Heat transfer calculations showed that cooling coils within the vessels would take too long to cool the ex-filter pregnant liquor down to the temperature required for precipitation. It was thus decided to install a shell and tube heat exchanger in the system such that the contents of each vessel could be cooled to 50°C in 1 hour when recirculated through the exchanger. Cooling water would be circulated through the heat exchanger for this purpose. The exchanger could also be used in a similar fashion in order to prevent precipitation when liquor was being held in a vessel, simply by using steam instead of cooling water.

Precipitation is a major potential research area. Because of this, one vessel has been designated for this purpose, and extra instrumentation provided. Scope for the following is eventually intended for this vessel:

(i) Operation at different temperatures
(ii) Interchangeable and adjustable paddle design
(iii) Adjustable paddle speeds
(iv) Varying tank geometry
(v) Variable residence time
(vi) The use of inserts such as draft tubes

Hydrate filtration and washing is carried out by a two pan batch operated vacuum filter system. It takes feed from any of the precipitation vessels. The operation therefore constitutes part of the allowable precipitation time and is carried out intermittently once per precipitation batch. Hydrate wash water is heated by steam sparger in a 75 litre capacity tank.

## 6.7 Evaporation and Liquor Storage

Spent liquor from hydrate filtration is stored in two lagged tanks, each of capacity 1075 litres, prior to evaporation. The combined capacity of these two tanks is equivalent to the output from one precipitation batch.

A climbing film evaporator was designed to concentrate the spent liquor for reuse in the process. The system consists of a vertically oriented shell and tube heat exchanger, centrifugal action flash vessel followed by a shell and tube vapour condenser. The system was designed to operate close to atmospheric pressure on an intermittent, 6 hours on, 6 hours off basis.

The concentrated liquor is passed to the test tanks for storage prior to recycle back to the slurrying and grinding circuit. Six storage tanks are provided for liquor storage, two of which are basically allocated for synthetic aluminate liquor and two others for making up caustic solution.

Each tank is of 800 litre capacity giving a total liquor storage capacity the same as that provided between predesilication and digestion.

A shell and tube heat exchanger is provided after Test Tank Liquor Storage to heat the liquor back up to process temperature before reuse.

## 7. INSTRUMENTATION

The pilot plant is well instrumented for flowrate, temperature and pressure measurement.

Magnetic flux meters are used for measuring liquid and slurry flow rates at various parts of the plant as follows:

Liquor flow to ball mill
Liquor flow to slurry holding tank
Slurry flow to slurry holding tank
Digester feed
Dilution line from washers
Mud line to mud pond
Pregnant liquor flow to precipitation system
Spent liquor flow

Temperature and pressure indicators are provided as shown on the flow sheets.

Instrumentation for the digestion system was supplied as part of the package.

In addition, conductivity meters are provided to indicate A/C ratios at the following points:

Digester feed
Blow off tank discharge
Precipitation underflow

A density guage is provided in the underflow discharge line from the mill.

## 8. BUILDING AND PLANT SERVICES

The pilot plant is located in its own building approximately 18.5 m long by 12.5 m wide. The building is of structural steel blocked to the ∿1.5 m level with open mesh above and full roof cover at a height in excess of 6 m. The building which has its own office, changing and toilet facilities, also houses the $\gamma$ ray laboratory.

The following general services are provided at appropriate parts of the plant:

(i) Electricity
(ii) Water
(iii) Compressed Air
(iv) Steam

The maximum process steam requirement is well within the capacity of the plant's steam generator.

An overhead crane is provided, capable of moving heavy equipment and raw materials over most of the building area.

Comprehensive analytical facilities are provided in the Process Laboratory, which is located close to the Pilot Plant Building.

## 9 PLANT LAYOUT

Because of the limited space available for housing the pilot plant, some difficulty was encountered in locating all the equipment in positions suitable for satisfactory operation and ease of maintenance. A pilot plant model was therefore constructed to solve this problem. The final plant layout divided into the various process areas and showing the major items of equipment is shown in Figure 9. In order to maximise space utilization, it was necessary to have the filtration area on two levels, the press being mounted on a platform above the filter feed and filtrate holding tanks.

The pilot plant model was found to be essential in devising pipework locations.

No serious access problems in operation and maintenance have been encountered with the plant.

## 10. CLOSURE

Basic and detailed considerations on the design of the Jamaica Bauxite Institute Bayer Process Pilot Plant have been described. The plant, which has significant built-in operational flexibility, allows for the evaluation of the processing characteristics of a wide range of bauxite ores as well as process research studies on all of the unit operations in the Bayer Process. It is also well suited for training purposes and, being a typical hydrometallurgical operation, may possibly also be used for processing non-bauxite ores. The plant is well suited to form the basis of technical evaluations into further developing the minerals processing industry in the Caribbean and wider regions, in addition to helping to improve current Bayer Process operations.

## ACKNOWLEDGEMENTS

The work reported in this paper was in fact carried out by many people, both United Nations Specialists and J.B.I. personnel. The author therefore wishes to acknowledge the significant inputs by all the people involved. These include, Dr. K. Solymar, Dr. T. Kalman, Mr. D. Morrison, Mr. F. Reid, Mr. N. Morgan, Mr. W. Lyew You, Mr. P. Harris, Mr. R. Osborne. Special thanks are however due to Dr. Conrad Douglas, U.N. Project Coordinator, whose inspiration, knowledge and management expertese were paramount in this project being completed so successfully.

TABLE 1

**Bauxite Analysis Used as Basis of Mass Balance Determination**

| | Wt. % Dry Basis |
|---|---|
| Total $Al_2O_3$ | 47.0 min |
| Total available $Al_2O_3$ | 43.7 |
| Boehmite | 4.0 |
| Gibbsite | 40.0 |
| $Fe_2O_3$ | 20.0 min |
| $SiO_2$ | 3.5 |
| $P_2O_5$ | 0.6 |
| $TiO_2$ | 2.8 |
| CaO | 0.4 |
| Total organics | 0.25 |
| Inorganic $CO_2$ | 1.0 |
| $Mn_3O_4$ | 0.3 |
| MnO | 0.2 |
| ZnO | 0.3 |
| $V_2O_5$ | 0.15 |
| $Cr_2O_3$ | 0.15 |
| Loss on Ignition | 25.5 |

| | |
|---|---|
| Density of bauxite | 2.6 gms $cm^{-3}$ |
| Free moisture content | 20% wet basis |

## TABLE 2

**MASS BALANCE FOR PILOT PLANT**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Mass Flow | $KGH^{-1}$ | 31.2 | 0.5 | 41.0 | 72.7 | 72.7 | 137.0 | 209.7 | 209.7 | 3.0 | 206.7 | 35.4 | 242.1 | 66.0 |
| Total Volume Flow | $LH^{-1}$ | 12.0 | 0.3 | 31.8 | 44.1 | 44.1 | 116.2 | 150.3 | 150.3 | 3.0 | 147.3 | 29.5 | 176.8 | 66.0 |
| Mass Flow of Liquid | $KGH^{-1}$ | 6.2 | - | 41.0 | 47.2 | 46.2 | 137.0 | 183.1 | 199.8 | 3.0 | 196.8 | 35.4 | 232.2 | 66.0 |
| Volume Flow of Liquid | $LH^{-1}$ | 6.2 | - | 31.8 | 38.0 | 38.0 | 106.2 | 144.2 | 147.4 | 3.0 | 144.4 | 29.5 | 173.9 | 66.0 |
| $Na_2CO_3$ flow in Liquid | $KGH^{-1}$ | - | - | 8.0 | 8.0 | 7.0 | 26.5 | 33.5 | 33.5 | - | 33.5 | 3.4 | 36.9 | - |
| $Na_2CO_3$ in Liquid | $GPL^{-1}$ | - | - | 250 | 209 | 184 | 250 | 233 | 228 | - | 232 | 115 | 212 | - |
| $Al_2O_3$ in Liquid | $KGH^{-1}$ | - | - | 2.5 | 2.5 | 2.5 | 8.5 | 11.0 | 21.8 | - | 21.6 | 2.0 | 23.8 | - |
| Bauxite (Dry Basis) | $KGH^{-1}$ | 25.0 | - | - | 25.0 | 24.4 | - | - | - | - | - | - | - | - |
| Lime | $KGH^{-1}$ | - | 0.5 | - | 0.5 | - | - | - | - | - | - | - | - | - |
| Hydrate Product | KG | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Temperature | $^oC$ | 30 | 30 | 90 | 60 | 90 | 80 | 90 | 245 or 145 | 100 + | 100 | 90 | 95 | 95 |
| Total Solids | $KGH^{-1}$ | 25.0 | 0.5 | - | 25.5 | 26.6 | 9.9 | - | 9.9 | - | 9.9 | - | 9.9 | - |

## TABLE 2 (cont'd)

### MASS BALANCE FOR PILOT PLANT

| | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Mass Flow | $KGH^{-1}$ | 8.8 | 50.3 | 231.1 | 231.1 | 231.1 | 231.1 | 231.1 | 15.4 | 15.5 | 231.1 | 231.1 | 184.2 | 46.9 | 2.6 |
| Total Volume Flow | $LH^{-1}$ | 6.8 | 39.6 | 177.8 | 177.8 | 177.8 | 177.8 | 177.8 | 15.4 | 6.3 | 186.9 | 186.9 | 139.6 | 46.9 | 2.0 |
| Mass Flow of Liquid | $KGH^{-1}$ | 8.8 | 40.4 | 231.1 | 231.1 | 231.1 | 231.1 | 215.7 | 15.4 | - | 231.1 | 231.1 | 184.2 | 46.9 | - |
| Volume Flow of Liquid | $LH^{-1}$ | 6.8 | 39.6 | 177.8 | 177.8 | 177.8 | 177.8 | 171.5 | 15.4 | - | 186.9 | 186.9 | 139.6 | 46.9 | - |
| $Na_2CO_3$ flow in Liquid | $KGH^{-1}$ | 1.7 | 1.6 | 33.8 | 33.8 | 33.8 | 33.8 | 33.8 | - | 0.1 | 33.7 | 33.7 | 33.7 | - | - |
| $Na_2CO_3$ in liquid | $GPL^{-1}$ | 250 | 40 | 190 | 190 | 190 | 190 | 197 | - | - | 180 | 180 | 241 | - | - |
| $Al_2O_3$ in liquid | $KGH^{-1}$ | 0.5 | 0.7 | 21.6 | 21.6 | 21.6 | 21.6 | 11.6 | - | - | 11.6 | 11.6 | 11.6 | - | - |
| Bauxite (Dry Basis) | $KGH^{-1}$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Lime | $KGH^{-1}$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hydrate Product | KG | - | - | - | - | - | - | 15.4 | - | 15.4 | - | - | - | - | - |
| Temperature | $^oC$ | 30 + 60 | 90 | 90 | 90 | 90 | 90 | 60 | 95 | 90 | 65 | 60 | 100 | 100 | 30 |
| Total Solids | $KGH^{-1}$ | - | 9.9 | - | - | - | - | 15.4 | - | - | - | - | - | - | 2.6 |

TABLE 3

ESTIMATED STEAM REQUIREMENT

| | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Steam Flows $KGH^{-1}$ | 7.7 | 11.1 | 5.3 | 2.2 | 10.1 | 5.3 | 5.3 | - | 7.5 | 142.2 | 42.8 |

FIGURE 1 - BLOCK AND LINE DIAGRAM FOR PILOT PLANT

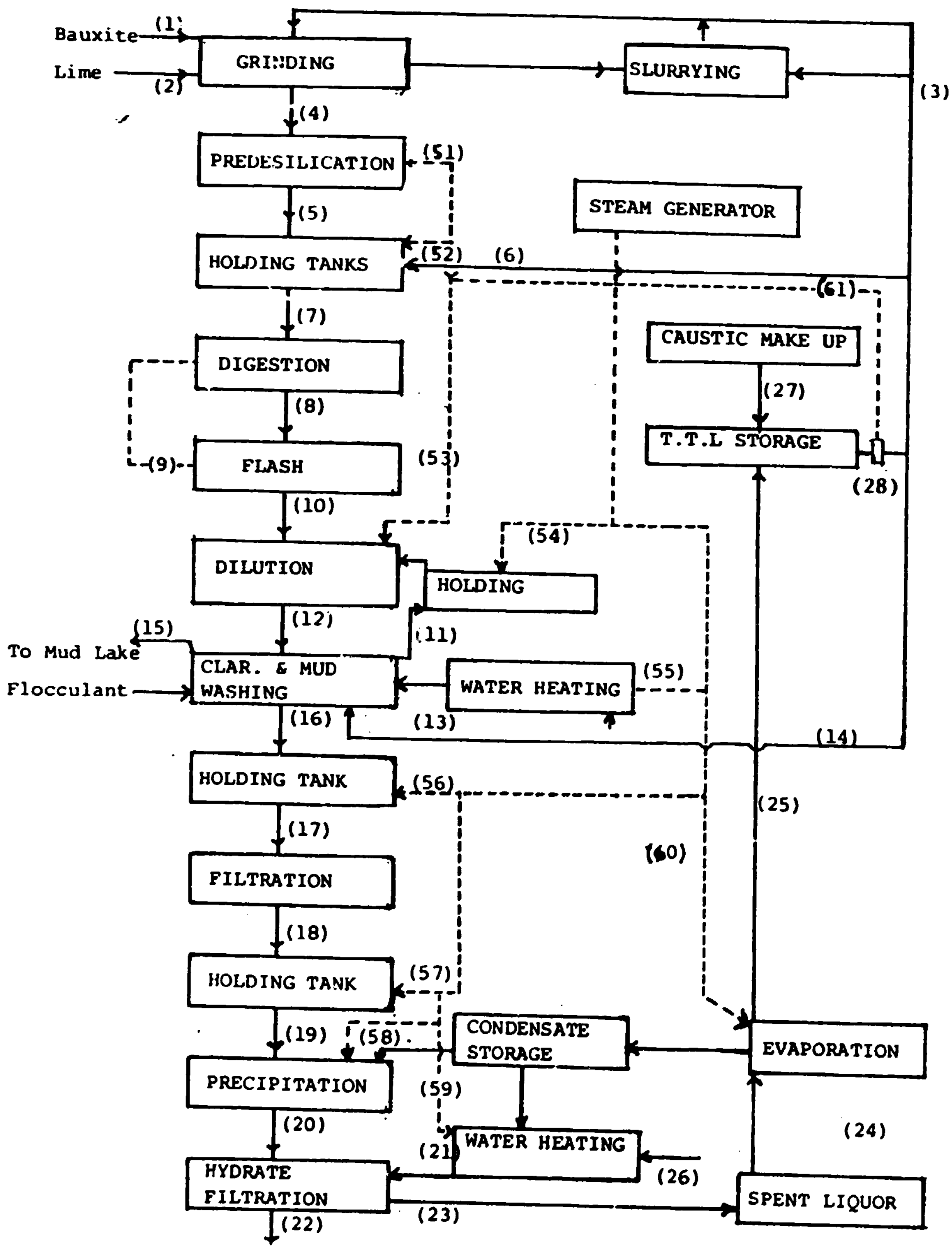

FIGURE 2 - BAUXITE GRINDING AND SLURRYING AREA FLOWSHEET

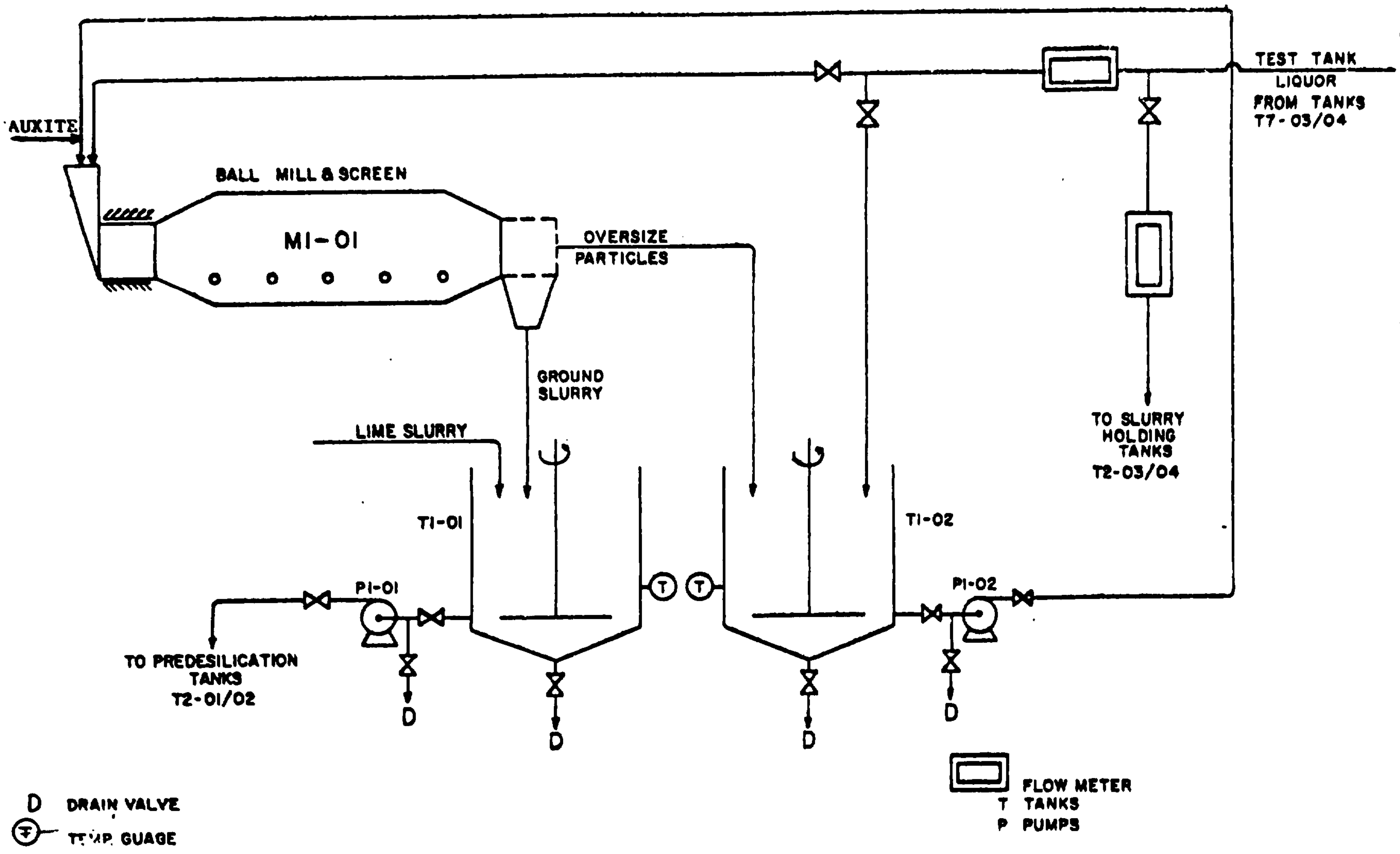

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FIGURE 3 - PREDESILICATION AND SLURRY HOLDING AREA FLOWSHEET

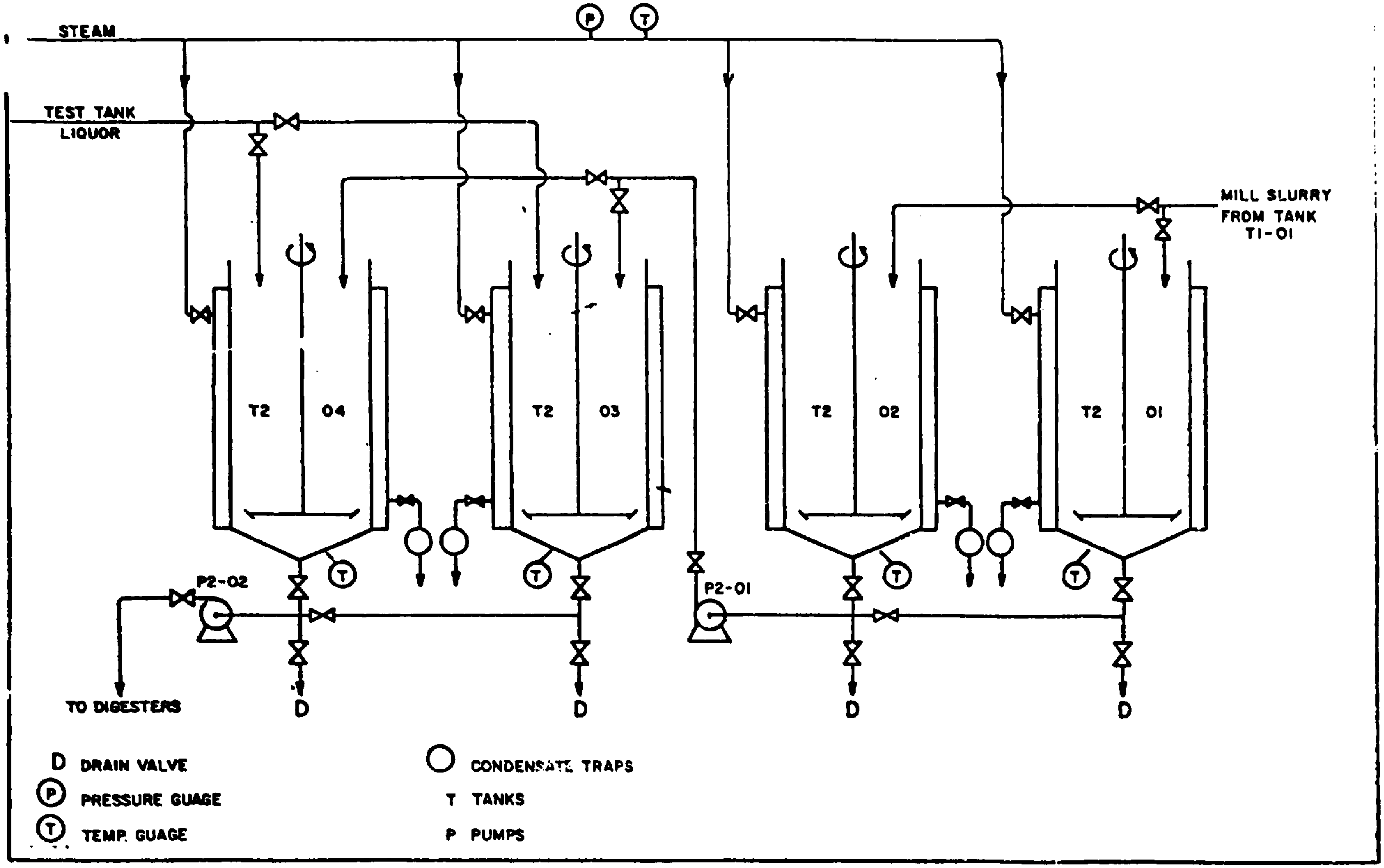

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FIGURE 4 - DIGESTION AREA FLOWSHEET

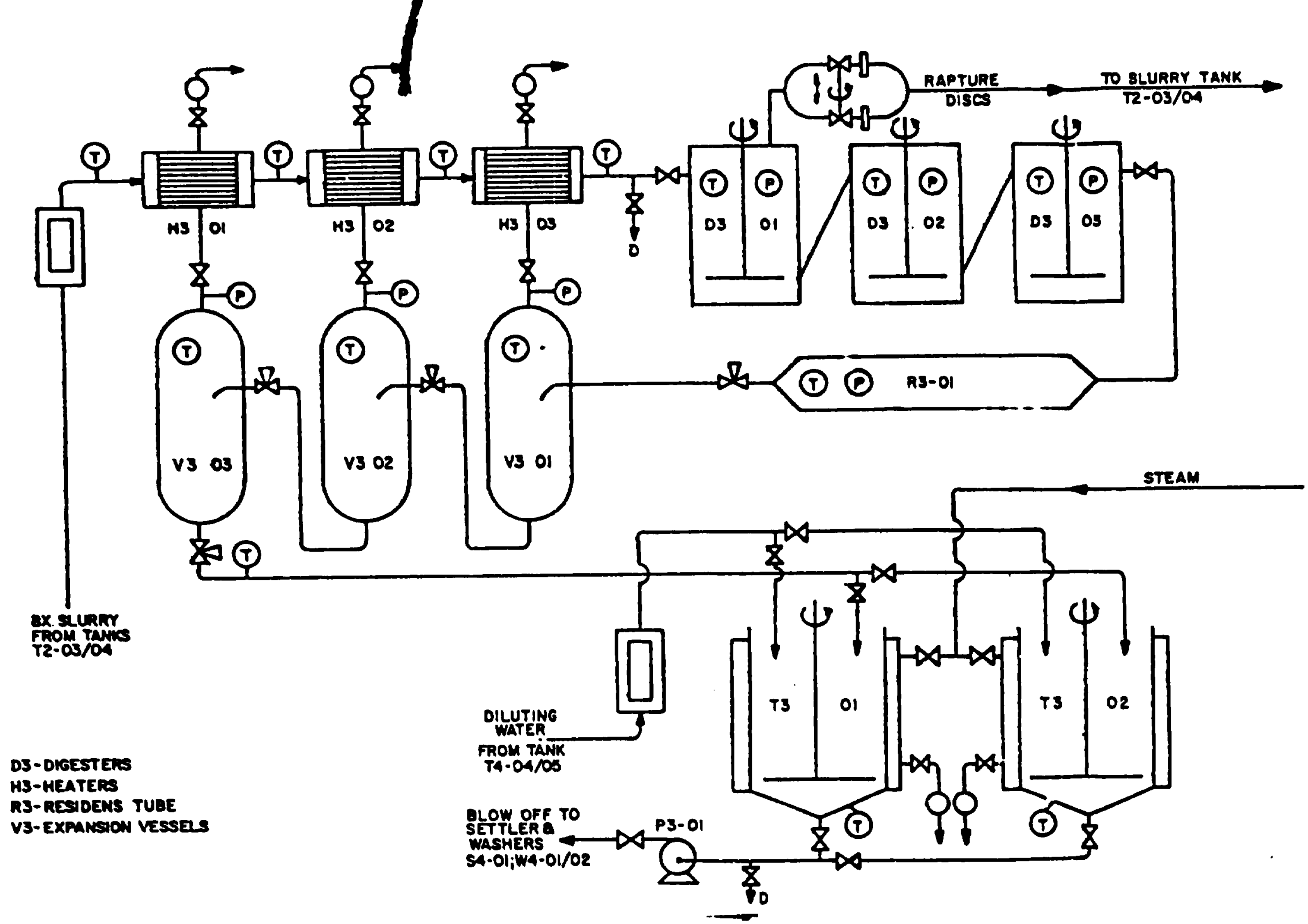

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FIGURE 5 - RED MUD STEELING AND WASHING AREA FLOWSHEET

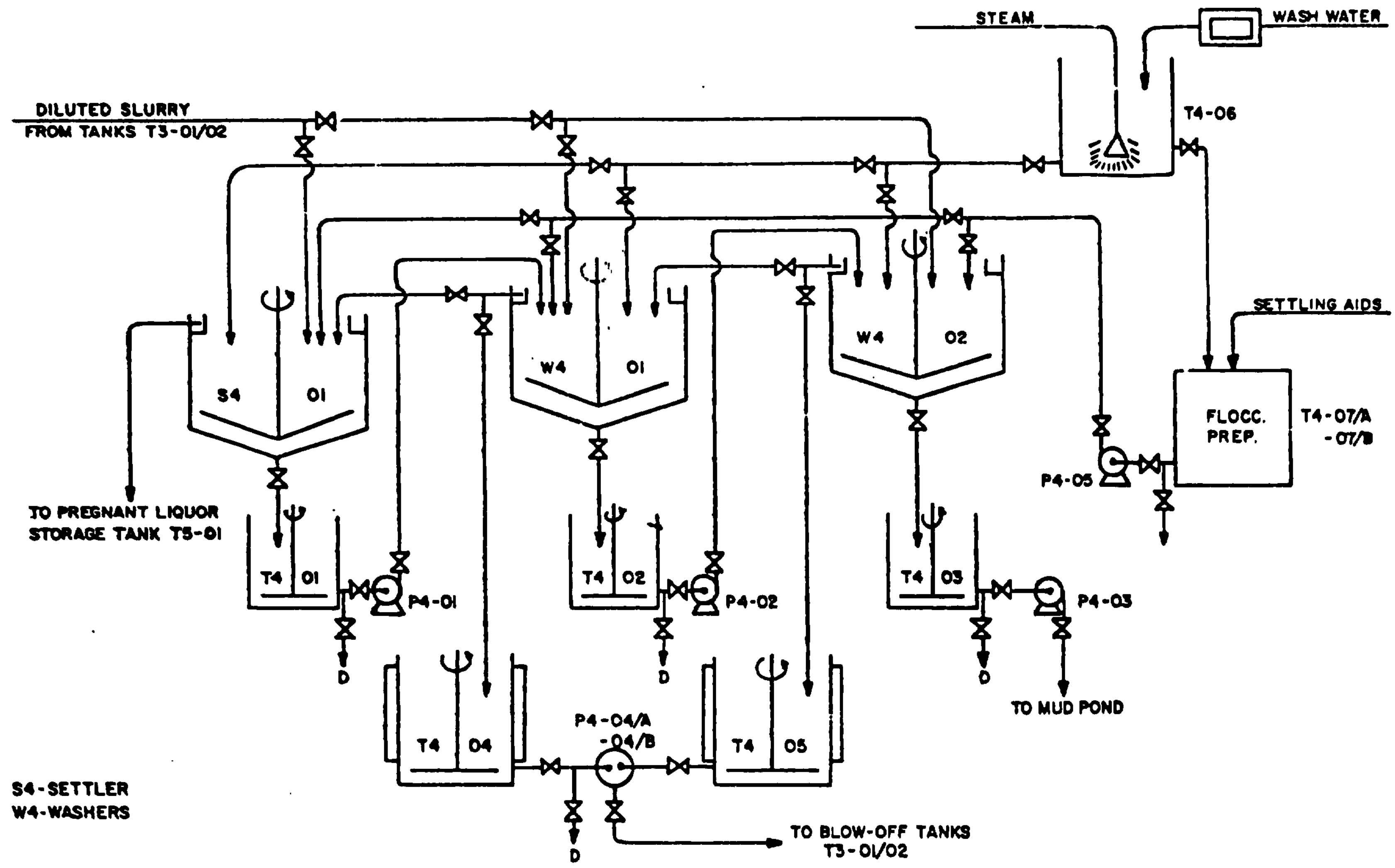

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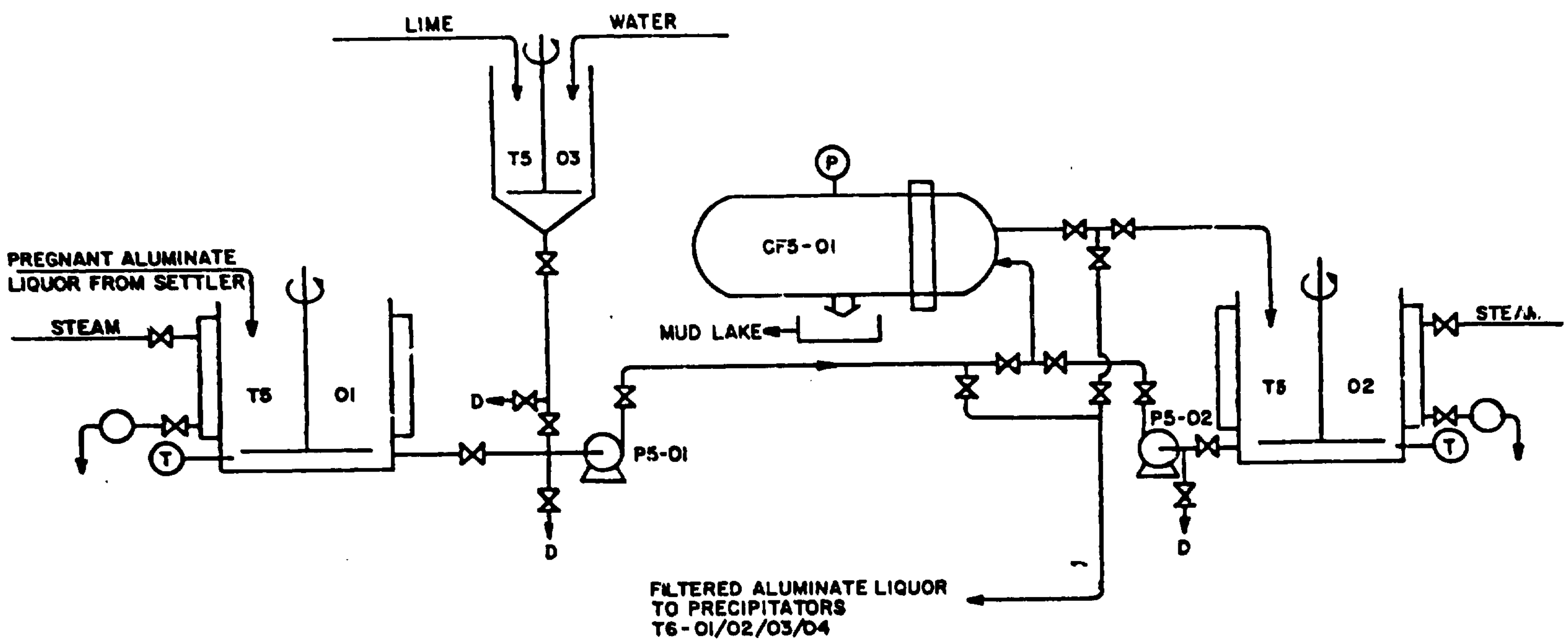
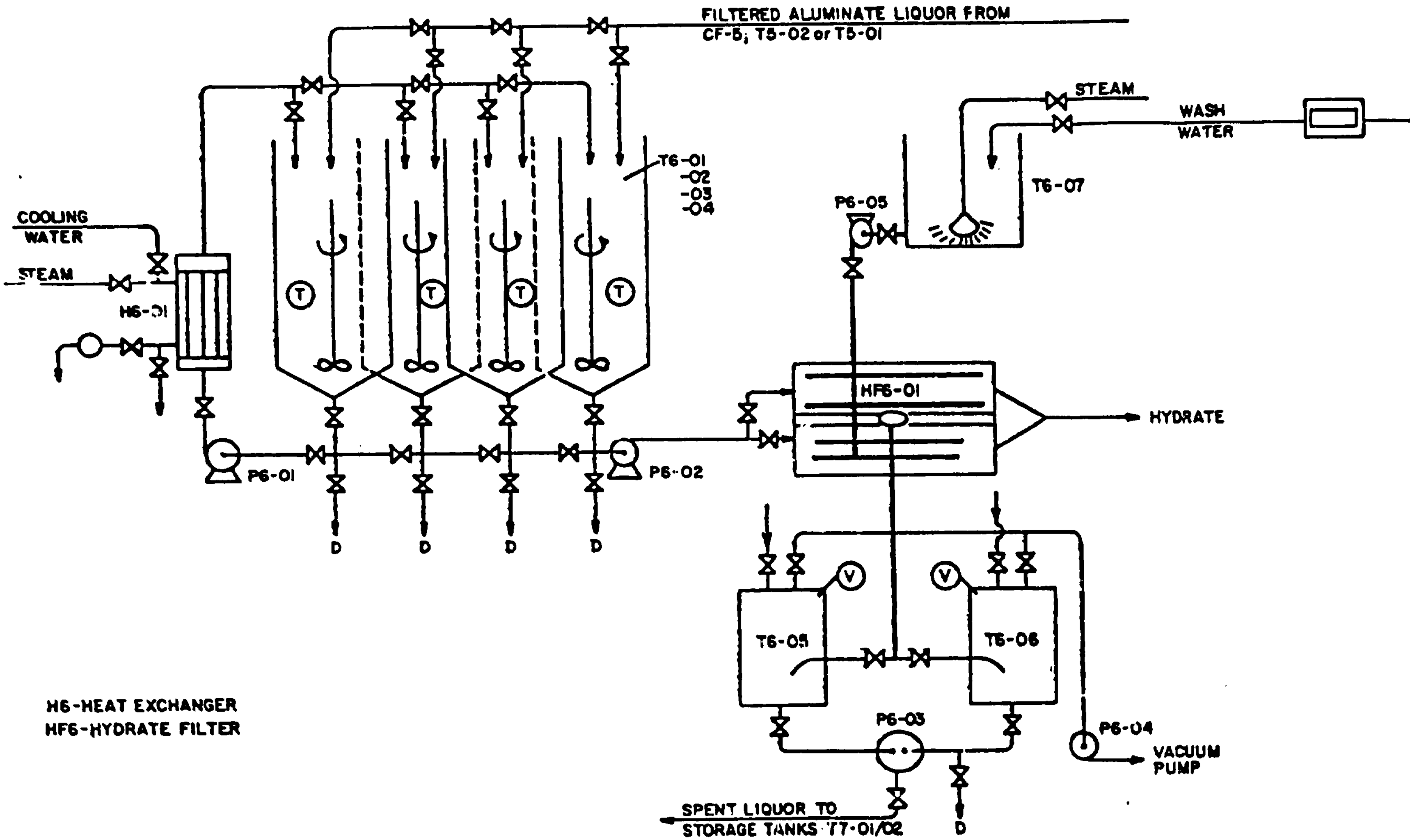
FIGURE 6 - PREGNANT LIQUOR FILTRATION AREA FLOWSHEET




CF5-PRESSURE FILTER

ST/JAM/80/001
REV. 3

FIGURE 7 - PRECIPITATION AND HYDRATE FILTRATION AREA FLOWSHEET




H6-HEAT EXCHANGER
HF6-HYDRATE FILTER

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FIGURE 8 - EVAPORATION AND LIQUOR STORAGE AREA FLOWSHEET

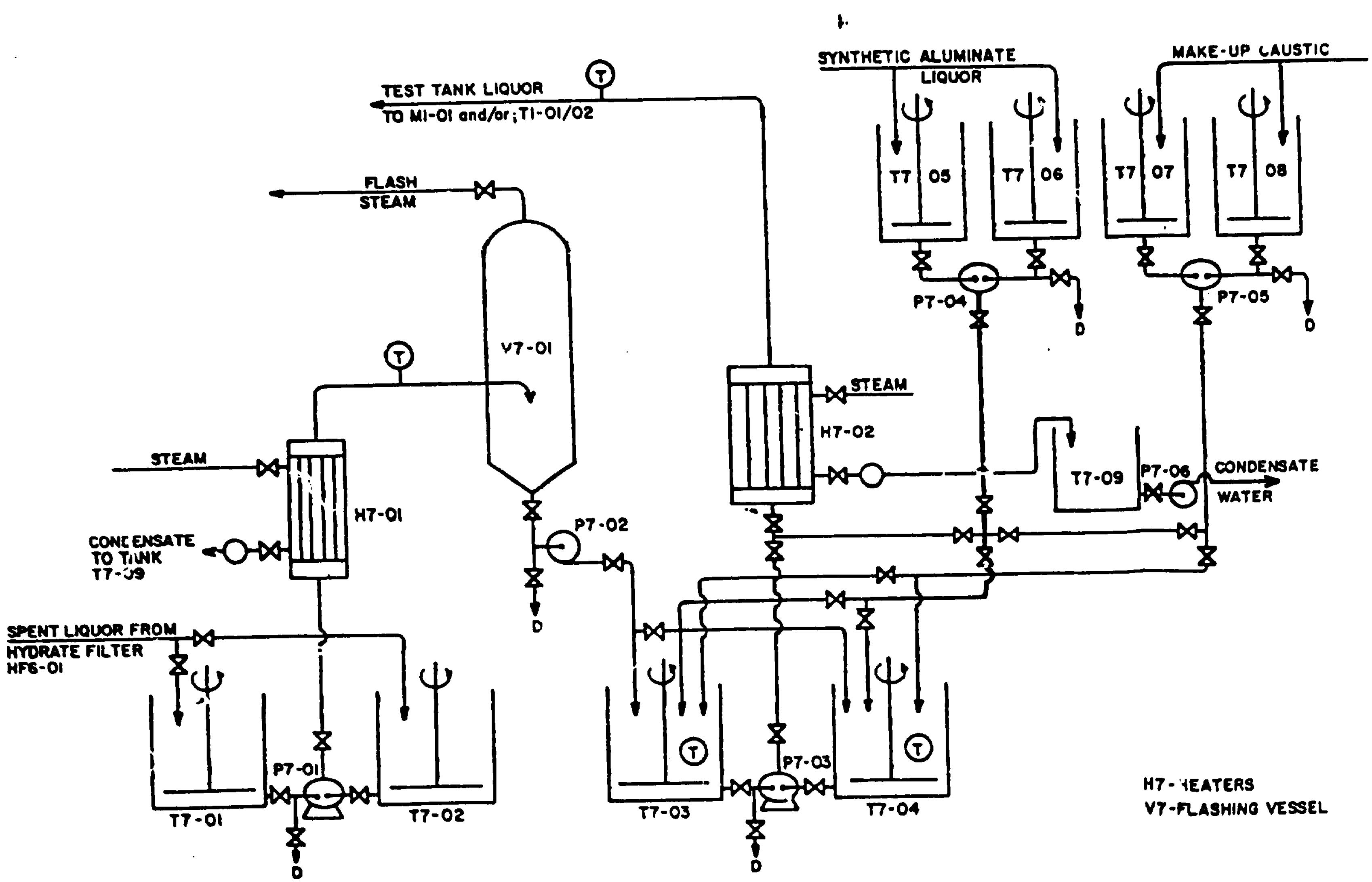
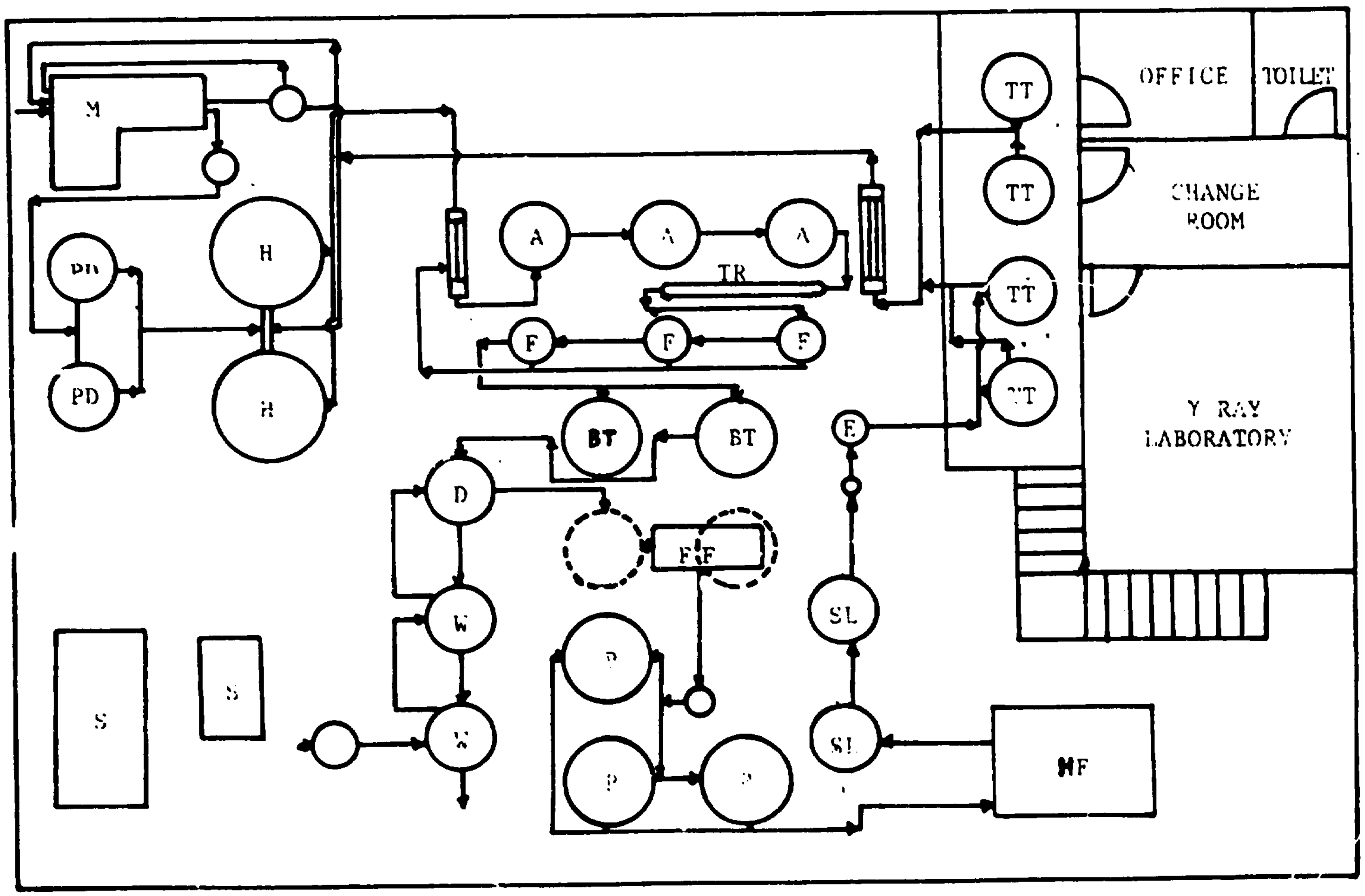


FIGURE 9 - PILOT PLANT LAYOUT




M - Mill
PD- Predesilication Vessel
H - Slurry Holding Tanks
A - Autoclaves
TR - Tube Reactor
F - Flash Vessels
BT - Blow Off Tanks
D - Decanter
W - Washers
PF - Pressure Filter
P - Precipitation Vessels
HF - Hydrate Filter
SL - Spent Liquor Tanks
E - Evaporator
TT - Test Tanks
S - Steam Generator