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# PROCESSING OF STANDARD ROCK, OTHER ROCKS AND ROCK-BLENDS IN A SAME PHOSPHORIC ACID PLANT

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## INTRODUCTION

Designing a phosphoric acid plant on one rock and running it only on that standard rock is a preferred practice world over. This is logical as different rocks vary widely in composition and characteristics with each other and if the plant is contemplated to be designed to take care of all these variations, the capital cost will be too high to justify its economic viability. The record of the existing plants also reveals that the plants running only on one rock are more stable and give consistently good performance.

However, for the countries like India and others which have to largely depend upon the imported rocks, occasion may arise when one has to use rocks other than the standard. Generally, this may be due to the non-availability of imported rock; however, sometimes, this may be due to the better reason such as the un-expected availability of indigenous rock, This is more significant for India with the discovery of its own rock phosphate deposits of Udaipur. Whatever may be the case, these rocks are bound to have different characteristics for which the plant is not designed and hence, are apt to pose new process problems. To what extent these are overcome, determines the techno-economics of phosphoric acid manufacture.

GSFC is unique in the world to have processed a recdrd number of rocks and rock-blends on large and varied scale in its 165 t/d dihydrate P.A. plant at Baroda. It may be noted that this plant was designed on Florida; it was commissioned on Morocco; it has run maximum on Udaipur blends of 1:1 and it has registered highest production on Senegal! Since it went on stream in June 1967, til to-date, it has processed for shorter or longer periods, as many rocks as Florida, Udaipur, Senegal, Morocco, Algerian, high grade Jordan, low grade Jordan, etc., and as many rock-blends as Udaipur:Florida 1:1, Udaipur:Senegal 1:1, Udaipur:Morocco 1:1, Florida:Senegal 1:1, etc. It is, therefore, thought to be in the fitness of the things to describe and discuss the techno-economics of processing these various rocks and rock-blends processed in GSFC; and that is the aim of this paper.

The first following three sections describe respectively, in brief, the manufacturing process at GSFC, how the plant-performance is affected while processing standard rock, other rocks and rock-blends and how they differ with each other in composition. The next three sections discuss in detail the processing in each case mentioned above. The final section is then devoted to show their economic comparison in general.

PROCESS DESCRIPTION OF P.A. PLANT AT GSFC

GSFC's dihydrate wet process phosphoric acid plant has the capacity of 165 t/d $P_2O_5$ in form of 45% P.A. When commissioned in June 1967, it was India's largest single-stream plant. The plant is designed by Chemico and is supplied on turn-key basis by M/s. Hitachi Zosen.

BASIS OF DESIGN

The plant is designed on the following assumed analysis of Florida rock:

| | | |
|---|---|---|
| $P_2O_5$ | - | 34.0% |
| CaO | - | 49.3% |
| $Fe_2O_3 + Al_2O_3$ | - | 2.5% |
| Acid insolubles | - | 5.0% |
| Fluorine | - | 3.8% |
| Chloride | - | 0.4% |
| Loss of ignition | - | 5.0% |
| | | 100.0% |

Raw materials and utilities consumption figures per t/d $P_2O_5$ are as follows:

| | |
|---|---|
| Rock | - 3.25 - 3.5 t/d |
| Sulphuric acid (98%) | - 2.8 - 3.0 t/d |
| Steam | - 2.5 - 3.0 t/d |
| Water | - 10 - 12 t/d |
| Water in circulation | - 200 - 250 t/d |
| Electricity | - 300 - 350 kWH |

PROCESS DESCRIPTION

The plant is divided in the following five sections:

1) Grinding
2) Digestion
3) Filtration
4) Concentration
5) Gypsum purification

Unground rock is stored in either of the two silos each having a capacity of 15,000 t . It is reclaimed through shovel loaders and conveyed to ball mill where it is ground to 60% through 200 mesh and 100% through 40 mesh. During grinding, it is dried to 1% moisture content by passing hot air, from natural gas fired furnace. C'assified ground rock from classifying cone is taken to ground rock storage, via dust recovery system.

From digester charge hopper, ground rock is metered in hopper scale and fed to the digester. 98% sulphuric acid and recycled P.A. from filtration section are mixed in a mixing head and fed to the digester Digester is a Chemico designed single tank, compartmentless vessel. It is made up of mild steel and lined with rubber and carbon brick. A hollow central baffle wall is provided in the center to prevent short circuiting of rock. Heat load is removed by flash cooler. Part of the cooled slurry is recycled to digester and remaining is sent to the filter via surge tank. The normal digester conditions are:

| | | |
|---|---|---|
| Slurry density | - | 1.56 - 1.59 |
| Free sulphuric acid | - | 2 - 3% |
| Slurry filtrate density | - | 1.32 - 1.33 |
| Recycled acid density | - | 1.18 - 2.00 |
| Liquid solid ratio | - | 1.5 - 1.6 |
| Temperature | - | 75 - 78°C |

30% P.A. gypsum slurry is filtered in Eimco's horizontal tilting pan filter. It comprises stepwise processing stages of filtration, first stage washing, second stage washing, cake drying, air blowing and cloth drying. Weak P.A. from gypsum purification section is used as wash liquor in the second stage. 30% P.A. is taken to the filtrate holding tank and 17% P.A. from wash section is recycled to the digester.

30% P.A. is concentrated to 41% in two staged single effect Struther's type concentrators. Low pressure steam at 0.5 kg/cm$^2$ is used in calendria to heat the circulating acid. Calendria tubers are made of special carbate material. Out of 3 concentrators, two are kept in operation and one is under cleaning and maintenance. Concentrated 41% P.A. is stored in MSRL storage tanks and pumped to DAP plant.

Gypsum discharged from pan filter with spray water is obtained in form of 40% slurry in repulping tank. It is then filtered in a horizontal rotary drum filter where soluble $P_2O_5$ is recovered and used as wash liquor in filtration. The washed gypsum, discharged from filters is sent either to A.S. plant or stored in the gypsum yard.

STANDARD ROCK, OTHER ROCKS AND ROCK BLENDS:- COMPOSITION AND PLANT PERFORMANCE

Although the GSFC plant is designed for 165 t/d $P_2O_5$ on Florida basis, the maximum production achieved so far on continuous basis is 140 t/d. Again, this is achieved with Senegal rock and not with the Florida rock. Hence, for practical considerations, Senegal has been taken as the standard rock and the performance of other rocks and rock blends are compared with respect to it.

At this juncture, it may be clarified that the reason for not attaining the rated capacity of 165 t/d is the design limitation. It is believed that the non-distinct slurry flow-pattern resulting in compartmentless single tank digester, single point addition of 98% S.A., very high designed temperature drop ($\Delta t$) in flash-cooler, low residence time in surge tank etc. have been responsible factors, adversely affecting rock-acid reaction. The slurry characteristics have always been far from satisfactory and filtration and washing have always been a limitation. This has ultimately limited the production. However, ironically, badly designed plants are good for comparison of rock characteristics as they reveal and magnify the minute changes; and hence, although it is not the scope of this paper, a mention has been made of the above design limitation.

Compositions of various rocks and rock blends are given in Table 1. It is seen that in Senegal, $P_2O_5$ content is high and other impurities are within a tolerable limit. In other rocks, apart from the wide variation in $P_2O_5$ content from 32 to 36% and CaO from 48 to 54%, variation in impurities is very wide - Silica from 2 to 8%, $CO_2$ from 1 to 7%, chlorides from 20 to 2800 ppm etc., all exceeding a tolerable design limit.

Moreover, sometimes, it is seen that even in the same rock, e.g. Udaipur, there is a wide variation in its own composition. This is seen from the statistical analysis of various samples of Udaipur rock.

It can be understood that no plant can be designed to take care of all these variations. This adversely affected the plant performance. The average production level went down from 120-140 to 80-100 t/d and efficiency was reduced from 85-90% to 75-80% (Table 2).

GSFC found the logical solution to this problem in rock blending. The composition of the rock blends show that the resultant rock-mix contains the intermediate characteristics within the allowable limit. This has helped a great deal in regaining the production level to 100-120 t/d and efficiency to 80-85%. This is summarised in Table 3.

Table I : Composition of standard rock, other rocks and rock blends processed in GSFC

| Sr. No. | Rocks & Rock blends | Average composition (dry basis | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $P_2O_5$ | CaO | $SiO_2$ | F | $Al_2O_3$ | $Fe_2O_3$ | $Na_2O$ | $SO_3$ | LOI | $CO_2$ | Chlorides (ppm) |
| 1. | Senegal | 36.80 | 51.51 | 2.97 | 3.93 | 1.21 | 0.67 | 0.30 | 0.29 | 2.45 | 1.61 | 28 |
| 1. | Udaipur | 36.21 | 50.26 | 7.35 | 3.39 | 1.30 | 0.73 | 0.10 | Traces | 1.18 | 1.04 | 25 |
| 2. | Florida | 33.16 | 48.14 | 4.91 | 3.89 | 1.14 | 0.70 | 0.45 | 0.80 | 5.08 | 2.60 | 44 |
| 3. | Morocco | 32.63 | 50.52 | 2.34 | 4.11 | 0.54 | 0.15 | 0.76 | 1.81 | 6.86 | 4.01 | 255 |
| 4. | Algeria + | 33.78 | 54.13 | 1.4 | 3.67 | 0.41 | 0.32 | - | - | - | - | - |
| 5. | High grade Jordan | 34.35 | 52.65 | 1.29 | 4.07 | 0.20 | 0.20 | 0.41 | 1.04 | 6.39 | 3.99 | 177 |
| 6. | Low grade Jordan | 32.75 | 51.26 | 4.45 | 4.00 | 0.35 | 0.30 | 0.40 | 0.95 | 8.41 | 6.20 | 2800 |
| 1. | U:F 1:1 | 34.44 | 49.40 | 5.07 | 3.62 | 1.22 | 1.12 | 0.35 | 0.64 | 2.94 | 2.08 | 40 |
| 2. | U:S 1:1 | 35.79 | 50.90 | 5.53 | 3.56 | 0.66 | 0.80 | 0.14 | Traces | 2.41 | 1.62 | 28 |
| 3. | U:M 1:1 | 34.49 | 50.52 | 5.15 | 3.60 | 0.87 | 0.69 | 0.36 | 0.82 | 3.93 | 2.91 | 262 |
| 4. | S:F 1:1 | 34.37 | 49.08 | 3.68 | 3.50 | 1.23 | 1.00 | 0.23 | 0.36 | - | 2.30 | 50 |

+ Used in the initial stages for a short period.

Table 2 : Quality of Udaipur Phosphate Rock

| Month | July 71 | Aug 71 | Sept 71 | Oct 71 | Nov 71 | Dec 71 | Jan 72 | Feb 72 | Mar 72 | Over all |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of samples | 5 | 4 | 4 | 5 | 5 | 4 | 5 | 4 | 4 | |
| CaO% average | 52.06 | 52.06 | 51.54 | 52.07 | 51.72 | 50.55 | 50.52 | 50.35 | 49.67 | 51.20 |
| range | 1.16 | 0.77 | 3.62 | 1.78 | 2.68 | 2.72 | 0.92 | 2.34 | 2.35 | 5.02 |
| T-$P_2O_5$% avg. | 38.51 | 34.23 | 38.66 | 37.53 | 36.75 | 36.53 | 35.89 | 35.48 | 35.16 | 36.93 |
| range | 1.64 | 1.58 | 3.35 | 2.43 | 4.65 | 4.46 | 2.18 | 4.10 | 2.45 | 4.50 |
| F% average | 3.65 | 3.68 | 3.57 | 3.62 | 3.45 | 3.43 | 3.44 | 3.41 | 3.25 | 3.50 |
| range | 0.14 | 0.04 | 0.39 | 0.47 | 0.40 | 0.27 | 0.30 | 0.26 | 0.21 | 0.65 |

Table 3 : Average production and overall efficiency in case of standard rock, other rocks and rock blends.

| Group | Category | Rocks & rock blends | Average continuous production t/d | Average overall $P_2O_5$ efficiency (%) |
|---|---|---|---|---|
| I | Standard rock | Senegal | 120-140 | 85-90 |
| II | Other rocks | (1)Morocco<br>(2)High grade Jordan<br>(3)Florida<br>(4)Udaipur<br>(5)Algeria<br>(6)Low grade Jordan | 80-100 | 75-80 |
| III | Rock blends | (1)Udaipur:Florida 1:1<br>(2)Udaipur:Senegal 1:1<br>(3)Senegal:Florida 1:1<br>(4)Udaipur:Morocco 1:1 | 100-120 | 80-85 |

PROCESSING OF STANDARD (SENEGAL) ROCK

Processing of Senegal rock has shown that its overall performance has been substantially good and higher production rates with fairly good efficiency can be achieved on a continuous basis. It may be noted that GSFC recorded its highest ever monthly production of 4,258 t $P_2O_5$ while processing Senegal rock. On average, this rock gives 120-140 t/d production with fairly good efficiency of about 90%. This is attributed mainly to its higher $P_2O_5$ content and balanced impurities content within the tolerance limit. Its performance is discussed below:

GRINDABILITY

Grinding capacity of ball-mill increases from 30 t/hr to 32 t/hr while grinding Senegal rock. This is because of the finer site of unground rock.

Table 4 : Screen analysis of unground Senegal rock

| Sr. No. | Screen size (mesh) | % of total |
|---|---|---|
| 1 | +6 | 0 |
| 2 | +14 | 0.3 |
| 3 | +20 | 0.3 |
| 4 | +40 | 33.2 |
| 5 | +60 | 0.7 |
| 6 | +80 | 5.5 |
| 7 | +100 | 13.7 |
| 8 | +150 | 15.5 |
| 9 | +200 | 7.5 |
| 10 | -200 | 23.3 |

DIGESTION

Digestion is fairly good. Reactivity is quite high and stable slurry conditions can be maintained consistently without difficulty. Gypsum crystals are of good shape and size, with a length and breadth ratio of 3-4 to 1. Desired slurry conditions are given on the next page:

Table 5 : Standard digestion condition for Senegal rock

| Sr. No. | Plant load t/hr. | Digester Condition | | | | |
|---|---|---|---|---|---|---|
| | | Slurry densit | Free S.A. | Slurry filtrate density | Liquid solid ratio | Digester temp. (°C) |
| 1 | 15 | 1.55 - 1.56 | 2.1 - 2.3 | 1.31 - 1.32 | 1.75 - 1.80 | 76 |
| 2 | 18 | 1.55 - 1.56 | 2.1 - 2.3 | 1.31 - 1.32 | 1.75 - 1.80 | 77 |
| 3 | 20 | 1.56 - 1.575 | 2.1 - 2.3 | 1.32 - 1.33 | 1.75 | 77 |
| 4 | 22 | 1.575 - 1.58 | 2.1 - 2.3 | 1.32 - 1.33 | 1.70 | 78 |

## FILTRATION

Filtration is consistently good. Only at the higher slurry density, it gets upset due to increased viscosity. Frequency of changing the filter cloth is less (Table 6) which saves considerable down-time.

Table 6 : Life of filter cloth

| Sr. No. | Rock or rock blend | Cycle time (days) | |
|---|---|---|---|
| | | Indigenous cloth | Imported cloth |
| 1 | Senegal | 10 | 22 |
| 2 | F:U 1:1 | 8 | 18 |
| 3 | F:S 1:1 | 5 | 14 |

FOAMING

Foaming is very low and this is evident from its low $CO_2$ content of 1-1.6%. Consumption of defoamer is, therefore, very low (Table 9).

PRODUCT ACID AND BY-PRODUCT GYPSUM

Quality of product acid (41% $P_2O_5$) is consistently good and does not pose any problem for DAP manufacture.

Quality of gypsum is also consistently good except that it contains somewhat higher moisture. It poses no problem in A.S. manufacture.

CORROSION

No significant corrosion effect is noticed. The chlorides are much less, below 50 ppm.

SCALING

No scaling problems. As observed in pan filter, calendria tubes and in pipelines and tanks, scaling is fairly low. The number of tubes getting scaled is less and also as the scale is soft, the time required for cleaning is also less. This quickens the cleaning cycle for calendria. Likewise, cleaning time in the panfilter is also reduced.

PROCESSING ROCKS OTHER THAN THE STANDARD ROCK OR EFFECT OF IMPURITIES IN DIFFERENT ROCKS ON THE PLANT PERFORMANCE

When rocks other than the standard were processed, as mentioned earlier, due to wide variations in impurities exceeding the tolerance limit, average production is reduced to 80-100 t/d and efficiency to 75-80%. Hence unlike in previous sections, here discussion is based as to how each component in rock affects the plant performance.

## $CaO/P_2O_5$ RATIO

$CaO/P_2O_5$ ratio is the indicative of the theoretical sulphuric acid requirement, for digestion which increases with the ratio. This is given below:

Table 7 : $CaO/P_2O_5$ ratios of different rocks and rock blends processed in GSFC

| Sr. No. | Rock and rock blends | $CaO/P_2O_5$ ratio |
|---|---|---|
| 1 | Senegal | 1.40 |
| 1 | Udaipur | 1.38 |
| 2 | Florida | 1.45 |
| 3 | Morocco | 1.54 |
| 1 | U:S 1:1 | 1.39 |
| 2 | U:F 1:1 | 1.43 |
| 3 | S:F 1:1 | 1.43 |
| 4 | U:M 1:1 | 1.46 |

Theoretical requirement of sulphuric acid (no free acidity) based on this ratio, available $SO_3$ and other impurities in rock has been calculated and is shown in Fig.2. This requirement is minimum, i.e. 2.56 t of 100% S.A. per t of rock in case of Udaipur to 2.70 in case of Morocco. This increase is substantial considering the high cost of imported sulphur in India. However, lower CaO content in Udaipur (along with lower $CO_2$ content) is believed to be one of the contributing factors for its lower reactivity. It may be noted that reactivity is higher in order as Morocco, Florida and Kola and so is the order of $CaO/P_2O_5$ ratio.

## SILICA

Silica in stoichiometric proportion with fluorine is reactive silica and is desirable to convert highly corrosive HF into non-corrosive fine silicates. The excess is unreactive silica and it poses many process problems.

Especially, Udaipur rock contains very high silica averaging 7-8%. The rock is very hard and the grinding capacity of ball-mill went down from 30 t/hr to 21.5 t/hr; a decrease of about 30%. The consumption of power as well as grinding balls per ton of rock ground have also gone up.

In digestion, silica must be interfering with rock S.A. reaction and also reducing its reactivity. The slurry is typically whitish and slimy and extremely difficult to filter and wash.

It causes severe erosion and abrasion on agitators, brickwalls etc. This aggravates when silica settles down at very much faster rate and collects at the bottom. Once at 8% level, silica was seen to be settled on the bottom of a slurry sampler used for collecting sample. Due to such a high solid content, the digester agitator gave way apparently eroding from the shaft. This caused plant shut-down. Emptying of the digester also took much longer because of the drain outlets and pipelines getting plugged with silica. The digester bottom was found covered with 4 -5 feet of silica. This further extended the shut-down. The plant then was run for some time on Udaipur:Florida 1:2 ratio instead of 1:1 to bring down the silica content.

Increased silica content requires higher feeding of recycle acid to digester to maintain a normal liquid-solid ratio. This dilutes the slurry (S.F.D. 1.29 instead of 1.32-1.33) increasing the load on concentration.

In filtration, the slurry is difficult to filter and wash. This increases $P_2O_5$ losses. Due to dilute slurry, cake cannot be completely dried and this increases $P_2O_5$ losses.

In gypsum purification sections, the problems are the same as in the digester. Gypsum quality is inferior due to high $P_2O_5$, silica and moisture that subsequently poses handling and process problems in A.S. plant also.

It is reported that a good deal of study is being done to reduce the impurities, especially silica, through various processes such as beneficiation, calcination etc. in Udaipur rock.

$Al_2O_3$ and $Fe_2O_3$

These cause $P_2O_5$ losses by consuming phosphoric acid to produce phosphates which are sticky in nature, increase sludge formation during concentration and increase $P_2O_5$ losses in gypsum as they precipitate out in them when their solubility is exceeded in 30% P.A. They also reduce the soluble $P_2O_5$ content of DAP and increase its hygroscopicity. The tolerance limit of $Al_2O_3$ + $Fe_2O_3$ in rock is 3%.

Fortunately, in all the rocks GSFC processed, these impurities have been within the 3%. However, compared to other rocks, a little higher $Al_2O_3$ + $Fe_2O_3$ in Senegal and Udaipur may be the cause of somewhat increased slurry density and viscosity. Also, in the case of Florida, this along with the high content of organic impurities must be the cause of sticky and viscous nature of the slurry.

$Na_2O$ and $K_2O$

These form sodium and potassium fluosilicates with fluosilicic acid already formed through HF and silica. These salts, along with gypsum, form very hard scale in the piping system and in the concentrator calendria tubes.

While using Florida rock, excessive scaling was noticed in all pipings pan filter cells, calendria tubes etc. This may be attributed to comparitively higher $Na_2O$ and silica content along with higher $Al_2O_3$ and $Fe_2O_3$. Scaling was so severe that the cleaning under the pan filter cells had to be done almost every day, resulting in a daily down-time of 5-6 hrs. The pipelines of 3" and above used to plug 50% just within 10 to 15 days. Even with less than 3% carry-over in 30% acid, concentrator calendria tubes were getting scaled up just within 5 days time (Table 8). This required frequent tube cleaning just after 6 days instead of possible 12 days.

Fume scrubber duct was also found plugged within month's time instead of usual 3-4 months.

We understand that Florida rock is successfully processed in many places. In our case, however, as mentioned earlier, the design is somewhat different, e.g. the flash cooler is designed for 11°C temperature drop instead of standard practice of 3°C. Such and other factors must be aggravating the scaling tendency.

Table 8 : Average time after which concentrator has to be cleaned

| Sr. No. | Rocks and rock blends | Time between concentrator cleaning (days) |
|---|---|---|
| 1 | Senegal | 15 |
| 1 | Udaipur | 12 |
| 2 | Morocco | 7 |
| 3 | Florida | 5 |
| 1 | S:U 1:1 | 13 |
| 2 | S:F 1:1 | 10 |
| 3 | U:M 1:1 | 9 |
| 4 | U:F 1:1 | 8 |

FLUORINE

Too high F can cause corrosion. Normally , all the rocks processed in GSFC contain 3 to 4% F and this has not posed any special problem.

$CO_2$ CONTENT

$CO_2$ gives rise to foaming which has to be suppressed by de-foamers. Table 9 gives de-foamer consumption (oleic acid) in various rocks, Florida and Morocco consume much higher quantity of costly de-foamer due to high $CO_2$.

ORGANIC IMPURITIES

They give rise to foaming, increase viscosity and impart dark colour to slurry and acid. In the case of Florida, due to these impurities, the slurry is sticky, viscous and dark brown in colour. The acid is also typically dark brown.

Table 9 : De-foamer consumption in various rocks

| Sr. No. | Rock and rock blends | Consumption of Oleic acid |
|---|---|---|
| 1 | Senegal | 3.6 |
| 1 | Udaipur | 1.0 |
| 2 | Morocco | 8.6 |
| 3 | Florida | 9.6 |
| 1 | U:S 1:1 | 2.6 |
| 2 | U:M 1:1 | 3.1 |
| 3 | U:F 1:1 | 4.6 |
| 4 | S:F 1:1 | 7.6 |

CHLORIDES

Chlorides cause corrosion and the effect is more pronounced in the case of agitators and pumps.

Initially, when low grade Jordan rock was used, its chloride content was always higher than 2000 ppm and went upto 4000 ppm. This caused very severe corrosion and unprecedented failure of equipment was experienced. This resulted in heavy loss and down-time.

The AISI 317L digester agitators were taken away just within five months whilst its expected life under normal chloride level is about 2 years. They were replaced by MSRL agitators but their performance was also not satisfactory.

Flash cooler charge pump made-up of carpenter-20 also gave way just within 3 months. To find the better material of construction, corrosion tests were carried out (Table 10) and it was found that CA-A-960 was best. However, it was not easily available and HV-9 which was much better than carpenter-20 was substituted. This worked well.

Similarly, the filter feed pump was changed from carpenter-20 to HV-9 and the concentration circulation pump was also changed from carpentier-20 to NARLLOY-3 after testing. These gave satisfactory performances.

The corrosion on the pan filter was also very severe and SS 316 L screens were eaten out just within one month.

Thus, chloride had almost a killing effect. Although the chloride limit stipulated in the design was 4000 ppm, it was found much too high and now, the safe limit is set at 150 ppm.

PROCESSING OF ROCK BLENDS

Rock blending is GSFC's logical solution to the problem of processing rock with extreme impurities. By adopting this practice, GSFC has been successful in obtaining out of two rocks of extreme composition, a rock-mix of intermediate composition within the tolerable design limit. With the availability of Udaipur rock, Indian manufacturers now face the challenge of putting it to its full use. Because of its high impurity content, there are a lot of difficulties in processing this rock on the plant scale. Under this condition, rock blending can serve as an intermediary step towards the total utilisation. GSFC has been the first to demonstrate this by blending Udaipur rocks with various other rocks.

For example, Udaipur contains high $P_2O_5$, impurities of high silica, tolerable Fe, Al and Cl and low $Na_2O$ and $CO_2$. Florida, on the other hand, has low $P_2O_5$, F and chlorides. Individually, Udaipur for its slimy characteristics and Florida for its scaling characteristics have adversely affected the plant performance as mentioned earlier. But, when equally blended, the resulting rock mix had a complementing effect and all impurities came down within the tolerable limit. This eliminated the problems of excess impurities mentioned in the previous section and improved the production from 80-100 to 100-120 t/d and efficiency from 75-80 to 80-85%.

Similarly, GSFC has blended Udaipur rock with Morocco, Senegal etc.

However, it may be noted that the practice of rock blending in a plant designed for handling single rock, poses some problems. These are discussed next.

Table 10 : Corrosion test in digester during processing of high chloride containing Jordan rock

(1) Test place - digester

(2) Test time - 87.5 hrs.

| Sr. No. | Materials of+ test piece | Test piece size($mm^2$) | TEST Wt.before test(g) | Wt.after test(g) | Loss in wt. (g) | Corrosion rate ($mg/cm^2$/87.5hrs) | Relative corrosion | Order of merit |
|---|---|---|---|---|---|---|---|---|
| 1 | CAA-960 | 1765 | 39.2654 | 39.2642 | 0.0012 | 0.068 | 1.00 | 1 |
| 2 | CAA-950 | 1750 | 37.6319 | 37.6299 | 0.0020 | 0.114 | 1.68 | 2 |
| 3 | CAA-900 | 1750 | 37.1417 | 37.1348 | 0.0074 | 0.425 | 6.25 | 6 |
| 4 | CAA-700 | 1725 | 35.7514 | 35.7481 | 0.0033 | 0.192 | 2.83 | 3 |
| 5 | HV-9 | 2468 | 54.1620 | 54.1545 | 0.0075 | 0.304 | 4.48 | 5 |
| 6 | NARLOY-3 | 2452 | 55.0844 | 55.0786 | 0.0058 | 0.237 | 8.50 | 4 |
| 7 | SUS-41 | 2429 | 52.6358 | 52.5667 | 0.0691 | 2.775 | 40.60 | 8 |
| 8 | HASTALLOY-C | 2447 | 55.5284 | 55.5076 | 0.0208 | 0.850 | 12.50 | 7 |
| 9 | CARPENTER-20 | 2432 | 49.5771 | 45.0127 | 4.5644 | 188,000 | 2770.00 | 9 |

+ Composition of materials is given in Table 11.

Table 11 : Composition of different materials tested for phosphoric acid service

| Sr. No. | Material | C | Si | Mn | P | S | Cr | Ni | Mo | Co | Fe | W | V | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CA-A960 | <0.11 | <1.00 | <1.00 | - | - | 26N 30 | BAL | 9N11 | - | 5.00 | - | - | - |
| 2 | CA-A950 | <0.10 | <1.00 | <1.00 | - | - | 36N 40 | BAL | 4N 6 | - | 5.00 | - | - | - |
| 3 | CA-A900 | <0.07 | <1.50 | <2.00 | - | - | 19N 22 | 28N 31 | 1.75N 2.75 | Cu 2N4 | - | - | - | - |
| 4 | CA-A700 | <0.10 | <1.50 | <2.00 | - | - | 22N 25 | 19N 22 | 1.75N 2.75 | - | - | - | - | - |
| 5 | (HV-9) | 0.04 | 0.82 | 1.83 | 0.022 | 0.01 | 22.15 | 25.78 | 4.85 | - | - | - | - | 0.51 |
| 6 | NARLOY-3 | 0.024 | 0.34 | 0.43 | 0.010 | 0.007 | 19.73 | 40.40 | 11.85 | - | - | - | - | - |
| 7 | SUS 41 | 0.07 | 0.94 | 1.49 | 0.028 | 0.006 | 22.25 | 12.20 | | | | | | |
| 8 | HASTELLOY-C | 0.08 | 0.67 | 0.73 | 0.05 | 0.011 | 15.53 | BAL | 15.40 | 0.17 | 6.10 | 3.55 | 0.21 | - |
| 9 | CARPENTER-20 | 0.05 | 0.72 | 1.57 | 0.023 | 0.014 | 20.07 | 29.08 | 2.50 | 2.64 | 0.65 | - | - | - |

PROBLEMS IN ROCK BLENDING

STORAGE

Simultaneous storage of various rocks in a single storage can create problems of storage limitation, and rock contamination. It creates difficulties in truck movements during unloading and in shovel-loader movements during charging.

GSFC too has faced these problems. For instance, once due to storage limitation, GSFC had to stack rock outside the silo in the open. In spite of taking the maximum care by covering it with tarpaulins etc., some rain water slipped through resulting in some increase in moisture content and handling loss through leaching.

GSFC has added one more silo just in front of the existing one. This has reduced the problems of storage limitation and contamination. The simultaneous unloading and charging has also become easy, safe and trouble-free.

UNIFORM BLEND RATIO

This is the most inherent and critical problem in blending. Blend ratio, for example 1:1, is brought about by simultaneously charging one bucket of shovel-loader operators, generally from two silos. This is purely a manual operation without any instrument control. Hence, to that extent, the consistency and reliability of blending are questionable.

Quite often, the charging is not in equal proportion and predominance of one rock over the other occurs. As the digester parameters are set for the equal blend condition, this predominance totally upsets the slurry condition and jeopardises digestion and filtration. Due to a large volume of digester, time of revival is quite long and many times, plant load has to be reduced to avoid $P_2O_5$ losses.

With the type of operation described above, it is practically not possible to run blends with proportions other than 1:1, such as 1:2 or 2:3 etc.

SEGREGATION

With rocks varying in size and density, there is a possibility of segregation when they are blended especially during grinding and ground rock storage. We checked this in the case of two rocks with extreme size difference (unground rock) i.e. Udaipur and Senegal, by continuously analysing the composition of ground rock mix. The composition was more or less uniform which indicates the absence of any appreciable segregation during the trial.

The ideal blending can be achieved by actual weighing of unground rocks through separate weigh-feeders. Rocks from two silos can be charged by two shovel-loader operators in two bucket elevators and fed to the unground charge hoppers. They can be let out from the bottom on to the respective weigh-feeders and from there on to a common conveyor to grinding. The charge hoppers can be provided with inter-locking system stopping both the conveyors in case the level in either of the hoppers has gone low. This will assure the uniform blend, and also makes it possible to have a blend in any desired proportion other than 1:1 as well. The economic advantages obtained through such well-defined a system can easily offset the initial cost of its installation and prove it a paying proposition.

COST OF PRODUCTION

In India, the cost of raw materials, viz. rock and sulphuric acid, is the biggest single contributory factor in determining the cost of production of phosphoric acid. This is because of the high price for the imported rock as well as for sulphur. Together, they account for nearly as high as about 80% of the total cost. From the remainder, the plant overheads constitute about 12%. These factors are dependent upon the production level and efficiency which, in turn, are different in each case of processing standard rock, other rocks and rock blends as described earlier.

A very generalised cost comparison is made between the above 3 cases and is shown in the Table 12. With the constantly changing rock and sulphur prices, high frequency of changing types of rock, and unpredictable composition of each new supply, it is not practical to give clearcut cost comparisons based on each individual rock or rock blend.

Hence, the comparison is made between the 3 broad groups of them. This will then not take into account the individual factors, e.g. higher individual cost of rock with respect to its $P_2O_5$ and impurity content or higher grinding cost in Udaipur rock or higher defoamer cost for Florida and Morocco rock etc. To this extent, the comparison is not actual but indicative. The common factors considered for 3 cases are:

| | | | |
|---|---|---|---|
| A) | Cost of rock | : | Rs. 800/t |
| | Cost of sulphuric acid | : | 400/t |
| | Cost of defoamer | : | 20/kg |
| B) | Cost of power | : | 18/100 kWH |
| | Cost of steam | : | 18/t |
| | Cost of water | : | 2/t |
| C) | Labour cost | : | 85/t $P_2O_5$ |
| D) | Plant overheads | : | |
| | Depreciation 10% of plant cost | | |
| | Interest 12% | | |
| | Maintenance 5% | | |
| | Insurance 1% | | 28% on plant cost. Plant cost Rs. 70 million Annual fixed charges are Rs. 19.6 million. |
| E) | Other overheads | : | Rs 25/t $P_2O_5$. It is fixed. |
| F) | Credit for by-product gypsum | : | Rs 40/t gypsum (If suitable for A.S. manufacture). |

The cost of P.A. production is approximately Rs 4,400/t in the case of standard rock. If other than standard rocks have to be processed, the cost is increased to approximately Rs 5,200/- i.e. about Rs 800/t $P_2O_5$ which is considerably high. Furthermore, when the rock blending is done the cost comes down to Rs 4,750/t or a decrease of Rs 450/t $P_2O_5$.

This shows that the techno-economics are adversely affected if rocks other than the standard are processed and also that they can be partially improved by adopting rock blending.

Table 12 : Cost of production while processing standard rock, other rocks and rock blends

($Rs 8.8 = \$1$ (Jan. '76))

| Sr. No. | Item | Basis | Cost of production Standard rock | Other rocks | Rock blends |
|---|---|---|---|---|---|
| 1. | RAW MATERIALS | Avg. efficiencies in 3 cases are: | | | |
| | a) Rock | 90%; 80% & 85% | | | |
| | a) Rock | $P_2O_5$ - 34% | 2,616.00 | 2,944.00 | 2,766.00 |
| | b) Sulphuric acid | SA/Rock 0.87% | 1,136.00 | 1,280.00 | 1,204.00 |
| | c) Defoamer | 1 kg/t rock | 65.00 | 73.00 | 69.00 |
| 2. | UTILITIES | Avg. efficiencies in 3 cases are: 90%, 80% & 85% | | | |
| | a) Power | 330 kWH/t $P_2O_5$ | 60.00 | 68.00 | 64.00 |
| | b) Steam | 3.5 t/t $P_2O_5$ | 63.00 | 70.00 | 66.00 |
| | c) Water | 10 t/t $P_2O_5$ | 20.00 | 22.00 | 21.00 |
| 3. | LABOUR | Same in all cases | 85.00 | 85.00 | 85.00 |
| 4. | PLANT OVERHEADS | Avg. production in 3 cases is 130, 90 & 110 t/d | 510.00 | 733.00 | 590.00 |
| 5. | OTHER OVERHEADS | Same in all cases | 25.00 | 25.00 | 25.00 |
| 6 | CREDIT FOR BY-PRODUCT GYPSUM | 100%, 50% & 75% Gypsum suitable for AS manufacture | (-)180.00 | (-)90.00 | (-)135.00 |
| | | | Rs 4,390.00 | 5,200.00 | 4,755.00 |
| | | Say | Rs 4,400.00 | 5,200.00 | 4,750.00 |

## CONCLUSION

Running a phosphoric acid plant only on one standard rock gives a consistently good performance in terms of production and efficiency. However, for the countries like India which have been largely dependent on the imported rock supply, it is inevitable that several different rocks are used varying widely in composition and characteristics. With one or more impurities exceeding the tolerance limits, they pose many process problems and adversely affect the production and efficiency. These problems can be overcome to a large extent by adopting rock blending which essentially gives the rock mix of intermediate composition within the tolerance limits. By adopting rock blending, GSFC has been successful in improving the techno-economics of P.A. manufacture and more significantly in achieving a continuous and maximum utilisation of indigenous Udaipur rock on a large scale. This is a big step towards India's pursuit of self-sufficiency and this can turn true for any other country which is in a similar position concerning rock phosphate to India.

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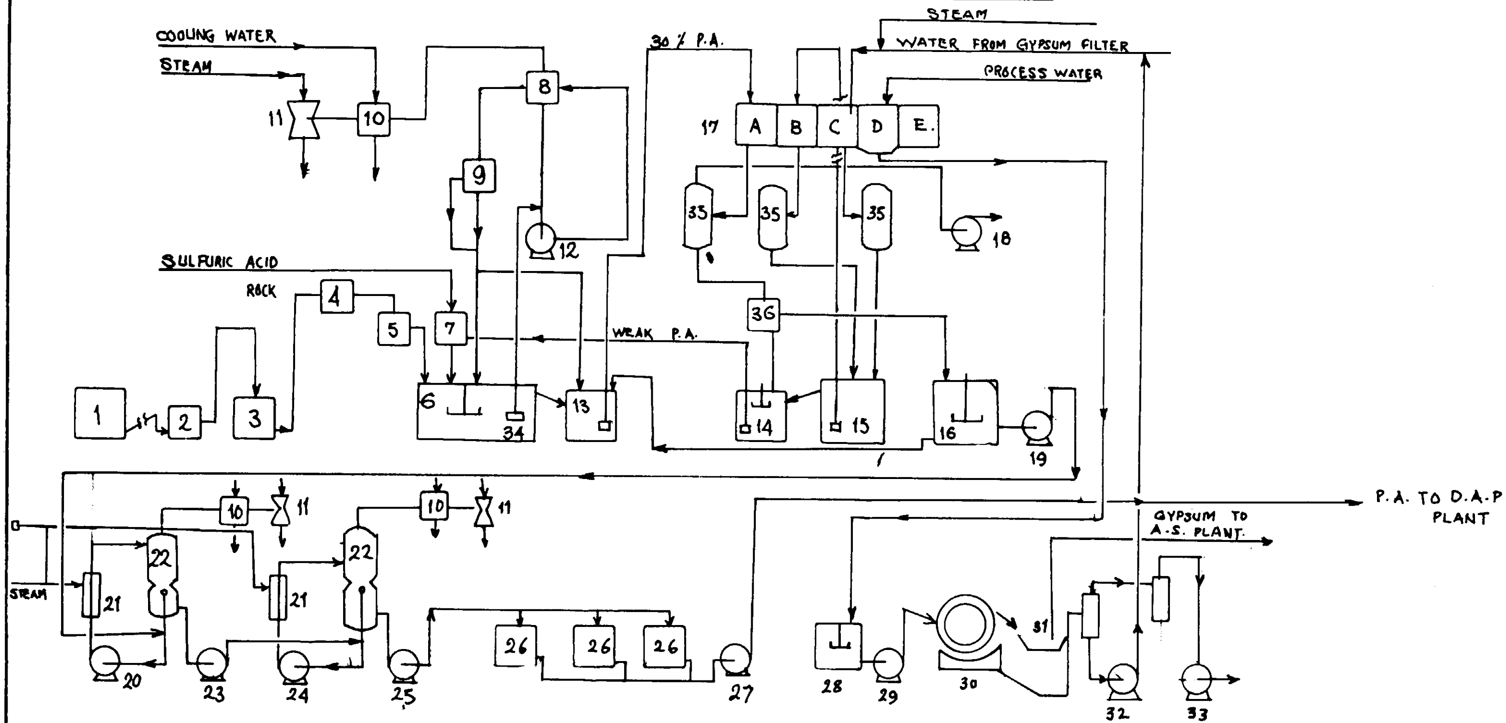
## FIG. I PROCESS FLOW OF GSFCS' 165 MT P.D. PHOSPHORIC ACID PLANT




### LIST OF EQUIPMENTS.

1. ROCK STORAGE
2. BALL MILL
3. GROUND ROCK STORAGE.
4. " " HOPPER
5. HOPPER SCALE.
6. DIGESTOR.
7. PREMIXER.
8. FLASH COOLER
9. COOLED SLURRY DRUM.
10. CONDENSER.
11. EJECTOR
12. CIRCN' PUMP.
13. SURGE TANK.
14. RECYCLE TANK.
15. FILTER DRUM.
16. FILTRATE HOLDING TANK.
17. PAN FILTER
18. VACUUM PUMP.
19. CONC. FEED PUMP.
20. CIRCULATING PUMP.
21. CALENDRIA.
22. CONCENTRATOR.
23. FEED PUMP.
24. CIRCULATING PUMP.
25. FEED PUMP.
26. P.A. STORAGE TANK.
27. ACID SLURRY PUMP.
28. REPULP TANK.
29. FEED PUMP.
30. DRUM FILTER.
31. GYPSUM CONVEYOR
32. FILTRATE PUMP.
33. VACUUM PUMP.
34. FLASH COOLER CHARGE PUMP.
35. RECEIVERS.
36. SPLITTER BOX.

FIG. 2. THEORETICAL SULFURIC ACID REQUIREMENT FOR VARIOUS ROCKS & ROCK BLENDS.