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EQUIPMENT DESIGN MAKES BOTH NEW PLANTS AND REVAMPS COST EFFECTIVE AS REGARDS ENERGY, MAINTENANCE AND RECOVERY

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INTRODUCTION

PRAYON has been a producer of phosphoric acid for over 70 years. During this time there has been a gradual and progressive development of phosphoric acid and associated process technology; however always being a production company has meant that on-line time, low maintenance costs and low energy costs have also been important and as such the design of reliable equipment meeting these aims has always accompanied process innovation.

Four major revamps have been carried out at the Engis phosphoric acid site during the last 30 years to maintain its profitability in changing market conditions whilst satisfying more restrictive environmental requirements. This "in house" experience has, after testing, been made available to our clients throughout the world by the continual up-dating of the licensed PRAYON technology. The development of equipment design during the last 40 years is quite remarkable and is only equalled by the developments in materials of construction during the same period.

Equipment modifications have also been enforced by process changes especially the operation in the hemihydrate mode. During a combined total of 35 years experience with the handling of hemihydrate in the two multi-crystal processes operated within the group (20 years at Engis & 15 years at Puurs), PRAYON engineers have been stimulated to design and redesign equipment to reduce the effects of scaling, corrosion and erosion to increase the on-line time of the hemihydrate sections of these units. This gives PRAYON a base "second to none" in terms of equipment design for their new range of high-strength hemihydrate attack phosphoric acid processes.

This paper will describe the development of equipment designs that enable the overall profitability of the production unit to be maximised either by the increase in on-line time & the reduction of maintenance costs or even process related aspects such as ability to utilize lower grade phosphates, reduction in energy consumption or increased efficiency. The topics that will be dealt with are as follows :

- Reactors
- Agitators
- Flash-coolers
- Flash-cooler circulation pumps
- Slurry pumps
- Sulphuric acid dilution units
- Air cooling
- Tilting-pan filters
- Belt filters

DEVELOPMENT

Progressive modification to the design of phosphoric acid equipment has been forced by a number of changing factors and also by a change in the standards of acceptance. The expected level of performance is much higher than it was in the past. There were times when pumps were not expected to have a normal service life because "nothing stands up to phosphoric acid slurry". Nowadays the operating company expects equipment compatible with the duty and rightly so.

Some factors that have influenced the design are listed below :

- Desire for a better utilization
- Desire for better access for cleaning
- Desire for less frequent cleaning
- Desire for more standardization
- Improved grades of stainless alloys
- Higher foaming phosphates
- Higher chloride phosphates
- Higher acid strengths & temperatures
- Handling of hemihydrate slurries
- Desire for a lower specific power consumption
- Desire for a higher process efficiency
- Desire for a higher overall efficiency

REACTOR DESIGN

The characteristic PRAYON reactor design came about through an evolutionary process of some 40 years that has accompanied the process changes that have occurred during that period, that is the development of the four phases of the PRAYON dihydrate process (Mark I to Mark IV) and the CENTRAL PRAYON PROCESS (CPP). This proven reactor design is also the basis of the family of high strength processes now offered by PRAYON.

- MARK I (1950s)

The first reactor was built on the site at Engis in Belgium and was one of the main elements in the 35 TPD P_2O_5 phosphoric acid plant built in 1945 along with the first PRAYON filter.

The reaction system (Fig. 1.A.) consisted of two vertical cylindrical lead tanks lined with anti-acid silica bricks. Each tank was divided into 4 compartments by two diametrical walls and each compartment was fitted with its own individual 10 HP radial-bladed agitator. As time went by this was superseded by the now common rubber and carbon brick lined carbon steel construction.

As plant sizes increased the design was adapted to utilize four tanks each with a single diametrical wall in each creating a total of 8 compartments (Fig. 1.B.). This reactor design was used for the unit at FISON's Immingham built in 1956 and which is still in operation today (now NORSK HYDRO FERTILIZERS LTD.).

This design was extremely satisfactory from a process point of view but suffered some problems in terms of the capability to accept highly foaming phosphates and the fact that the corners of the segments suffered deposition of solids. The foaming problem caused spillages in the overflow launders between the tanks where no agitation existed, this problem was reduced but not eliminated in later designs by placing the reactors as close as possible to one another. These problems increased down-time, maintenance costs and losses and a solution was sought to reduce these negative points.

- MARK II (1960s)

When the decision was taken to increase the capacity of the phosphoric acid production at the Engis site by building a new 100 TPD P_2O_5 unit in 1962, PRAYON's engineers decided on a solution to the above problem which was then a totally new concept in the construction of phosphoric acid reactors.

The new concept was a direct result of the desire to eliminate the launders between the tanks of the Mark I design in order to reduce spillage losses thus improving the overall production efficiency and plant reliability. The idea was to have a single compartmented tank divided into 8 compartments. This concept also improved the space utilization factor by reducing the wasted space between a number of round tanks.
Initially studies with an annular or circular design were made but it rapidly became obvious that a rectangular tank divided into a number of square compartments was the best solution from a process and operating point of view, enabling good agitation patterns without baffles and also reducing the deposition tendency in comparison with the corners of the segmented compartments of the previous design. This new shape initially gave some headaches in the design department as they tried to create a metallic structure sufficiently rigid to accept rubber and carbon brick lining. At this time the possibility of building the tank in concrete was studied and found to be the most cost-effective method to construct a reactor of this shape that would have the rigidity to ensure the flex-free surface required to enable a fully-guaranteed bricklining to be applied. The underflow/overflow ... pattern of slurry-flow was maintained to prevent short circuiting of the reactor.

The monobloc concrete design has two other advantages, the first is that the concrete tank top can be designed to support the agitators eliminating the costly agitator steelwork and secondly gives better conditions for access & maintenance, giving the operator a chance to keep the tank top clean having total safety whilst walking directly on the tank top.

A second advantage is the fact that the concrete shell maintains a constant wall temperature giving better brick-lining adherence and less scaling on the walls.

The first concrete reactors used outside PRAYON were built in 1962 for IMC's plant at Bonnie, FLORIDA (now CF Industries) then, at 400 tpd P_2O_5 each, the biggest single stream capacity in the world (Fig. 2 & Ref. 1.2).
A similar sized unit built for ESSO Chemicals in Redwater has been progressively revamped to its present capacity of up to 1100 tpd P_2O_5, however the reactor remains the same and two additional filters have been added. Florida phosphate is processed and the overall efficiency is above 95 % on an accounting basis.

The modular concept of this design enabled identical agitators to be used and also when a plant boost was envisaged, at Engis, in 1965 it was quite simpleto add two more compartments between Nos. 4 & 5 designated 4' and 5' to increase the reaction volume by 25 %. At this time the first attempt was made to provide maturation volume separate from the recycle circuit prior to filtration to allow de-supersaturation of the liquid phase . This was done by adding a single rectangular concrete tank with two agitators, this was the beginning of the Mark III concept.

- MARK III (1970s) (Convertible)

The reactor design of this era incorporated features to enable it to be used for the Dihydrate PRAYON Process (DPP) and also the CENTRAL-PRAYON Dihydrate/Hemihydrate Process (CPP). The experience in the boosted dihydrate plant at Engis was used enabling the first stage to be operated with high recirculation and agitation levels and the second stage acting to de-supersaturate the liquid phase which only requires gentle agitation as there are no rapid reactions occurring (Fig. 3.A.).
The main result of this increase in digestion volume was a more stable cooler slurry feed to the filter, reducing scaling effects, improving filtration rates & reducing wash frequency. There was also a great reduction in the overall power requirements, the multicompartmented reactor concept enabling the levels of agitation to be adjusted to the individual needs of each zone of processing. The freeboard of the second stage could also be less as the foam was eliminated in the first stage by surface impellers of the GTA type.

The other main modification was to the internal dividing walls that were changed from the underflow/overflow pattern to lateral openings, the reason for this being the increased flow rate being used around the reactor and the subsequent need to reduce the pressure-drop, along with a greater capability to deal with the increased foaming tendencies of the lower grade phosphates that began to be marketed during this period (Ref. 3.4.5).

With the lower agitation levels used in the second stage of the reactor it was possible to dispense with the carbon bricks on the walls and as such there was the possiblity to utilize either square concrete tanks or cylindrical rubber-lined carbon steel ones depending on local conditions.

- MARK IV (1980s)

The latest design of reactor has been well publicized in articles about the third phosphoric acid train at IMC in New Wales (Fig. 3 B & Ref. 6.7.8). As such it need only be stated that the design has large vertical windows between the compartments and provision for the low level flash cooler (LLFC). As usual this project included only features that had been previously tested and proven in the production unit in Engis.

AGITATORS

In the original Mark I design, with the tanks divided into four compartments each, the agitation was provided with a single agitator fitted with one or two sets of radial blades. When the design was modified to tanks with semicircular sectors PRAYON decided to build a full-scale test tank to be able to analyse fully the agitation patterns and to evaluate the effects of interference between the agitators and to set up the agitator design data. This was felt to be necessary as this **semicircular tank** differed quite markedly from the classical fully baffled type of circular tank that is found in the agitation literature. The interaction between two agitators from a mechanical point of view cannot be fully predicted when they are both operating in the same tank and although it was felt that this may have been the cause for premature failure of a number of units it could not of course be proved conclusively. However in the Mark II reactor design it was decided that the philosophy of one agitator per compartment was to be followed. The use of a larger number of smaller agitators is often considered to be less cost effective than a reduced number of large agitators but this is not necessarily true. If the agitator designs are sufficiently standardized then the value of spare parts to be carried in stock can in fact be reduced. The total value of spares can be lower in this case than the case where a larger number of larger rotors, shafts or gearboxes of different sizes have to be kept in stock for an eventual failure that occurs with a relatively low frequency. The plant with smaller agitators can also have the capability of continuing operation with an air lance during the repair or replacement of the defective unit thus improving on-line time. The modular concept also maintains the ability to use agitators with a proven track record instead of each new design being the result of a specific process engineering and mechanical calculation, conveying a higher level of confidence in the suitability of the agitation unit from both process and mechanical aspects.

The radial-bladed agitators provided a great deal of shear, consumed a great deal of power but did not have very good properties in terms of overall homogenisation of the tank. PRAYON was aware of this at this time and quickly realised that the pumping of agitators was as important if not more important than the shear (Fig. 4 B).

A full scale square tank was built to test the effect of pitched blade agitators (Fig. 4 A) and from this data a process design was defined.

The Engis unit was switched to agitators with pitched-bladed axial flow rotors in 1970 and these proved to be energy efficient whilst improving the process efficiency, (lower unattacked phosphate losses, lower co-crystallised losses and better filterability). With the gradual increase in the foaming tendency of phosphates it was found necessary to add some surface agitation to act as mechanical foam-breakers and initially a set of radial bladed paddles was fitted at the surface. During the meeting to discuss the level that they should be installed it became obvious that the blades should have a large vertical section & the GT design was developed to cope with the variable foam height. By full scale testing in a square concrete tank specially built for the previous agitator studies it was possible to optimize the design in order to make the design more energy efficient, the design encountered at that time, the GTA, is still considered to be the ultimate in shaft mounted foam-breakers.

This GTA design also gave an additional bonus in terms of air cooling. By careful design of inlet and outlet ducting it was possible to obtain good heat and mass transfer without entrainment, and this cooling effect has been utilized to a greater or lesser extent on all the designs since this date. The liquid level of the compartments with the GTAs is maintained constant by an overflow to the next section of the attack tank, the amount of foam gradually decreases as the reaction proceeds to completion.

But this success was still not considered sufficient by the operations people at Engis who where looking to reach even higher levels of homogenisation at the same levels of power used on the 45' pitched blades turbines. The square section concrete tank was again used and thence began the development of the PHT range of agitators. PHT stands for PRAYON Helicoidal Turbine.

This development of a progressive pitch axial flow pumping agitator was undergone "in house" until a satisfactory standard design from a process point of view was obtained. However there did exist some problems in terms of mechanical design (problems with cast blades etc...) and although the solution of pressing the blades in a multiprofiled die was found at Engis it was considered that in order to supply our licensed units with a high integrity product it would be necessary to set up a licence agreement with a specialist in the area, thus the PRAYON-LIGHTNIN' agitator was born.

LIGHTNIN' was chosen as they had themselves embarked on a similar type of impeller the A-210. They were able to apply their high-tech. laser laboratory studies to the PHT. This was the beginning of the PRAYON-LIGHTNIN A-310 design, which is now in use not only in phosphoric acid but also in all fields of chemical processing. This hydraulic tweaking of the PHT enabled the power/pumping ratio to be decreased a further 5 % and the LIGHTNIN skills from a design & fabrication aspect enabled PRAYON to offer a range of reliable units compatible with the various standard tank sizes. These latest PRAYON-LIGHTNIN units give more pumping than the old 45° pitched blade turbines at half the consumed power.

The standard agitator in the latest Mark IV designs is the PRAYON-LIGHTNIN A-310 (or 4-PHT) with two sets of axial blades and a GTA at the liquid level (Fig. 4.C.). In compartments where less foaming is expected a simplified GT type agitator is used, the GTS.

This design is also envisaged for the PRAYON high strength processes and has already seen active service in this duty as replacement units in an existing hemidihydrate process that had agitator problems. The development of the agitator design is demonstrated in Fig. 5.

FLASH COOLERS

Ever since the first PRAYON plant was built in 1945 flash cooling has always been a trade-mark of the PRAYON designs, although additional cooling was achieved by means of H_2SO_4 dilution coolers and the usage of the air through the reactor has been progressively increased giving a contribution too. The progression of flash-cooler designs does not directly follow the reactor designs but there have been four stages too, the progression can be followed on figures 6 & 7.

- MARK I 1945 ...

The original flash cooler was perfectly adequate to remove the heat load necessary for the 35 TPD plant but it was necessary to look at a more sophisticated design to cope with the heat loads of the later larger plants.

- MARK II 1950s

The modified design looked to increase the slurry surface area within the unit whilst reducing the hold-up of slurry within the body of the unit. The device used was that of a funnel except that the slurry entered axially through the base and overflowed the rim causing a cascade with a very large surface area. The base was the same as the earlier design a truncated cylindrical form with the outlet at the lowest point.
This design was most successful needing only limited cleaning every 6-10 months but with the increase in the foaming tendency of the lower-grade phosphates it was necessary to change from an up-flow to a down-flow design. Larger units requiring two slurry pumps had a double inlet, double cone design.

- MARK III 1965 ...

In this design the truncated cylindrical base was maintained but a downwards directed spray-pipe was used. The rubber and carbon-brick lining was also modified in the area subjected to erosion by the sprayed slurry. This design enabled greater heat fluxes to be used progressively without the problem of entrainment even on highly foaming phosphates such as Gafsa. This design change eventually demonstrated that higher linear velocities could be used without problems thus reducing the size of the equipment, the more compact distributor also meant a reduction in the quantity of stainless alloy, both these features created a better design at acheaper price whilst increasing the efficiency of the unit.

- MARK IV (LLFC) 1980s

The idea of the low-level flash cooler was not new to PRAYON as the concept was first applied to the PRAYON No. 4 evaporation unit flash chamber in 1971, this idea was first tested as an additional flash-cooler in an attack section when a small trial unit was fitted to the 150 TPD P205 CENTRAL-PRAYON unit at Engis in 1973. Its success justified its inclusion in full scale on the later 380 TPD P205 CENTRAL-PRAYON unit in 1974. The third unit was built at IMC only in 1981 as the radial design was not offered externally until it had been proven on a variety of phosphates "in house" on the Engis unit. The advantages of this design are the ability to circulate triple the flow of slurry, reducing the temperature differential by a factor of 3, whilst requiring only one third the power in comparison with the previous design. This is gained by a reduction in the total developed head of the pump. Figure 8 shows the difference in elevations, 10 meters for the Mark II design and 4,5 meters for the LLFC Mark IV design. This higher flow gives greatly reduced scaling tendencies and great improvements in filtrability. The 1500 tpd P_2O_5 third train at IMC-New Wales is fitted with 2 LLFCs whilst the 2 x 600 tpd units at PHILPHOS are fitted with one LLFC each.

FLASH-COOLER CIRCULATION PUMPS

The PRAYON factory at Engis is located within 20 kms of Liège, when the first plant was built during the second world war it was only possible to obtain equipment from local suppliers. Luckily, there existed a pump company at Ensival in Belgium that was also located in the Liège region. This started a long relationship between the two companies that still exists today.

The first pumps used were of the Ensival vertical submerged type (Fig. 9 A) and this particular feature continued for some considerable time. In the USA HAZELTON vertical pumps were used and although they operated satisfactorily they did need quite a lot of adjustment and maintenance; pump life was typically 6 - 12 months. At a round-table of PRAYON operators in INNISBROOK Florida in 1977 this particular topic was one of the most discussed.

Problems of cavitation and corrosion/erosion plus the desire for increased flows caused gradual change to ASH horizontal, low speed centrifugal pumps located at grade and isolated by guillotine valves. This solved the suction problem associated with foaming phosphates whilst in severe cases it was possible to use rubber-lined pumps to combat highly corrosive/erosive slurries.

Axial-flow pumps had been used for reactor circulation pumps in the Mark III reactor design where the flash cooler flow was too low for the reaction recirculation. So when it was envisaged to have a higher flash cooler flow it is not surprising that the same type of pump is used (Fig. 9 B). The experience of this type of pump in this duty is quite surprising, the rotor requires changing every 3 - 4 years whereas the casing wear-ring has lasted about 2 years. The position of this pump is normally in the down-leg ensuring a cooler, de-gassed slurry to be pumped thus reducing the effects of cavitation.

SLURRY PUMPS

Initially the PRAYON Process relied on the flash cooler pumps to provide the reactor recirculation, but even the early designs incorporated means to regulate the reaction recirculation flow separately from the flash cooler flow by means of a splitter box. This however was only possible whilst the desired reactor recirculation was less than the flash cooler flow.

The use of vertical submerged pumps was superseded by horizontal pumps for flash cooler duties but the very low required head for reactor recirculation meant that an axial-flow pump of very high flow to power ratio could be used with advantage. If a variety of phosphates was to be processed then adjustable speed could be included in the specification to vary the reactor recirculation flow independently from the flash-cooler flow. With the advent of the low level flash cooler (LLFC), the flash-cooler flow became equal to or greater than the required reactor recirculation flow for most commercial phosphates and if necessary the flow can be split to optimize the reactor recirculation.

The filter feed pumps for dihydrate units have almost always been of the vertical submerged type but more recently horizontal centrifugal units have been increasingly used. In order to increase pump life variable speed drives have been added to both vertical and horizontal pumps for flow control. One specific application that has been developed by PRAYON is the filter feed on the Hemihydrate section of the CENTRAL-PRAYON Process. This slurry is particularly abrasive due to the form of the golfball shaped hemihydrate crystals and particularly corrosive due to the operating conditions (90-105°C, 25-30 % P_2O_5, and 7-18 % H_2SO_4) under these conditions an alloy pump has a limited life and the plant maintenance costs can be decreased and the on-line improved by using an air-lift pump to feed the filter. This type of pump has no moving parts and is constructed solely of polypropylene, a simple and practical solution to an exceptionally difficult application (Fig. 10).

SULPHURIC ACID DILUTION UNITS

The earlier process designs, Marks I & II, both required sulphuric acid dilution cooling in addition to flash-cooling. The earliest dilution units were lead coils in lead tanks but soon were modified to graphite tube heat exchangers which suffered due to scaling in various magnitudes depending on the quality of the dilution water at each specific site. This problem was offset by the reorientation of the units to have the tubes in a vertical plane, this simple modification improved the reliability of these units to an acceptable level, the 4 units at FESA in Huelva Spain, are still in operation and are considered reasonably trouble free equipment items.

The earlier problems with dilution coolers had given these units a bad reputation and as such when the Mark III design was developed the chance was taken to remove these units from the flowsheet to reduce treated water usage, to enable wet-rock grinding to be used and the utilization of the two-wash filter.

AIR COOLING

The Mark I & II designs did not utilize the potential cooling effect of the air draught on the reactor but once the GTA type foam-breaking impellers were used there was a chance to utilise this effect to a greater or lesser degree depending on specific plant conditions and air pollution standards. In fact during the industrial trail of the PH 11 PRAYON's single stage hemihydrate plant at Engis it was possible to run at 300 TPD P_2O_5 without the use of the flash-cooler, this demonstrates the very efficient air flow pattern that was envisaged for the latest Engis reactor. On small units and especially for example for a small cooling duty on a multi-stage hemi/dihydrate such as the PH 2 it is envisaged that full use will be made of this phenomena. In large units great savings can be made by the maximum use of flash cooling and only limited use of the air cooling effect.

TILTING PAN FILTERS

The original PRAYON filter constructed "in house" during the war years and started up in 1945 has a similar type of development to the jeep, from very simple beginnings they have both become quite specialized designs for the environment that they operate.

The biggest modification in terms of design of the PRAYON filter is the material of construction. The first filter was constructed with almost all the wetted parts in lead, the only material locally available during the latter part of the war. Later units used various grades of stainless alloys for the pans but it was some time before the central distributor valve was changed from lead to a cast alloy design. It was later modified to a fabricated stainless alloy design.

Most of the design changes were incorporated due to experience from the operation of the first CENTRAL-PRAYON (Dihydrate/Hemihydrate) plant at Engis. In this unit an existing PRAYON filter was progressively modified to enable the filtration of an unstable Hemihydrate slurry with an acceptable on-line time.

The phase diagram (Fig. 11) shows why the filtration of Hemihydrate in the CENTRAL-PRAYON Process is a little more difficult than in the strong acid processes. The CENTRAL-PRAYON slurry has a tendency to convert to dihydrate if it cools 10-15°C whereas in the high strength process slurry can cool up to 40°C before reaching the same conditions.

The original wartime PRAYON filter had a grooved wooden support for the cloth bolted to the base of the pan but this was soon changed to the rubber mat design (Fig. 12.A.). In hemihydrate service solids built-up between the mat and the pan causing the mat to rise thus destroying the horizontality of the cloth and subsequent distribution problems. The rubber mat was replaced by a roll-form support in the USA for dihydrate service but in Europe the mats were replaced with a perforated plate support and sloped bottom pans to satisfy the hemihydrate case but this was also maintained as an improvement for dihydrate filtration (Fig. 12.B.).

The pan-wash system was also amplified for hemihydrate service, after the normal pan-wash that cleans the cloth and also recovers the residual acid in the pan; the pan is washed again prior to slurry feed in the horizontal position to vigorously wash the cloth and to ensure that there is no residual hemihydrate in the cells. This "prewash" with hot water also preheats the cell and the piping to the central distributor valve to prevent cooling during the filtration of the mother liquor (Fig. 13.A.).

For the CENTRAL-PRAYON Process only, the cells are also fitted with an internal pan wash too to remove any traces of Hemihydrate remaining in the pan after the normal wash period (Fig. 13.B.).

The central distributor valve also received attention to reduce the cooling effect in the lines between the valve and the separators which were prone to scaling. The modification was to preseparate within the valve reducing the time that the cold air and the hot slurry are in contact. The valve design was called the AC type (Central Aspiration) and also gave a bonus that the filter could be designed at a lower elevation than previously possible as the barometric legs start from the flanges at the base of the central valve. The clearances within the valve were also much larger as the central vacuum offtake duct has a much greater area than several smaller vacuum ducts. The duct was also fitted with a large clean-out door for inspection and eventual access. The valve was also redesigned to allow steam injection where necessary and the possibility of lagging/steam tracing as required (Figs. 14 A & B).

Another improvement was developed for the filtration of metallurgical slurries where cake thickness is extremely thin also improving the performance of the filter in hemihydrate operation was the pan levelling device that enable the horizontality of the pan to be maintained by relatively simple adjustment.

The slurry feed and wash box designs were also modified to prevent sedimentation of solids in all conditions, and attention to the design of spillage areas to enable access and subsequent good house-keeping.

From the comments made above it is quite obvious that the conversion of a plant from dihydrate operation to hemihydrate operation is not solely the modification of the process parameters but also requires a knowledgeable & practical analysis of all the process equipment to ensure that the plant will operate for more than just a three day test run.

PRAYON-EIMCO BELT FILTER

The PRAYON and BIRD-PRAYON filters have been the hub of phosphoric acid plants both of PRAYON and of other processes but the advance of technology in the design of belt filters has not passed by unnoticed and recently PRAYON has set up an agreement with EIMCO for the joint development of belt-filters. This does not mean that the tilting pan filter is dead, both companies will continue with their own tilting pan designs, but the fact is that in smaller sizes and in some specific cases and with certain local conditions the belt filter is an attractive alternative to the tilting pan design.

The present range of belt filters on the market are basically machines developed from metallurgical processes and do not completely fulfil the requirements for phosphoric acid filtration. Often clients who have bought turn-key plants have been dissatisfied with the reliability of the belt-filters supplied by the engineering company involved. The goal of PRAYON & EIMCO was to define a tight specification for phosphoric acid belt-filters and through continuing development improve this machine to be a worthy stable-mate to the tilting pan filter for phosphoric acid applications.

The areas that have been subjected to close scrutiny so far are :

- the vacuum box
- the belt and curb design
- the minimization of dilution of the acid
- the slurry feed and wash box designs
- the maximization of cloth life
- the maintenance of a clean spill-free unit

The details of this filter design will be the subject of a separate paper to be presented in the near future (Fig. 15).

STATE OF THE ART

The history of equipment design linked to the development of the PRAYON process has been demonstrated but what does this mean in present day terms. PRAYON has been a force in the licensing of phosphoric acid technology for a great number of years and has even been considered by some people to be "just little bit **too** conservative" but having seen the progressive development that has taken place one must admit that they never stood still. The one thing that often delayed the commercialization of new features was the desire only to offer proven technology to our clients and this sometimes meant waiting for industrial results.

PRAYON was the pioneer in higher strength phosphoric acid production with their CENTRAL-PRAYON process in 1966 where acid at 35 % P_2O_5 is obtained but any further increase above this value requires initial attack in the hemihydrate phase. The necessity to produce merchant grade gypsum meant that the simpler hemihydrate process routes were not acceptable to the operating people at Engis and as such the development of the three stage process PH 3 (Hemi/Di/Hemi) took some time to complete. The co-production of a high strength acid and a merchant grade gypsum is not an easy task. Once having proven this process the pilot-plant at Engis was used to study the simpler two-stage process PH 2 (Hemihydrate/Dihydrate) and the single stage process PH 11 (Hemihydrate).

The production management at Engis recently decided to make the most of low seasonal activity and after a few minor changes to instrumentation and piping they operated the CENTRAL-PRAYON plant in the strong acid/ hemihydrate attack mode with full success.

The CENTRAL-PRAYON flowsheet is somewhat more complicated than the PRAYON PH 11 process requires having two filtration stages but the plant was operated in the single stage hemihydrate mode (Fig. 16 & 17).

Production reached the nominal capacity of 350 tpd P_2O_5 whilst producing acid above 45 % P_2O_5. The transition from dihydrate to hemihydrate took place overnight in a very progressive and controlled way demonstrating a total command of the operating parameters. The high utilization factor obtained with the existing equipment (reactors, agitators, pumps, flash-cooler, filters etc.) used during hemihydrate operation also demonstrates their total suitability for high strength acid production.

SUMMARY

Present day process analysis is so often made on computers with a "spreadsheet analysis" of all the processes being considered. This may be an effective way to optimize the heat recovery loops in a refinery but is hardly applicable to the phosphoric acid case without a considerable amount of practical knowledge.

It is often said that the results of a computer study are only as good as the numbers that are fed in and in fact this is very true. It is also stated that economic analysis can be adjusted to give any desired result and this can also be applied to this case too.

The level of confidence in the numbers stated in phosphoric acid process literature varies with the experience with the type of phosphate being studied, the process margin accepted by the process licensor & the client's level of success in operating the unit on an annual basis according to the principles set down in the operating manual. Often, when studying revamps, a straight comparison is erroneously made between the present annual average figures of the existing unit (usually having been designed for a former better grade of phosphate) and the expected best performance of the revamped unit. One major factor apart from these process factors is the equipment reliability as this is the multiplier that gives the annual margin of such a plant. Thus equipment selection & design is as important, if not more important, than the process and this has always been respected by PRAYON. Looking at attack tanks with over 20 years of operation show how important the equipment design factor is, in general a PRAYON tank looks as new due to its construction and the ability to maintain the cleanliness of the unit.

PRAYON is unique in being able to offer both dihydrate and hemihydrate technologies of the highest level and as such do not need to make exaggerated claims for any particular process route. If you require an unbiased analysis PRAYON engineers are available to discuss the details in a frank and honest manner. PRAYON's additional emphasis on proven equipment designs enables the confidence in any project to reach levels at which potential clients can trust not only in the performance of the unit from a process of pointview but from a production one too.

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6. M. L. Walton et al. : Optimization of Energy Consumption and Recovery in the World's Largest Single-Train Phosphoric Acid Plant, IFA Kallithea 1982
7. A. Davister et al. : Processes and Equipment Developed to meet the Challenge Put to the Phosphate Industry by High Energy Costs and Varying Quality of Raw Materials, IFA Kallithea 1982
8. Reactors for Phosphoric Acid P & K N° 114, Jul/Aug 1981 30-32

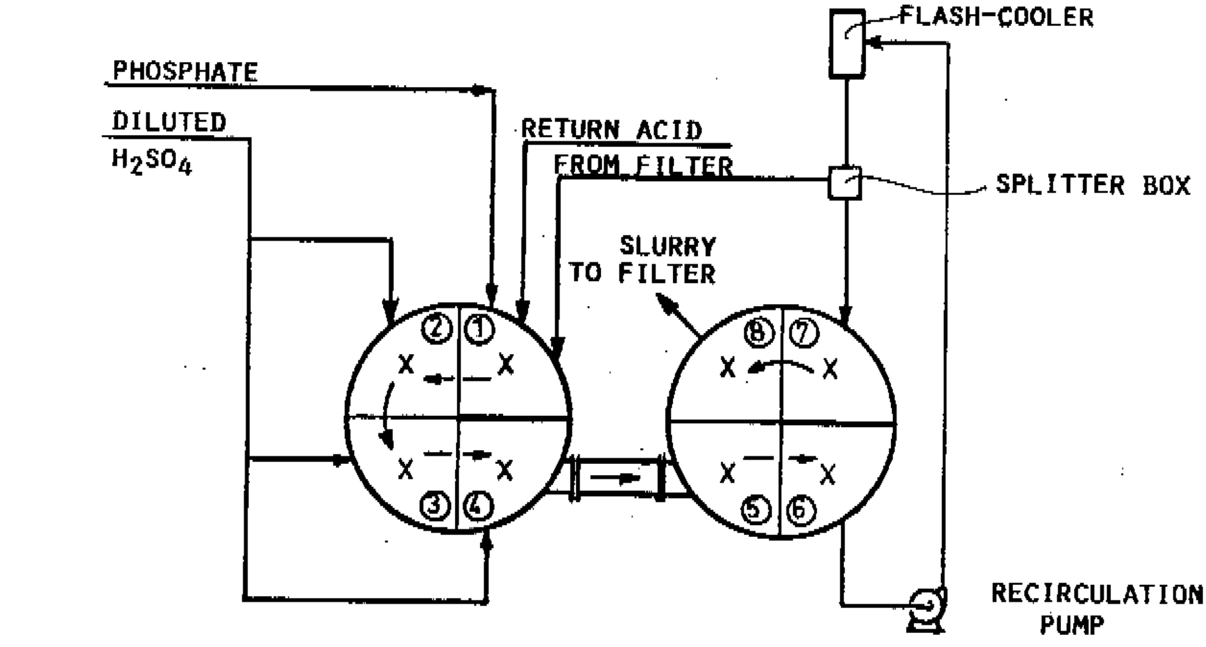


FIG. 1.A.- EARLY MARK I REACTOR LAYOUT : ENGIS 1945

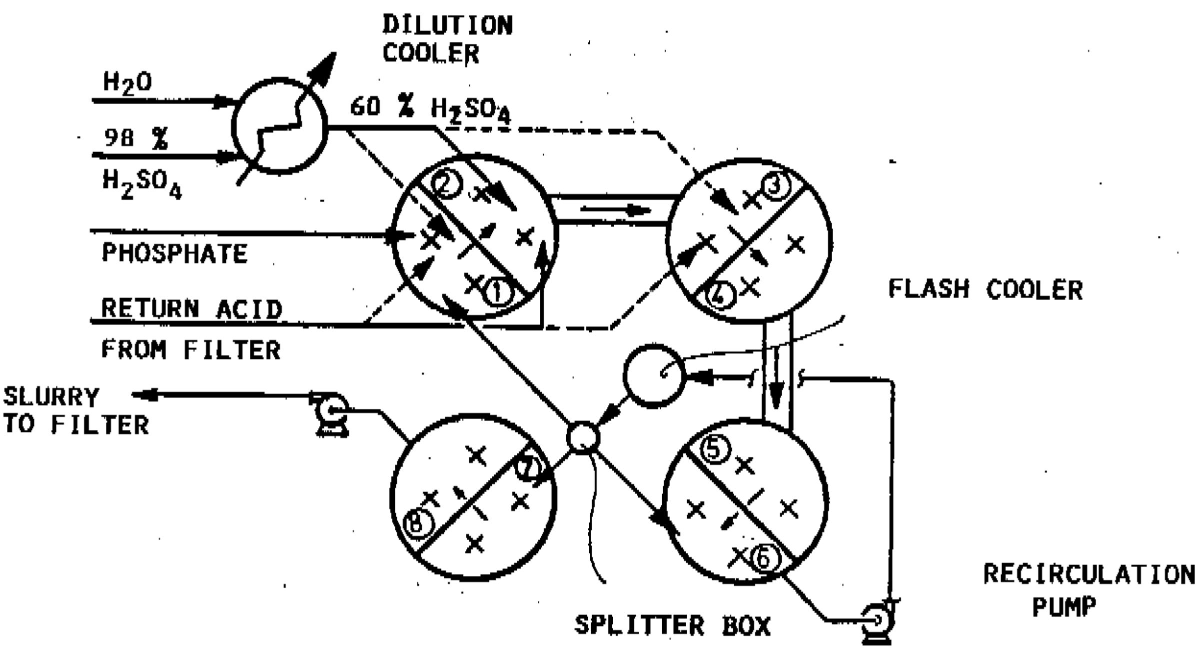


FIG. 1.B.- LATER MARK I REACTOR LAYOUT : FISONS IMMINGHAM 1956

FIG. 1 MARK I PRAYON PROCESS

FIG. 2 - MARK II PRAYON UNIT
IMC - BONNIE 1962

FIG. 2.A. SCHEMA DE FABRICATION : ATTAQUE.
FLOW-SHEET : ATTACK-SECTION.

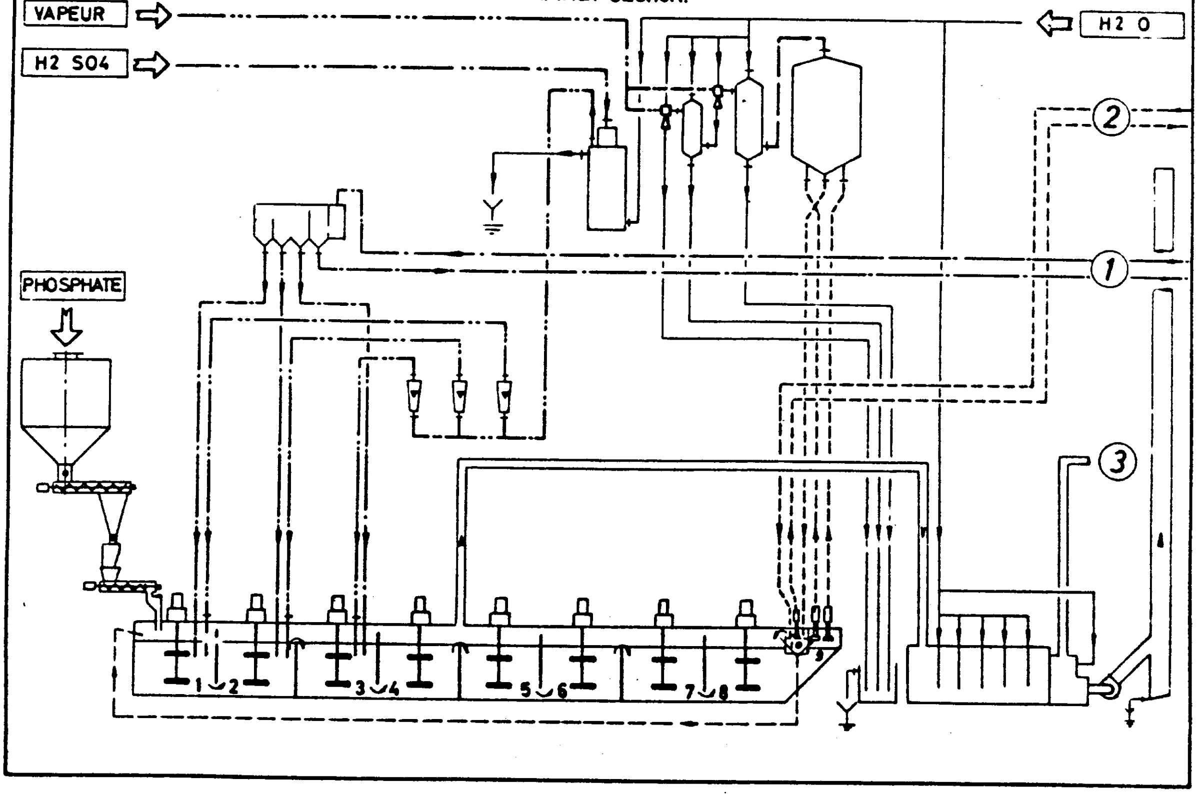


FIG. 2.B. VUE EN PLAN, AU SOL.
TOP VIEW AT GROUND LEVEL.

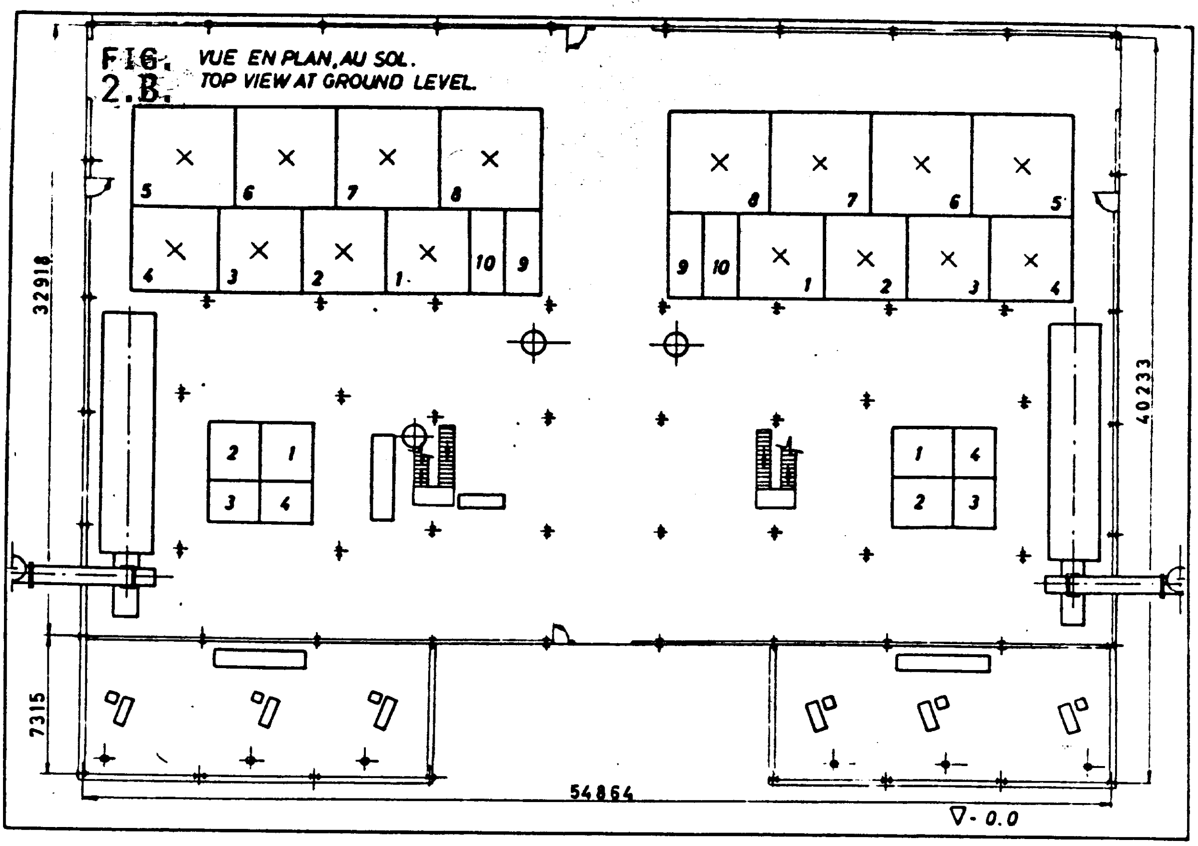
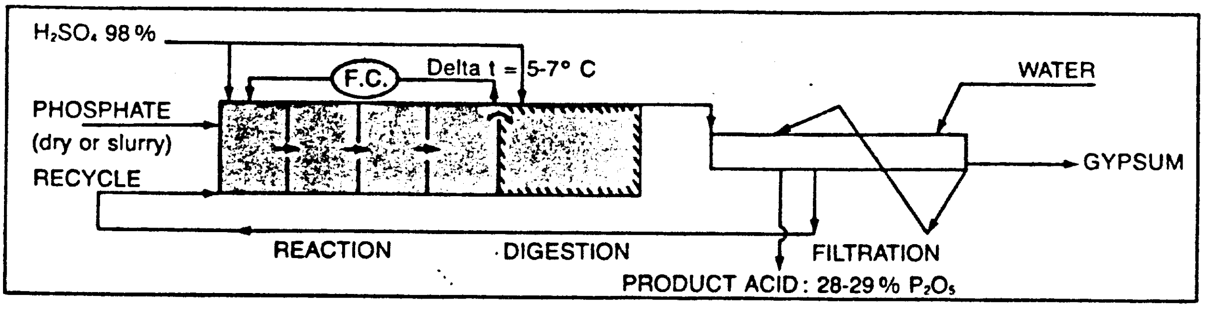


FIG. 3.A. PRAYON MARK III DESIGN

Third generation

Main aims:
- to deal with rocks higher than 4 % CO_2 (mean % BPL 70).
- to better control the slurry flows.

Multicompartmented concrete tank is fitted with vertical low pressure drop communications and foam breaking agitators.



Flash coolers are equipped with entrainment proof feeders to accomodate high foaming rocks.

Aging section is expanded to one third of total volume, to improve crystals and reduce energy.

Filter hydraulics and mechanics have been improved.

20 plants with capacities ranging from 500 to 1500 MT P_2O_5 per day.

Some of these plants were fitted with two filters in parallel.

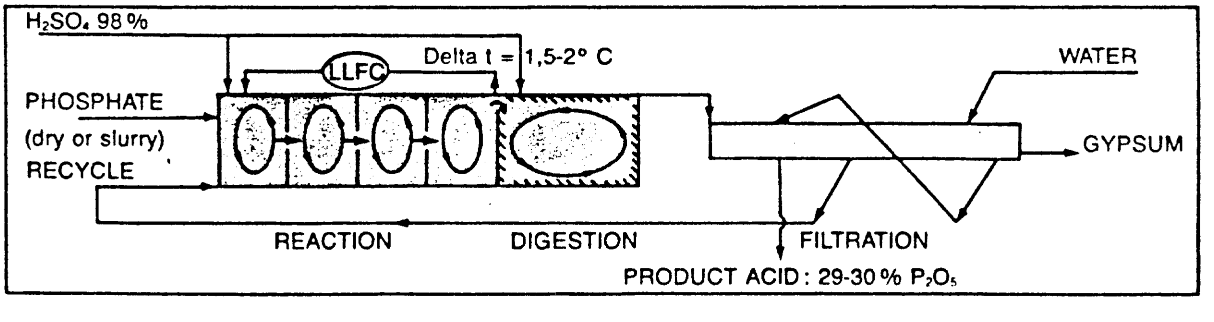
FIG. 3.B. PRAYON MARK IV DESIGN

Fourth generation

Main additional aims:
- to deal with low grade rocks (mean % BPL 65/67).
- to minimize energy consumption.

First application of low level flash cooler, reducing energy consumption & scaling.

Optimization of the three main flows:
- through the tank
- through the flash cooler
- inside each compartment.



Development:
- with LIGHTNIN of high performance mixers.
- with BIRD of modern tilting pan filters up to 250 square meters.

The qualities and advantages of these MARK IV units are detailed in two additional pamphlets. To date, 4 plants are operating from 600 to 1800 MT P_2O_5 per day.

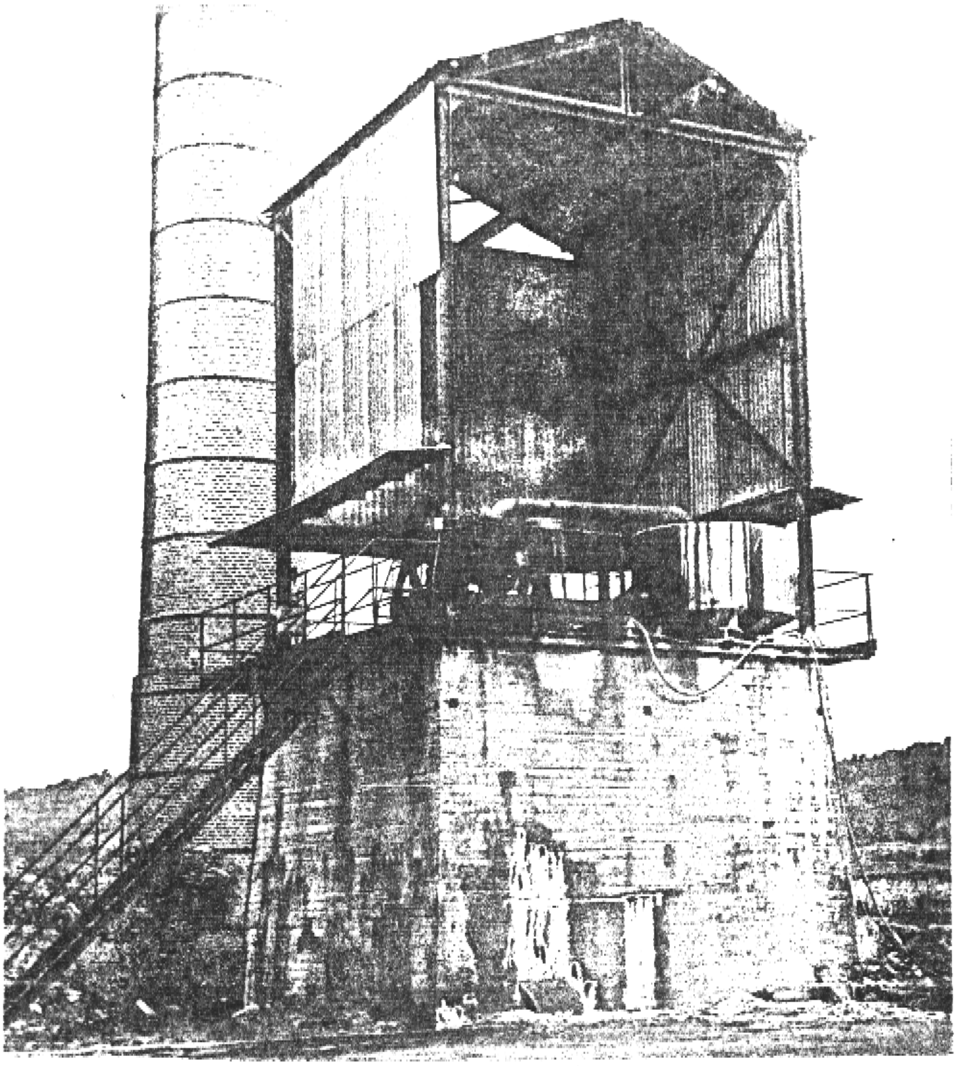


FIG. 4.A.
FULL SCALE AGITATOR TEST RIG.

FIG. 4.B.
PRAYON RADIAL BLADED AGITATOR

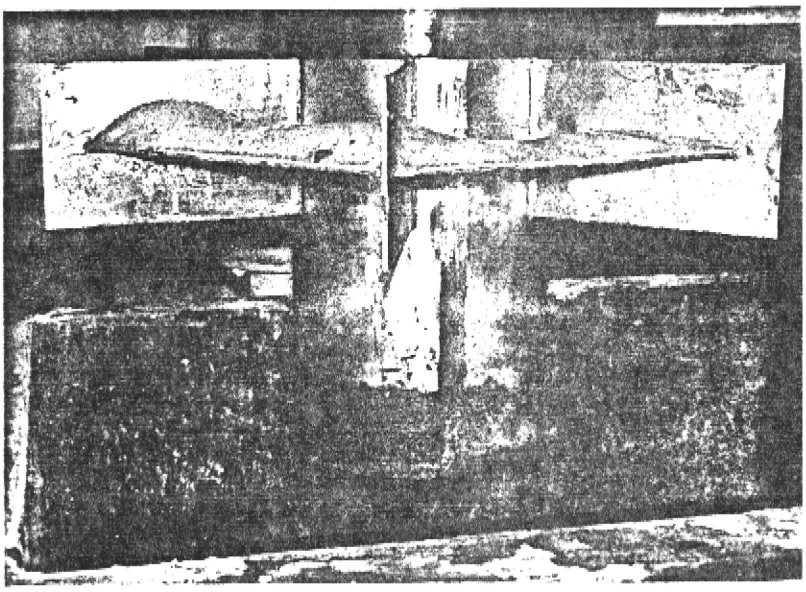
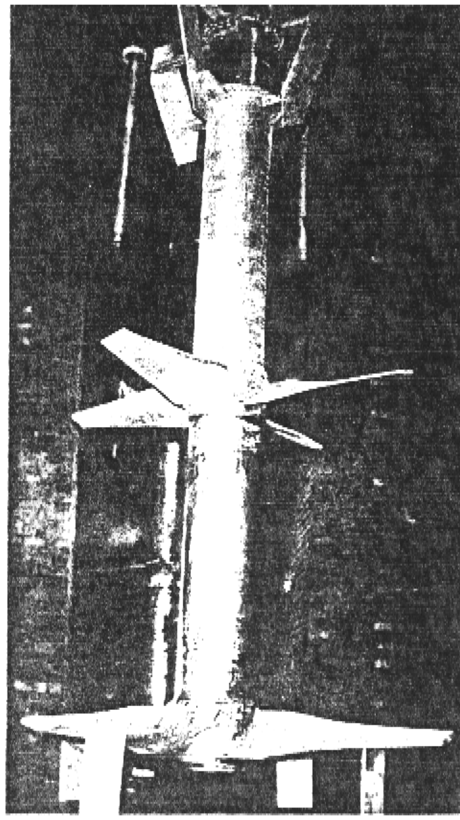


FIG. 4.C.
PRAYON-LIGHTNIN HELICOIDAL AGITATOR + GTA SURFACE AGITATOR



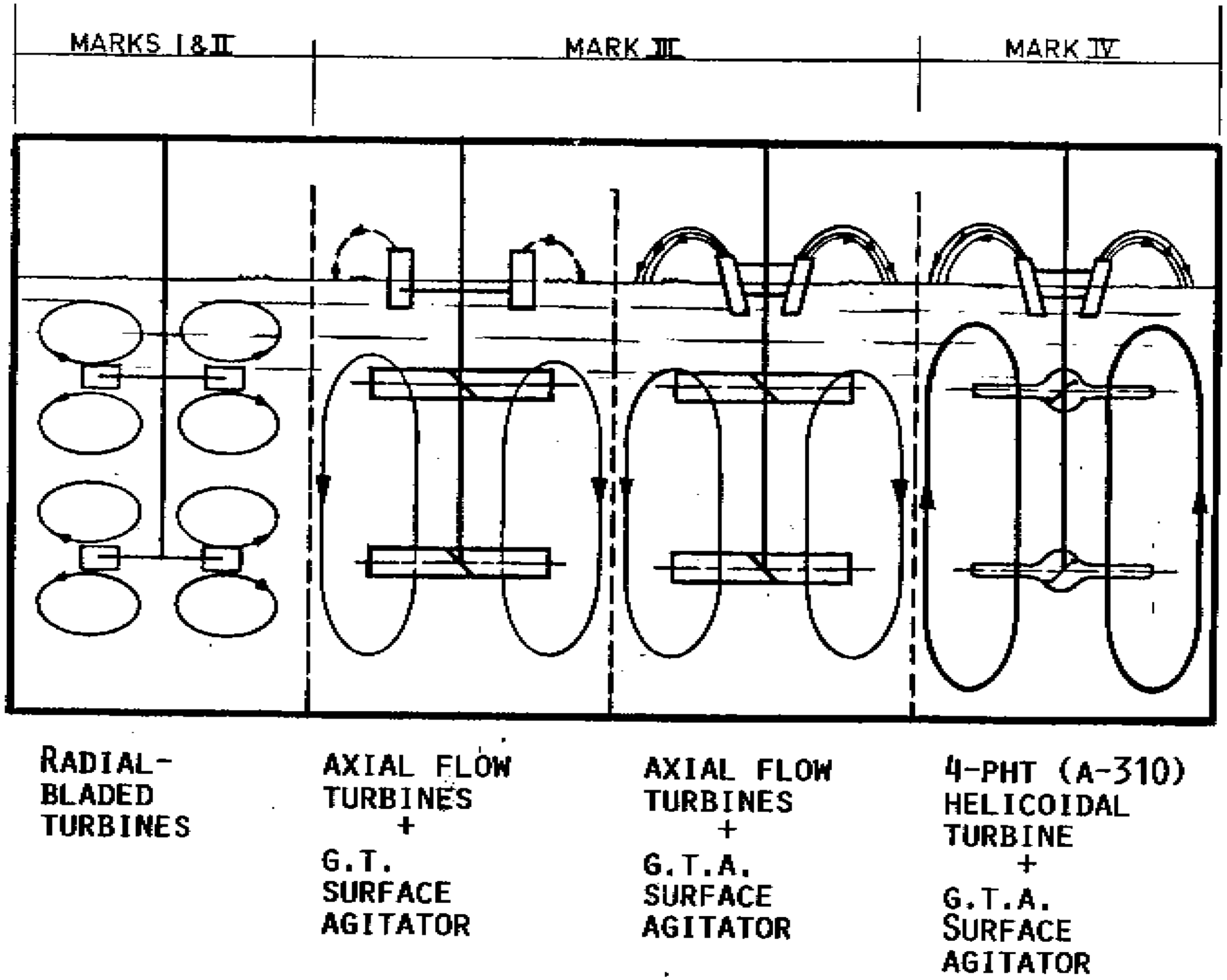


FIG. 5 - DEVELOPMENT OF PRAYON AGITATOR DESIGNS

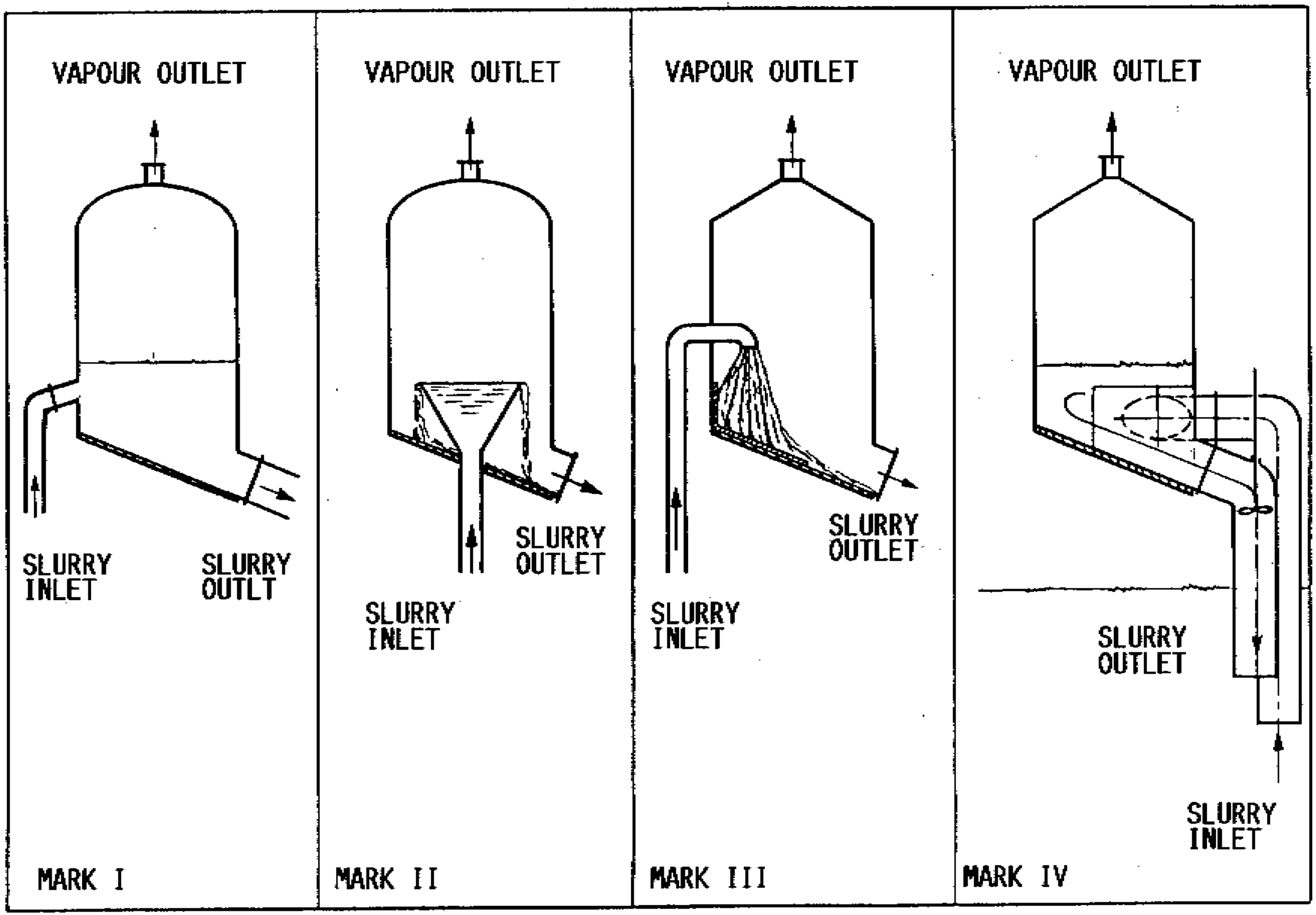


FIG. 6 - DEVELOPMENT OF THE PRAYON FLASH-COOLER

FIG. 7 FLASH-COOLERS "1945-1981"

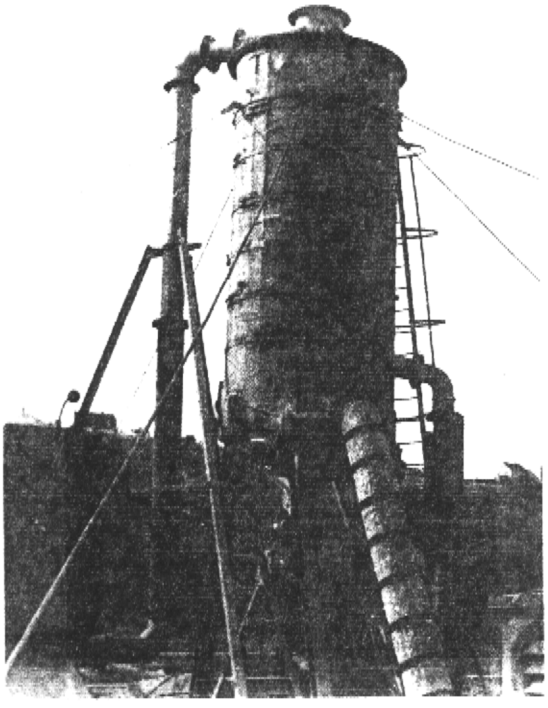


FIG. 7.A. "1945" ENGIS 35 TPD P205

DIAMETER 980 MM
MATERIAL 80 MM WOOD, LEAD LINED ON OUTSIDE 8 MM

INLET PIPE 150 MM/170 MM LEAD

OUTLET PIPE 300 MM 12 MM LEAD
LATER 300 MM 6 MM HV7

INCLINED BASE

PUMP 60 M^3/H ; 15 KW (ABS.)

ΔT = 12° C

FIG. 7.B. "1981" IMC - NEW WALES 1500 TPD P205

DIAMETER 7000 MM
MATERIAL RUBBER LINED CARBON STEEL WITH CARBON BRICKS ON BASE

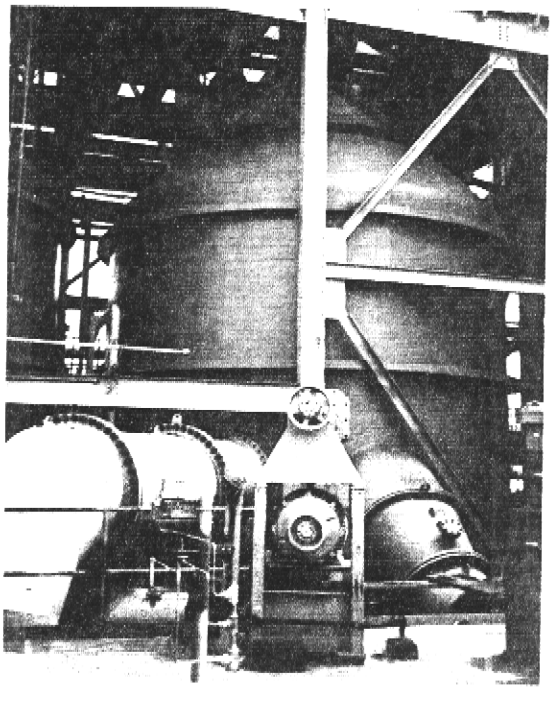
INLET PIPE 1400 MM

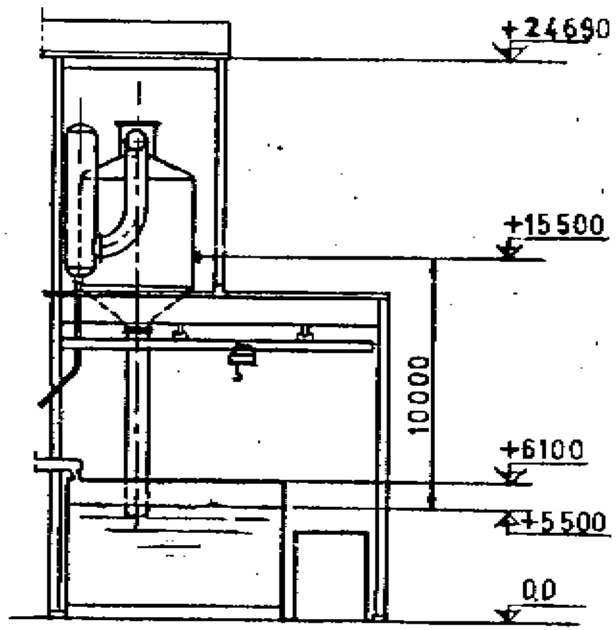
OUTLET PIPE 1200 MM

INCLINED BASE

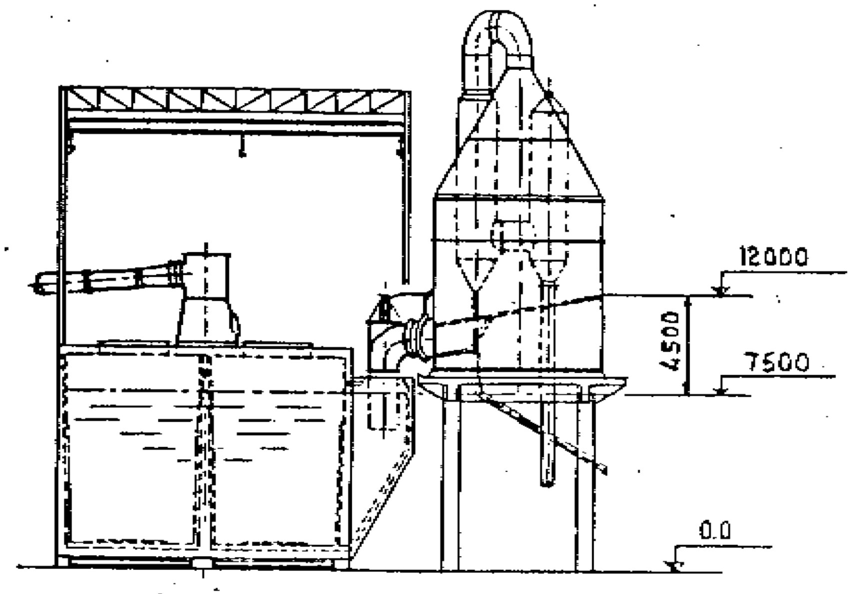
PUMP 8600 M^3/H ; 90 KW (ABS.)

ΔT = < 2° C





8.A. IMC - BONNIE 1962

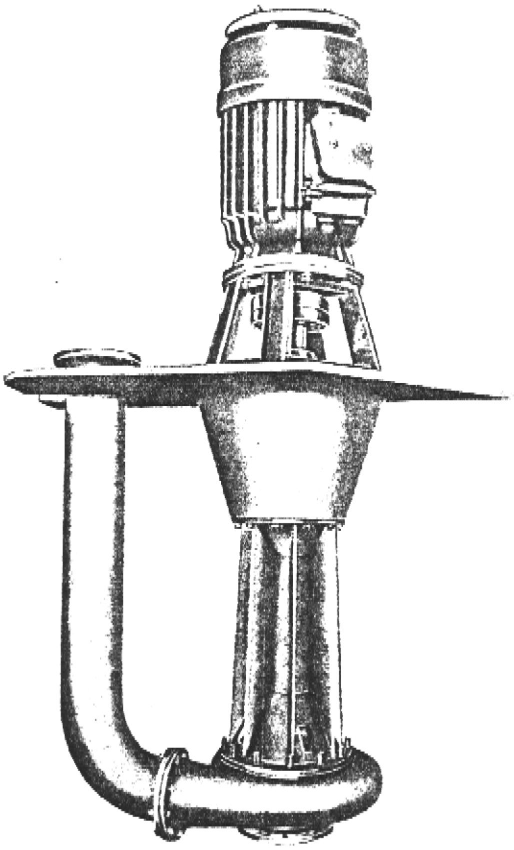


8.B. PHILPHOS - 1984

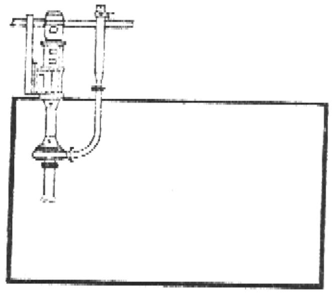
FIG. 8 - COMPARISON OF ELEVATIONS OF MARK II & MARK IV FLASH-COOLERS

FIG. 9

FIG. 9.A. FLASH-COOLER PUMP MARK II



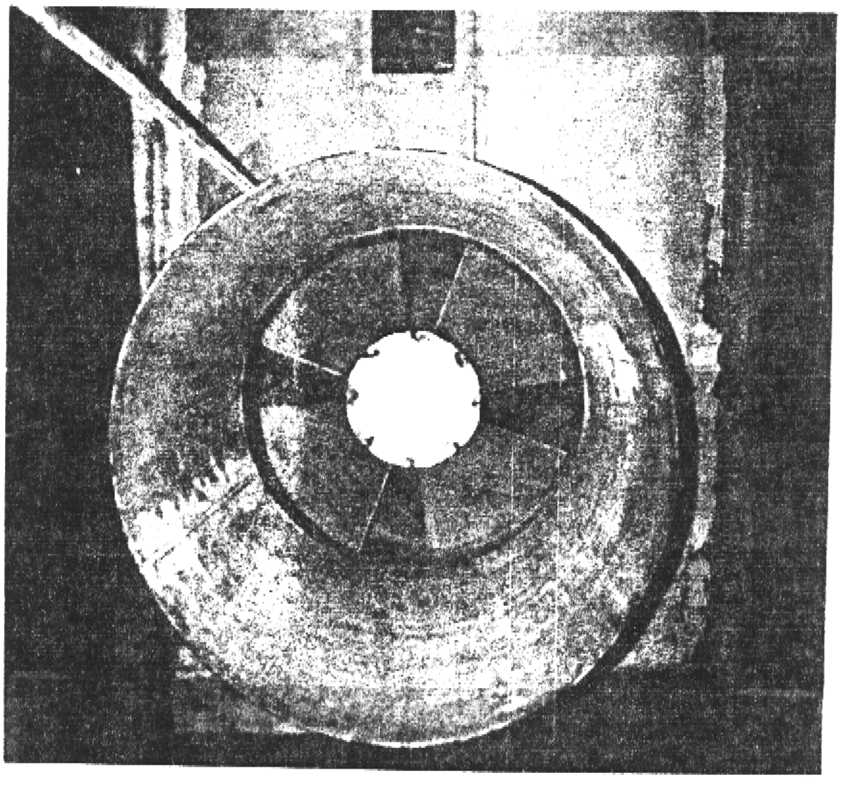
CIRCULATION RATE 60 M^3/H
TOTAL DEVELOPED HEAD 20 M
POWER 20 (15 ABS.) KW
KW/1000 $M^3/H \cong 250$



ENSIVAL "VAP"

FIG. 9.B. FLASH-COOLER PUMP MARK IV

CIRCULATION RATE 8560 M^3/H
TOTAL DEVELOPED HEAD 0,9 M
POWER 125 (90 ABS.) KW
KW/1000 M^3/H = 10



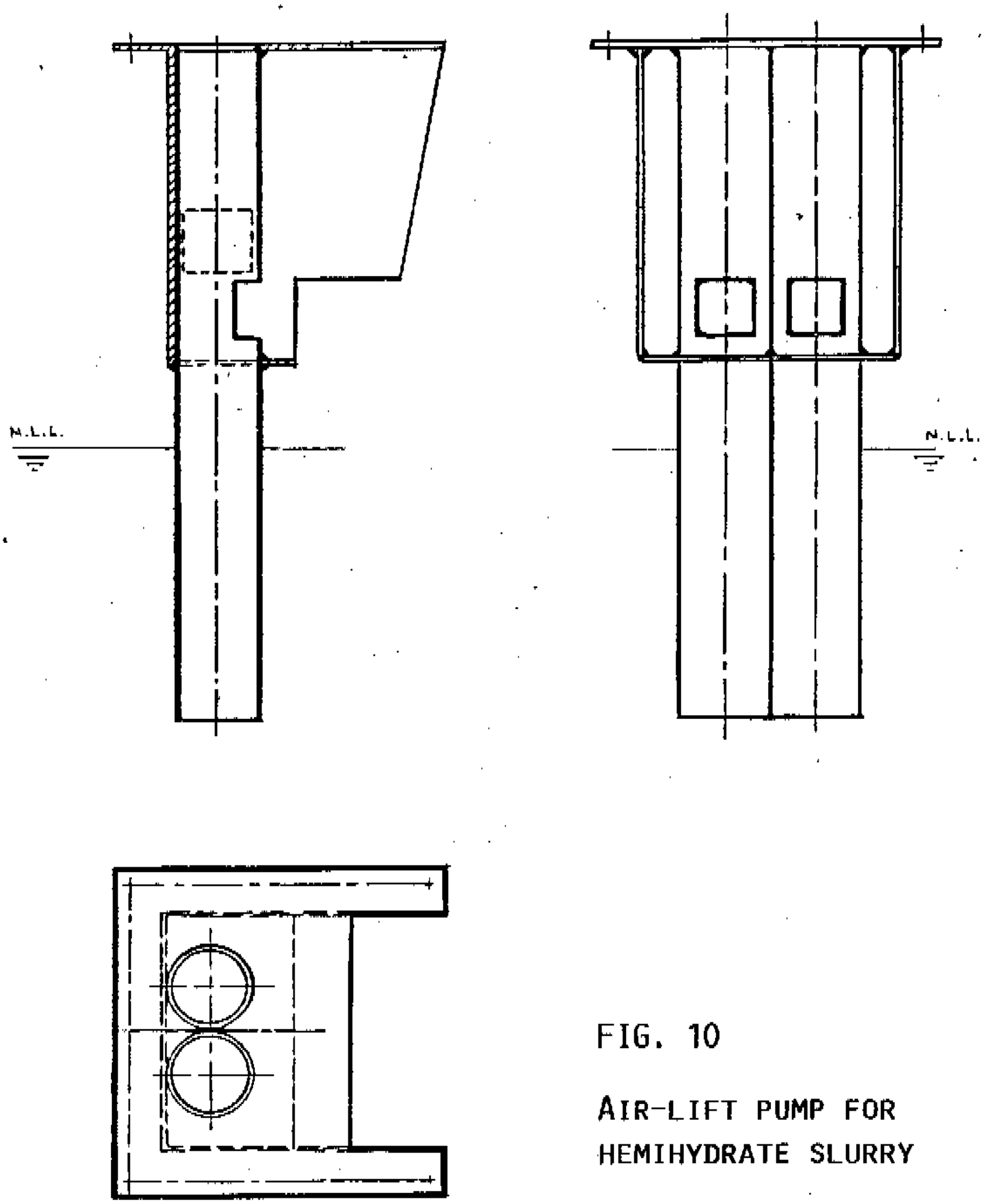
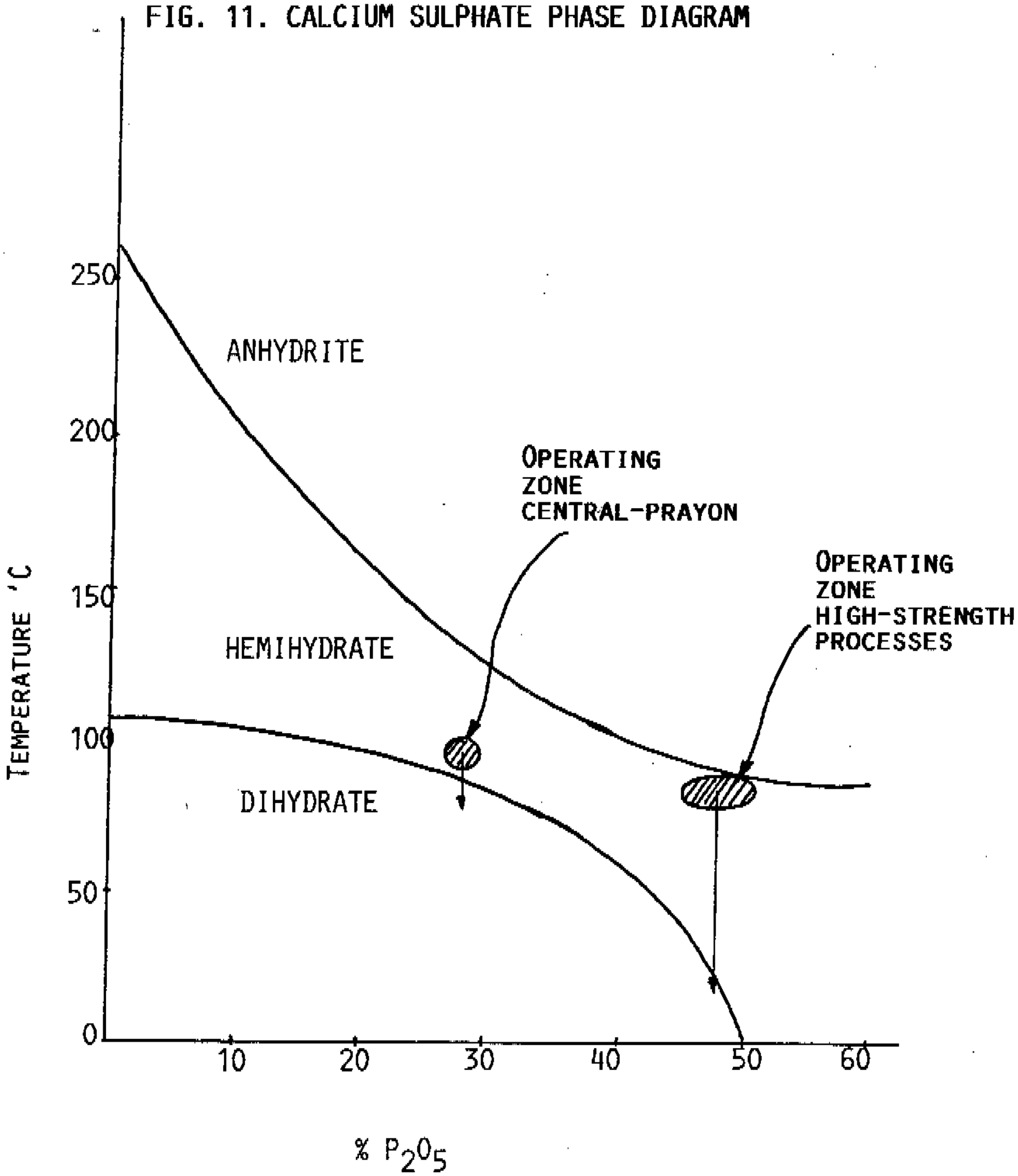


FIG. 10

AIR-LIFT PUMP FOR
HEMIHYDRATE SLURRY

FIG. 11. CALCIUM SULPHATE PHASE DIAGRAM



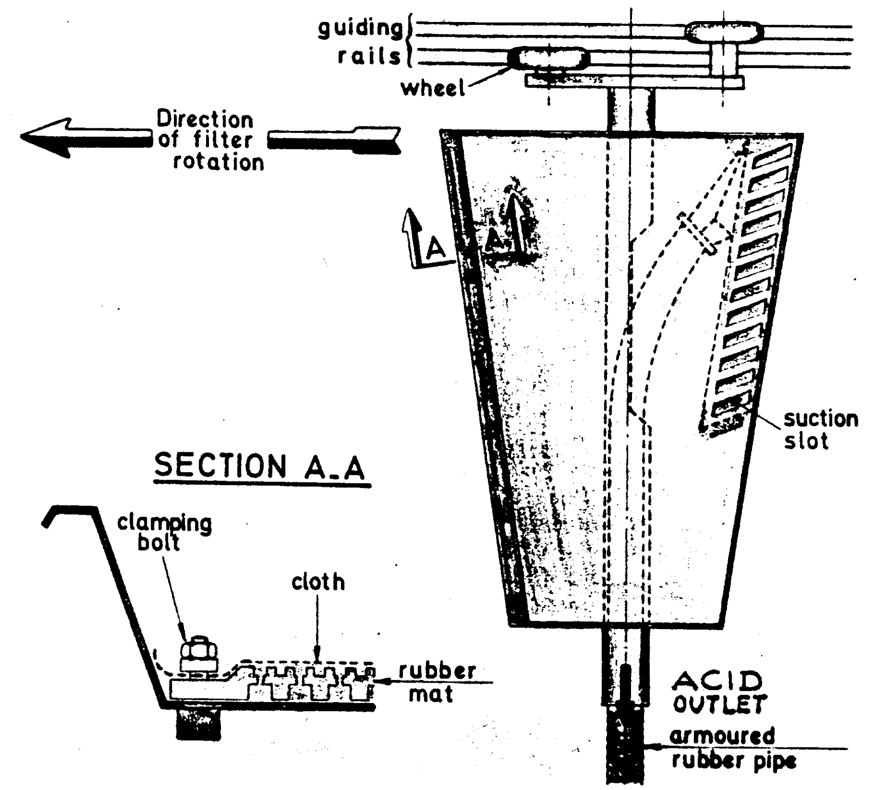


FIG. 12.A. OLD PAN DESIGN (RUBBER MAT)

FIG. 12.B. NEW PAN DESIGN (PERFORATED PLATE)

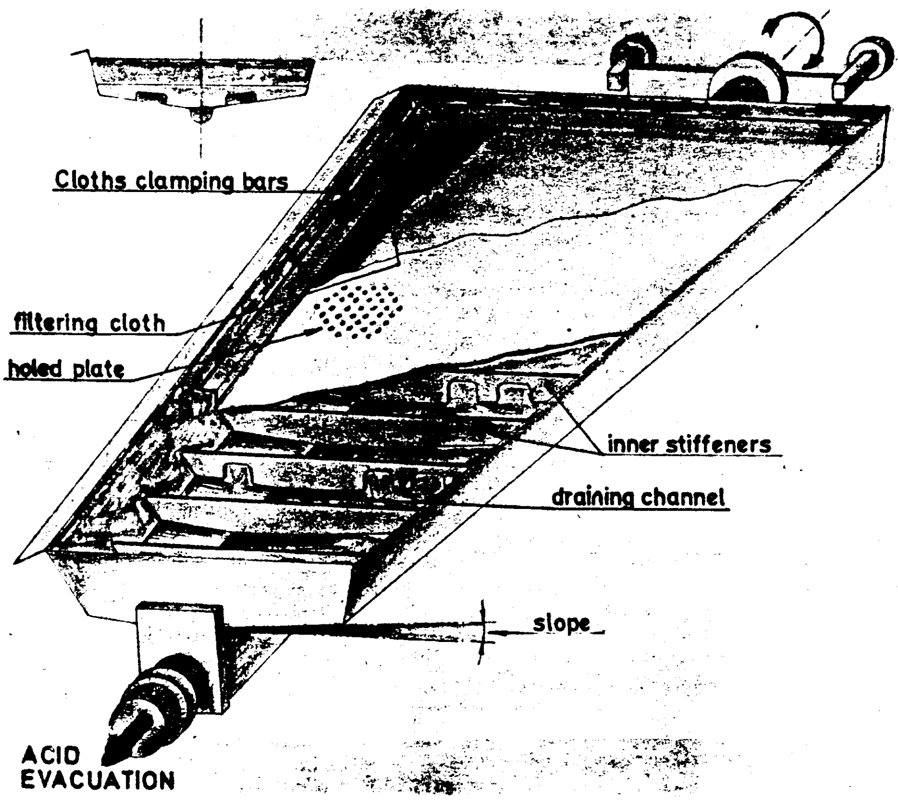


FIG. 12 DEVELOPMENT OF PRAYON FILTER PAN

FIG. 13.A.
PREWASH SYSTEM

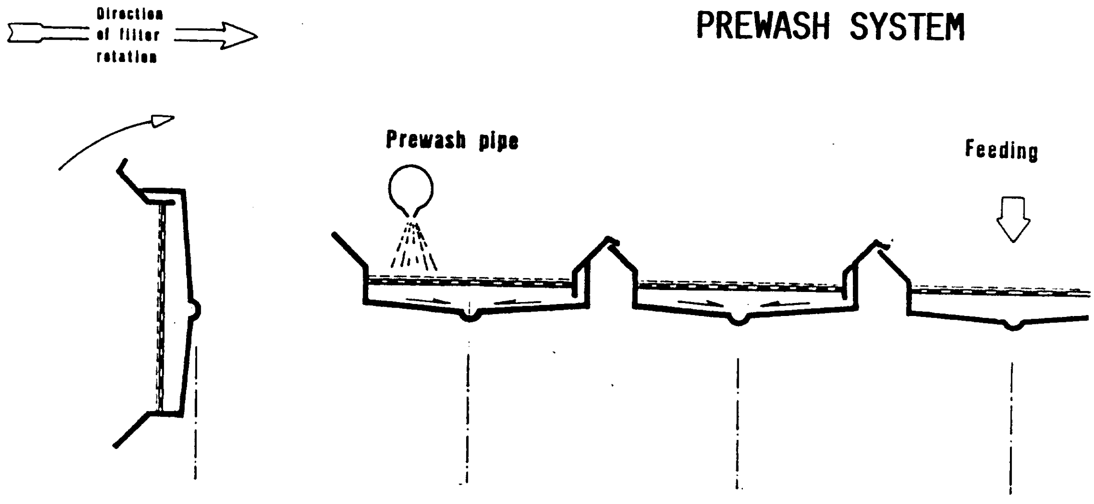
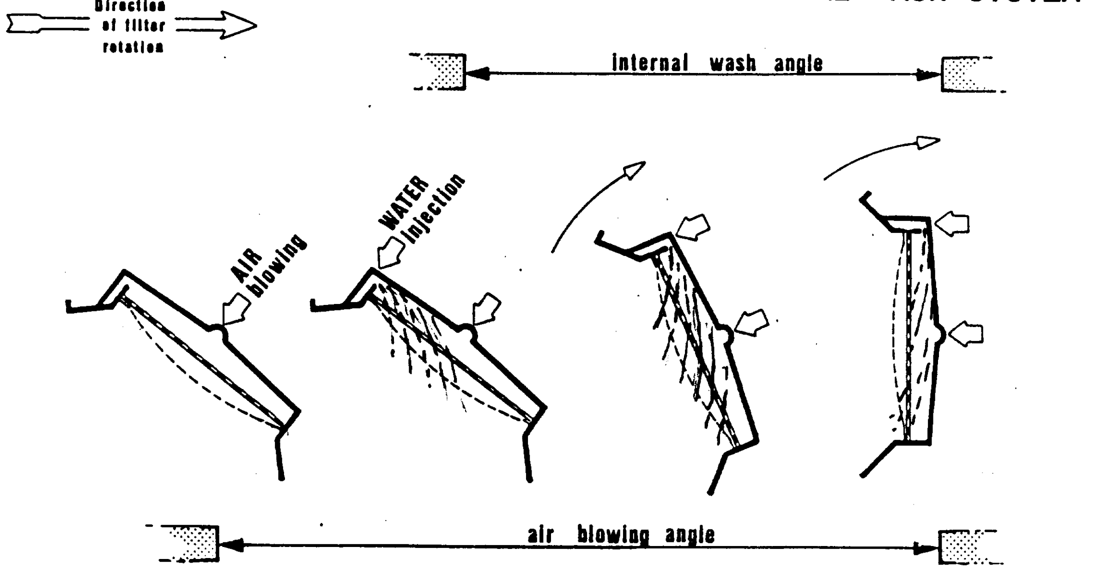


FIG. 13.B.
INTERNAL WASH SYSTEM



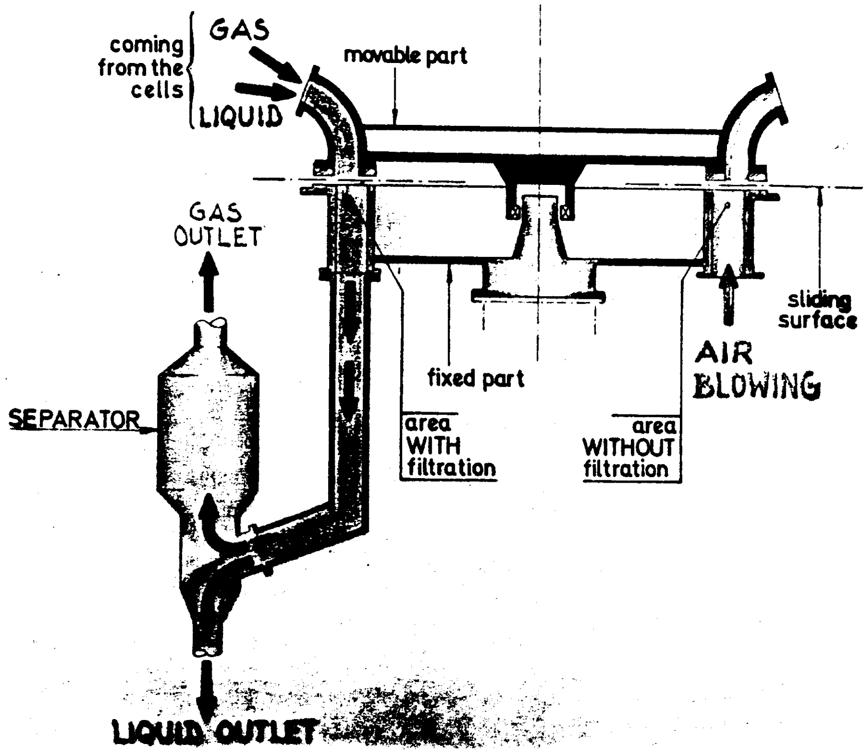


FIG. 14.A. SECTION THROUGH CLASSICAL PRAYON CENTRAL VALVE

FIG. 14.B. SECTION THROUGH PRAYON "AC" CENTRAL ASPIRATION VALVE

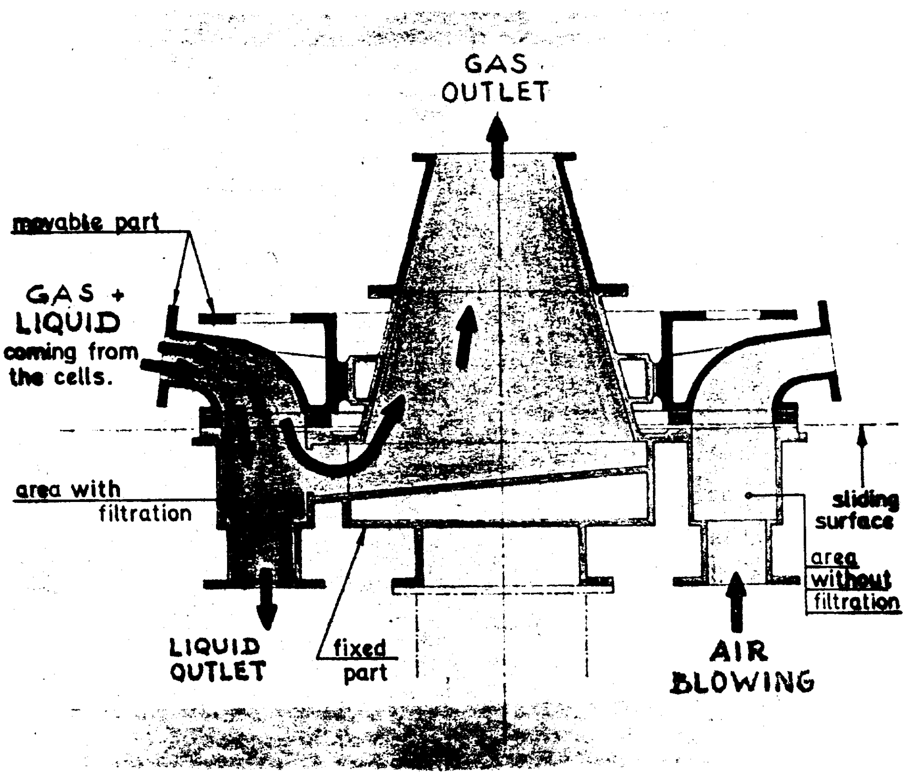


FIG. 14 - MODIFICATIONS TO THE PRAYON CENTRAL VALVE

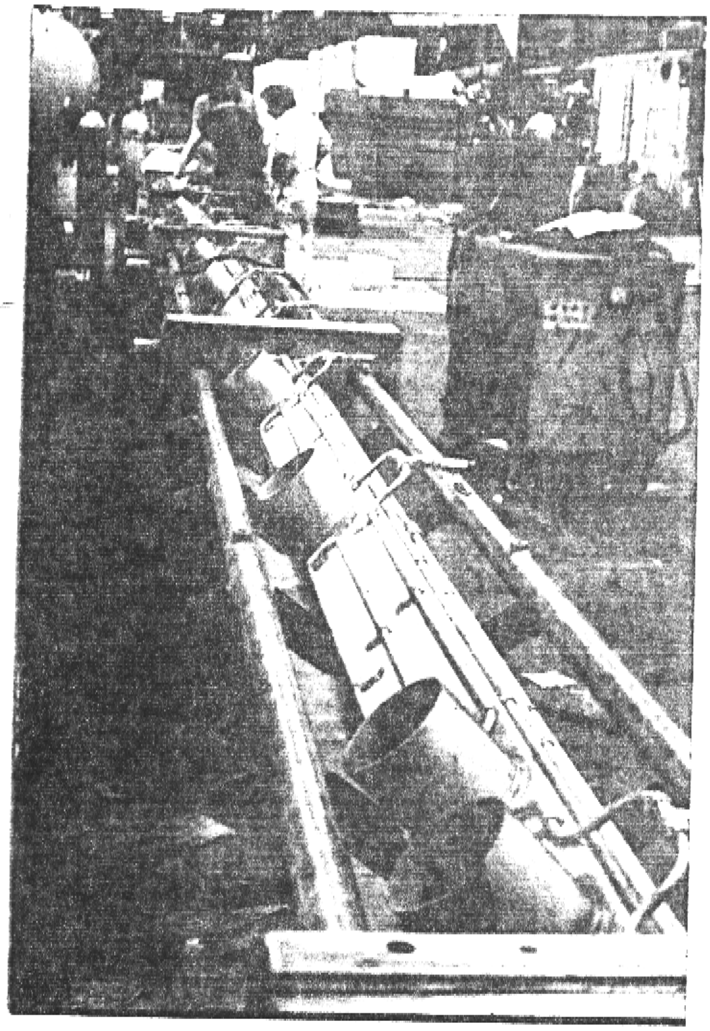
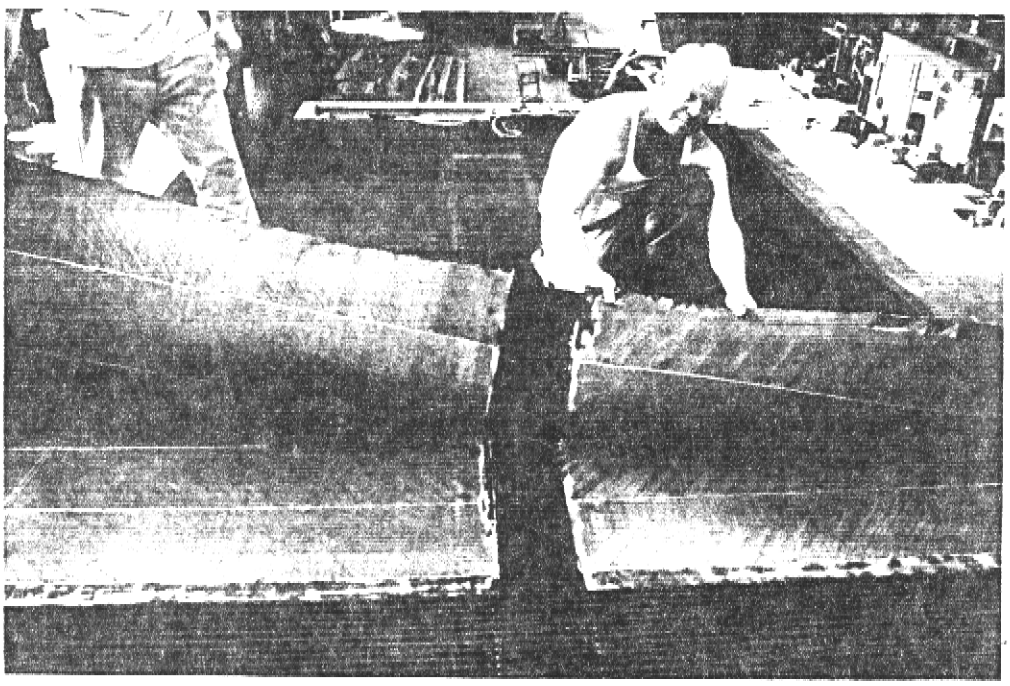


FIG.15.A.

VACUUM BOX OF FILTER SUPPLIED BY EIMCO FOR PHOSPHORIC ACID SERVICE.

FIG.15.B.

BELT SPLICING ON EIMCO PHOSPHORIC ACID FILTER.



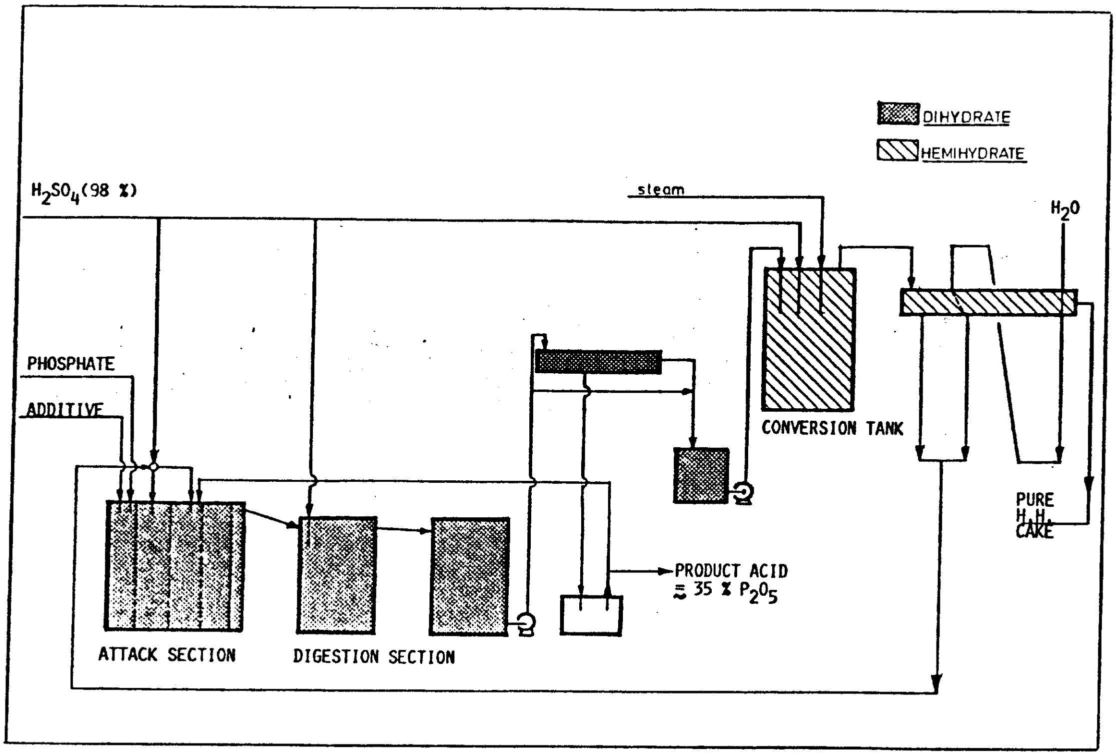


FIG. 16.A. BASIC CENTRAL-PRAYON PROCESS

FIG. 16.B. PH 11 OPERATION

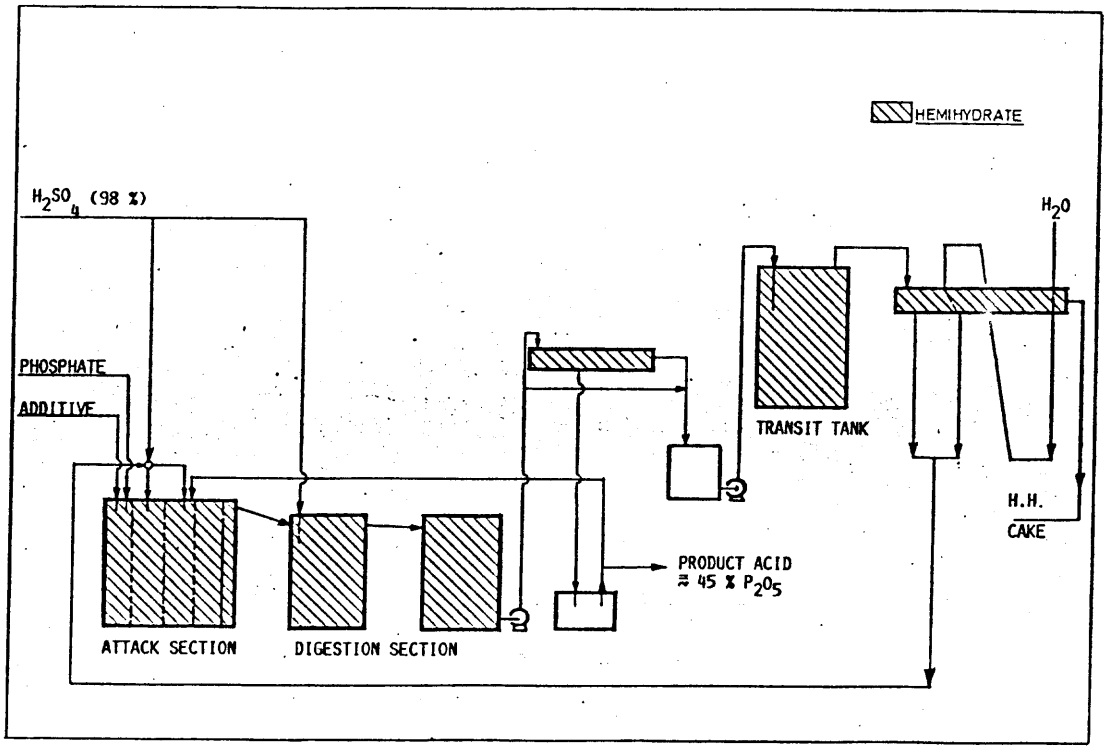


FIG. 16 - FLOW-SHEETS SHOWING CONVERSION OF ENGIS CENTRAL-PRAYON PLANT TO OPERATION IN PH 11 (SINGLE STAGE PRAYON HEMIHYDRATE PROCESS).

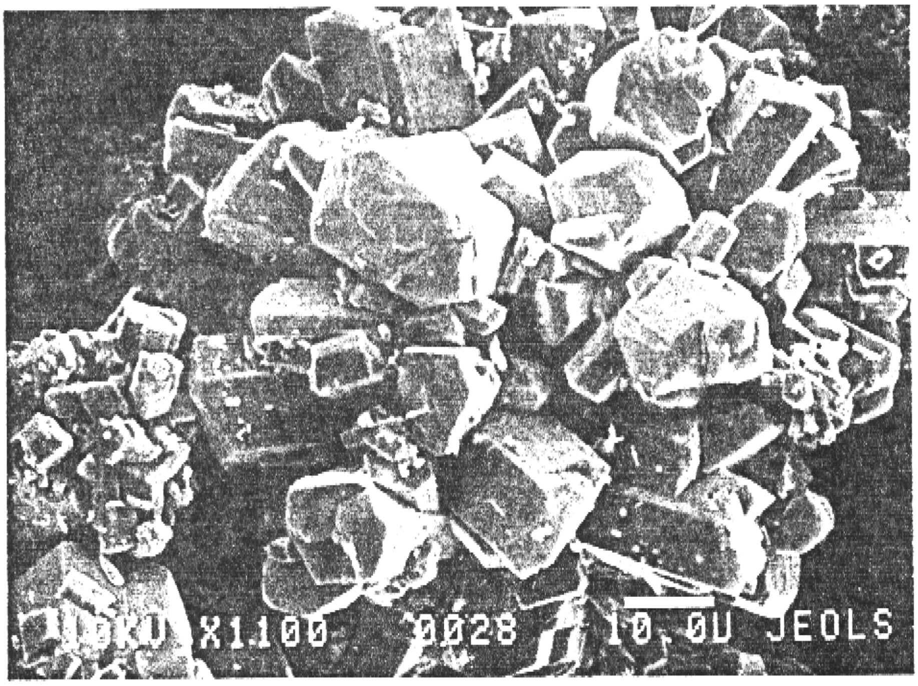


FIG. 17.A. MAGNIFICATION X1100

FIG. 17.B. MAGNIFICATION X 400

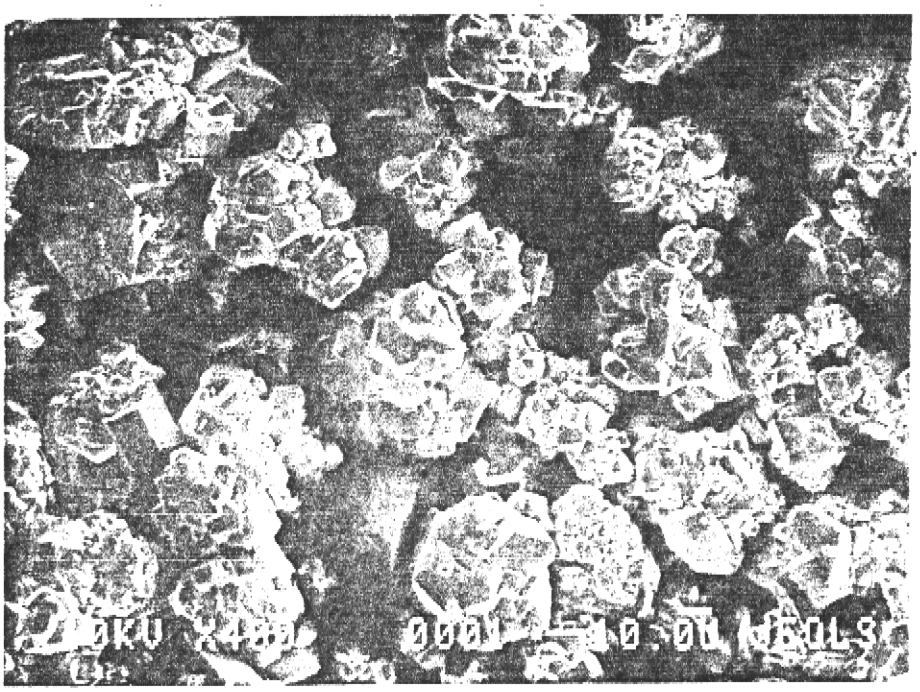


FIG. 17. PHOTOGRAPHS OF HEMIHYDRATE CRYSTALS TAKEN WITH ELECTRON SCANNING MICROSCOPE (P.H. 11 - ATTACK SECTION)

TA/86/3 Equipment design makes both new plants and revamps costs effective as regards energy, maintenance and recovery by A. Davister, A. Bourgot & P.A. Smith, Société Chimique Prayon-Rupel, Belgium

DISCUSSION : (Rapporteurs Messrs M. Barloy, SCPA, France & A. HAMDI, SAEPA, Tunisia)

Q - Mr. J.D. CREHAR, Norsk Hydro Fertilizers Limited, U.K.

Comparison A 310 - pitched blades.

A - The A 310 impeller was specifically studied to get a maximum flow of fluid with a minimum energy consumption; this is achieved with the optimum profile of the blades which avoids energy consuming frictions and whirling. The A 310 impeller does not indicate radial flow losses, since the whole flow is axial. The straight inclined blade is definitely of a more simple concept, but it produces a lot of turbulences and a radial flow which, in the end, reduces the ratio effective axial flow/energy consumed.

Q - What is the percentage kept for air cooling?

A - This percentage varies according to the project; in view of the objectives, about a quarter of the total cooling required.

Q - What is the additive?

A - The additive commonly used is active silica.

Q - Mr. M. BARLOY, SCPA, France

What is the range of size you prefer for the belt filter?

A - Because of its higher translation speed, the belt filter is suitable for filtering difficult slurries. In the other filtration cases, the comparison of the total investment for the filtration section with belt filters on rotational filters determines the choice between the two systems.

Q - Mr. Y. LOUIZI, SIAPE, Tunisia

You compared the unit consumptions and the efficiencies obtained in the case of the two processes, but you did not mention the investments for the revamping and their amortization.

Can you indicate the expenditures involved and the duration of the amortization?

A - The economic study of the conversion of the Central-Prayon unit at Engis to the PH3 process (= hemi-di-hemi) considered an investment of about 1.6 million US dollars for the addition of a high strength P2O5 reaction head and the various connections with the present building, excluding construction.

The saving on steam would by itself pay off the investment in a maximum of two years.

Q - Are the results obtained with the phosphate processed applicable to other qualities?

A - The results obtained at the Engis works during the PH 11 operation (hemihydrate reaction) are applicable to other types of phosphates taking account of the level of their soluble impurities. It is well known that high iron, aluminium and magnesium levels in the acid reduce the filtrability of the pulp whereas, in association with fluorine, aluminium and silica promote the crystallization of hemihydrate and dihydrate (a specific external supply must sometimes be considered, see paper by Mr. Monaldi, Agrimont).

Q - Mr. N.W. KOLMEIJER, Windmill, Netherlands

What is the phosphate used for the PH 11 demonstration?

A - The phosphate was a 50%-50% mixture of Phalaborwa and Bucraa which was commonly used in our plant at that time.

Q - Mr. B. GOLIBRODSKI, SPIE Batignolles, France

In a recently published paper, I noted that, in the case of revamping, a plant built according to your dihydrate process could produce a 38% P2O5 acid.

1) Is it true?
2) If so, in which plant?
3) With which phosphate?

A - It refers to our "Double Dihydrate" process specifically developed to produce concentrated phosphoric acid in the American plants in Florida and Louisiana, in which wet grinding is used. In that way the phosphate supplied as a slurry brings so much water in the process that it is impossible to operate with the hemihydrate route.

On the other hand, it is quite possible to operate with dihydrate at concentrations ranging between 36 and 38% and compensated by a low sulphate content as commonly done in Central-Prayon.

The product acid is separated and the solid is then processed again in a medium with more sulphuric acid to improve filtrability and reduce the co-crystallized P2O5 content, so that the P2O5 efficiency is the same as in the Prayon MK IV dihydrate process.

Q - Mr. B.T. CROZIER, Norsk Hydro Fertilizers Ltd, U.K.

Concerning the flash cooler, the decrease in the t results in an increased size: would it not be preferable, on the contrary, to try and reduce the cost by reducing the size with a higher Δ t?

A - The present system low level flash cooler + circulation pump with a low Δ t is cheaper than the old F.C. cooling system high head + centrifuge pump in which the higher Δ t favors the development of scaling in the barometric seal leg.

Q - Your revamping layout shows a plant with 3 filters and the corresponding reaction volumes: this must be costly, can you mention the cost?

A - When comparing the cost of a project, one should always consider the overall objectives and not one aspect of the technical solution adopted.

In the case under consideration, the client was looking at the same time for an increased capacity, a reduced steam consumption, a higher process efficiency, and the possibility of producing a merchant grade calcium sulfate.

A - The solution adopted to produce directly, with the addition of a Central-Prayon section, a pure and dry calcium sulphate avoids the alternative dihydrate purification + drying/calcination, higher energy consumer.

The cost of the additional equipment is about US Dollar 4 million for the modified unit as shown on the screen.