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INVESTIGATIONS TO USE LOW-GRADE ROCK PHOSPHATES FROM MUSSOORIE ROCK PHOSPHATE DEPOSITS IN INDIA

STUDY NO. 2

Pilot Plant-Scale Partially Acidulated Phosphate Rock (PAPR) Studies, Process Design, Equipment Specifications, and Plant Layout

Final Technology Report

for

United Nations Industrial Development Organization (UNIDO)
Vienna, Austria

by

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April 1986

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STUDY NO. 2

Pilot Plant-Scale Partially Acidulated Phosphate Rock (PAPR) Studies

Summary

The production of partially acidulated phosphate rock (PAPR) using ground run-of-mine (ROM) Mussoorie rock has been investigated by IFDC in pilot-plant scale. A conceptual process flow scheme had been developed during earlier bench-scale research.

Single-step acidulation/granulation (SSAG) of Mussoorie ROM rock with a blend of phosphoric and sulfuric acids to produce a product containing about 18% by weight of P_2O_5--approximately 40% of which is water soluble--resulted in a weak product (crushing strength of 0.4 kg/2.6-mm granule, equivalent to 7 kg/cm^2) due to impurities present in the ore. No difficulties were encountered in using Mussoorie concentrate in the SSAG process. Curing of this SSAG product for a period of about 2 weeks considerably improved the quality of the fertilizer (crushing strength increased to about 1.45 kg/2.6-mm granule, equivalent to 27 kg/cm^2). The SSAG production of PAPR using Mussoorie rock and a blend of acids requires close supervision, particularly the granulation control parameters. A high free-acid content of the product discharged from the granulator (even if only for a short period) results in blockage of the screens, chutes, and chain mill. Close control of the granulator--particularly the bed temperature and the free-acid content of the product--is a necessity.

In contrast, the production of run-of-pile (ROP) PAPR using ROM Mussoorie ore resulted in a product that could be transported easily and allowed pile curing. Since the recycle ratio in the SSAG process is high (approximately 7 to 1), steam granulation of the cured ROP product results in a more economical plant operation. Not only are the final production costs of the fertilizer lower for steam granulation of cured ROP, but a more stable production is obtained due to the significantly easier process operations. Thus, this final report recommends

the installation of an ROP PAPR plant and describes the equipment for granulating the ROP PAPR if PPCL decides that granulation is economically feasible. ROP PAPR is made from ROM Mussoorie rock using a mixture of sulfuric and phosphoric acids. PPCL will investigate the most economical acid combination.

Introduction

Much of India's fertilizer phosphate is imported due to the small amount of high-grade phosphate ores indigenous to the country. The drain on India's foreign exchange resources created by these imports can be partially alleviated if ways are found to process the available lower grade ores. One such ore is found in the Mussoorie area (State of Uttar Pradesh) at the foothills of the Himalaya Mountains. As shown in Table 1 this ore is high in carbonates, silica, and other gangue materials. Pyrites, Phosphates & Chemicals Ltd. (PPCL), a Government of India undertaking, is presently mining, crushing, and grinding this rock for use as a direct-application phosphate fertilizer on acid soils. The dustiness and difficulties in transportation, and thus the inherent losses that result in unfavorable response from the farmers, prompted PPCL to search for alternative processing techniques that would provide a more acceptable form of fertilizer. Also, they wanted a product that would be agronomically acceptable on alkaline soils.

In January 1983 IFDC began work on a project to perform laboratory-scale evaluation of minigranulation and partial acidulation processes using phosphate rock from the Mussoorie area. As an extension of this project (UNIDO Contract No. 82/99; Project No. DP/IND/81/019; and IFDC Contract 00519/83), IFDC conducted pilot-plant tests during September 1985 to (1) confirm laboratory test results and (2) serve as a basis for defining equipment specifications for the demonstration plant to be built in India. A draft final report was submitted in November 1985.

Minigranulation produces small granules from finely ground phosphate rock without any chemical processing other than the addition of a suitable binder to impart strength to the granules. The PAPR process uses a portion of the sulfuric or phosphoric acid normally required to fully acidulate phosphate rock to single superphosphate (SSP) or triple superphosphate (TSP) and yields a material that contains a mixture of water-soluble, neutral ammonium citrate-soluble, and insoluble P_2O_5.[1] The results from the work performed under the first part of this contract were reported to UNIDO in the Final Technology Report in June 1985 (1). These results show that when operating with ground ROM ore in laboratory scale, both processes are technically feasible, although the granule strength of the PAPR product was low when used in the SSAG process. The strongest product was obtained when acidulation was carried out in two steps. The first step decomposes some of the calcite present, and the second step mainly attacks the rock and forms PAPR granules. Tests conducted using two phosphate concentrates (one prepared at IFDC by attrition scrubbing the material with 5% HNO_3 and the other one prepared by Sala International, Sweden) showed the concentrates to be suitable raw materials for the production of PAPR by the SSAG process.

On the basis of the preliminary laboratory-scale results, a conceptual process flow diagram was prepared for PPCL for partial acidulation of Mussoorie rock. Additionally, on the basis of a desired 3- to 5-mtph capacity, preliminary estimates were given for the battery-limits process equipment of a pilot plant that could be used by PPCL for optimization studies of this process. The report emphasized that the process design package data were estimated since only laboratory-scale operation had been performed.

As an extension of this contract, larger scale operation (using IFDC's pilot plants) was performed to confirm the design package presented at the end of the first phase. In these tests the ROM material was used.

Pilot-Plant PAPR Tests

It is the purpose of this report to convey the information obtained during the pilot plant-scale operation and to update the design package so that a PAPR plant may be procured by PPCL. A meeting was held with PPCL representatives during January 27-29, 1986, to finalize plant operating options and to revise the Draft Final Report submitted on November 13, 1985. This Final Report completes all work to be performed under UNIDO Contract No. 82/99; Project No. DP/IND/81/019.

1. In this report neutral ammonium citrate-soluble P_2O_5 is determined by the Association of Official Analytical Chemists (AOAC) procedure; the sum of water-soluble and neutral ammonium citrate-soluble P_2O_5 is referred to as "available" P_2O_5.

Following more laboratory-scale tests designed to determine the best arrangement for adding acid, two test runs were performed in the IFDC granulation pilot plant based on the SSAG process using ROM ore. During these tests a total of 8 mt of PAPR was produced during a total operating period of 36 h at an average production rate of 350 kg/h. The number and duration of these tests were limited by the small amount of Mussoorie rock available at IFDC. A description of the IFDC granulation pilot plant follows.

SSAG Process Description

In both SSAG tests Mussoorie ROM phosphate ore, ground to 75% passing a 0.075-mm opening screen (Table 2), was fed to a pug mill using a screw-type feeder. The feed rate was controlled by adjusting the rotational speed of the screw.

Sulfuric acid was fed into the pug mill to preacidulate and decompose part of the calcite to obtain stronger granular material. This acid (91.3% H_2SO_4) was fed from a storage tank under air pressure, metered by a magnetic flowmeter, and dribbled into the feed end of the pug mill immediately ahead of the phosphate rock feed. The sulfuric acid feed rate was adjusted manually.

The pug mill was 20 cm wide, 61 cm long, and 30 cm high, including head room for disengagement of gases, and was equipped with two horizontal, variable-speed shafts. The shafts were fitted with 36 intermeshing Type 316L stainless steel paddles (18 on each shaft) which were 30 mm long, 25 mm wide, and 3 mm thick with a 45° forward pitch to obtain the desired material depth and turbulence. The tip-to-tip diameter of each shaft, including paddles, was 100 mm; the clearance between the paddles and the bottom of the pug mill housing was about 12 mm. The rotation of the shafts (one clockwise, the other counterclockwise) was such that fertilizer material was lifted along the centerline of the pug mill. The rotational speed of the shafts was 400 rpm, which is equivalent to a paddle tip speed of 2.1 m/s. The material discharged from the pug mill and flowed by gravity into the drum granulator.

The drum granulator was 92 cm in diameter (internal) by 181 cm long and divided into a granulating section (120 cm long) on the feed end followed by a smooth section (61 cm long) on the discharge end. These sections were separated by a retaining ring (13 cm high) to maintain a holdup of about 105 kg in the granulating section. The retention time in the granulating section of the drum granulator varied between 2.0 and 3.4 min, depending on the production rate and the recycle-to-product ratio. The drum, which was located with its longitudinal axis at an angle of 2° from horizontal (sloping toward the discharge end), was rotated at 18 rpm. This is equivalent to about 41% of the critical speed for a drum of this diameter.

The undersize material and a portion of the product-size material from the product sizing step (screening and crushing, described later) were fed into the drum granulator by a separate system. The feed rate of this recycle material varied, depending upon the process conditions. The phosphoric acid (as required by the formulation), saturated steam (100°-150°C), and water were also fed into the granulator when required to control granulation. Central Florida phosphoric acid (54% P_2O_5) was used for all tests (Table 1). A centrifugal pump and a magnetic flowmeter were used to introduce the acid into the granulator about 31 cm from the feed end of the drum. The acid was sprayed through a 6.33-mm opening nozzle (Jac Air Atomizer®) onto the bed of rolling granulating material. The steam and the water were introduced into the granulator through a perforated stationary sparger (a 92-cm pipe with 9 equally spaced 3-mm holes) inserted under the rolling bed of granulating material about 7 cm from the wall of the drum.

The off-gases from the pug mill and the drum granulator were directed by induced draft into a reinforced polyester venturi-type scrubber using a Type 316L stainless steel fan located at the scrubber discharge. The scrubber was used to remove acid fumes and dust from the exhaust gases before releasing them into the atmosphere. A Type 316L stainless steel tank was used as a recirculation tank for the scrubbing process. Water was used for makeup to control concentration in the recirculation tank. No attempt was made to recover the absorbed gases, fumes, or dust, nor to determine the extent of contamination or losses from the pug mill or drum granulator.

The moist, plastic material from the granulator was discharged by gravity into a rotary dryer. The rotary dryer (92 cm in diameter and 730 cm long) was operated with a cocurrent flow of air that was heated in a propane-fired combustion chamber located at the inlet (material feed end) of the dryer. The operating temperature of the dryer was controlled indirectly by controlling the temperature of the air in the dryer discharge breeching with automatic adjustments of the amount of propane burned. A cyclone-type dust collector was located in the process air duct between the dryer discharge and the exhaust fan. The flow of air through the dryer was measured and controlled using an orifice-type flowmeter and damper in the exhaust stack. The dryer was usually operated at a rotational speed of 7 rpm, an airflow rate of 3,800-4,000 m^3/h (measured at outlet conditions), and an air temperature which ranged from 110° to 125°C (dryer outlet). Under these conditions the superficial velocity of the air through the dryer was about 1.6 m/s (outlet conditions).

A centrifugal discharge-type bucket elevator was used to transfer the material from the dryer to a double-deck, mechanically vibrated (unbalanced flywheel) screen with a screening area per deck equal to 1.6 m^2. The screen was fitted with Ty-rod® oversize and undersize sieves. The screening was done using 2.36- and 1.18-mm openings during the first test run and 4.75- and 1.7-mm openings during the second test run. Oversize material from the screen was routed to a single-shaft chain mill. The material discharged from the chain mill was returned to the screen. The undersize material and a controlled fraction of the product were returned (recycled) to the granulator according to the requirements of the granulation operation.

The material handling equipment for the recycle system consisted of a horizontal drag conveyor, a small (0.4-m^3) live-bottom surge bin, a positive discharge-type bucket elevator, and an inclined drag-type flight conveyor. In all tests the live-bottom surge bin was operated in an overflow mode so that no recycle surge capacity was actually used.

The pilot plant was equipped with a fugitive dust collection system. This system consisted of a network of pickup ducts connected to a bag-type dust collector. The dust collector was fitted with polyester filter bags. A centrifugal fan exhausted the filtered air into the atmosphere.

Except for the pug mill paddles and the venturi scrubber, its recirculation tank, and its exhaust fan (materials of construction have already been mentioned), other process equipment components were made from mild steel coated on the outside with a zinc-epoxy corrosion-resistant material. The interior of the process equipment was not coated.

The portion of product-sized material not returned to the granulator as recycle was routed out of the plant by a belt conveyor without further processing, cooling, or conditioning. It was collected in 1-mt capacity portable bins. Representative samples of the product from each test were evaluated in IFDC laboratories to determine chemical analyses, physical properties, and storage and handling properties.

SSAG-PAPR Results

Two tests were completed in the IFDC granulation pilot plant with ground ROM Mussoorie rock in the SSAG process using a mixed acid-based (MAB) PAPR process (Tables 3 and 4). The first run (7-429) was made to determine the operating parameters for which MAB-PAPR production was feasible. Initial operating conditions were as determined in earlier bench-scale tests (described in IFDC's Final Technology Report of June 1985) and during some exploratory bench-scale experiments performed prior to these pilot-plant experiments. During these exploratory experiments, it was determined that at the reduced acid consumption rate requested by PPCL (see telex 09-12-1985), preacidulation of the rock with sulfuric acid in a pug mill granulator resulted in an end product with somewhat better physical properties as compared with a product obtained through preacidulation using phosphoric acid. The pilot-plant product obtained through this variant had an initial crushing strength of about 0.4 kg/2.6-mm granule (equivalent to 7 kg/cm^2) whereas after preacidulation with phosphoric acid, the product obtained from previous laboratory tests had a crushing strength of only about 0.21 kg/2.6-mm granule (equivalent to 3.9 kg/cm^2). The weaker product obtained through preacidulation with phosphoric acid was in all probability caused by granulation occurring in the pug mill due to the higher amount of liquid phase when using phosphoric acid. The granular particles leaving the pug mill, which subsequently reacted with sulfuric acid in the drum granulator, gave rise to nonhomogeneous reaction of rock and sulfuric acid, resulting in a weak, easily fragmented end product. The operating conditions during the second run (7-430) were such that granulation as well as improved physical properties of the end product was promoted.

As mentioned earlier all of the sulfuric acid in the pilot-plant tests was mixed with the phosphate rock in the pug mill. Both feedstocks were supplied at the feed (inlet) end of the pug mill. To ensure homogeneous mixing, the pug mill was operated at approximately 400 rpm (equivalent to a tip speed of 2.1 m/s). With all paddles set on forward thrust, the total retention time was about 2 s. The mixing efficiency of the pug mill was monitored by frequent analysis of the free-acid content of the preacidulated rock. During normal operation this free-acid content was close to zero.

The preacidulated rock, together with the recycle stream (consisting of fines and some recycled product-size material), was fed into the drum granulator. This resulted in a granular product that was less sticky and stronger.

To arrive at the required granule quality, a number of process conditions needed to be maintained. The main operating parameters were the retention time, the granulator and dryer temperatures, and the amount of water fed into the granulator (2). By close control of the recycle ratio and the various temperatures, the required combination of retention time and reaction rate was obtained. This resulted in a satisfactory free-acid content of about 5%-6% in the granulator discharge product. Stable operation of the granulator was obtained, which resulted in the production of a nonsticky product. The performance of the fine screens and the crusher was largely dependent on the product being sufficiently nonsticky. It should be pointed out that the steam supplied to the drum granulator was basically used to increase the temperature of the granulator discharge. A granulator discharge temperature of about 90°C in combination with a recycle-to-product ratio of approximately 7 resulted in a free-acid content of the product of less than 6%.

In order to achieve good granulator performance, it was determined that water and a sufficient amount of phosphoric acid were required. During the IFDC pilot-plant tests, the granulator performance was unsatisfactory when using less phosphoric acid than 85 kg/mt product. Even at high water feed rates, an excessive amount of fines was produced, which resulted in a very high recycle ratio. Good granulation was obtained using 86 kg of phosphoric acid per metric ton of product, and the recycle-to-product ratio was stabilized at about 7. The product-size material was recycled to control the recycle-to-product ratio.

Special attention was paid to the method used to add phosphoric acid to the granulator. By choosing the appropriate spray nozzle, the granules were contacted with a small amount of acid (fine spray) during each passage through the granulator. Subsequently, this acid was allowed to react with the rock in the recycle loop (total retention time was approximately 15 min at 90°C) to prevent the occurrence of local high-acid concentrations (causing sticky particles). This procedure resulted in optimum performance of the fine screen and the chain mill. This also improved the quality of the end product considerably since granules containing too much free acid are easily fragmented and very sticky, which promote blockage of the screens and crusher.

The SSAG process conditions for good granulation of the sulfuric-acid preacidulated Mussoorie ROM rock in the IFDC pilot plant are summarized as follows:

--Phosphoric acid consumption: 86 kg 54% P_2O_5/mt product

--Water consumption: 190 kg/mt product

--Steam consumption: 36 kg/mt product

--Recycle ratio: 7 to 1

--Bed temperature: 90°C

The operation of the dryer was mainly to promote a chemical reaction rather than to evaporate water. The retention time in the dryer was approximately 14 min, the air velocity was 1.6 m/s (outlet conditions), and the inlet temperature was about 120°C. At the above-mentioned process conditions, the product leaving the dryer was free flowing but relatively soft (crushing strength about 0.4 kg/2.6-mm granule). No sticking of the product was noticed on the lifting flights or on the dryer walls during either run, even when the free acidity was as high as 10%. The free water content of the screened product was about 0.1%.

During the first run screening was occasionally difficult. When the high free-acid content of the dryer discharge was 6% and higher, the sticky product readily adhered to the screens. The product screen was particularly sensitive to plugging. Since IFDC uses double-deck screens, the product screen was rather inaccessible and therefore difficult to clean.
Because of the difficulties with screening during the first run, screens with larger openings were used for the second run. The undersize material during the second run was coarser (minus 1.70 mm instead of minus 1.18 mm) and did not cause plugging of the screens.

It should be pointed out, however, that control of the main operating parameters in the IFDC pilot plant was very strict and on a frequency not representative of normal plant operation. Since a slight increase in free acidity (or in stickiness) of the material may lead to plugging of the screens, the operation was monitored closely. To minimize potential screen plugging, it is highly recommended that single-deck screens be installed and operating parameters as well as sieve efficiency be closely monitored. Furthermore, the screens need to be very accessible to facilitate cleaning. Also, since the undersize material tends to stick to chutes and ducts, the equipment handling the undersize material should be easily accessible for cleaning.

The oversize material from the screens was fed into a chain mill to be crushed. The chain mill was rather sensitive to clogging because of the stickiness and softness of the material. During the first run the chain mill had to be cleaned several times. Because of the close control of the granulation loop during the second run, no problems were encountered with the chain mill. However, some (not serious) buildup of material was noticed after completion of this run. Since cleaning of the crusher means temporary shutdown of the plant, it is recommended that the plant layout be designed so that a second (parallel) crusher can be installed without major plant modifications. Furthermore, the crusher should be very accessible to minimize cleaning difficulties.

As mentioned earlier part of the product-size material was recycled to balance the system. To recycle part of the product, a splitter (diverter) valve was installed in the product-to-warehouse chute. Due to the stickiness of the product during the first run, plugging of the splitter valve occurred from time to time. Because the product quality was improved during the second run, no problems were encountered with the splitter valve.

A sample of the granulated product produced in the IFDC pilot plant was stored under conditions that simulate pile curing of the material (temperature ±60°C). A sample of this cured material was analyzed on a regular basis (Table 5). From these results it can be seen that reactions were still proceeding slowly after 7 days of curing, resulting in a higher availability of P_2O_5. Given the lower free-acid content of the product, it is expected that curing the offsize material before recycling it will result in better process operations (lower recycle ratio and lower free-acid content).

The crushing strength of the product was determined at various intervals during the curing period (see Figure 1). The initial crushing strength was about 0.3-0.4 kg/2.6-mm granule (Table 5), but it significantly increased during a 7-day curing period. After 7 days of curing time, the crushing strength was about 0.8-1.1 kg/2.6-mm granule. As shown in Figure 1, equilibrium was reached after about 14 days of curing. The PAPR product has its best crushing strength (about 27 kg/cm^2 or 1.45 kg/2.6-mm granule) after this curing period.

Under the conditions mentioned earlier, the SSAG process required a high recycle ratio (about 7 to 1). Since only a small amount of phosphate rock was available, the main emphasis during the second experimental run (7-430) was to produce PAPR from Mussoorie ROM rock rather than to establish optimum operating conditions. Therefore, further research on the SSAG process to optimize the operating conditions is required.

SSAG- Versus ROP-PAPR Processes

To evaluate the merits of the SSAG process, the process needs to be compared with the production scheme in which ROP-cured material is made followed by steam granulation (double-step process). This comparison has been made for the sulfuric acid-based PAPR production (2), not including phosphoric acid and with a rock of low impurity content. From this process evaluation, it can be concluded that under optimum process conditions, the SSAG process offers slightly better process economics. Under those conditions and for a particular location, the production costs for the SSAG process amount to US $478.20/mt of P_2O_5 versus US $491.40/mt of P_2O_5 for the double-step process. To arrive at these figures, full utilization of the heat of reaction released in sulfuric acid production and a product-to-recycle ratio of 1 to 2 in the SSAG process were assumed.

Since sulfuric acid is not produced by PPCL, utilization of steam obtained from sulfuric acid production to heat the air used in the rotary dryer in the SSAG-PAPR process is not possible. Therefore, the dryer will have to be heated by fuel oil. Under the process conditions at IFDC's pilot plant, the fuel oil consumption estimated for the demonstration plant is about 44 kg/mt of product. Due to this high fuel oil consumption in combination with the high recycle ratio (mentioned earlier), the use of the SSAG process by PPCL is less attractive than the ROP process in which a granular product is obtained through steam granulation of the cured ROP material. A low recycle ratio (approximately 1.5 to 1) as well as lower fuel oil consumption is expected for granulation of ROP PAPR product.

ROP-PAPR Results

Some preliminary experiments were performed on the ROP production of PAPR using ROM Mussoorie rock and a combination of sulfuric and phosphoric acids. The load on the pug mill mixer was equal to the previously described SSAG operations--300 kg/h rock, 84 kg/h sulfuric acid (91.3% H_2SO_4), and 30 kg/h phosphoric acid (53.9% P_2O_5). To obtain a reaction slurry that was sufficiently fluid, the addition of 66 kg/h of water was necessary (Table 3).

Following a retention time of 2 s at 85°C, the product from the pug mill was discharged onto a conveyor belt and transported to a hopper (simulated curing pile). The total retention time on the belt was only 12 s. Despite this short reaction time, the product could be discharged from the belt easily although the material was still somewhat sticky. To arrive at a nonsticky ROP product, a reaction time of about 8 min was required. The chemical analysis of the ROP product is presented in Table 6.

As shown in these analyses, a curing period of approximately 8 days is required to decrease the free-acid content of the material to less than 1% (as P_2O_5). The cured ROP product contained about 8.9% water and had a total P_2O_5 content of 18.5%. The nonsticky material can be easily reclaimed from the pile. No significant lump formation was noticed. The amount of ROM rock available for this ROP experiment was insufficient to operate the granulation plant. Based on prior experience it is expected that the recycle-to-product ratio in the granulation process for ROP material will be low (approximately 1-1.5:1). Additional experiments, which do include operation of the granulation plant, are needed to confirm this expectation.

Since the preacidulation environment may cause excessive corrosion of the equipment (i.e., erosion-corrosion), the corrosion rate was measured on selected paddles during the IFDC pilot-plant operations. Six paddles from the pug mill--two located at the feed end, two in the center, and two located at the discharge end--were weighed before the pilot-plant runs. Weight loss during the pilot-plant operations was determined by reweighing the paddles after completion of the experiments.

Shown below are the results of erosion-corrosion tests in the pug mill.

Paddle No.	Location	W_0[a]	W_1[b]	ΔW[c]	ΔH[d]
		(g)			(mm)
1	Feed end	42.1655	40.5265	1.6390	2.73
2	Feed end	42.2830	39.5658	2.7172	4.53
3	Center	43.1090	42.4284	0.6806	1.13
4	Center	42.4097	42.2542	0.1555	0.26
5	Discharge end	44.5800	44.1172	0.4628	0.77
6	Discharge end	42.6816	41.9053	0.7763	1.29

a. Weight before pilot-plant run.
b. Weight after pilot-plant run.
c. Weight loss during pilot-plant operations, about 36 h.
d. Length difference due to erosion-corrosion.

As shown in the table there was considerable erosion-corrosion to the paddles on the feed and discharge ends (severe decrease in length) during the pilot-plant operations. The original paddles were 30 mm in length; after approximately 36 h of operation, one of the paddles (No. 2) was only 25 mm long.

The paddles in the IFDC pug mill are fabricated of Type 316 stainless steel, which is quite sensitive to erosion. It is recommended to use erosion-resistant materials to fabricate the paddles or the paddle tip. Furthermore, a special lining for the pug mill trough should be considered.

Conclusions and Recommendations

The SSAG process using ground ROM Mussoorie rock and a blend of sulfuric and phosphoric acids to produce PAPR (containing about 18% by weight P_2O_5, approximately 40% of which is water soluble and 65% is available) is technically feasible when using the sulfuric acid in a preacidulation stage. In contrast, preacidulation with phosphoric acid prior to acidulation/granulation with sulfuric acid results in a process that is difficult to operate and yields a weak product with a low initial crushing strength (about 0.1 kg/2.6-mm granule). Use of sulfuric acid in the preacidulation step results in a higher initial crushing strength (about 0.4 kg/2.6-mm granule). It is possible that the operating conditions evaluated at IFDC were not optimum. Further optimization of the operating conditions could result in production of a granular product with a relatively higher crushing strength. The product obtained by the SSAG process is free flowing and nonsticky, although the free-acid content is relatively high (about 5% by weight).

Simulation of an SSAG-PAPR process variant in which the unscreened granulator discharge was pile cured for 14 days demonstrated that the physical properties of the granule were considerably improved. After curing, the material could be screened to remove the product and the offsize material returned to the granulator as recycle. The return of the recycle to the granulator would close the granulation loop and result in a continuous process.

During the IFDC pilot-plant operations using the SSAG process with ground ROM Mussoorie rock, it was noticed that close control of the free-acid content of the product is required. Temporary operation of the plant at a high free-acid content (+7% by weight) results in immediate blockage of the product screen, crusher, and chain mill. Because of this intrinsic operational problem, the screens and crusher should be readily accessible and easy to clean. The layout of a plant should be such that installation of parallel screening and crushing equipment is possible without major modifications.

Since preacidulation is carried out in an acidic environment with relatively large amounts of quartz present and in equipment with a high shear rate, it is recommended that the tips of the paddles and the trough of the pug mill be protected by using erosion-corrosion resistant material.

The SSAG process using ground ROM Mussoorie rock and a blend of sulfuric and phosphoric acids (as operated in the IFDC pilot plant) required a high recycle-to-product ratio (7 to 1).

Better process economics can be obtained using the double-step process in which rock is mixed with acid in a pug mill, and the resulting material is granulated after curing in a pile for about 15 days. This variant of the process is strongly recommended. From the first step, nongranular PAPR is produced and marketed; in the second step, a granulation plant is used to produce granular product.

IFDC is of the opinion that the SSAG process for PAPR from Mussoorie ROM rock is not as attractive as the option to make ROP-PAPR, followed by curing; PPCL may choose to market ROP-PAPR only or to convert it to a granular material. Information on the ROP option is given in the subsequent section.

Description of PPCL PAPR Process

Based on the results of the pilot-plant studies and subsequent discussions with PPCL engineers, the battery-limits process equipment was sized for a 10-mtph plant using a double-step process for the production and granulation of PAPR from ROM Mussoorie phosphate rock. This process involves the production of ROP-PAPR in step one, and the steam granulation of cured ROP-PAPR in step two. Marketing of PAPR from either step one (ROP) or step two (granular product) is optional with this process. In-depth discussions have been held with PPCL representatives to discuss the options available to them. They requested that equipment specifications be developed for the double-step process.

The original equipment configuration for the proposed SSAG-PAPR process was similar to that used in the IFDC demonstration runs. However, the latest pilot-plant tests revealed a marginal deficiency in granule strength and a relatively high recycle-to-product ratio using the SSAG method and ROM Mussoorie rock. This contributed to the decision that the process for steam granulation of ROP-PAPR be used.

Step One

The ground (75% passing 75-μm) phosphate rock is transported to a surge silo by means of a bucket elevator. The surge silo is provided with a distribution cone and can be aerated by compressed air to ensure a steady flow of rock into the silo discharge screw conveyor. This conveyor discharges into a bucket elevator which returns the rock to the top of the storage silo and completes a recirculation loop. The proper amount of phosphate rock is fed to the pug mill by a screw conveyor with a variable-speed drive and a weigh feeder. The screw conveyor is fed with rock through a small hopper located in the discharge chute of the bucket elevator. This ensures a steady flow of aerated rock and prevents flooding of the screw conveyor. Adjustment of the rock flow is obtained by adjusting the rotational speed of the screw conveyor. The rock flows by gravity from the weigh belt to a seal screw and then into the pug mill.

Using a flow-control system, sulfuric acid (about 91% H_2SO_4) and phosphoric acid (54% P_2O_5) are pumped and fed from storage tanks to the pug mill through separate lines. In the pug mill the ground phosphate rock is vigorously mixed with the acids and water to ensure homogeneous reaction through complete mixing. The retention time in the pug mill is about 2 s, implying that rapid and vigorous mixing is required. The off-gases from the pug mill are vented to a venturi scrubber to remove fluorine and phosphate rock dust.

The pug mill acidulate discharges onto a belt den that transfers the material to a curing shed using a cross belt. The length and the speed of the conveyor belt (curing den) are such that the fluid material discharging from the pug mill solidifies before reaching the end of the belt. This enables the material to discharge onto the curing pile. After the curing period (21 days), the material is reclaimed and transferred to the granulation plant where the material is steam granulated as described in step two.

Step Two

After curing, the ROP PAPR is recovered and fed into the lump breaker which discharges into the hopper that feeds a variable-speed belt through an adjustable discharge gate. The belt discharges into the boot of the granulator feed elevator. Recycle material from the screens and the dust from the dry cyclones are also fed to this elevator. These materials discharge from the elevator by means of a chute into the rotary-drum granulator where a rolling bed is formed. Granulation occurs in this rolling bed aided by a steam sparger located beneath the bed. Clarified water from the settling pond may be added with the steam as needed to aid granulation.

The granulator discharge (containing 4%-6% free water) feeds by gravity into the rotary dryer. In the dryer the free-water content of the granulator discharge is reduced to about 1% free water. The rotary dryer is operated with a cocurrent flow of air which is heated in a combustion chamber using fuel oil. Dust losses in the rotary dryer are expected to be 4%-8% of the throughput. To recover this dust the off-gases are sent to a dry cyclone where the dust is separated from the air and returned with the recycle material to the granulator.

From the rotary dryer the fertilizer is discharged into a bucket elevator for transfer to a vibrating, single-deck, oversize screen. Here the oversize (plus 4-mm) material is separated, sent to a chain mill-type crusher, and returned to the oversize screen. The material passing the oversize screen is transferred by gravity to the product screen where the product-size material (minus 4- plus 2-mm) is separated. The undersize material (minus 2-mm), an appropriate fraction of the screened product, and the dust from the cyclones are recycled to the granulator as previously mentioned. The screened product is conveyed to storage.

Gases containing fluorine and dust from the granulator, dryer, cyclones, screens, and other transfer points are treated in a wet-scrubber system using water (in a recycle loop) as the scrubbing medium. From this scrubber a continuous bleed of scrubbing liquor is discharged into a settling and treatment pond for treatment with lime or limestone. The clarified pond water is returned to the pug mill and granulator for use as process water and to the granulator and wooden wet scrubber as makeup water.

Pollution Control

Since fluorine is a common constituent in phosphate rock, the acidulation of these rocks results in the release of gaseous fluorine compounds into the atmosphere. Fluorine gases, even in small quantities, are very toxic to plant and animal life. Removal of fluorine from process gas streams before they are exhausted into the atmosphere is essential and is closely monitored by pollution control authorities in many countries.

Because of the relatively small flow rates and the limited number of experiments in pilot plant-scale operations, actual fluorine measurements during acidulation and subsequent processing steps were not possible. However, analyses of products (granular and ROP) show that about 40% of the fluorine contained in the rock is evolved during the production of PAPR. Of this amount about 40%-80% would be evolved during denning (ROP process) and the remainder would be evolved during the initial acidulation reactions. Hence, it is recommended that in a demonstration-scale unit the off-gases from the pug mill and curing belt be treated in a venturi scrubber before they are exhausted into the atmosphere.

In addition to the gaseous pollutants (fluorine compounds), particulates (dust) generated during the handling of finely ground phosphate rock and the manufacturing and bagging operations are also of concern. Hence, every effort should be made to design and operate the system to minimize the escape of dust. Low speed-type positive or continuous discharge bucket elevators are essential for handling the dusty phosphate rock feed and recycle materials. Totally enclosed screw-, chain drag-, or belt-type conveyors are also well suited for use in these processes.

In the PAPR process a cyclone-type dust collector is recommended for removing most of the particulate matter in the hot air exhausted from the dryer. Similar equipment is also recommended for the fugitive dust collection system. The drum granulator off-gases do not pass through a cyclone due to their high moisture content, but are treated in a column scrubber. The fugitive dust pickup system for the plant should be designed to ventilate the bucket elevators, conveyors, screens, crushers, and all dry material transfer points. Adequate ventilation of these units and material transfer points will ensure that a minimum of dust and fluorine escapes into the plant area.

The dry collection systems are treated in a wet scrubber before the gases are exhausted into the atmosphere. The management and processing of the liquor discharged from the scrubber system usually depend upon local economics (availability and cost of water) and effluent control regulations. Regulations in India prohibit the discharge of contaminated water that contains appreciable amounts of dissolved and suspended solids. Thus, an effluent pond (included in the auxiliary and support facilities) is recommended for settling suspended solids and for storage and recirculation of clarified water back to the scrubber. Additionally, the pond water is also used to control granulation in the drum granulator or to provide liquid phase in the pug mill (ROP). This effluent pond system is simple, easy to control, and environmentally safe because the effluent pond serves as a "safety valve" in the event of a major process upset or spill that could otherwise be detrimental to the local waterways and environment. This type of wastewater management system also usually affords the most economic use of fresh makeup water. It is anticipated that periodic dredging of settled solids would be required. These solids can be disposed of according to environmental regulations set by the Indian Government.

A small fraction of the clarified water may need to be diverted to the local wastewater stream for disposal. A pH control system and a treatment system are recommended for this stream to ensure that this discharge meets the acceptable criteria. A pH control system is also recommended for the scrubber liquor system to protect the scrubber and related equipment from the presence of fluorosilicic acid.

Process Equipment Specifications

The principal process equipment items and the abbreviated equipment specifications are shown in Table 7. The process equipment and supporting facilities for the demonstration unit are described in this section. The specifications given here assume an ROP and a granulation plant for PAPR with a capacity of 10 mtph at a recycle-to-product ratio of 1.5:1 (25-mtph throughput).

It should be noted that severe corrosion and erosion problems, along with load surges during startups, require special care during design of fertilizer plants so that all equipment is constructed of proper materials and is powered by heavy-duty drives. Specifications for fertilizer plant equipment may appear excessive to the casual observer, while actual experience indicates that they are merely adequate. Costly downtime usually results if inadequate materials or equipment are installed in a fertilizer plant.

General

All equipment items should be constructed of mild steel unless otherwise noted. All construction should be designed for extra heavy duty with maximum attention given to reliable operation and minimum maintenance. All systems should be manually operated using a minimum of specialized or automatic systems.

In the case of welded fabrication, including support steel, all welding on external surfaces should be solid or full. Skip welding of external braces, supports, and joints should not be allowed. Full welding of external joints is specified to prevent corrosion and seepage from joints that will decrease the service and appearance of the protective coating system (described later). Likewise, when bolted construction and fabrication techniques are used, all metal surfaces (hidden or exposed) should be treated with the appropriate protective coating system after holes are drilled but before assembly.

When concrete is used (either above or below ground), the reinforcing steel should be covered by at least 7.6 cm (3 inches) of concrete. This coverage is recommended to minimize corrosion of the reinforcing steel caused by the penetration of moisture and corrosive salts (fertilizer) into the concrete structure.

Fans--Fans are required to maintain a positive draft in certain types of equipment, such as the (1) dryer, (2) pug mill, (3) drum granulator, and (4) fugitive dust system. Since the air passing through the fan might be laden with dust, an open material handling (OMH)-type fan is required. To enable inspection and/or cleaning of the fan, quick access inspection doors are required in the housing. The housing of the various fans should be flanged on the inlet and outlet sides and be equipped with a bottom drain plug (minimum 25-mm diameter). All fans should be belt driven; the maximum rotational speed of the wheel should not exceed 2,800 rpm.

Cyclone-Type Dust Collector--The primary sources of dry dust in the granulation plant are expected to be the (1) rotary dryer, (2) bucket elevators handling nongranular material, (3) oversize crusher, and (4) screens. These equipment systems are ventilated by an induced draft flow of air. This air, which is laden with dust (average particle size diameter about 75 μm), should be treated in a dust recovery system before being exhausted into the atmosphere. A dry cyclone-type dust collector system with a separation efficiency of 95% or more is required. It is highly recommended to provide the cyclones with a flail chain to prevent blockage of the dust discharge by sticky particles. The material of construction should be mild steel with a minimum thickness of 5 mm (3/16 inch). All exhaust air ducting should be sized to maintain an air velocity of 16 m/s. If possible, all duct elbows should have a radius of three duct diameters. In order to facilitate cleaning of the ducts, all major duct bends should be flanged. The length of unflanged straight sections of the ducts should not exceed 3 m. All pickup points should be provided with butterfly valves to enable balancing the system. The dust collected by the cyclone is discharged automatically into the recycle system. To prevent air from leaking into the cyclone, a gravity operated, flap-type valve is used at the dust outlet.

Conveyors--Preferably, horizontal or moderately inclined belt-type conveyors are used to transport the granules between the various units. With the exception of handling ground phosphate rock, the use of screw-type conveyors should be avoided because of the hygroscopic, plastic nature of the fertilizer. These units may fail because of internal buildup of material (formation of a rind) and excessive power consumption. Furthermore, unless specially designed a standard belt-type conveyor should not be used at an incline in excess of 20° above horizontal. The speed of the conveyor belts should not exceed 1 m/s to avoid excessive wear. The width of the belt-type conveyors should be standardized to simplify spare part inventories as well as maintenance. All belts should be provided with troughing idlers with an incline of 20°-35° to the axis of the belt. To minimize dust pollution, all belts are to be enclosed in mild steel or wood covers and connected to the fugitive dust collection system. Ample access doors should be provided for the enclosure.

Pumps--Final cleaning of the air is done in a wet scrubber before it is released into the atmosphere. To promote the washing effect of this scrubber and to minimize the requirements of fresh water used in this unit, pumps are used to recirculate water from the scrubber sump and the settling pond.

All pumps are centrifugal type provided with a stuffing gland. The maximum rotational speed is 1800 rpm. An in-line strainer should be placed on all pump inlets. The pumps should be constructed of mild steel and equipped with a rubber-lined head and a rubber-coated impeller.

Chutes--The three material fractions from the screening system--oversize, product, and undersize (fines)--can be routed to the appropriate process location using chutes or conveyors, depending upon the layout of equipment. All chutes should be large and steeply inclined (60° minimum above horizontal). They should be fitted with numerous cleanout doors to facilitate easy inspection and cleaning.

The dryer discharge chute should be perpendicular to the end of the dryer and enter the dryer elevator boot from the side. This will allow the option of washing sticky material from the dryer without flooding the elevator.

Protective Coating System

All mild steel items (external surfaces) should be sandblasted to a nearly white color and coated with a zinc primer (60-75 μm [2.5-3.0 mil] dry thickness) and with a chemical-resistant epoxy or similar coating (minimum 125 μm

[5.0 mil] dry thickness). The surface preparation (degreasing and sandblasting), primer, and topcoat should be viewed as a system. The coating supplier should specify the material and procedural details specific to the application of the coating system offered.

The coating of stainless steel and nonsteel items (concrete, wood, and reinforced plastic) is not required but can be done if desired (to improve appearance, as a color coding for safety, or to protect the concrete against absorption of moisture and corrosive salts). These specialized coating systems should be clearly specified with specific regard to expected service, condition of substrate, and climatic conditions.

Electrical

All process equipment items should be furnished with chemical-proof construction electric motors. The motors should be designed for three-phase, 50-cycle, 220/440-volt electrical power unless otherwise specified due to a change in the local supply of power. The service factor for all motors should be at least 1.15. The motors should be sized for continuous duty at the maximum instantaneous load that may occur during normal batching or surge operation. Totally enclosed fan-cooled motors are required. The cooling fans must be constructed of corrosion-resistant or nonmetallic material. Aluminum or mild steel fans are not acceptable because severe corrosion by fertilizer salts occurs, resulting in imbalance and vibration. Reinforced plastic fans are acceptable.

All motor starters, including circuit breakers and start-stop stations, should be installed in tightly sealed, corrosionproof (National Electrical Manufacturers Association [NEMA] 4X) enclosures (or equal) with start-stop-reset buttons and stop/running indicator lights installed in the cover or at a nearby remote location. All starters should be equipped with auxiliary contact blocks in the event a second start-stop station is required.

Rigid-type steel conduit coated with polyvinyl chloride (PVC) or other corrosionproof coating should be used for all field (process plant and building) wiring. Cable trays should be used only in enclosed electrical switchgear and electrical distribution rooms where the possibility of corrosive dust and mechanical damage is minimal. In no event should cable trays be used in the process-plant building or fertilizer storage buildings where there is a high risk of damage caused by corrosive fertilizer materials or by maintenance, welding, or other activities that are routinely performed in the vicinity of the electrical cables and control wiring.

The location of the motor starters can be either centralized (motor control center [MCC]) or localized (field mounted). If the MCC method is used, the center should be located in an air-conditioned (controlled relative humidity and temperature) room that is pressurized to exclude corrosive fertilizer dust. The MCC should be constructed according to NEMA-12 (minimum) standards. The NEMA-12 enclosure for the MCC is fitted with gaskets and is essentially dustproof, but it is not corrosionproof or completely moistureproof (atmospheric and spills); therefore, it is essential that the MCC be located inside a properly conditioned and dustproof room.

In all cases, for the purpose of operator and machine safety, a motor start-stop station should be located within view of the drive motor. If needed for convenience, a remote (second) start-stop station may be located away from the view of the drive motor. In practice, all machines should be started by the operator who is actually viewing the machine. The practice of remote or blind starting of machines should be avoided, and the control room-type start-stop control panel (if installed) should be used only for emergency stopping of the machinery.

Process Equipment

The following equipment specifications and features should be included in the tender documents. Although these specifications are considered essential for durable construction and long-term operation of the equipment, vendors should be encouraged to offer alternative specifications if, in their opinion, such alternatives would result in a more functional or cost-effective system. Refer to Figure 2 for location of each equipment item within the overall processing system. A summary of the estimated capacity data (material throughput and power requirements) for the major equipment items is shown in Table 7.

Item 1--Phosphate Rock Elevator--The duty of this unit is to feed finely ground (75% minus 75-μm) phosphate rock to the phosphate rock storage silo. The load to this elevator will be (1) 10 mtph rock from the grinding mill and (2) 20 mtph from the storage silo discharge screw conveyor. There will be occasional surges in the rock load so that this elevator should have a 40-mtph capacity. The belt-driven gear reducer should be equipped with a backstop ratchet to prevent elevator from running backwards in the event of a power failure. The power requirement is 15 kW (20 hp) TEFC electric motor. The elevator should be a continuous discharge type and a single-chain design. The continuous discharge-type buckets should be fabricated from malleable iron or mild steel. If mild steel is used, the minimum thickness should be 3.2 mm (1/8 inch) for casing and 9.5 mm (3/8 inch) for head section and boot. The buckets should be sized to deliver the desired capacity with an average fill of 40% and an average material bulk density of 644 kg/m^3 (40 lb/ft^3). The low fill is specified to account for the low bulk density of the highly aereated rock.

The chain should be combination Type C-111 with cast iron center links, high-tensile strength sidebars, and hardened steel cross pins. Bucket attachments (K-2 style links) should occur every second link. Buckets should be attached to the K-2 links using self-locking nuts to avoid subsequent loosening. The head and boot sprockets should be fully split (bolt-together style) and constructed of either chilled-rim cast iron or cast steel; if constructed of cast steel the wearing surfaces should be hardened. The top (head section) bearings should be the heavy-duty, self-aligning, pillow-block type. The bottom (boot section) bearings should be double-seal takeup or hardened cast iron dry type, depending upon the manufacturer's specific takeup design and recommendation.

Items 2, 3, and 4--Ground Phosphate Rock Storage and Recirculation System--The purpose of this unit is to provide a 20-mtph recirculating loop of phosphate rock fed from a rock storage silo through a discharge screw conveyor into a bucket elevator (Item 1) that discharges into a gravity return chute connected to the top of the silo. The gravity return chute will contain a bleed pocket-hopper that will supply rock to a variable-speed screw feeder. The screw feeder will discharge rock onto a weigh belt that discharges into a seal screw feeder which feeds the pug mill (Item 8). The recirculation of the phosphate rock is necessary in order to aerate (fluidize) the rock for accurate metering.

The storage silo should have a capacity of 32 m^3 (approximately 2.5 h of operation--21 mt) for phosphate rock and be fabricated of 6.4-mm (1/4-inch) thick mild steel plate with external bracing. The silo should be equipped with a mechanical-shaker baghouse vent system and have six side-entry (spaced at 120° intervals about the circumference of the silo just below the chine) air spargers (open-end pipes) of a minimum 12.7-mm (1/2-inch) inside diameter for initial fluidization of the rock by compressed air. The silo should have a rotary vane discharge valve located in a 45° cone bottom with a flanged outlet.

The silo discharge screw conveyor should have a hardened steel screw measuring 35.6 cm (14 inches) in diameter with hardened steel (Ni-Hard, or equal), dry hanger bearings, and a 7.6-cm (3-inch) shaft diameter. The first 1.2 m of the screw should be shrouded and half-pitch while the remainder of the screw should be unshrouded and full-pitch. The screw should be contained in a flanged U-trough fabricated of 6.4-mm (1/4-inch) mild steel with a 3.2-mm (1/8-inch) mild steel cover attached with quick release clamps. The drive should be a belt-driven steel gear reducer with a 6-kW (7.5-hp) motor. This unit should deliver 20 mtph (31.0 m^3/h) of product. This conveyor should be slightly inclined to prevent flooding of the screw.

The chute returning the rock from the elevator discharge (Item 1) by gravity to the top of the silo should have an inside diameter of 25.4 cm (10 inches) and be fabricated of a 4.8-mm (3/16-inch) mild steel plate.

A baghouse should vent from the top of the silo to eliminate a pressure buildup inside the silo while preventing the escape of dust into the atmosphere. One bag (acrylic or polyester) of approximately 0.9 m^2 (10 ft^2) equipped with a mechanical shaker (or equal) should be provided with the silo. The power requirements for the fan of this unit would be approximately 1 kW (1 hp).

Items 5 and 6--Ground Phosphate Rock Feeder System--The purpose of this unit is to meter and control the flow of the fluidized phosphate rock.

The pocket-hopper/screw-feeder assembly should be mounted in the midsection of the gravity return chute. The pocket hopper should have a 1.0-m^3 (35.3-ft^3) capacity and be fabricated of a 4.8-mm (3/16-inch) mild steel plate. The feeder screw should be 25.4 cm (10 inches) in diameter and be fabricated of hardened steel. The first half of the screw should be shrouded and half-pitch while the last half of the screw should be unshrouded and full-pitch. The dry-hanger bearings should be constructed of Ni-Hard steel (or equal). The screw shaft should be 7.6 cm (3 inches) in diameter. The feeder flanged U-trough should be fabricated of 6.4-mm (1/4-inch) mild steel with a 3.2-mm (1/8-inch) mild steel cover. This unit should deliver 10 mtph (15.5 m^3/h) at its maximum speed. The drive for this unit should be a variable-speed, direct-current motor with power furnished by a silicone current rectifier complete with remote speed control. The drive should be automatically controlled by a signal from the weigh belt. The estimated power requirement is 9 kW (7.5 hp).

The weigh belt should be of load cell design with a remote readout located close to the feeder speed control for manual operation in the event of instrument failure. The belt should be flat and have side skirts. The belting should be smooth rubber with a minimum of three plies and a thickness of 6.4 mm (1/4 inch). The belt width and speed ratio control should allow accurate measurement at 8 (±2)-mtph rates. The estimated power requirement is 2 kW (2.5 hp).

Item 7--Phosphate Rock Seal Screw Feeder--The seal screw conveyor should have a hardened steel, full-pitch screw measuring 35.6 cm (14 inches) in diameter with hardened steel (Ni-Hard, or equal), dry hanger bearings, and a 7.6-cm (3-inch) shaft diameter. The screw should be contained in a flanged U-trough fabricated of 6.4 mm (1/4 inch) mild steel with a 3.2-mm (1/8-inch) mild steel cover attached with quick-release clamps. The feeder should be equipped with a seal gate located at the discharge end to avoid suction from the pug mill hood draft. The drive should be a belt-driven steel gear reducer with a 4-kW (5-hp) motor. This unit is to deliver 10 mtph (15.5 m^3/h) of material. This conveyor should be inclined to avoid flooding of the screw and to ease washing operations.

Item 8--Double-Shaft Pug Mill--The purpose of this unit is to provide thorough mixing of the phosphate rock and the acids before delivery to the ROP curing belt (Item 9). This pug mill should have a mixing trough 0.6 m (2 ft) wide by 2.2 m (7 ft) long. The mixing paddles should be adjustable for advancing or reversing the pitch and be mounted on two shafts extending the length of the trough. The trough should be fabricated of 12.7-mm (1/2-inch) thick steel. The trough should be lined with erosion and corrosion protective material such as acid-resistant brick set with acid-proof mastic. The square shafts should be 10.16-cm minimum (4-inch) cold-rolled steel with one shaft turning clockwise and one turning counterclockwise to provide a lifting motion to the fertilizer down the center line of the trough. The mixing paddles should initially be set at 45° to advance the fertilizer. Optimization of the mixing action of the pug mill through adjustment of the paddles is to be investigated. The paddles should be fabricated of 12.7-mm (1/2-inch) thick Ni-Hard steel (or equal). The drive assembly should consist of a 20-kW (25-hp) motor with a belt drive and a steel gear speed reducer. The output shaft of the speed reducer should be connected by a steel gear drive to the mixing shafts. The shaft bearings must be a heavy-duty, pillow-block design. The speed reducer should have a gear ratio that will result in a paddle tip speed of 1.9 m/s. If variable-speed control is desired, a hydraulic-speed reducer may be used with this unit.

The pug mill should be equipped with an enclosed wooden fume removal hood 0.9 m (3 ft) high, 2.2 m (7 ft) long, and 0.6 m (2 ft) wide. The hood should be framed of 4.8-mm (3/16-inch) thick mild steel plate and have wooden lift-off doors along each side for easy access to the paddles. The hood frame should be flanged along the bottom for attachment to the pug mill trough flange. The pug mill and drive assembly should be mounted horizontally on a heavy-duty unitized structural steel frame.

Due to the highly erosive and corrosive environment inside the pug mill, a spare set of mixing paddles and acid-resistant brick should be supplied with the mill.

Item 9--Curing Belt--The purpose of this unit is to provide curing (set) time for the material discharged from the pug mill. This belt should be located under the pug mill discharge.

The curing belt should be 122 cm (48 inches) wide (measured flat) by 27.3 m (90 ft) long and troughed at 45° from horizontal. The belt should be made from high-temperature (200°C [400°F]), chemical-resistant material. The conveyor frame should be heavy-duty structural steel with chemical-resistant coating. All conveyor rollers should be constructed of plastic with treated wood (Argudo wood) bearings for resistance to a corrosive-type atmosphere. The drive should be a belt-driven, steel-gear speed reducer powered by a 6-kW (7.5-hp) motor. The drive should produce a belt speed of 1.8 m/min (6 fpm) for a 15-min belt curing time. A cutter wheel is not needed with this belt.

The entire curing belt should be enclosed in a wooden den for fume control. The den should be vented for fume removal at the feed end, midsection, and discharge end.

The exhaust gas ducting extending from the pug mill and curing den to the column scrubber should be square in shape and constructed of wood to resist fluorine attack. The sides, or tops, should be removable to facilitate cleaning the ducts. It will be necessary to clean these ducts often due to deposits of dust and other solids. The ducts from the pug mill (1) and the curing den (3) should be 20 cm square, and the main trunk line duct to the venturi scrubber should be 41 cm square.

Item 10--Venturi Scrubber and Fan--The total air load to the venturi scrubber is about 10,895 m^3/h (6,400 ft^3/min) at a temperature of approximately 35°C. This air is laden with dust and fluorine from the pug mill and from the curing belt. Since effluents in general, and fluorine effluents in particular, can be harmful to the biosphere, treatment of the air streams is required.

Since the air coming from the pug mill and curing belt contains fluorine, a high efficiency air treatment system is required. A venturi scrubber is a high-efficiency scrubber which will strip the fluorine and dust before the air is exhausted into the atmosphere. The venturi scrubber system should be constructed of fiberglass reinforced polyester with a fluorine resistant lining. The light material will avoid an expensive supporting structure. The approximately 227 L/min scrubbing water flow will circulate through the scrubber by means of the recirculation pumps (see Item 45).

An OMH-type fan will be installed downstream of the venturi scrubber to create an induced draft. The fan should have at least a 75.3-cm (29-5/8-inch) wheel, with a 30-kW (40-BHP) TEFC electric motor at 50.8-cm (20-inch) static pressure. Fan must be constructed of type 316L stainless steel, or other fluorine-resistant material.

The venturi scrubber tank will overflow by gravity into a trench that will discharge the liquor into the pollution treatment pit. The level will be controlled with fresh makeup water, depending on the liquor concentration.

Item 11--Product (ROP-PAPR) Cross-Belt Conveyor--This belt is used to transport product from the curing belt to the shuttle belt in the storage shed. The required capacity of this belt is 12 mtph. A belt width of 60 cm wide by approximately 32 m long with a lift of 11 m at an 18° angle from the horizontal. The power requirement of this unit is estimated at 4 kW (5 hp). The gear reducer on this conveyor should be equipped with a ratcheted backstop to prevent the belt from running backwards in case of a power failure. The conveyor should meet the specifications as mentioned in the general section on conveyors.

Item 12--Shuttle Belt--It should be a three-ply rubber belt, 60 cm wide (measured flat) by 33 m long, with reversible discharge. The speed reducer is to be belt driven by a 4-kW (2-hp) TEFC electric motor. The belt should have a speed of 46 m/min and be troughed 20°-30°. The belt frame should be mounted on steel tracks with steel wheels. The tracks are to be 66 m long so that the belt can be discharged along the entire length of the storage shed. The drive for the wheels shall be reversible and powered by a 6-kW (7.5-hp), TEFC electric motor with suitable gear reducer or equal hydraulic power unit.

Item 13--Lump Breaker--The duty of this unit is to crush lumps that normally form during pile curing. This type of lump formation is usually referred to as "pile set" (a mechanical bonding of cured materials). Some lumps may also form as a result of "crusting" of the pile surface, caking caused by absorption of atmospheric moisture, or other characteristics of the material. The lump breaker should be designed to gently crush (condition) 20 mtph of the lumpy material to about 6 mm or less. The feed hopper should be wide enough to accommodate a small front-end loader bucket (about 2 m [6 ft] wide). Material discharges from the unit by gravity directly into the variable-speed belt feed hopper. The lump breaker feed hopper should be fitted with a removable top grid (cross-bars) to ensure that the material passing through the unit is completely delumped. The lump breaker does not contain a discharge screen. The openings in the grid should be 8 cm by 8 cm to ensure effective delumping. The drive unit is powered by a 5-kW (7.5-hp) TEFC electric motor. The drive is by roller chain and steel gear reducer.

Item 14--Variable-Speed Belt Conveyor--This belt will be fed by a hopper with an adjustable discharge gate. The hopper should be located under the lump breaker and be gravity fed. The belt will be constructed of three-ply rubber and be 60 cm wide (measured flat) by 2.5 m long, with a 20° trough from horizontal. The drive will be powered by silicon controlled rectifier (SCR) direct current, variable-speed, 2-hp, electric motor, and belt driven. The frame will be heavy duty and coated for corrosion protection.

Item 15--Granulator Feed Bucket Elevator--This item is identical to Item 1 except for discharge height.

Item 16--Rotary-Drum Granulator--The purpose of this unit is to granulate the PAPR with steam and water. The rotary-drum granulator should be 1.8 m (6 ft) in diameter by 3.7 m (12 ft) long complete with a retention ring (approximately 75 cm high) at the feed end. There should also be one internal retention ring (30 cm high) located 1 m from the discharge end of the drum. The shell of the drum should be constructed of a 1.3-cm (1/2-inch) thick steel plate and lined with 1.3-cm thick (1/2-inch) rubber panels (at least three plies). The rubber panels should be constructed of chemically resistant material that can withstand a temperature of 200°C. The tires should be seamless, free floating, machined face, and fabricated of 1045 carbon steel (or equal). The wheels should have machined faces and be fabricated of 1045 carbon steel (or equal). The wheel bearings should be a tapered, self-aligning, pillow-block type. The wheel shafts should be of cold-rolled steel. The drum should have a chain drive with steel cut-tooth girth and pinion sprockets. The girth sprocket should be flanged, and the pinion sprocket should be flame hardened. The drum should have two thrust rollers on the high-end tire (feed end of drum) to control axial movement. The thrust rollers should have machined faces and be fabricated of high-carbon steel, complete with double-roller bearings for longitudinal control of the drum. Heavy-duty bi-directional adjusting screws should be provided for alignment of all wheels, drives, and thrust-roller assemblies. The drum discharge-end hood and chute should be fabricated of 6-mm (1/4-inch) steel plate. Heavy structural steel should be used to fabricate the support for the trunnions, the pinion sprocket gear, and the drive unit. All trunnion wheels should have nip-point guards fabricated of 4-mm (3/16-inch) steel and graphite block (or equal) lubrication. The drum should be provided with a Type 316 stainless steel, under-bed steam sparger and heavy-duty sparger support extending along the axis of the drum. The drum should have a 2°-3° inclination sloping toward the discharge end. The drum and drive structural steel frames should be unitized.

The drum granulator drive assembly should consist of an electric drive motor and heavy-duty speed reducer. The electric motor should be totally enclosed and fan cooled for chemical duty, have a service factor of 1.15, and a power of 34 kW (45 hp). The motor should be top (or side) mounted with relation to the speed reducer and fitted with belt-drive for a speed reduction of 3 (600 rpm) to the input shaft of the speed reducer. The speed reducer should be geared to produce a drum rotational speed of 12 rpm (39% critical speed). The output shaft of the speed reducer should be connected to the pinion sprocket gear with a flexible coupling. The pinion sprocket gear should drive the girth gear by means of a heavy-duty roller chain. The entire drive assembly should be mounted on a heavy-duty frame fabricated of structural steel attached to the structural steel drum frame.

Item 17--Combustion Control System--The purpose of this unit is to safely provide the controlled combustion of fuel oil required in the drying process of the rotary dryer (Item 18). The unit should be an induced draft combustion chamber mounted on the inlet end of the dryer to provide a cocurrent flow of heated air through the dryer shell. It should have an automatic (with manual override) valve to meter the flow of oil to the combustion chamber. The valve should be controlled by the dryer exit gas temperature. It should also have an oil burner safety control system to automatically shut off the fuel supply on flame failure or loss of draft and to ensure proper airflow and purging of the system prior to startup. It should have an audible alarm signal on failure.

Item 18--Rotary Dryer--The purpose of this unit is to reduce the moisture content of the granulator discharge to less then 1%. The dryer shell should be 1.52 m (5 ft) in diameter by 10.67 m (35 ft) long. The shell should be fabricated of 9.53-mm (3/8-inch) steel plates. The tires should be seamless, free floating, have machined faces, and be constructed of 1045 carbon steel (or equal). The wheels should have machined faces and be constructed of 1045 carbon steel. The wheel bearings should be a tapered, self-aligning, pillow-block type. The thrust rollers should have machined faces of high-carbon steel with double roller bearings for longitudinal control of the drum. All wheels and driver and thrust rollers should have heavy-duty, bidirectional, adjusting screws for alignment. Lubrication should be furnished to all wheels and tires by graphite blocks (or equal). The dryer drive is provided by chain-driven girth and pinion sprockets. The girth gear sprocket is flange-mounted, cut-tooth steel. The pinion gear sprocket is flame-hardened, cut-tooth steel. The flighting should be full-curtain (compound bend) formed-steel flights with advancing flights at the inlet end. The shell should be equipped with six gravity-operated knockers on the inlet end. The dryer drive should be a 38-kW (50-hp) motor and gear-type speed reducer connected to the pinion sprocket. The dryer rotational speed should be 6 rpm, with an inclination of approximately 2° toward the discharge end.

The oil-fired combustion chamber should have a 1,900,000 kcal/h (7,500,000-Btu/h) burner for an operational demand of 1,600,000 kcal/h (6,500,000 Btu/h).

Item 19--Dryer Discharge Cyclone and Fan--The air discharged from the dryer contains dust which must be separated from the air and subsequently recycled to the process to improve process efficiency as well as to minimize air pollution. The total capacity of the dust recovery system is 20,000 m^3/h (12,000 ft^3/min) of dust-laden air at a temperature of about 120°C and a pressure of about 960 cm (378 inches) Wc (absolute).

The dimensions of the cyclone are approximately:

Inlet opening:	610 mm □ (2 ft)
Air outlet opening:	760 mm φ (2.5 ft)
Dust outlet:	150 mm φ (0.5 ft)
Cylindrical height:	2,590 mm (8.5 ft)
Conical height:	3,500 mm (11.5 ft)

Since the air is relatively hot, insulation of all ducts and the cyclone is required for safety reasons. This will also avoid cold spots which could cause condensation, resulting in plugging of the system. The cyclone should meet the specifications as mentioned in the general section on cyclones.

The dryer cyclone draft will be induced by a mild steel fan equipped with an open material handling wheel. The wheel diameter should be about 115 cm (45 inches). The fan capacity must be 20,000 m^3/h at 120°C and 40 cm pressure differential. Rotational speed should not exceed 2,800 rpm. The power requirement should be about 35 kW (50 hp).

Item 20--Cyclone and Fan for the Fugitive Dust System--To remove possible dust at various points (bucket elevators, screens, and conveyor belts) in the plant, a fugitive dust collecting system should be installed. To improve plant efficiency, this dust is separated by means of a cyclone and recycled to the process by the recycle system. The capacity of the fugitive dust collecting system is 9,000 m^3/h (5,400 ft^3/min) at a temperature of about 30°C and a pressure of 960 cm (378 inches) Wc (absolute).

The approximate dimensions of the cyclone are:

Inlet opening:	460 mm □ (1.5 ft)
Air outlet opening:	460 mm φ (1.5 ft)
Dust outlet:	90 mm φ (0.3 ft)
Cylindrical height:	1,370 mm (4.5 ft)
Conical height:	1,980 mm (6.5 ft)

To avoid condensation of water during cold and humid weather conditions, it is recommended that a steam-operated air-heating facility be installed in the inlet to the cyclone. The cyclone should meet the specifications as mentioned in the general section on cyclones.

A fan is needed to induce a continuous positive draft in this system, and should be constructed of mild steel. The capacity of this unit needs to be about 9,000 m^3/h (5,400 ft^3/min) of dust-laden air at about 30°C and a pressure differential of about 40 cm (16 inches) Wc. The fan wheel should be open material handling type. The wheel diameter should be about 75 cm (30 inches); the estimated power requirement is approximately 18 kW (25 hp). The fan should meet the specifications as mentioned in the general section on fans.

Item 21--Wet Scrubber for Dust and Fluorine Recovery--The total air load on the scrubbing system is 29,000 m^3/h (17,400 ft^3/min) at a temperature of approximately 60°C. This air is laden with dust and fluorine, mainly from the rotary-drum granulator, and slippage from the cyclones in the dryer and fugitive dust collecting systems. Since effluents, in general, and fluorine effluents, in particular, can be harmful to the biosphere, treatment of the air streams is required.

Since the air coming from the granulator may be moist, any dry-type dust collecting system could be prone to plugging. Therefore, because of the required fluorine removal, passing the air through a wet scrubber is recommended before exhausting it into the atmosphere.

A low-pressure, spray-type wet scrubber is recommended. The scrubber is constructed of wood and consists of two separate sections (an inlet downflow section and an outlet upflow section), each having a cross-sectional area of 5 m^2. The overall outside dimensions of the scrubber are 3 m by 3 m square. All bolts, nails, and fasteners used in construction must be stainless steel. All nonwood must be either stainless steel or plastic. Mild steel is unacceptable for this unit. Internally, both the downflow and the upflow sections are provided with staggered, wooden slats having a free surface area of approximately 50%.

Liquor is recycled from the seal sump to the scrubber through two operating centrifugal pumps and three spray banks. One bank is located above the wooden slats in the downflow section, the second bank below the slats in the upward flow section, and the third bank above the wooden slats in the upward flow section. Recycled pond water is used in the third spray bank to scrub the air before it is exhausted into the atmosphere. The sprayers used in the scrubber banks are a full-cone type. The pressure drop across the sprayers should not exceed 2.0 atmospheres. The total capacity of each sprayer bank is 25 m^3/h (110 gpm). The sprayers should be constructed of Type 316L stainless steel.

Fresh water is continuously fed to the scrubber seal sump in order to prevent excessive buildup of solids or high-fluorine concentrations. A freshwater flow of about 2 m^3/h (8.8 gpm) is required. The sump overflows to an open concrete trench through which the scrubber liquor flows to the settling pond. The sump should be constructed of concrete.

Item 22--Dryer Discharge Bucket Elevator--This item is identical to Item 1 except for discharge height.

Item 23--Oversize and Product Screens--The duty of these units is to continuously separate the total material throughput into three fractions--oversize material in excess of about 4 mm; product in the size range of approximately 2-4 mm; and undersize or fine material less than about 2 mm. The maximum feed rate to the oversize screen is expected to be about 32 mtph if the process (primarily the crushers) performs as indicated. At these conditions the feed to the product screen would be approximately 25 mtph. The required screen surface at this load is 1.8 m^2 for the oversize screen. The screening machines should be identical (except for mesh of screen cloth) to simplify inventory of spare parts and maintenance.

The screen cloth for each unit should be a slotted design made of Type 316 stainless steel. A vibrating, inclined, unbalanced flywheel-type screen is recommended.

Single-deck screening machines are recommended over the double-deck units because the single-deck units can be easily observed and cleaned while they are fully assembled and in operation. The double-deck units are more compact and less costly but are more difficult to observe and clean while fully assembled and in operation. The power required to operate a single-deck, vibrating-type screen is about 5 kW (7.5 hp).

Item 24--Chain Mill Crusher--The purpose of this unit is to crush the oversize material from the screens. This chain mill should be a single-shaft design capable of crushing 10 mtph of 4- to 20-mm (.16-.79 inch) oversize material. A crushing efficiency of 60% or more is required. The rotational speed of the chain mill shaft should be 600-800 rpm. The housing of this mill should have the maximum area possible designed as access doors because the slightly sticky nature of the fertilizer to be crushed may require frequent cleaning of the mill. The mill should be belt driven by a 7-kW (10-hp) motor. Heavy-duty roller bearings of pillow-block design should be used on the chain shaft. The chains should be equipped with impact hammers of flame-hardened steel.

Item 25--Recycle Belt--The recyle belt is used to transport the recycled material from the product screen and the various dust collectors to the rotary drum granulator. The required capacity of this belt is 30 mtph. A belt width of approximately 60 cm (24 inches) is required for this capacity. The length of this belt-type conveyor should fit the layout of the equipment. A power requirement of 4 kW (5 hp) is estimated for the conveyor. The conveyor should meet the specifications as mentioned in the general section on conveyors.

Item 26--The Product Cross-Belt Conveyor--This belt is used to transport product from the product screen to storage. The required capacity of this belt is 12 mtph. To effect standardization of the equipment, a belt width of approximately 60 cm (24 inches) is recommended. The length of the belt should fit the layout of the equipment. The power requirement of this unit is estimated at 4 kW (5 hp). The gear reducer on this conveyor should be equipped with a backstop to prevent running backwards in case of power failure. The conveyor should meet the specifications as mentioned in the general section on conveyors.

Item 27--Shuttle Belt--It should be a three-ply rubber belt, 60 cm wide (measured flat) by 33 m long with reversible discharge. The speed reducer is to be belt driven by a 4-kW (5-hp) TEFC electric motor. The belt should have a speed of 46 m/min and be troughed 20°-35° from horizontal. The belt frame is to be mounted on steel tracks with steel wheels. The tracks are to be 66 m long so that the belt can be discharged along the entire length of the storage shed. The drive for the wheels shall be reversible and powered by a 6-kW (7.5-hp) TEFC electric motor with suitable gear reducer or equal hydraulic power unit.

Item 28--Package Boiler--The duty of this unit is to supply saturated steam for granulation, heating of the fuel tank, and general services. A 100-hp boiler with a capacity of 1.8 mtph of saturated steam at 7 kg/cm^2 should meet the requirements of the plant. The package boiler supplied by the vendor should include (1) boiler and trim; (2) burner for either oil, natural gas, or combination of both; (3) windbox; (4) forced-draft fan assembly; (5) control system (electric or pneumatic, single point); (6) flame safety system; and (7) water treatment unit.

Item 29--Boiler Feed Water Pumps--These pumps will be used to feed water (boiler feed water) into the boiler for steam generation. One pump will be operational and one will serve as standby. Usually these pumps are specified by the boiler vendor to fulfill the required specifications of the boiler. The pumps should be centrifugal and constructed of mild steel with an approximate capacity of 2 m^3/h at a pressure of 10 kg/cm^2. The pumps will be direct coupled to a 3-kW (4-hp), 1,800-rpm, TEFC electric motor.

Item 30--Air Compressor--The duty of this unit is to provide compressed air for (1) the boiler and dryer combustion systems, (2) the rock storage recirculation silo, and (3) general purposes. A packaged air compressor unit is a factory engineered and assembled unit consisting of:

1. Compressor, water cooled with instrumentation.

2. V-belt drive, including compressor sheave, motor sheave, and necessary V-belts with provision for adjusting tension.
3. Totally enclosed V-belt guard.
4. Nema "T" frame (208,230 or 460 volt) 3-phase, 50-cycle, 1.15-service factor motor.
5. ASME stamped air receiver and combination moisture separator with safety valve and automatic condensate trap.
6. Water cooler, filter, silencer, and all air piping plus water cooling piping from inlet to outlet of the compressor unit factory installed.

The unit should deliver 7 m^3/h (247 ft^3/min) at a pressure of 7 kg/cm^2 (100 psig). The unit should be nonlubricated type for oil-free service.

Item 31--Water Storage Tank--This tank will serve as a reservoir to supply process water to the granulation unit as well as makeup water to the scrubbers and the boiler-feed water treatment unit. This tank was designed to meet the process requirements of the ROP and granular PAPR plants and to provide general purpose water for cleaning and washing the production site. This tank could be increased in size if some other uses are anticipated before construction. This tank should have a 100-m^3 capacity, an open roof, and be constructed of mild steel with 6.35-mm (0.25-inch) wall and floor thickness.

Item 32--Water Pumps--The duty of these pumps is to supply water to the drum granulator, boiler feed water treatment unit, venturi and wet scrubbers (makeup), air compressor (cooling water), and for general purposees. These pumps (one operational and one standby) should be centrifugal type, constructed of mild steel, and have a capacity of about 7 m^3/h (31 gpm) at a pressure of 5 kg/cm^2 (71 psig). These pumps will be direct coupled to a 4-kW (5-hp), 1,800-rpm TEFC electric motor. In case of an elevated water tank these pumps will not be needed if the tank has enough elevation to provide water with the flow and head required.

Item 33--Fuel Storage Tank--The purpose of this unit is to store a 40-day supply (200 m^3) of fuel oil for firing the boiler and dryer combustion systems. The tank should be fabricated of 6.4-mm (0.25-inch) wall and floor thickness approximately 6 m (20 ft) in diameter by 5 m (23 ft) high and mounted on a concrete base. The tank should be equipped with an internal oil-heating steam coil approximately 4 m in diameter (minimum of two turns) and fabricated from Schedule 80 (heavy-duty) black iron pipe. The design of the tank was based on an average fuel oil consumption of 100 gph for both combustion systems. An option will be to install two smaller tanks 4.9 m (16 ft) in diameter by 5.5 m (18 ft) in height.

Item 34--Fuel Oil Pumps--These pumps (one operational and one standby) will transfer the fuel oil from the fuel oil storage tank to the combustion systems of the boiler and dryer. These gear-type pumps should be constructed of mild steel and brass gears, and with a capacity of 400 L/h at the pressure required by the boiler and dryer burner manufacturers. The pipeline connecting the discharge of these pumps with the combustion system should be fabricated of black iron and fitted with a relief valve. These pumps should be direct coupled to a 1.5-kW (2-hp) TEFC electric motor.

Item 35--Fuel Oil Receiving Pump--This pump will be used to unload fuel oil from tankers or tank cars to the storage tank. If a reliable alternative for unloading can be established (by means of air pressure), this pump will not be needed. This pump should be a brass gear type with a capacity of 5 m^3/h. The discharge pressure will depend on whether the fuel oil will arrive by rail or truck. It should be direct coupled to a 4-kW (5-hp), 1,800-rpm TEFC electric motor.

Item 36--Sulfuric Acid Storage Tanks (2)--The purpose of these tanks is to hold a 2-week supply of sulfuric acid (91% H_2SO_4). These tanks should be 5.2 m (17 ft) in diameter by 3.7 m (12 ft) high, have cone-roof tanks, and be constructed of mild steel mounted on a concrete base. The top of the concrete base should have grooves for acid leak detection. They should have a wall and floor thickness of 6.4-mm (1/2-inch) and 4.8-mm (3/16-inch) roof. Tanks should be equipped with shell manway, ladder, roof manway, vent, liquid level indicator, and inlet and outlet pipelines. These tanks should be surrounded by an earthen embankment to hold the total volume of both tanks in the event of a tank leak. The earth embankment is shown in the general plant layout and detailed sketches in Appendix A. An alternative to installing these tanks would be to install one tank that would be 7.7 m (25 ft) in diameter by 7.3 m (24 ft) in height.

Item 37--Sulfuric Acid Receiving Pump--This pump will be used to unload sulfuric acid (91% H_2SO_4) from railcar or tank trucks to storage tank. If a reliable alternative for unloading can be established (by means of air pressure), this pump will not be needed. This pump should be an alloy 20 stainless steel centrifugal type with a capacity of 5 m^3/h at a pressure of 5 kg/cm^2. It should be direct coupled to a 4-kW (5-hp), 1,800-rpm TEFC electric motor.

Item 38--Sulfuric Acid Pumps (2)--These pumps will be used to transport sulfuric acid from the storage tanks to the pug mill. One pump will be operational and one will serve as spare. These pumps should be identical to Item 37 (sulfuric acid receiving pump) for inventory purpose.

Item 39--Phosphoric Acid Storage Tanks (2)--The purpose of these tanks is to hold a 14- to 20-day (depending on acid concentration) supply. These open-top tanks should be 6.1 m (20 ft) in diameter by 5.5 m (18 ft) high and be constructed of 9.5-mm (3/8-inch) mild steel (wall and bottom). They should be protected with a 60-mil PVC liner. They should be equipped with ladder, liquid level indicator, and inlet and outlet lines. The outlet line should be as close to the bottom as possible and constructed of 316L stainless steel. Depending on acid quality, the tanks will need to be cleaned about once a year. A detailed sketch of these tanks is shown in Appendix A. As an alternative to these tanks, an API cone roof-type tank can be installed. These tanks will have the same dimensions as the open tanks, but they will include a sweeping agitator to keep the acid and solids in motion. The wall will be 9.5-mm (3/8-inch) mild steel lined with 13-mm (1/2-inch) neoprene, and the bottom of the tanks will be made of acid-brick liner. These tanks will have an earthen-containment surrounding bank similar to the one described in Item 36.

For both alternatives (open and closed tanks) another option is to install one tank only, with 6.1 m (20 ft) in diameter by 5.5 m (18 ft) high.

Item 40--Phosphoric Acid Receiving Pump--This pump will be used to unload phosphoric acid (merchant grade) from the railcar or tank trucks to the storage tanks. If a reliable alternative for unloading can be established (by means of air pressure), this item may be deleted. This should be a centrifugal pump constructed of alloy 20 with a capacity of 5 m^3/h at 5 kg/cm^2. This pump will be direct coupled to a 5-hp, 1,800-rpm TEFC electric motor (power consumption 4 kW).

Item 41--Phosphoric Acid Feed Pumps (2)--These pumps will be used to transport phosphoric acid from the storage tank to the pug mill. One pump will be operational, and one will serve as spare. These pumps will be identical to Item 40 of this list.

Item 42--Treatment Pit and Pollution Pond--The small treatment pit (3 m wide by 6 m long by 1 m deep) receives the scrubber effluent liquor from the venturi scrubber (Item 10) and the wet scrubber (Item 21). This liquor contains dust and hydrofluorosilic acid and has a low pH. This liquor must be treated by the addition of powdered calcium hydroxide in order to neutralize the hydrofluorosilic acid and thereby raise the pH to an acceptable level (assumed to be in the range of 6.0-9.0). The calcium hydroxide is added to the pit by hand at the rate of 25 kg every 15 min (assuming 10 mtph production rate). Mixing is provided by the recirculation of the liquor (see sketch in Appendix A).

The liquor from the treatment pit overflows by gravity into the settling pond (20 m wide by 40 m long by 2 m deep). This pond has a plastic (PVC) liner under a 30-cm backfill to prevent seepage into the ground water (see sketch in Appendix A). The clarified liquor is removed from this pond by a centrifugal pump positioned at the side opposite the inlet and returned to the pug mill, granulator, and wooden wet scrubber. The venturi scrubber uses only fresh water makeup feed.

Item 43--Pollution Pond Treatment Pit Pumps (2)--These pumps will be used to recirculate the scrubber effluent liquor from the lower level of the treatment pit to the upper level on the opposite side of the pit (see sketch of treatment pit in Appendix A). The purpose of this recirculation is to aid in mixing the approximately 100 kg/h feed of calcium hydroxide with the scrubber effluent for pH control. When properly mixed, the hydrofluorosilic acid in the scrubber effluent will react with the calcium hydroxide to form calcium fluoride and thus increase the pH. One pump will operate while the other serves as spare. The pumps are centrifugal type, constructed of mild steel with rubber lining, with rubber-coated impellers. They will pump at a rate of 7 m^3/h at 4 kg/cm^2. They are direct coupled with 4-kW (5-hp), 1,800-rpm TEFC electric motors.

Item 44--Pollution Pond Pumps (2)--The purpose of these pumps will be to transport clarified pond liquor to the wet scrubbers, pug mill, and drum granulator. The incorporation of this liquor into the fertilizer will close the effluent liquor loop under normal operating conditions.

These centrifugal-type pumps are constructed of mild steel with rubber lining and rubber-coated impellers. They are direct coupled with 1,800 rpm, 4 kW (5 hp) TEFC electric motor drives. They will pump 14 m^3/h at 4 kg/cm^2. One pump will serve as spare while the other one operates.

Item 45--Venturi Scrubber Pumps (2)--The purpose of these pumps will be to spray scrubbing liquor into the venturi throat. These centrifugal-type pumps are constructed of mild steel with rubber lining and rubber-coated impellers. They will pump 14 m^3/h at 4 kg/cm^2. The pumps will be direct coupled to an

1,800-rpm, 4-kW (5 hp) TEFC electric motor drive. One pump will operate and one will be used as spare. These units are identical with those of Item 44 of this list.

Item 46--Wet (Wooden) Scrubber Pumps (3)--These centrifugal-type pumps are used to recirculate scrubbing liquor from the scrubber sump to the spray banks at the top of the downflow and upflow sections and at the bottom of the upflow section. The capacity of the pumps is 40 m^3/h delivered at 4 kg/cm^2 TDH (total dynamic head). The power requirement of the pumps amounts to about 11 kW (15 hp). Three pumps are required--two in operation and one as standby. These three pumps must be interconnected by piping so that the downward flow section spray bank can be operated in case of failure of any two pumps. The pumps should be direct coupled to TEFC electric motors. They should be constructed of mild steel with rubber lining and rubber-coated impellers.

Item 47--Granulator Scrubber--The purpose of this spray column scrubber is to treat the dust and moisture-laden air from the drum granulator (Item 16). The air is transported to the scrubber by a 40.6-cm (16-inch) round duct constructed of 3.2-mm (1/8-inch) thick mild steel. The total load to the scrubber is 8,994 m^3/h (5,000 ft^3/min). The spray column scrubber should be 1.5 m in diameter by 2.9 m in height with tangential entry of the air duct centered 50 cm above the flat bottom. The scrubber should be constructed of type 316L stainless steel or other fluorine-resistant material. The scrubber should contain 2 downward spraying, centrifugal, hollow-cone nozzles constructed of type 316 stainless steel. These sprays should be mounted in the center of the scrubber on the vertical axis about 30 cm apart. The treated air will discharge through a 40.6-cm round duct in the top of the scrubber after passing through the sprayed scrubber medium (clarified pond liquor).

The scrubber liquor feed tank should be constructed of type 316 stainless steel and be 1.0 m in diameter by 2.0 m in height. The tank should have sloping (or cone) bottom with a 7.6-cm overflow line discharging by gravity to the trench feeding the pollution treatment pit. It should be located adjacent to the scrubber. A fresh makeup water line should be supplied to this tank for control of the scrubber liquor concentration.

Item 48--Granulator Scrubber Fan--The purpose of this fan is to create an induced draft in the granulator scrubber (Item 47). This should be an OMH-type fan and have at least a 75.3-cm (29-5/8-inch) wheel, with a 30-kW (40-BHP) TEFC motor at 50.8 cm (20 inch) static pressure. The fan must be constructed of type 316L stainless steel or other fluorine-resistant material.

Item 49--Granulator Scrubber Pumps (2)--The purpose of these pumps is to supply scrubbing liquor to the scrubber sprays. These pumps are identical to those of Items 44 and 45 listed previously. The power consumption will be 4 kW. One pump will operate and one will be used as a spare.

References

1. IFDC. 1985. "Investigations to Use Low-Grade Rock Phosphates From Mussoorie Rock Phosphate Deposits--India," Final Technology Report prepared for the United Nations Industrial Development Organization, Vienna, Austria.

2. IFDC. 1986. Sulfuric Acid-Based Partially Acidulated Phosphate Rock--Its Production, Cost, and Use, Technical Bulletin, IFDC-T-31.

3. IFDC. 1985. "Investigations to Use Low-Grade Rock Phosphates From Mussoorie Rock Phosphate Deposits in India--Study No. 2: Preliminary Process Design and Equipment Specifications for Granulation of Partially Acidulated Phosphate Rock (PAPR)," Draft Final Technology Report prepared for the United Nations Industrial Development Organization, Vienna, Austria.

Table 1. Chemical Analysis of Ground Run-of-Mine Mussoorie Phosphate Rock and Central Florida Phosphoric Acid Used in Pilot Plant-Scale PAPR Production Tests

	Mussoorie Rock (wt %)	Central Florida Acid (wt %)
P_2O_5	18.6	53.9
CaO	43.8	0.07
F	1.8	0.5
MgO	1.4	0.58
Fe_2O_3	4.0	0.88
Al_2O_3	1.7	0.8
CO_2	13.6	NA[a]
SiO_2	15.4	NA
S	2.3	1.2
H_2O	0.17	21.2
Organic C	1.4	0.3
Na_2O	0.26	0.1
K_2O	0.45	<0.01
SO_4	7.12	3.6
Loss on ignition	10.8	NA

a. NA = not analyzed.

Table 2. Particle-Size Distribution of Run-of-Mine Mussoorie Phosphate Rock Used in Pilot Plant-Scale PAPR Production Tests

Opening of Sieve		Retained on Sieve	Cumulative	
Mesh-Tyler	mm	(wt %)	Retained (wt %)	Passing (wt %)
65	0.212	4.3	4.3	95.7
100	0.150	4.3	8.6	91.4
150	0.106	5.2	13.8	86.2
200	0.075	12.7	26.5	73.5
270	0.053	10.8	37.3	62.7
400	0.038	9.1	46.4	53.6

Table 3. Formulations Used in Pilot Plant-Scale PAPR Production Tests--SSAG and ROP Processes

	Amount Used (kg/h)	Unit Consumption (kg/mt)
First SSAG Test Run (7-429)		
Mussoorie phosphate rock	300	750
Phosphoric acid, 53.9% P_2O_5	30	75
Sulfuric acid, 91.3% H_2SO_4	84	210
Second SSAG Test Run (7-430)		
Mussoorie phosphate rock	275	786
Phosphoric acid, 53.9% P_2O_5	30	86
Sulfuric acid, 91.3% H_2SO_4	84	240
First ROP Test Run (7-431)		
Mussoorie phosphate rock	270	725
Phosphoric acid, 53.9% P_2O_5	37	100
Sulfuric acid, 91.3% H_2SO_4	75	202
Water	66	178

Table 4. Summary of Data Obtained in Pilot Plant-Scale PAPR Production Tests--SSAG Process

Date	9/18/1985	9/23/1985
Test number	7-429	7-430
Granulation duration, h	24[a]	12
Production rate, kg/h	400	350
Pug mill		
Phosphate rock feed rate, kg/h	300	275
Sulfuric acid concentration, % H_2SO_4	91.3	91.3
Sulfuric acid feed rate, kg acid/h	84	84
Shafts rotational speed, rpm	400	400
Paddle tip speed, m/s	2.1	2.1
Calculated retention time, s	2	2
Discharge conditions		
Free acid content, % P_2O_5	1.3	1.4
CO_2 content, % CO_2	6.3	NA[b]
Recycle		
Feed rate, kg/h	1,450	2,800
Temperature, °C	72	85
Recycle-to-product ratio, kg/kg	4-1	7.5-1
Size distribution (% retained)		
Screen opening		
4.75 mm	NA	1.4
3.35 mm	NA	8.2
2.36 mm	0.5	12.1
1.70 mm	3.0	21.2
1.18 mm	43.5	27.1
850 µm	50.2	15.3
600 µm	2.3	NA
425 µm	0.6	NA
Pan	0.1	14.7
Drum granulator		
Phosphoric acid concentration, % P_2O_5	53.9	53.9
Phosphoric acid feed rate, kg/h	30	30
Steam feed rate, kg/h	7.5	12.5
Rotational speed, rpm	18	18
Rotational speed, % of critical	41	41
Discharge conditions		
Temperature, °C	86	91
Free acid content, % P_2O_5	5.7	4.8
CO_2 content, %	5.8	NA

(Continued)

Table 4. Summary of Data Obtained in Pilot Plant-Scale PAPR Production Tests--SSAG Process (Continued)

Date	9/18/1985	9/23/1985
Test number	7-429	7-430
Dryer		
Temperature of air from combustion chamber (dryer inlet), °C	130	119
Air temperature at outlet, °C	125	115
Air through dryer shell, m^3/h	4,000	4,000
Air velocity in dryer (outlet conditions, empty dryer), m/s	1.6	1.6
Total throughput, kg/h	2,000	3,000
Propane used, kg/h	11	10
Discharge conditions		
Temperature, °C	110	115
Free acid content, % P_2O_5	≅5.0	≅5.4
Screens[c]		
Top screen opening, mm	2.36	4.75
Bottom screen opening, mm	1.18	1.70
Ambient conditions		
Dry bulb temperature, °C	NA	24
Wet bulb temperature, °C	NA	22
Relative humidity, %	NA	85
Weather conditions	Dry	Rainy

a. Intermittent operation.
b. NA = not available.
c. Inclined at an 18° angle.

Table 5. Chemical and Physical Analyses of Products Obtained in Pilot Plant-Scale PAPR Production Tests--SSAG Process

Date	9/18/1985	9/23/1985
Test number	7-429	7-430
Size distribution (% retained)		
Sieve opening		
4.75 mm	NA[a]	7.5
3.35 mm	NA	18.2
2.36 mm	7.9	32.1
1.70 mm	26.7	41.1
1.18 mm	45.7	0.9
850 µm	19.3	0.1
600 µm	0.3	NA
425 µm	0.0	NA
Pan	0.0	0.1
Chemical analysis (as made)		
Total P_2O_5, %	18.1	19.0
Water-soluble P_2O_5, %	6.5	7.7
Neutral ammonium citrate-soluble P_2O_5, %[b]	1.0	0.4
Available P_2O_5, % of total P_2O_5	41.6	42.6
Free acid, % as P_2O_5	5.7	5.2
Total sulfur, % as SO_4	21.7	21.0
Free water (by vacuum desiccation), %	<0.1	<0.1
F, %	1.2	1.2
CO_2, %	5.6	5.0
Crushing strength, kg/2.6-mm granule	NA	0.3-0.4
Chemical analysis (after curing 1 day at 60°C)		
Total P_2O_5, %	18.6	NA
Water-soluble P_2O_5, %	7.2	NA
Neutral ammonium citrate-soluble P_2O_5, %[b]	0.5	NA
Available P_2O_5, % of total P_2O_5	41.4	NA
Free acid, % as P_2O_5	5.4	NA
Total sulfur, % as SO_4	21.5	NA
Free water (by vacuum desiccation), %	<0.1	NA
F, %		
CO_2, %		
Crushing strength, kg/2.6-mm granule	NA	≅0.1
Chemical analysis (after curing 4 days at 60°C)		
Total P_2O_5, %	NA	19.0
Water-soluble P_2O_5, %	NA	7.9
Neutral ammonium citrate-soluble P_2O_5, %[b]	NA	0.7
Available P_2O_5, % of total P_2O_5	NA	45.3
Free acid, % as P_2O_5	NA	3.7
Total sulfur, % as SO_4	NA	21.9
Free water (by vacuum desiccation), %	NA	0.6
F, %	NA	1.3
CO_2, %	NA	4.3
Crushing strength, kg/2.6-mm granule	NA	≅0.7

(Continued)

Table 5. Chemical and Physical Analyses of Products Obtained in Pilot Plant-Scale PAPR Production Tests--SSAG Process (Continued)

Date	9/18/1985	9/23/1985
Test number	7-429	7-430
Chemical analysis (after curing 7 days at 60°C)		
Total P_2O_5, %	19.0	19.1
Water-soluble P_2O_5, %	6.2	6.0
Neutral ammonium citrate-soluble P_2O_5, %[b]	2.2	3.2
Available P_2O_5, % of total P_2O_5	44.2	48.2
Free acid, % as P_2O_5	2.8	2.0
Total sulfur, % as SO_4	22.7	21.1
Free water (by vacuum desiccation), %	2.3	0.5
F, %	1.2	1.2
CO_2, %	4.7	4.1
Crushing strength, kg/2.6-mm granule (after curing 7 days at 60°C)	NA	0.8-1.1
Crushing strength, kg/2.6-mm granule (after curing 14 days at 60°C)	NA	1.30-1.55

a. NA = not available.

b. Does not include water-soluble fraction.

Table 6. Chemical Analyses of Product Obtained in Pilot Plant-Scale PAPR Production Tests--ROP Process

Date	10/2/1985
Test number	7-431
Chemical analysis (as made)	
Total P_2O_5, %	16.6
Water-soluble P_2O_5, %	7.3
Neutral ammonium citrate-soluble P_2O_5, %[a]	1.1
Available P_2O_5, % of total P_2O_5	50.6
Free acid, % as P_2O_5	2.2
Total sulfur, % as SO_4	18.2
Free water (by vacuum desiccation), %	16.0
F, %	1.6
CO_2, %	1.8
Chemical analysis (after curing 1 day at 60°C)[b]	
Total P_2O_5, %	16.5
Water-soluble P_2O_5, %	5.4
Neutral ammonium citrate-soluble P_2O_5, %[a]	2.4
Available P_2O_5, % of total P_2O_5	47.3
Free acid, % as P_2O_5	0.9
Total sulfur, % as SO_4	17.6
Free water (by vacuum desiccation), %	15.4
F, %	1.4
CO_2, %	1.9
Chemical analysis (after curing 2 days at 60°C)	
Total P_2O_5, %	16.6
Water-soluble P_2O_5, %	5.4
Neutral ammonium citrate-soluble P_2O_5, %[a]	2.7
Available P_2O_5, % of total P_2O_5	48.8
Free acid, % as P_2O_5	1.2
Total sulfur, % as SO_4	17.8
Free water (by vacuum desiccation), %	15.2
F, %	1.6
CO_2, %	1.5

(Continued)

Table 6. Chemical Analyses of Product Obtained in Pilot Plant-Scale PAPR Production Tests--ROP Process (Continued)

Date	10/2/1985
Test number	7-431
Chemical analysis (after curing 8 days at 60°C)	
Total P_2O_5, %	18.5
Water-soluble P_2O_5, %	4.2
Neutral ammonium citrate-soluble P_2O_5, %[a]	3.5
Available P_2O_5, % of total P_2O_5	41.6
Free acid, % as P_2O_5	0.6
Total sulfur, % as SO_4	16.9
Free water (by vacuum desiccation), %	9.5
F, %	1.6
CO_2, %	1.9
Chemical analysis (after curing 14 day at 60°C)[b]	
Total P_2O_5, %	20.1
Water-soluble P_2O_5, %	5.6
Neutral ammonium citrate-soluble P_2O_5, %[a]	3.9
Available P_2O_5, % of total P_2O_5	47.3
Free acid, % as P_2O_5	0.3
Total sulfur, % as SO_4	19.9
Free water (by vacuum desiccation), %	0.1
F, %	1.7
CO_2, %	2.2
Chemical analysis (after curing 21 days at 60°C)	
Total P_2O_5, %	18.3
Water-soluble P_2O_5, %	4.1
Neutral ammonium citrate-soluble P_2O_5, %[a]	3.8
Available P_2O_5, % of total P_2O_5	43.2
Free acid, % as P_2O_5	0.5
Total sulfur, % as SO_4	20.0
Free water (by vacuum desiccation), %	7.4
F, %	1.6
CO_2, %	1.6

a. Does not include water-soluble fraction.
b. Product container in all probability not completely sealed.

Table 7. Equipment List--10 mtph ROP/Granulation PAPR Plant

Equipment Item Number (Refer to Figure 1)	Description and Approximate Size or Capacity	Required Power/Unit (kW)
1	Phosphate rock feed bucket elevator--continuous discharge single chain, low speed to recirculate phosphate rock to storage silo. Bucket elevator must be sized to transport 40 mtph of aereated finely powdered phosphate rock (bulk density of about 644 kg/m^3) at 40% bucket fill.	15
2	Phosphate rock pocket hopper--designed to hold 1 m^3 of material (5 min supply), 1 m x 1 m x 1 m	-
3	Phosphate rock silo--designed to hold 32 m^3 of material(2.5 h supply), 3 m in diameter by 6.1 m high with a 45° bottom cone, equipped with bag house vent system.	1
4	Discharge screw conveyor--to recirculate phosphate rock from silo to bucket elevator with a capacity of 20 mtph fixed speed electric motor driven.	6
5	Variable speed screw feeder--equipped with variable speed electric motor controlled by weigh belt with interlock with weigh belt electric motor. Designed for 10 mtph capacity.	9
6	Phosphate rock weigh belt feeder--capacity of 8(±2) mtph of powdered phosphate rock. Electric motor driven with interlock with seal screw feeder electric motor.	2
7	Phosphate rock seal screw feeder--capacity of 10 mtph of powdered phosphate rock with seal gate. Electric motor driven with interlock with pug mill drive.	6
8	Pug mill--double shaft 0.6 m wide and 2.2 m long (mixing trough), with a paddle tip speed of 1.9 m/s. Complete with enclosed vent hood. Electric motor with belt drive and steel gear reducer (variable speed drive optional).	20
9	Curing belt conveyor--to handle hot and acidic product from the pug mill discharge. Belt to be made from high-temperature chemical resistant material, 122 cm wide by 27 m long with idlers positioned on 45° to form a trough; running at a speed of 1.8 m/min.	6
10	Venturi scrubber--reinforced polyester plastic type with an efficiency of 95%. Fan should be type 316L SS or reinforced, polyester plastic, OMH 13,600 m^3/h at 50.8 cm static pressure.	30

Table 7. Equipment List--10 mtph ROP/Granulation PAPR Plant (Continued)

Equipment Item Number (Refer to Figure 1)	Description and Approximate Size or Capacity	Required Power/Unit (kW)
11	Product (ROP-PAPR) cross belt conveyor--60 cm wide by approximately 32 m long with a lift of 11 m at at 18° degree angle from the horizontal.	4
12	ROP-PAPR storage distributor shuttle belt conveyor--60 cm wide by 33 m long, reversible, track mounted electric motor driven.	10
13	Lump breaker--designed for big lumps (+2 cm). Capacity 20 mtph maximum throughput with 18 cm by 8 cm open area grid top mounted.	5
14	Variable speed belt conveyor--to handle reclaimed ROP-PAPR, 60 cm wide by 2.5 m long with a capacity of 10 mtph.	2
15	Granulator feed bucket elevator--continuous discharge, single chain, sized to transport 40 mtph of reclaimed ROP-PAPR and recycle material (identical to item 1).	15
16	Drum granulator--1.83 m in diameter by 3.66 m long, with a retention ring 30 cm high located 1 m from discharge end, rubber panel-type liner and fitted with a sparger and support for steam and/or water.	34
17	Dryer combustion chamber--to operate burner automatically or manually based on temperature of air discharged from dryer. Combustion chamber to furnish 7.5 x 10^6 Btu/h. Complete with instrumentation controls, safety devices, combustion air fan, and operating instructions to be supplied by vendor.	2
18	Rotary dryer--1.52 m in diameter by 10.67 m long, ring gear and pinion sprocket drive with a rotational speed of 6 rpm and an inclincation of 2° toward the discharge end.	38
19	Dryer cyclone-type dust collector system--20,000 m^3/h air at 120°C. Exhaust fan OMH type, 20,000 m^3/h at 120°C, 40 cm pressure differential.	35
20	Fugitive dust cyclone-type dust collector system--9,000 m^3/h at 30°C. Exhaust fan OMH type, 9,000 m^3/h at 30°C, 40 cm pressure differential.	18
21	Wet scrubber--wood construction with slat packing, 10 m^2 total cross section area, two compartments, 5 m^2 each (downflow and upflow) with concrete sump.	

Table 7. Equipment List--10 mtph ROP/Granulation PAPR Plant (Continued)

Equipment Item Number (Refer to Figure 1)	Description and Approximate Size or Capacity	Required Power/Unit (kW)
22	Dryer discharge bucket elevator--continuous discharge, single chain sized to transport 40 mtph granular PAPR (identical to item 1).	15
23	Oversize and product screens--single deck inclined, mechanical vibrated, 60 cm wide by 1.83 m long screen area.	5
24	Oversize crusher--chainmill type, single shaft with 10 mtph, 4-10 mm oversize crushing capacity.	7
25	Recycle belt conveyor--to handle undersize material from product screen and dust collector, 30 mtph capacity, troughing idlers, 60 cm wide by 14.50 m long, enclosed to minimize dusting.	4
26	Granular product cross belt conveyor--60 cm wide by approximately 20 m long with a lift of 6.5 m at an 18° angle toward the horizontal.	4
27	Granular PAPR product distributor shuttle belt conveyor--60 cm wide by 33 m long (identical to item 12).	10
28	Package boiler--100 hp boiler, 1.8 mtph steam at 7 kg/cm^2 pressure. Accessory equipment instruments and safety devices should be supplied by vendor.	NA
29	Boiler feed water pumps (2)--centrifugal, 2.0 m^3/h at 10 kg/cm^2 total discharge head.	3
30	Air compressor--packaged air compressor unit type to deliver 7 m^3/min at 7 kg/cm^2 pressure. Non-lubricated type for oil free service. Instruments, control, and safety devices to be provided by vendor.	38
31	Water storage tank--open roof type, constructed of mild steel 6.35-mm wall and floor thickness with a capacity of 100 m^2.	
32	Water pumps (2)--centrifugal with a capacity of 7 m^3/h at 5 kg/cm^2.	4
33	Fuel oil storage tank--6.1 m diameter by 7 m high, approximately 200 m^3 (40-day supply) including oil heating steam coil. Tank walls should be 6.35 mm mild steel and the coil approximately 4 m in diameter (minimum of two turns) black iron pipe.	
34	Fuel oil pumps (2)--mild steel gear pumps with a capacity of 400 LPH.	1.5

Table 7. Equipment List--10 mtph ROP/Granulation PAPR Plant (Continued)

Equipment Item Number (Refer to Figure 1)	Description and Approximate Size or Capacity	Required Power/Unit (kW)
35	Fuel oil receiving pump--mild steel gear pump with a capacity of 5 m^3/h.	3
36	Sulfuric acid storage tanks (2)--API cone roof, constructed of mild steel, mounted on a concrete base. Wall and floor thickness of 6.35 mm and 4.76 mm roof. Tanks should be 5.2 m in diameter by 3.7 m high to hold about a 2-week acid supply.	
37	Sulfuric acid receiving pump--centrifugal, alloy 20 stainless steel, 5 m^3/h at 5 kg/cm^2.	4
38	Sulfuric acid pumps (2)--centrifugal, alloy 20 stainless steel, 2 m^3/h at 5 kg/cm^2.	4
39	Phosphate acid storage tanks (2)--open roof tanks constructed of mild steel with a 60 mill PVC liner. Tanks will be 6.1 m in diameter by 5.5 m high to hold about a 14- to 20-day supply, depending on acid concentration.	-
40	Phosphoric acid receiving pump--centrifugal, alloy 20, 5 m^3/h at 4 kg/cm^2.	4
41	Phosphoric acid pumps (2)--centrifugal, alloy 20, 1 m^3/h at 5 kg/cm^2.	4
42	Pollution pond and treatment pit--	
43	Pollution pond treatment pit pumps (2)--centrifugal, rubber lined, 7 m^3/h at 4 kg/cm^2.	4
44	Pollution pond pumps (2)--centrifugal, rubber lined, 14 m^3/h at 4 kg/cm^2.	4
45	Venturi scrubber pumps (2)--centrifugal, rubber lined, 14 m^3/h at 4 kg/cm^2.	4
46	Wooden wet scrubber pumps (3)--centrifugal, rubber lined, 40 m^3/h at 4 kg/cm^2.	11
47	Granulator spray scrubber--1.5-m diameter by 2.9-m height, constructed of stainless steel or plastic, containing 2 stainless steel sprays.	-
48	Granulator scrubber fan--fan should be type 316L SS or reinforced, polyester plastic, OMH 8494 m^3/h at 50.8 cm static pressure.	30
49	Granulator scrubber pumps (2)--centrifugal, rubber-lined, 14 m^3/h at 4 kg/cm^2.	4

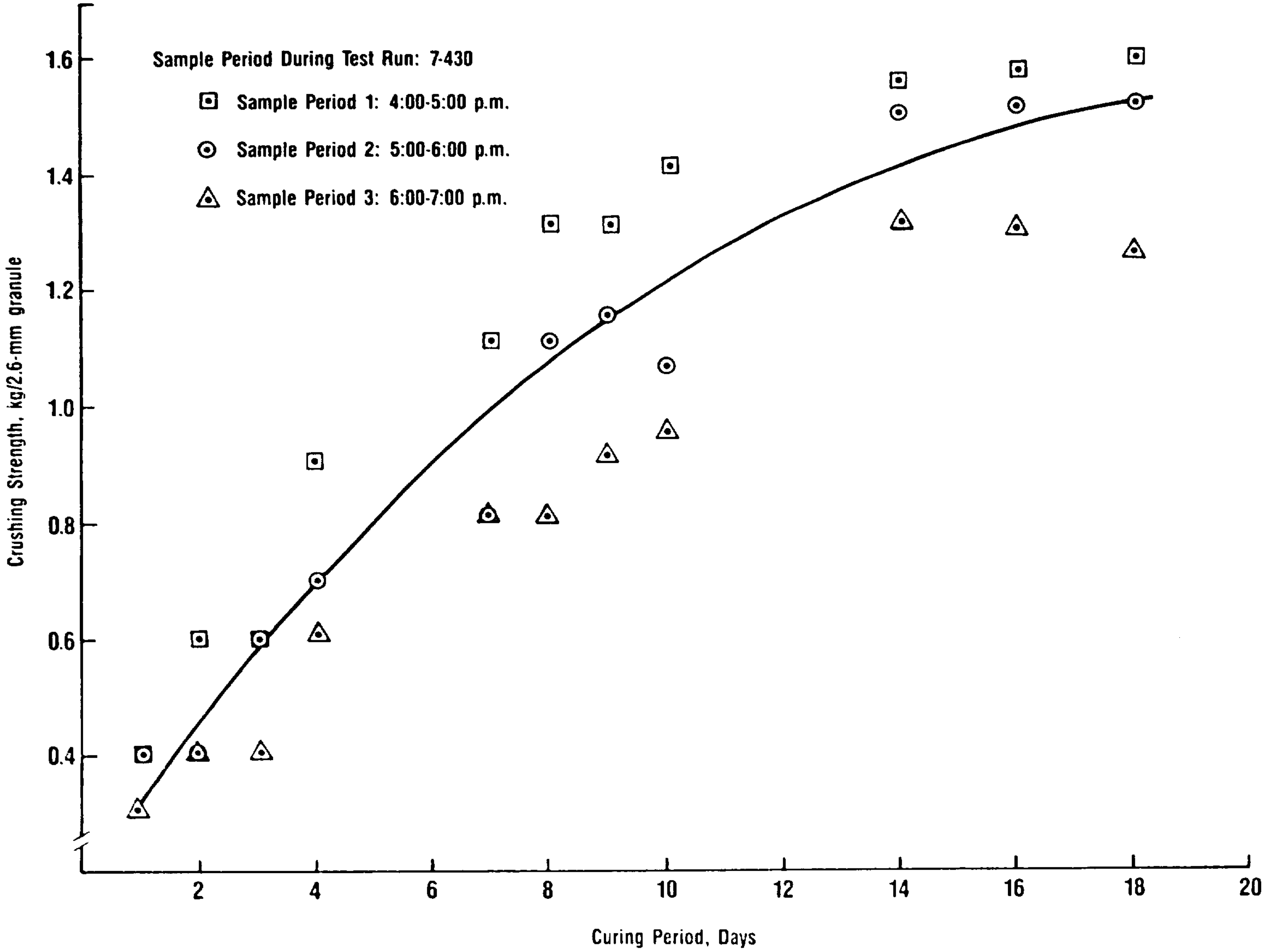


Figure 1. Crushing Strength of MAB-PAPR Product Made by SSAG Process Versus Curing Time.

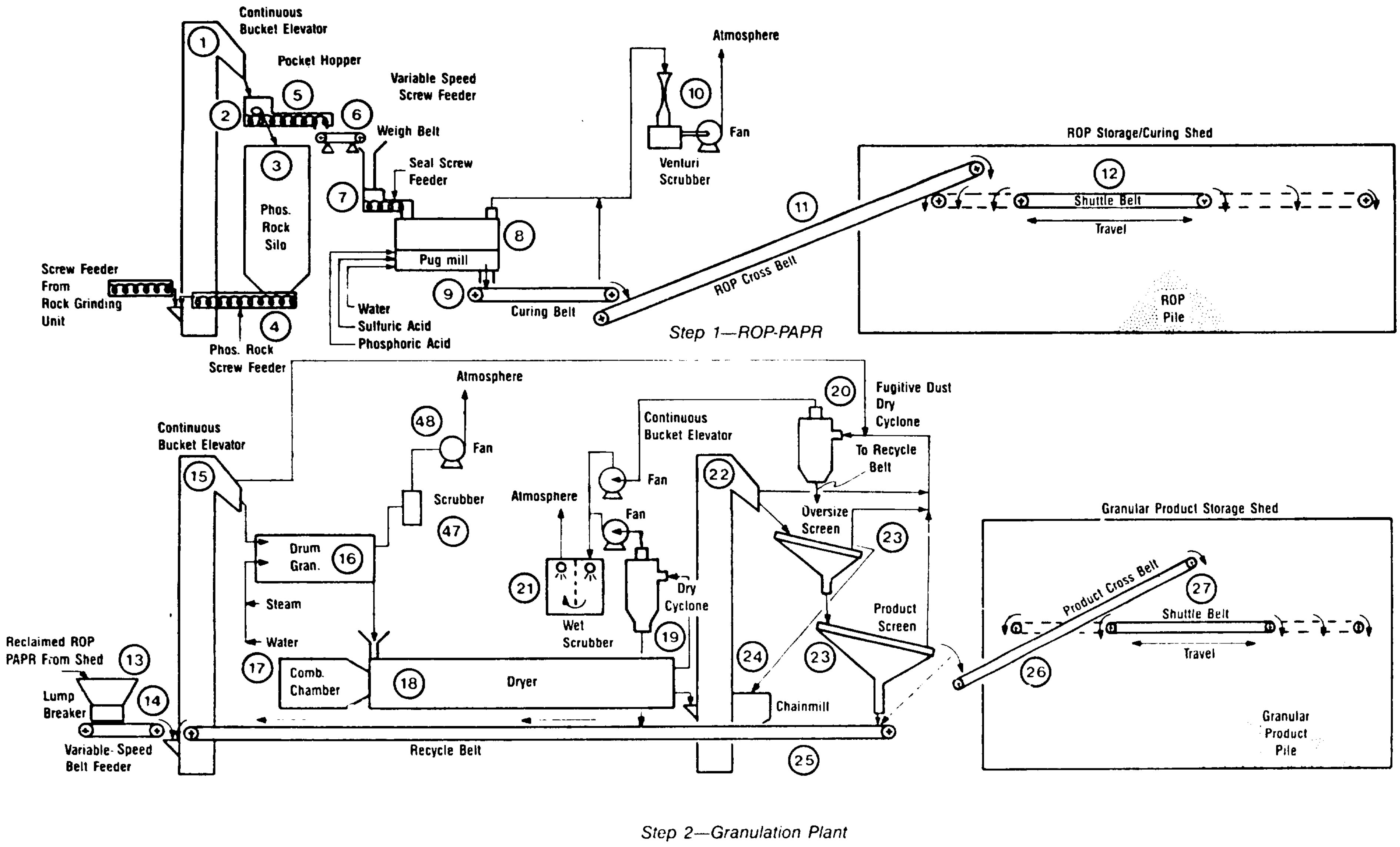


Figure 2. Process Flow Diagram—PPCL 10-mtph ROP/Granulation PAPR Plant.

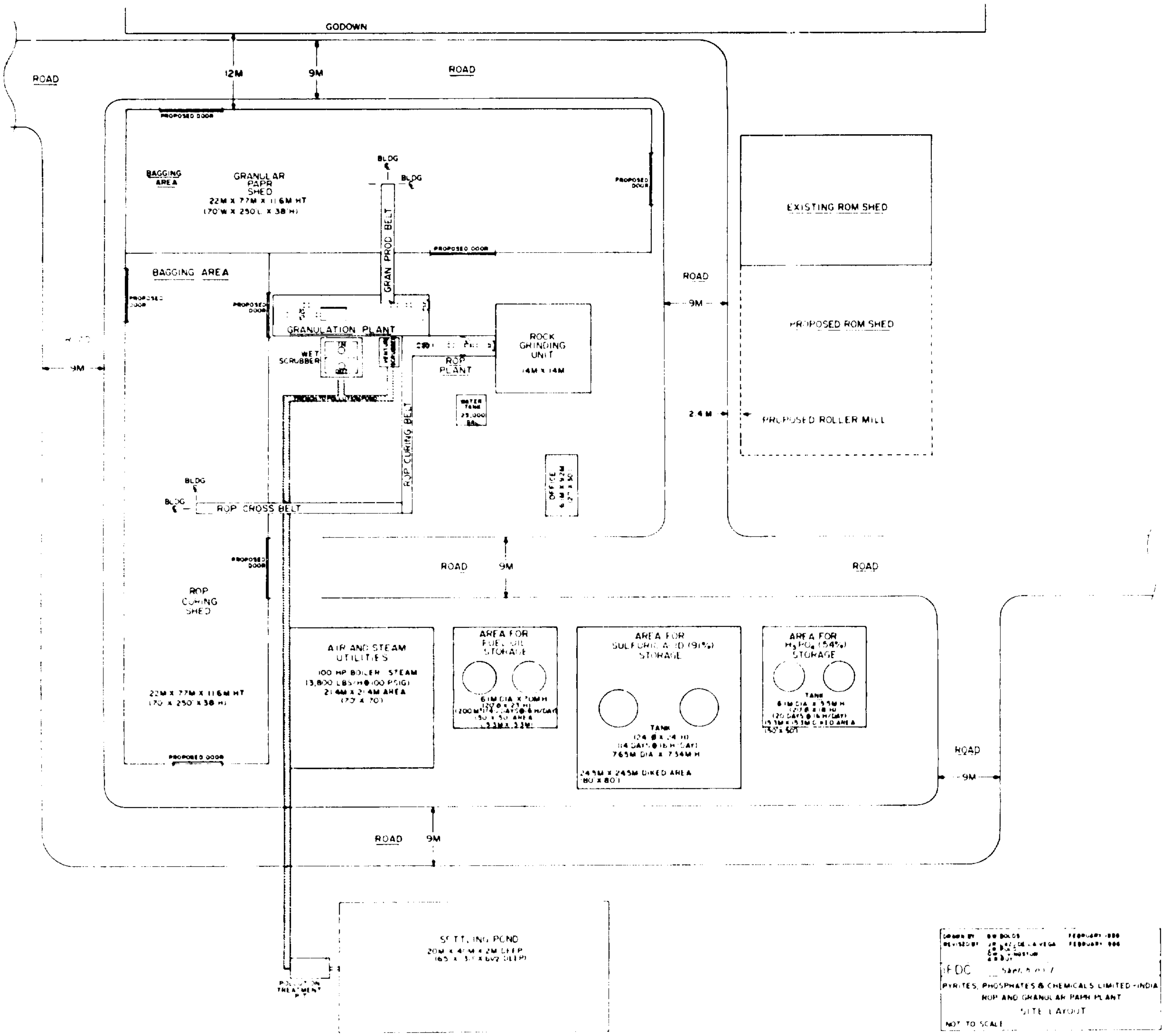
APPENDIX A

PPCL-PAPR Plant--Preliminary Layout Sketches

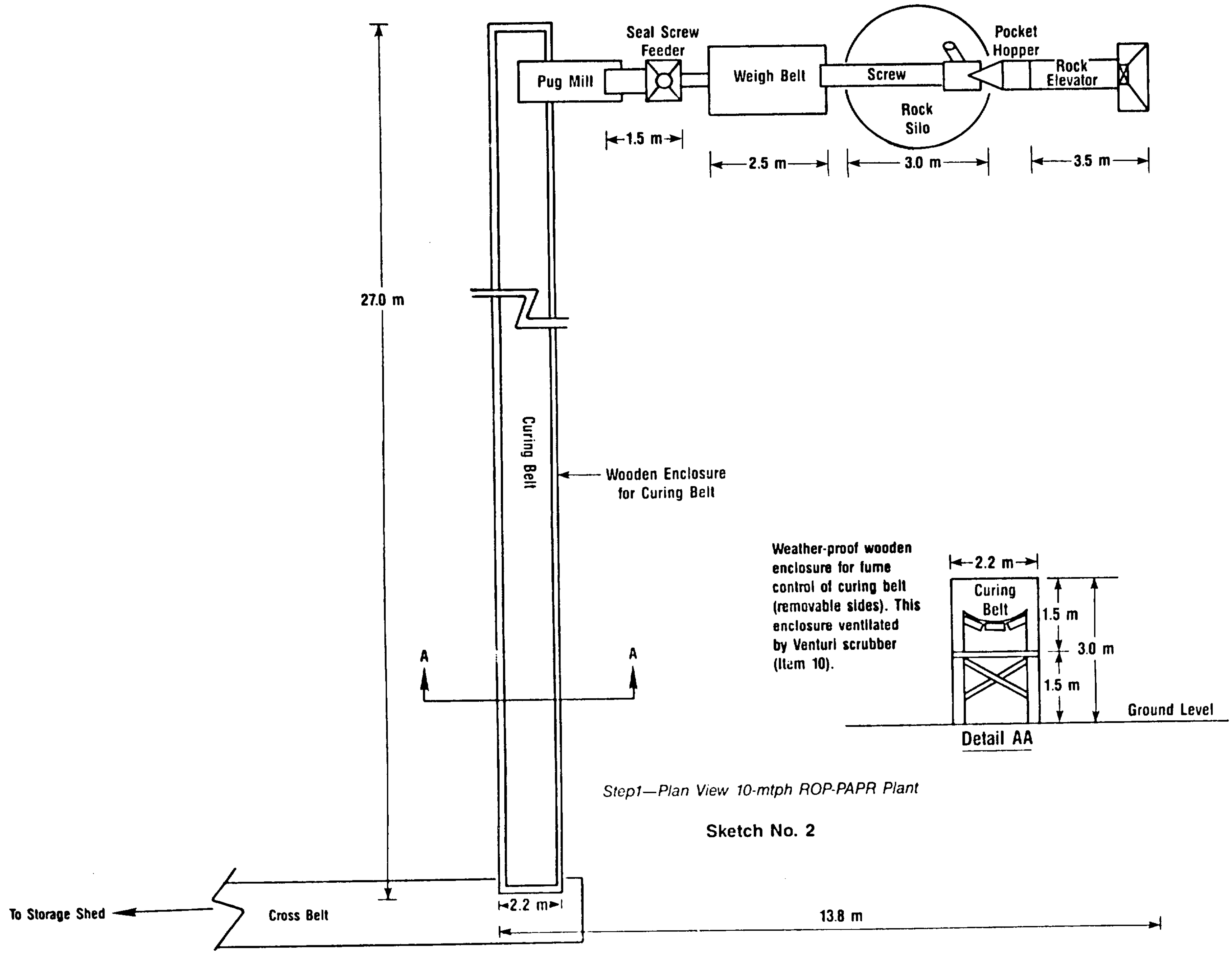
(Step 1 and Step 2)

PPCL-PAPR Plant--Preliminary Layout Sketches (Step 1 and Step 2)

Sketch No.	
1	Site layout--plan
2	ROP plant (Step 1)--plan
3	ROP plant (Step 1)--elevation
4	Granulation plant (Step 2)--plan
5	Granulation plant (Step 2)--elevation
6	P and I (piping and instrumentation)--schematic
7	ROP/granulation storage shed--end elevation
8	ROP/granulation storage shed--side elevation
9	Pollution effluent treatment pit--cross section
10	Pollution settlement pond--cross section

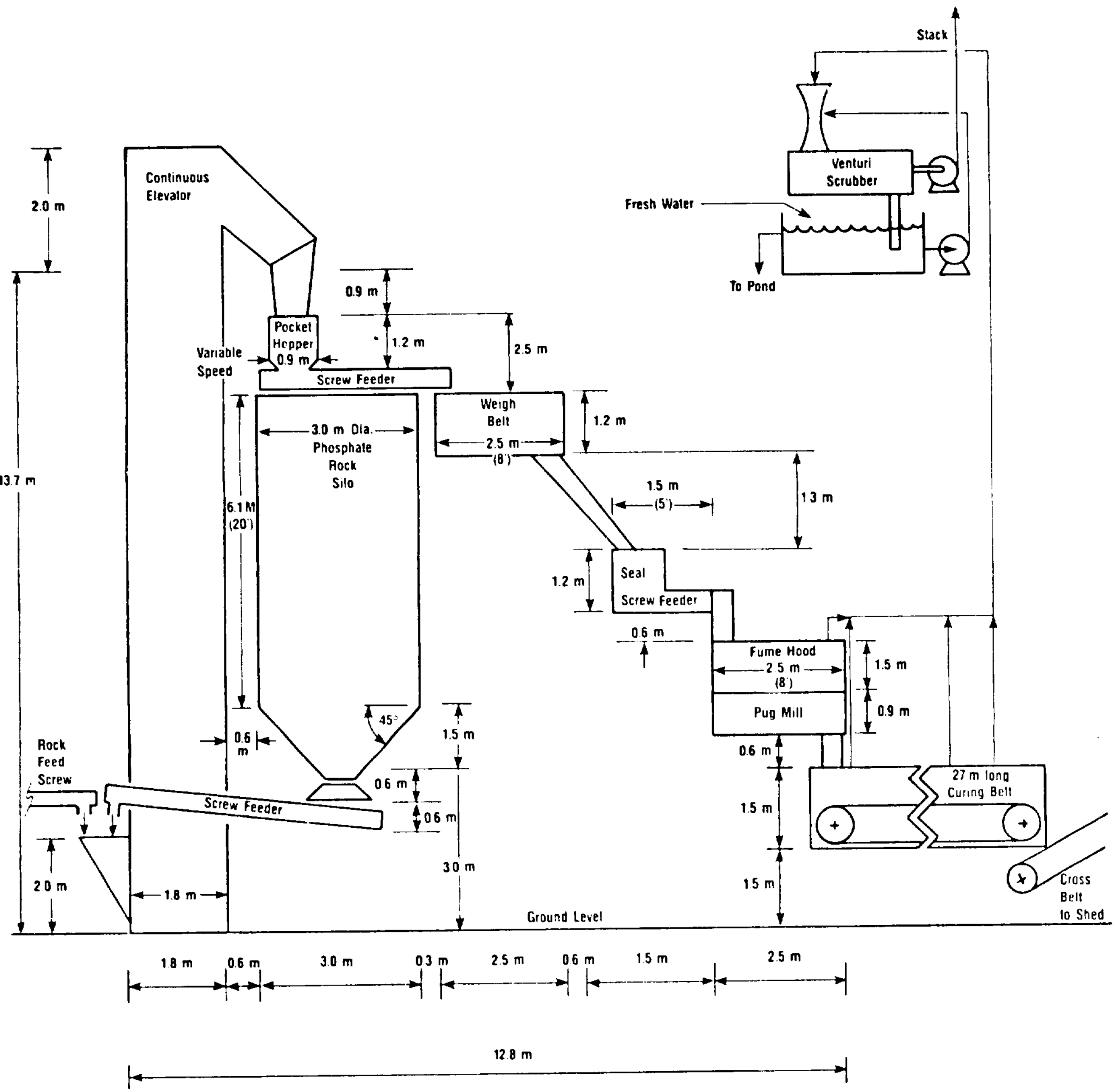


GODOWN
ROAD
12M
9M
ROAD
PROPOSED DOOR
BAGGING AREA
GRANULAR PAPR SHED
22M X 77M X 11.6M HT
(70'W X 250'L X 38'H)
BLDG
GRAN PROD BELT
PROPOSED DOOR
PROPOSED DOOR
BAGGING AREA
PROPOSED DOOR
GRANULATION PLANT
WET SCRUBBER
ROCK GRINDING UNIT
14M X 14M
ROP PLANT
WATER TANK
ROP CURING BELT
OFFICE
ROP CROSS BELT
BLDG
PROPOSED DOOR
ROP CURING SHED
22M X 77M X 11.6M HT
(70' X 250' X 38'H)
PROPOSED DOOR
AIR AND STEAM UTILITIES
100 HP BOILER - STEAM
13,800 LBS/HR@100 PSIG
21.4M X 21.4M AREA
(70' X 70')
AREA FOR FUEL OIL STORAGE
AREA FOR SULFURIC ACID (91%) STORAGE
TANK
24.5M X 24.5M DIKED AREA
(80' X 80')
AREA FOR H_3PO_4 (54%) STORAGE
TANK
ROAD
9M
EXISTING ROM SHED
PROPOSED ROM SHED
PROPOSED ROLLER MILL
2.4M
ROAD
9M
ROAD
ROAD
9M
SETTLING POND
20M X 47M X 2M DEEP
POLLUTION TREATMENT PT.
IFDC
PYRITES, PHOSPHATES & CHEMICALS LIMITED - INDIA
ROP AND GRANULAR PAPR PLANT
SITE LAYOUT
NOT TO SCALE



Step1—Plan View 10-mtph ROP-PAPR Plant

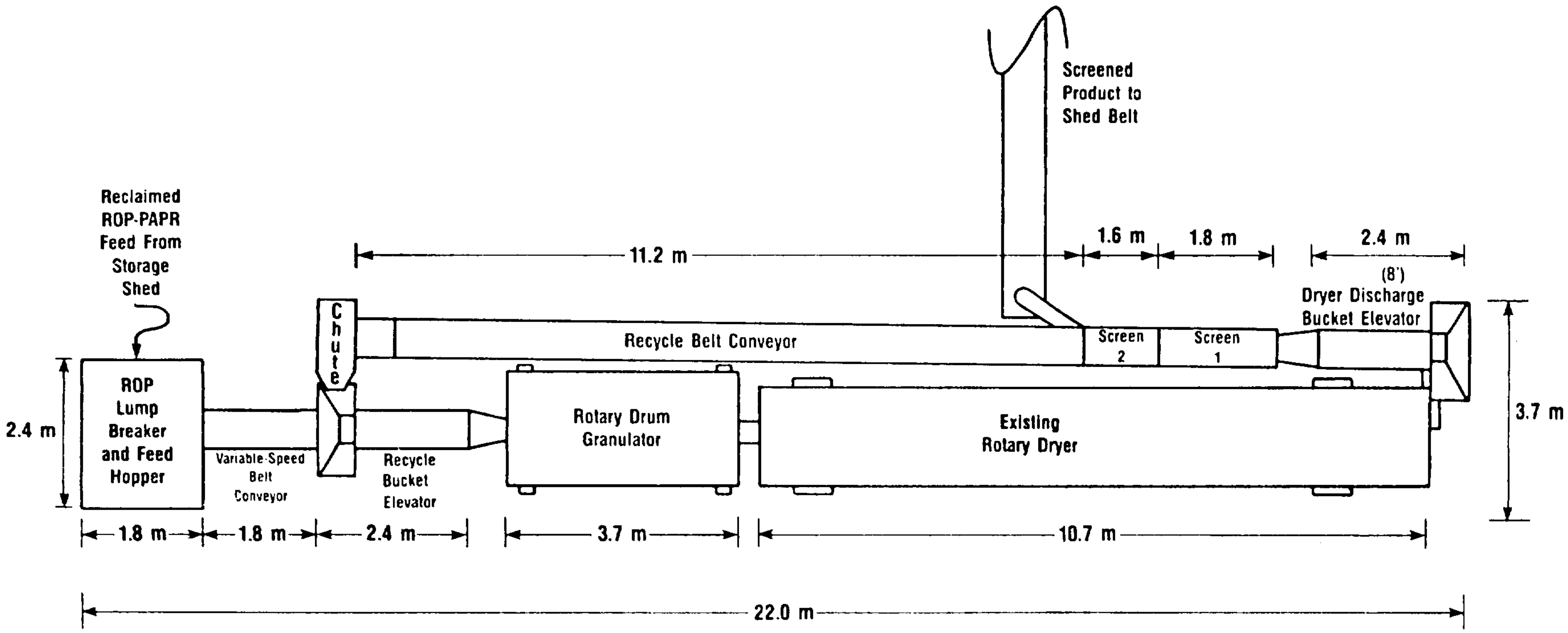
Sketch No. 2



Sketch No. 3

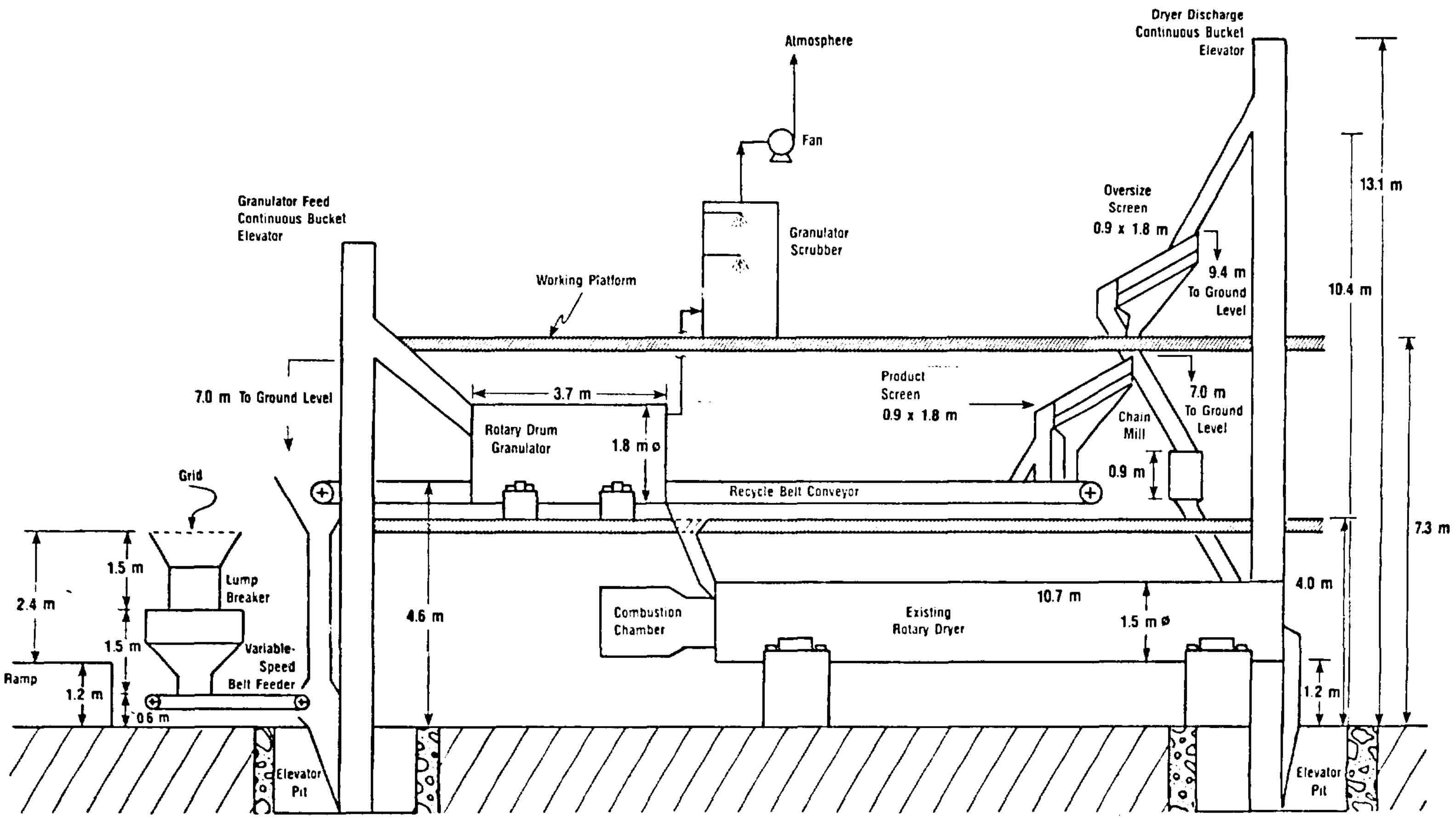
Step 1

Elevation View—ROP-PAPR 10-mtph Plant

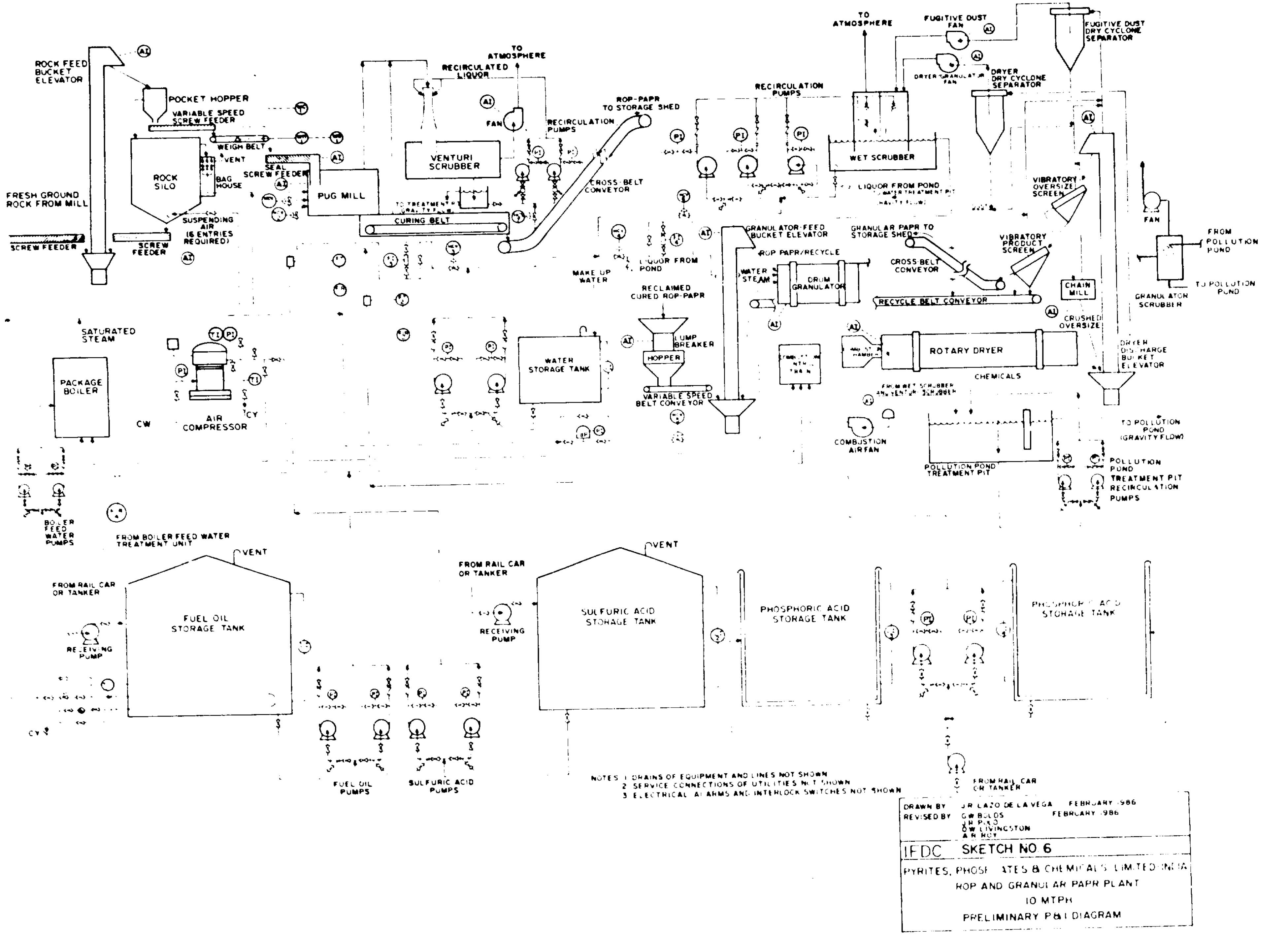


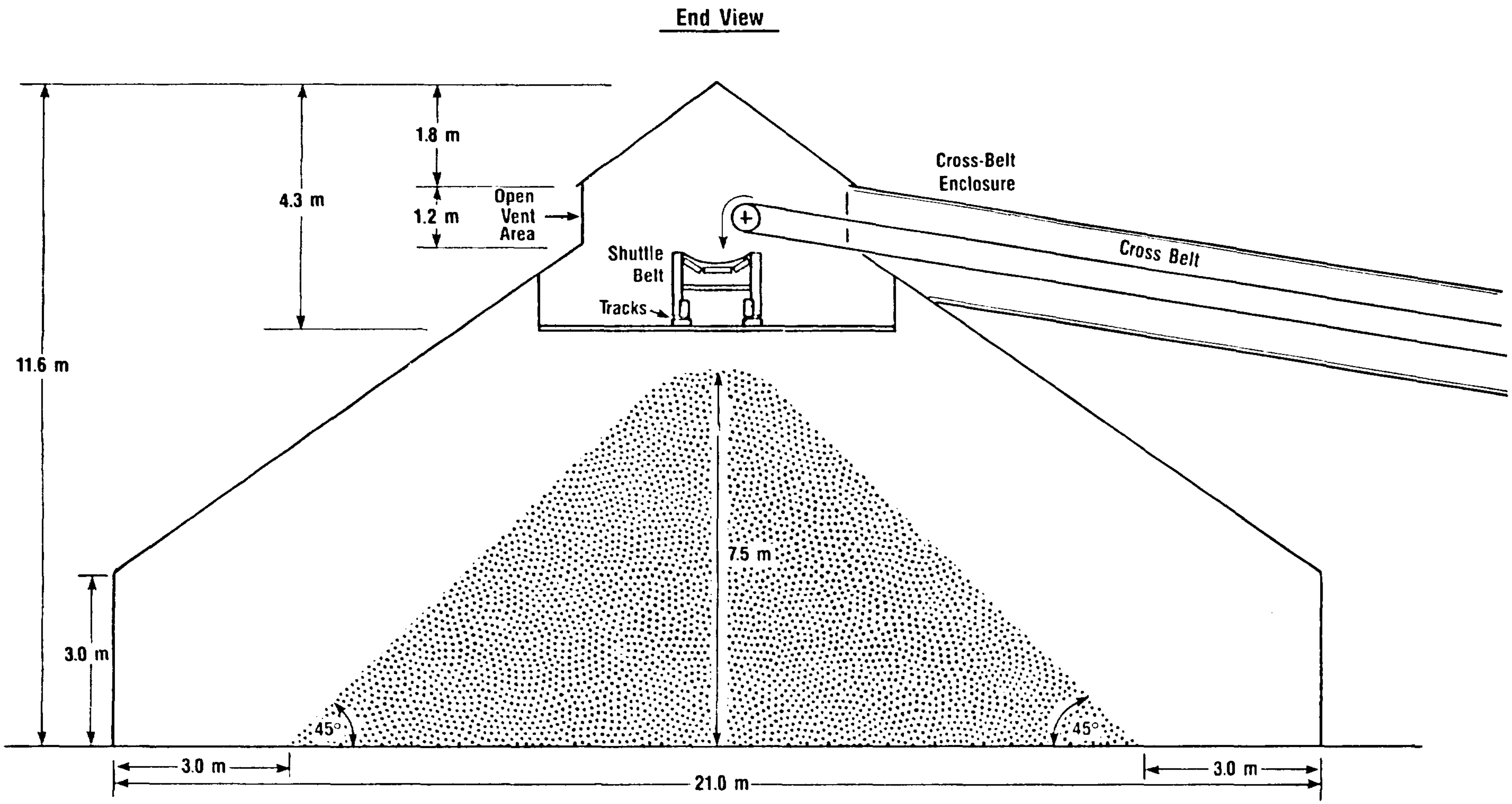
Sketch No. 4

Step 2—Plan View 10-mtph Steam Granulation Plant



Sketch No. 5
Step 2
Elevation View—10 mtph Steam Granulation Plant


ROCK FEED BUCKET ELEVATOR
POCKET HOPPER
VARIABLE SPEED SCREW FEEDER
WEIGH BELT
VENT
ROCK SILO
BAG HOUSE
SEAL SCREW FEEDER
PUG MILL
FRESH GROUND ROCK FROM MILL
SCREW FEEDER
SUSPENDING AIR (6 ENTRIES REQUIRED)
TO ATMOSPHERE
RECIRCULATED LIQUOR
FAN
VENTURI SCRUBBER
RECIRCULATION PUMPS
CURING BELT
ROP-PAPR TO STORAGE SHED
CROSS-BELT CONVEYOR
MAKE UP WATER
LIQUOR FROM POND
RECLAIMED CURED ROP-PAPR
LUMP BREAKER
HOPPER
VARIABLE SPEED BELT CONVEYOR
WATER STORAGE TANK
SATURATED STEAM
PACKAGE BOILER
CW
AIR COMPRESSOR
CY
BOILER FEED WATER PUMPS
FROM BOILER FEED WATER TREATMENT UNIT
TO ATMOSPHERE
FUGITIVE DUST FAN
FUGITIVE DUST DRY CYCLONE SEPARATOR
DRYER DRY CYCLONE SEPARATOR
WET SCRUBBER
LIQUOR FROM POND
GRANULATOR FEED BUCKET ELEVATOR
GRANULAR PAPR TO STORAGE SHED
ROP PAPR/RECYCLE
WATER STEAM
DRUM GRANULATOR
CROSS-BELT CONVEYOR
VIBRATORY OVERSIZE SCREEN
VIBRATORY PRODUCT SCREEN
RECYCLE BELT CONVEYOR
CHAIN MILL
CRUSHED OVERSIZE
ROTARY DRYER
CHEMICALS
DRYER DISCHARGE BUCKET ELEVATOR
COMBUSTION AIR FAN
POLLUTION POND TREATMENT PIT
TO POLLUTION POND (GRAVITY FLOW)
POLLUTION POND TREATMENT PIT RECIRCULATION PUMPS
FAN
FROM POLLUTION POND
TO POLLUTION POND
GRANULATOR SCRUBBER
FROM RAIL CAR OR TANKER
RECEIVING PUMP
VENT
FUEL OIL STORAGE TANK
FUEL OIL PUMPS
SULFURIC ACID STORAGE TANK
SULFURIC ACID PUMPS
PHOSPHORIC ACID STORAGE TANK
FROM RAIL CAR OR TANKER
NOTES: 1. DRAINS OF EQUIPMENT AND LINES NOT SHOWN
2. SERVICE CONNECTIONS OF UTILITIES NOT SHOWN
3. ELECTRICAL ALARMS AND INTERLOCK SWITCHES NOT SHOWN
DRAWN BY J.R. LAZO DE LA VEGA FEBRUARY 1986
REVISED BY G.W. BULDS FEBRUARY 1986
IFDC SKETCH NO 6
ROP AND GRANULAR PAPR PLANT
10 MTPH
PRELIMINARY P&I DIAGRAM

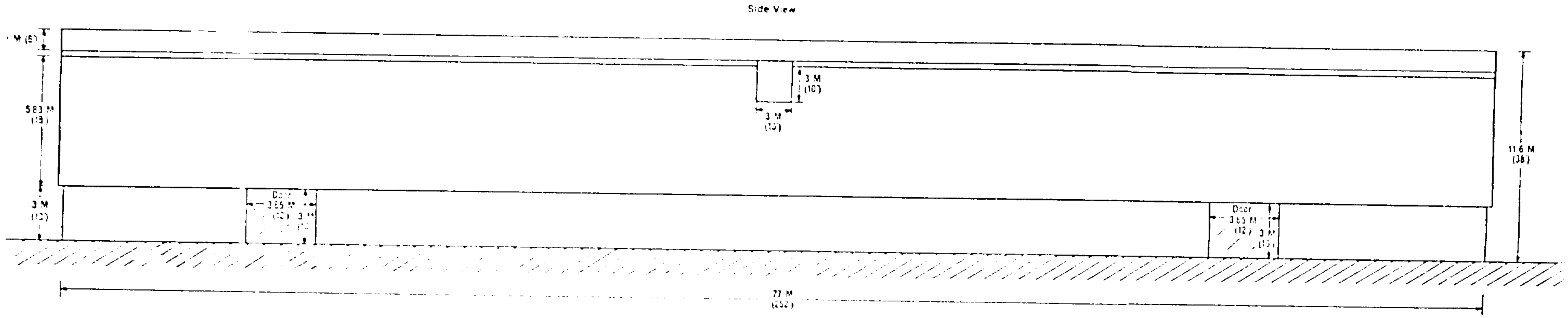


Sketch No. 7

Step 1—ROP-PAPR Storage Shed

Also

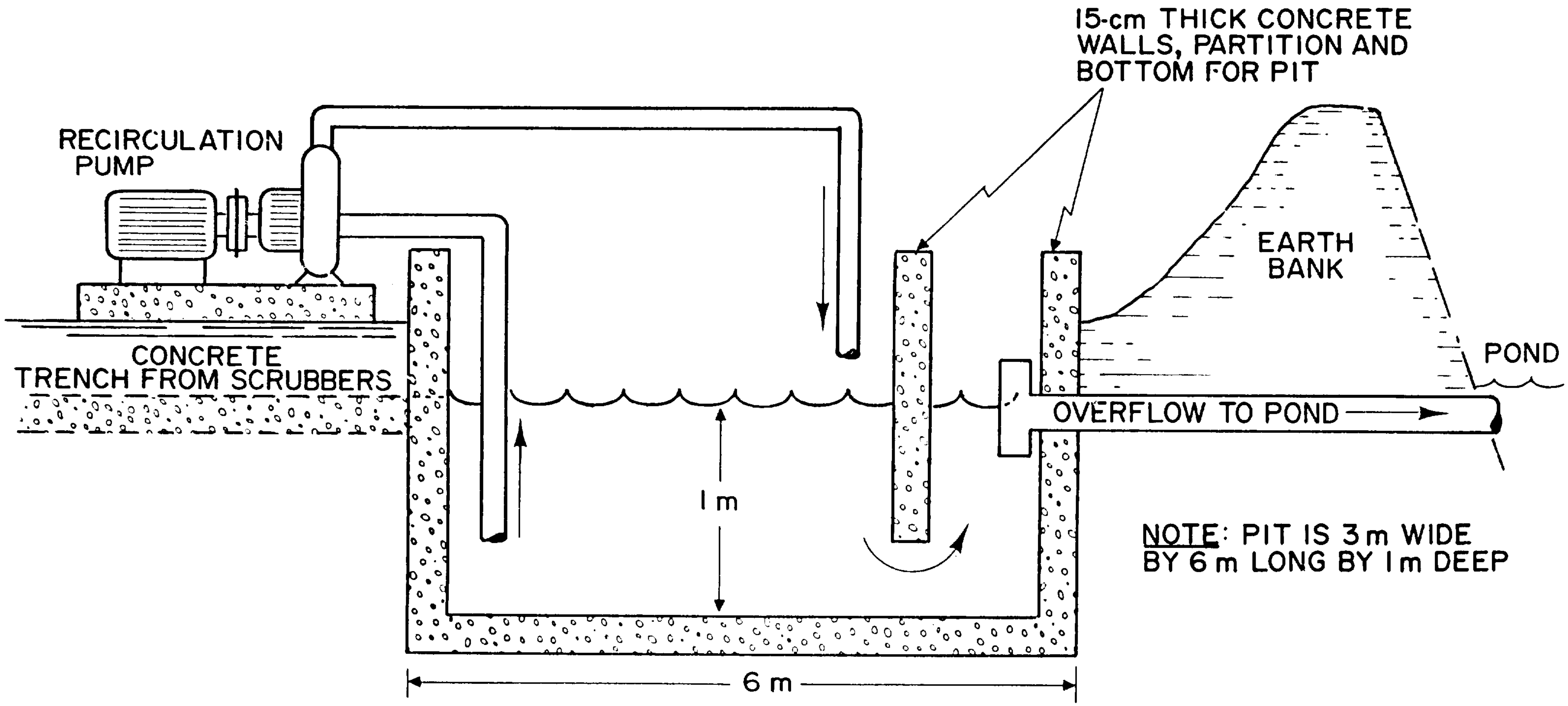
Step 2—Granular PAPR Storage Shed



Sketch No. 8
RCP Granulation Storage Shed—Side Elevation

Note: Location and number of doors should be specified on final drawings

NOT TO SCALE



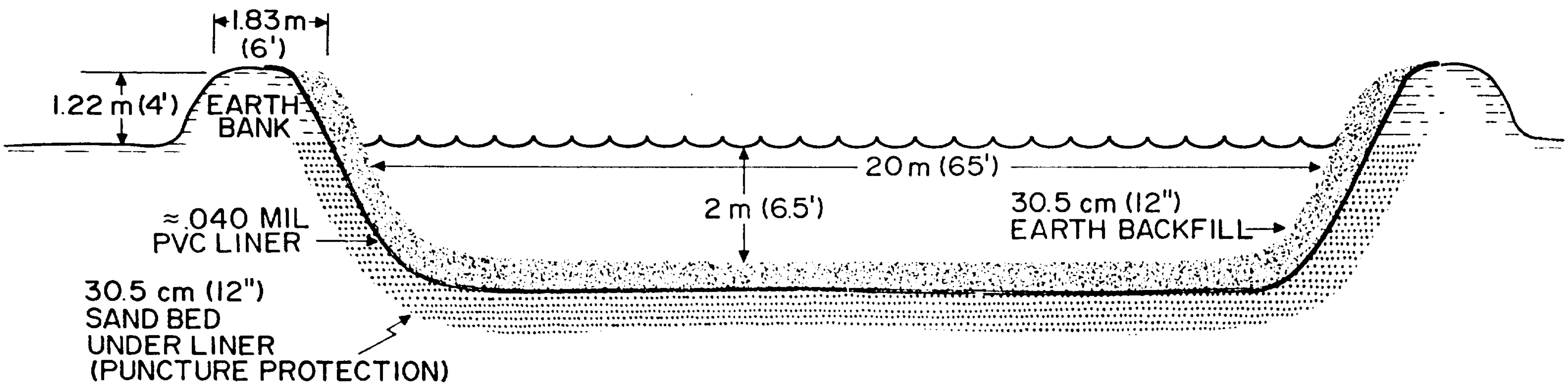
CROSS SECTION DETAIL SKETCH

POLLUTION TREATMENT PIT—PPCL-PAPR PLANT

SKETCH NO. 9

SKETCH NO. 10

POLLUTION CONTROL SETTLEMENT POND---PPCL PLANT



CROSS SECTIONAL DETAIL OF SETTLEMENT POND