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RECENT PERFORMANCE AND INNOVATIONS IN DORRCO PROCESS PHOSPHORIC ACID PLANTS

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I. INTRODUCTION

The first Dorrco "Single Tank Reactor" was installed at Kellogg, Idaho in 1961. At present there are 21 reactors in operation which are widely dispersed geographically as listed in Figure 1. This list also indicates the different phosphate rocks that have been treated in the Dorrco reactors. Approximately 2 million tons per year of P_2O_5 is produced in these reactors.

TABLE 1

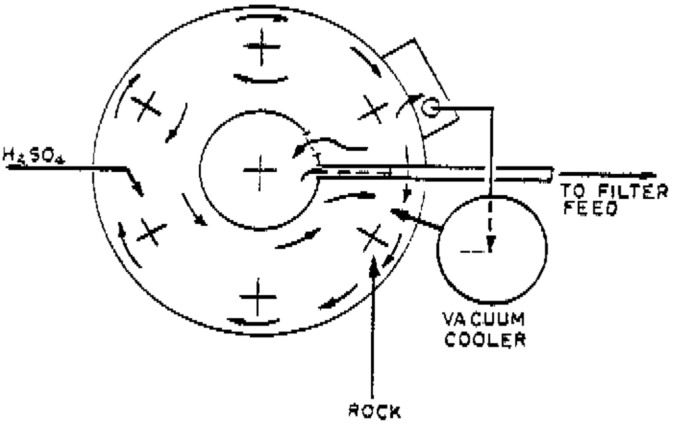
DORRCO SINGLE TANK REACTOR PHOSPHORIC ACID PLANTS

YEAR IN OPERATION	CLIENT AND LOCATION	ORIGINAL DESIGN CAPACITY t/d P_2O_5	ROCK USED
1961	Bunker Hill Company Idaho, U.S.A.	70	Conda calcined; Vernal; Leefe calcined
1963	A.B. Forenade Superfosfatfabriker Sweden	70	Gafsa, Khouribga, Florid
1965	Fertilisers & Chemicals, Travancore Ltd. South India	110	Jordan; Khouribga
1965	Guanowerke AG, Nordenham Germany	100	Florida
1964	Consolidated Mining & Smelting Kimberley, B.C.	120	Leefe, Conda, Vernal
1965	Imperial Chemical Industries England	200	Senegal - Israel
1965	American Agricultural Chemical Florida, U.S.A.	350	Florida
1965	Esso Standard Fertilizers Philippines	230	Florida
1965	W. R. Grace & Co. (SATEC) France	100	Togo
1966	American Agricultural Chemical-Expansion Florida, U.S.A.	350	Florida
1965	Central Phosphates Florida, U.S.A.	500	Florida
1966	Knapsak AG Germany	220	Kola
1968	Coromandel Fertilisers India	280	Florida

AR IN RATION	CLIENT AND LOCATION	ORIGINAL DESIGN CAPACITY t/d P_2O_5	ROCK USED
1966	Occidental Agricultural Chemical Florida, U.S.A.	650	North Florida
1966	A.B. Forenade Superfosfatfabriker Sweden	125	Gafsa; Khouribga; Flo
1967	CSBP & Farmers Ltd. Australia	110	Christmas Is.; Nauru, Queensland
1970	Zorka Sabac Yugoslavia	165	Khouribga, SAFI, GAFS
1968	Ultrafertil, S.A. Brazil	250	Florida
1969	Rikkihappo Oy Finland	250 (HYS)	Kola
1975	Instituto Venezolano de Petroquimica Venezuela	250	Venezuelan
1973	Consolidated Mining and Smelting Trail, B.C., Canada	120	Vernal, Montana

Most of these installations utilize a reactor configuration as shown in Figure 1. The flow scheme involved an annular shaped reactor where the rock is added at the first agitator, sulfuric acid "downstream" and the reactor underflowed to a center compartment then overflowed through a launder to the filter feed tank. The initial installations were air cooled but the later ones are vacuum cooled. Reactors up to 17 meter in diameter are in operation at current rates in the 850 to 900 t/d P_2O_5 range.

FIGURE 1
DORRCO REACTOR, FLORIDA, CIRCA 1965



Many of these installations are operating as originally installed, without significant modifications, on a very satisfactory basis. Many, due to changing plant economics such as increased raw material, labor, and utility costs, or changing market conditions have been modified to increase productivity and to reduce operating costs per ton of product.

The original reactor designs produced very filterable gypsum from over 15 different types of rock. The plants demonstrated relatively high recoveries and easy sulfate control. Some of the plants however did encounter relatively high defoamer consumption using Florida rock, evidence of short circuiting and some lining failure. These problems were overcome and modifications have resulted in substantially increased production, on-stream availability and reduction in operating costs.

This paper will describe the major modifications incorporated, economic factors involved in reactor designs, trade-offs and also discuss some future trends and possibilities.

II. MODIFICATIONS TO DORRCO SINGLE TANK REACTORS

1. Agitation

Most Dorrco reactors were originally designed at about 1.25 to 1.42 m^3 of reactor slurry volume per installed horsepower. This level of agitation is sufficient to maintain suspension for the normal ground rock, about 50% minus 200 mesh.

The Dorrco reactors on Florida rock have generally been increased in agitation power input to a level of 0.6 to 0.7 m^3/installed HP, with an operating range of about 0.85 to 1.0 m^3 per horsepower consumed. This level of agitation exists only in the reactor itself and at the low detentions being run the actual reactor kWh/t P_2O_5 produced is in the range of 20 to 30. The total digestion system requirement is about 35 to 45 kWh per ton of P_2O_5 including slurry recirculation and cooler vacuum pump power.

In addition, a major change has been made in several reactors with the introduction of paddler type defoamer impellers located at the slurry liquid level. At the same time reactor freeboard has been increased.

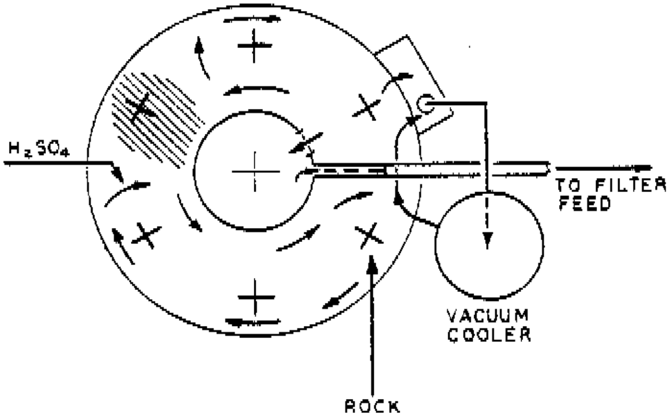
The combination of agitation modifications and increased freeboard has resulted in remarkable decreases in the quantity of defoamer required at high production rates. We will cover these aspects in more detail later in this paper.

2. Flow Pattern Modifications

The original reactor configuration shown in Figure 1 provided an opening in the wall between the last agitator in series and the first. This opening was intended to allow well reacted slurry to mix with new rock feed to maintain a uniform sulfate level and to provide substantial pulp recirculation. It has been determined by liquid phase analyses that the sulfate content in the reactor acid is remarkably uniform throughout the reactor. Substantial, even massive, slurry recirculation exists. However, evidence indicates that the principal mechanism for this recirculation is by back mixing of slurry from one agitator to the next.

It has also been established that tracers introduced with the rock at the first agitator appeared at the last agitator before appearing in the vicinity of the next to last mixer in the annulus. Pursuing this point further, it has been established that if one agitator is out of service a resistance is presented to slurry flow in the intended direction around the reactor and at this time and even after the agitator is put back in service this restriction serves to force slurry from the first agitator backward through the "recirculation" opening. This flow pattern is shown in Figure 2.

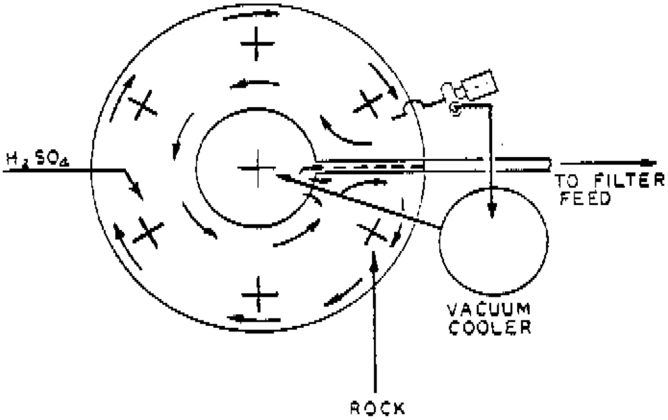
FIGURE 2
DORRCO REACTOR, FLORIDA, CIRCA 1965
FLOW PATTERN WITH ONE AGITATOR OUT OF SERVICE



The entire reactor is not being utilized in terms of providing its intended detention. If any residual constrictions exist, the tendency will remain to force the bulk of the reaction to take place in the loop from the first agitator, through the "recirculation" opening to the vacuum cooler suction lines then to the cooler and back to the first agitator. In effect the plant under these flow conditions exhibits symptoms characteristic of reduced and marginal reactor capacity such as sulfate control problems, sensitivity to rock quality and grind, reduced filterability, and increased defoamer consumption.

All of the Dorrco reactors in Florida have had the "recirculation" opening bricked closed. The effect has been increased reliability of performance without incurring any evidence of reduced recirculation. In fact one operator reports a reduction in solid solution loss after closing the opening. We believe this is due to increased shear at the first agitator area and better rock dispersion. Consequently the flow pattern now in operation in a typical Dorrco reaction system here in Florida is shown in Figure 3. This configuration provides for increased freeboard and full utilization of the reactor volume at all times.

FIGURE 3
DORRCO REACTOR, FLORIDA, CIRCA 1978



Freeboard is about 6 feet with downward pumping agitators. Because of the annular shape of the reactor there has never been a problem with severe wear or erosion below the impellers. Tramp is thrown to the side and cannot erode through the brick, and therefor a double course of brick under the lower impellers provides rather permanent protection.

In general, cooler feed pumps are ASH horizontal pumps operating from siphon legs. There are six vacuum coolers installed on the four Dorrco reactors in Florida. Three are the original upflow units, three are downflow type. The downflow coolers exhibit less P2O5 carryover and can accomodate higher slurry flow rates.

The quantity of slurry pumped through the vacuum cooler or coolers is primarily dependent on cooler operation itself. Pulp recirculation in the Dorrco reactors is not dependent on this flow. This was demonstrated in one Dorrco reactor where two large ASH pumps were installed to provide about 5,450 m^3/h total recirculation through the cooler. The operators could not establish any benefits in filterability or recovery for operating two pumps in parallel and have since used only one.

III. OPERATING RESULTS

1. Agrico, South Pierce, Florida

In 1965 a paper(1) was presented at the Fertilizer Industry Round Table describing the performance of the Dorrco phosphoric acid plants at Agrico, South Pierce. We would like to compare the results reported at that time with present performance.

TABLE 2

COMPARATIVE PERFORMANCE, AGRICO, SOUTH PIERCE, FLORIDA

	1965-66	1978
Operating Rate, t/d P_2O_5	360	550-625
Rock Feed	Dry	Wet Slurry
Grind	65%-200 mesh	35-45% - 200 mesh 3- 5% + 35 mesh
Analysis	68 BPL	64 - 67 BPL
Losses, % of P_2O_5 Fed	3.1	4.5-5.0
Defoamer, lb/t P_2O_5	5 - 10	10 - 12*

*25% active

The above 1978 operation shows a modest decrease in P_2O_5 recovery at rates about 60% more than the initial plant rate. This is due mainly we believe to the use of generally coarser phosphate feed although lower detention and higher filter loading are also factors. A detailed costing of this operation would show substantial savings for the higher output.

Agrico reports they have recently run for about one month on one reactor using the filters from two lines. Output was about 950 t/d P_2O_5 at a reactor detention of less that 2.5 hours. Losses across the filter were virtually unaffected. Defoamer consumption was increased about 10%.

We believe such operation, namely relatively short reactor detention with adequate agitation, especially aimed at mechanical defoaming, and with relatively generous filter capacity is what we will be seeing in future dihydrate phosphoric acid plants. Reactor agitation is generally cheaper than chemical defoamers and by minimizing the reactor size, lower capital and power charges per ton P_2O_5 will more than offset increased P_2O_5 cost.

2. CF Industries, Plant City, Florida - Dorrco Line

TABLE 3

PERFORMANCE OF DORRCO LINE AT CFI, PLANT CITY, FLORIDA

Operating Rate, t/d P_2O_5	800 - 900	
Rock Feed	Wet Slurry, 64-65% Solids	
Particle Size	3% - 6% + 35 mesh	
Analysis	64 - 67 BPL	
Losses, % of P_2O_5 Fed	c.i.	0.5-1.5
	c.s.	1.8-2.7
	w.s.	1.6-2.4
	Total	3.9-6.6
Defoamer, lb/t P_2O_5		11 - 15*

*Increased freeboard, minimal paddler installation

The results reported above are somewhat improved over those reported by Loughrie in 1976(2). The use of wet rock slurry appears to produce results nearly as good as previously experienced with dry rock which contained substantially more surface area.

IV. PRESENT DAY ECONOMICS OF PHOSPHORIC ACID MANUFACTURE

Obviously labor, capital, fuel, power and defoamer costs are going up. In addition the quality of phosphate rock is going down, at least for many users. There are a limited number of steps that can be taken to cope with these problems; we would like to examine some priorities in this area.

First, there are several operations in the process of making phosphoric acid that are subject to scrutiny. Starting with the rock beneficiation process, rock drying now costs from \$5.00 to \$6.00 per ton of P_2O_5. This is a relatively high cost item compared to other manufacturing costs exclusive of rock itself and sulfuric acid costs. Perhaps the next most important "controllable" cost item is grinding the rock for acid manufacture. This can be another \$3.00 to \$4.00 per ton of P_2O_5 whether grinding is wet or dry. A further major cost is the cost of evaporation from 28% P_2O_5 or so to 42% to 43% P_2O_5 or higher. For evaporation to 42% P_2O_5, if steam is costed in at current fuel costs, the bill is about \$15/t of P_2O_5, and we are using a very clean, premium fuel, steam. We will cover the prospects of saving this cost by a hemihydrate process later in this paper but we mention it here to put the savings into perspective with rock drying and grinding costs.

1. Wet Ground Rock

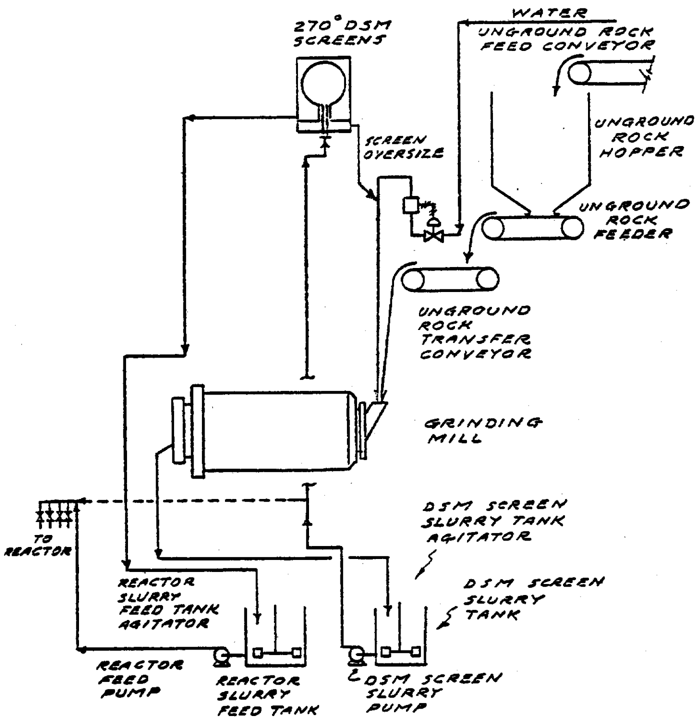
In a recent survey we conducted on this subject we found some reluctance among present processors to adopt wet grinding because the performance of some existing systems apparently is felt to be short of comparable performance on dry rock.

We believe the Dorrco reactor has demonstrated quite good performance on wet ground rock as described previously in this paper. We should point out, that the first three phosphoric acid reaction systems to use wet rock are Dorrco reactors and that a certain proportion of the momentum generated toward processing wet rock was due to the successful performance of these plants. The Dorrco Single Tank Reactor is well suited to wet rock because it has demonstrated it can handle undiluted 93% H_2SO_4 without significant loss of gypsum filterability. In addition the good sulfate control inherent in a single tank reactor makes it easier to process wet ground rock, which has substantially less surface area than dry rock. Further, the ability to separate rock and sulfuric acid addition points in the Dorrco reactor improves rock dispersion and wetting and makes sulfate control easier. Wet ground phosphate rock is ground with higher efficiency than is possible in dry grinding; less ultra fine material is produced and less overall horsepower is consumed in the wet grinding. This reduced surface, we believe, has resulted in some of the difficulties reported in phosphoric acid reaction systems using wet rock.

Jacobs Engineering and its Dorrco and Pridgen Engineering Divisions participated in two of the first wet rock grinding systems and we offer both open circuit grinding and an optional closed circuit system. The flowsheet for the latter is shown in Figure 4. The use of DSM centrifugal screens is based on wet cement grinding practice where there are about 100 screens installed. Wet cement grinding is quite similar to phosphate grinding and seeks to make a 48 mesh separation. Most installations were originally open circuit. A survey conducted in the mid 1960's of cement plants using the DSM screen indicated an average increase in capacity after installation of the screens of 29% and an average reduction of + 50 mesh particles in the kiln feed from 3.6% to 1.9%.

We believe that wet grinding is an important development to save fuel and reduce operating costs and that the Dorrco reactor has proven itself to be superior in handling wet rock slurries. In addition, we believe that present and future power costs warrant consideration for a proven closed circuit grinding system.

FIGURE 4
WET ROCK GRINDING SYSTEM - CLOSED CIRCUIT FLOWSHEET



2. Use of Coarse "Unground" Rock

Table 4 shows the particle size of a number of phosphates that are treatable without further grinding or with screening and minimal grinding. Using rock without grinding can save about $1.00 to $1.50 per ton of rock or about $4.00 per ton of P_2O_5.

TABLE 4 - SIZE ANALYSIS, PHOSPHATE ROCK

Cumulative % Plus

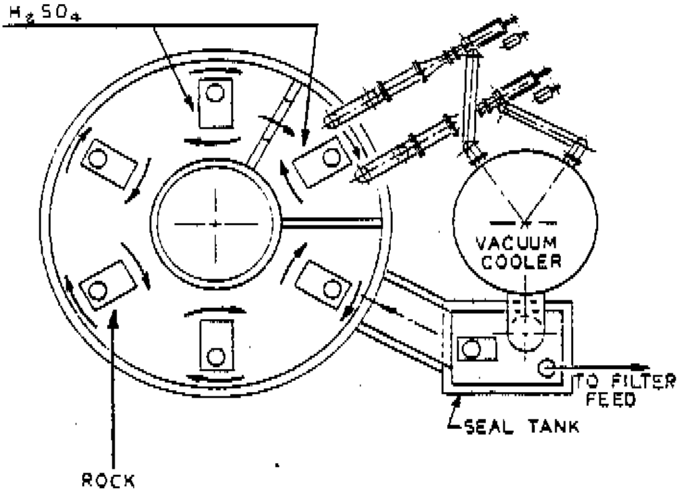
	Morroco *				Central Florida - 75 BPL Float Concentrate				Western		
Tyler Mesh	Khour.	Safi	* Taiba	North Carolina	* Typical	Scalped at 20 Mesh	* N. Fla.	N. Fla. Screened	Wyo.*	Idaho*	Vernal
									Calcined		
14					2.5				5.5	11.4	
20	3.0		0.5		4.2	0.2	4.5	0.2	8.5	15.3	
28	7.0	2.0	4.0	1.9	5.3	1.4	9.0	1.8	13.3	21.8	0.2
35	15.0	7.0	11.0	8.1	15.1	11.6	30.0	12.7	19.1	29.6	2.4
48	30.0	17.0	22.0	28.0	30.7	27.8	52.0	35.8	26.9	39.0	9.0
65	52.0	32.0	39.0	68.0	56.2	54.5	85.0	71.4	36.8	48.4	27.0
100	78.0	65.0	55.0	92.8	88.9	88.5	96.0	85.1	51.1	58.0	56.0
150	94.0	86.0	70.0	99.0	97.2	97.0	99.0	91.7	64.0	66.5	78.0

*Require screening or benefiting by screening prior to digestion. Screening should take place in the beneficiation plant so that a wet feed can be handled and drying omitted, except in cases where calcined rock is used.

In the future we see more effort being made to integrate rock beneficiation processes with phosphoric acid manufacture. It does not make sense to make a 28-35 mesh separation during beneficiation and then mix the coarse and fine products and finally grind everything for acid manufacture. The use of "unground" wet rock improves the plant water balance as compared with ground rock slurry since it can be fed at 16% moisture or less. This is a 65% reduction in the water fed with the rock.

The Jacobs-Dorrco Single Tank Reactor presents an option for running relatively coarse phosphates as shown in Figure 5. This system utilizes the bulk of reaction volume to digest coarse rock at an optimum sulfate level; this is as high as possible to minimize solid solution loss and to minimize poorly filterable gypsum but low enough to prevent rock coating. Other systems attempt "rock wetting" in relatively small digestors where the finer phosphate is preferentially attacked at low sulfate levels. In the Dorrco system a second stage sulfate adjustment to provide optimum filtration is accomplished by further sulfuric addition to the vacuum cooler feed compartment. The reactor configuration in Figure 5 is actually our present reactor design, the only variation being that with relatively coarse rock we have the option of running what is essentially a very large rock dissolving stage.

FIGURE 5
JACOBS-DORRCO REACTOR FOR COARSE ROCK



In the system shown here the sulfate levels in the two zones may be varied by anything from zero to as much as 1.0% or more depending on particle size and reactivity of the rock. The first rock digestion zone may be maintained, for example, at 2.0 ± 0.2% total SO_4 and the second zone maintained at 2.5 ± 0.2% total SO_4.

Of course, pebble cannot be handled this way but some relatively coarse phosphates can be treated by a preliminary screening on 20 or 28 mesh and grinding only this fraction. Phosphate rocks from the new South area deposits in Florida may fit into this category, which would include phosphate rocks containing from 20 to 40% plus 35 mesh.

Providing the above features to the basic Jacobs-Dorrco phosphoric acid system does not add significantly to the capital cost of the plant or to the operating costs. However, the increased ability to use rock without grinding can be economically very significant. The average costs involved in grinding, whether it be wet or dry, can be given as follows:

TABLE 5 - ROCK GRINDING COSTS

	$/t Rock	$/t P_2O_5
Power 10-15 kWh/t Rock	0.30-0.45	$1.00-$1.50
Interest & Depreciation @ 10% of capital		$1.50-$2.00
Labor		$ .10
Maintenance		$ .35-$ .40
Overhead, taxes, insurance		$ .50-$ .65
		$3.35-$4.65

Range, average, about $4.00/t

Against above \$4.00/t P2O5 savings in operating and capital costs, some increased solid solution loss, estimated at \$1.00 per ton of P_2O_5 (for rock cost @ \$20 to \$30/ton) are expected from this system compared to using a finely ground rock. For some users this may sound like a low rock cost, but it is probably a high number since most acid is now being made at or near mining areas. The net savings for unground rock are in the range of \$2.00 to \$3.00 per ton of P2O5. If a 3 to 5 year payout for incremental capital is used instead of 10 years, the savings for unground rock are possibly double the above values, and are steadily on the increase since power and capital are generally increasing faster than the cost of phosphate rock.

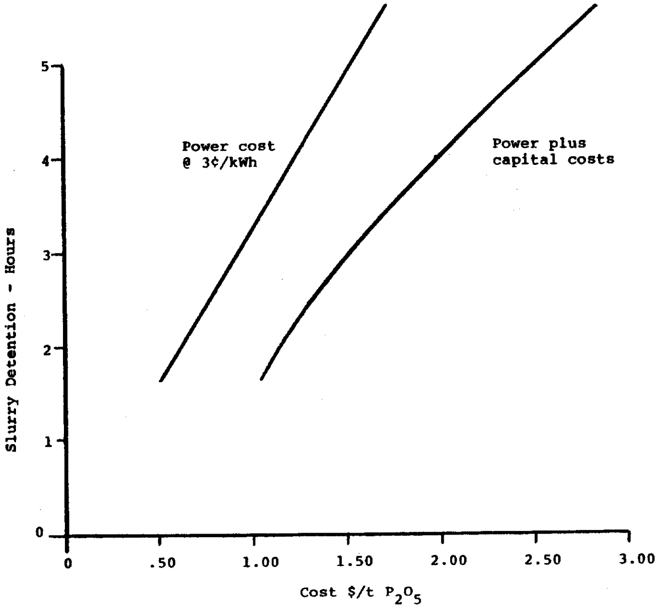
3. Phosphoric Acid Reactor Design

There has been some effort in recent years to reduce the power used in dihydrate phosphoric acid digestion systems, in some cases by utilizing one large mixer of one variety or another. One reference(3) indicates reactor power as low as 14 kWh/t P2O5. Power consumption for the Jacobs-Dorrco reactor will run about double this, about \$0.40 to \$0.50 per ton of P_2O_5 more, based on 3 cent power.

However, we believe this is money well spent because it maintains a clean reactor and also offers the means for substantial cost savings in defoamer. As mentioned previously in this paper, early Dorrco reactors consumed relatively high quantities of defoamer especially at high operating rates and low detentions. Figures in the range of 20 to 30 pounds per ton of P2O5 were reported at times. This problem has been greatly relieved by increased freeboard and by the installation of paddlers. However, we believe there is substantial room for improvement yet. In our latest design we offer a proprietary paddler configuration which is field adjustable to draw as much as 15% of the total agitation power at the slurry interface. This degree of energy input for defoaming has not been achieved in any Dorrco reactor to date but we believe that energy levels like this, which only represent \$0.10 to \$0.15 per ton of P_2O_5, will replace many times as much chemical cost plus reduce downstream rubber problems, even with the very dirty rocks which may need to be treated in the future.

Figure 6 shows partial operating costs for a Jacobs-Dorrco reactor. The figures represent an operation at 680 t/d of P2O5 instantaneous rate, using 3 cent power and a 5 year payout on the capital cost of the reactor.

FIGURE 6
JACOBS-DORRCO REACTOR POWER AND CAPITAL COSTS



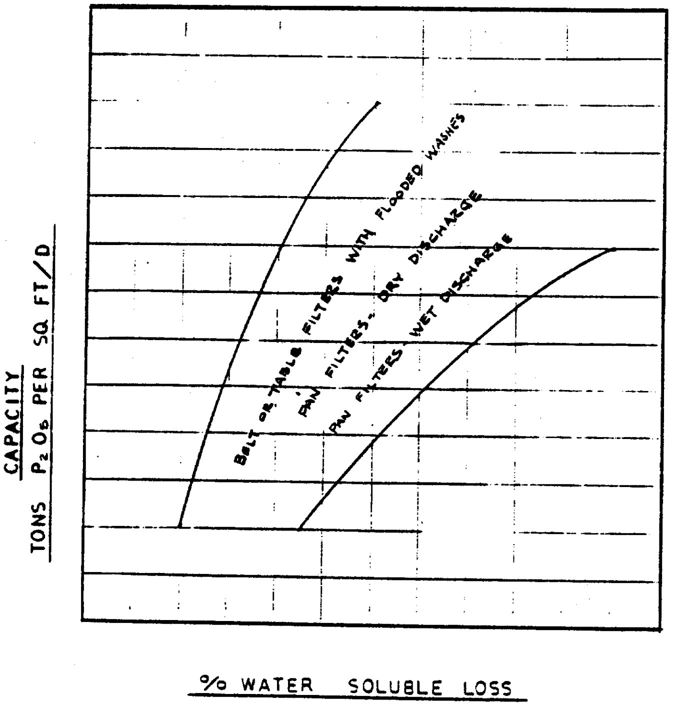
The data shows that reducing detention time by a factor of two within the range considered, will reduce operating costs by about $1.00 per ton of P_2O_5. Against this must be charged any increase in defoamer and in losses. According to the Agrico Dorrco reactor performance, it would appear that the higher throughput would result in savings. However, the data also shows these savings not be be substantial compared to using wet rock, "unground rock" or even the savings possible in filtration station design which we will cover next.

The agitation system in the latest Jacobs-Dorrco reactor design provides positive downward pumping by means of two pitched blade turbines on each shaft. Together with the annulus walls which deflect slurry upward, this impeller configuration provides good top to bottom slurry turnover.

4. Filtration Station Design

Dorrco plants have been constructed with Bird-Prayon, Prayon, Eimco and Landskrona filters. We have collected a lot of data on wash efficiency of the filters used in phosphoric acid making and our data shows the general correlation given in Figure 7.

FIGURE 7 - FILTER WASH EFFICIENCIES



Belt or table filters with flooded washes, in our experience, show a higher wash efficiency for a given filtration rate. Their efficiency can be approached by tipping pan filters using a dry discharge and washing the wet heel and cloth with water which is subsequently put on the filter and used as process wash water. There are several Dorrco plants operating abroad with this dry discharge system using tipping pan filters.

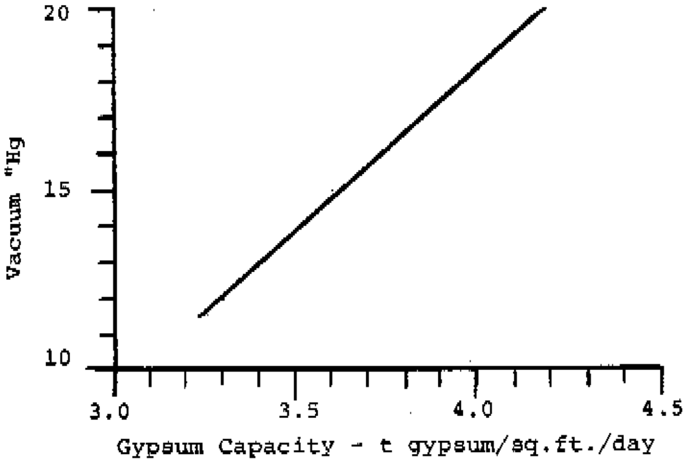
Water soluble losses generally vary from about 0.5% to 1.0% up to 2.0% to 2.5% of the P_2O_5 fed for operation in reasonable ranges of capacity. While there are some other factors that affect this loss, the loss is generally a function of capacity of operation and the type of filter used for a given phosphate rock. In many instances it is possible to save at least 1.0% to 1.5% of the P_2O_5 fed, by judicious selection of the type and size of filter. This means we are looking at a saving of about $2.00 to $2.50 per ton of P_2O_5, based on 1% water soluble P_2O_5 being worth $1.50.

Although belt filters have been around a long time, there is substantial renewal of interest and several new and relatively large belt filters are now available in wider belt configurations.

Belt filters, have another significant potential advantage in operating at shorter filter cycles, where P_2O_5 capacity per square foot of area is substantilly higher. Nordengren(4) has indicated a correlation in which capacity is very nearly a function of the square root of the cycle time. Leaf tests by the Dorrco procedure[5] do not show quite this much advantage for the shorter cycles, but the advantage is still significant and at least in the range of 20% to 30%, and much greater if a single large rotating pan filter is compared with multiple belt filters.

Belt filters generally operate at less vacuum than pan or table filters. This is probably inherent in their design because of the necessity for having long sliding surfaces. In essence they trade away the capacity advantages of higher vacuum operation for the higher capacity available because of shorter filter cycle time. Figure 8 shows a correlation on a gypsum test slurry using the Dorrco test procedure[5] to illustrate the effect of vacuum on capacity. There are indications that filter scaling at the strong acid receivers and lines can be greatly reduced by operating in the 12" to 15" Hg vacuum range.

FIGURE 8
GYPSUM FILTRATION CAPACITY
VERSUS VACUUM



We believe there will be a trend to the use of more filter area and very likely to more use of belt filters. Larger filter areas will have the following benefits:

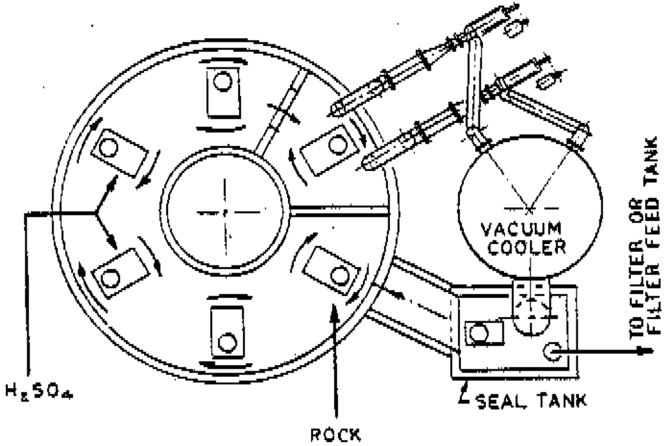
(a) Better water soluble recovery
(b) Better on-stream factor
(c) More area available, therefor higher product acid strength is possible due to less dilution of strong acid.

Also more area offers the capability to filter slurries containing higher strength acid. A one percent increase in P_2O_5 strength at the 28% P_2O_5 range is worth about $1.00 per ton P_2O_5 at present fuel oil costs.

V. JACOBS-DORRCO REACTOR DESIGN

The configuration of the Jacobs-Dorrco Reactor constructed in concrete is shown in Figure 9. The design has been worked out to include the best features from existing Dorrco plants as modified and some further modifications that we see as improvements.

FIGURE 9
JACOBS-DORRCO PHOSPHORIC ACID REACTOR SYSTEM



The general annular configuration of the reaction zone has been preserved from the original Dorrco design. The system incorporates the following features:

1. Agitation using downward pumping twin turbine impellers with rugged paddlers, field adjustable for minimum defoamer consumption. Reactor designed to handle low grade, "coarse" rock.

2. A separate vacuum cooler feed compartment to provide for degassing of the cooler feed slurry for improved pumpability and reduced vacuum requirements.

3. A field adjustable weir located where the annulus slurry overflows to the cooler feed compartment. This offers the option of trading freeboard for slurry volume according to the type of rock being used and to provide further level adjustment for improved paddler action.

4. Downflow cooler design.

5. Option of spare installed cooler feed pump. Option of two coolers.

6. Elimination of slurry short circuiting; rock and gypsum must travel around the annulus to the cooler feed compartment.

7. Filter feed is cooled slurry.

8. Optional filter feed tank. Reactor freeboard provides substantial slurry storage, but filter feed tank can be provided if desired.

9. Option of the use of wet rock as slurry or as unground float concentrate (-28 mesh).

10. A proprietary system of Dorrco design for the introduction of 93% of 98% H_2SO_4 into the digestor.

11. The Jacobs-Dorrco Reactor is offered in concrete construction with membrane and carbon brick lining. The Dorrco concrete reactor at Coromandel in India, 15 meter diameter vessel, has been in service since 1968, without significant maintenance.

VI. FUTURE TRENDS

1. Modifications as a Strategy to Increased Production

We have already seen the addition of substantail filter capacity to six wet acid plants in the U.S. and Canada as a means for increasing capacity and/or for utilization of rocks exhibiting poor gypsum filtration characteristics.

Many existing plants can be run at substantially higher capacities by additional filtration and cooling facilities. We see this also as a trend in new dihydrate plant design - smaller reactors and larger filters.

2. Jacobs-Dorrco Convertible System for High Strength Acid

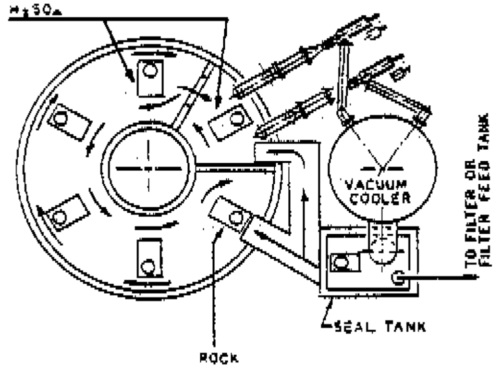
Earlier in this paper we touched upon various factors that influence the cost of making phosphoric acid. A major cost item is evaporation. About three quarters of the energy required to evaporate acid to 50% - 54% P_2O_5 is expended getting to the 42% - 44% level. This cost is roughly about \$15.00/t of P_2O_5 including capital and labor. So compared to using wet rock which saves \$5 to \$6 or "unground" rock which might save \$3 or \$4 per ton P_2O_5, the cost to evaporate is fairly substantial if steam is charged in at normal fuel costs.

Dorrco engineered the first large double crystallization hemihydrate plant for 250 t/d P_2O_5 at Rikkihappo (now Kemira Oy) in Siilinjarvi, Finland.(6) The plant made 42% to 44% P_2O_5 acid directly off the filter, and operated successfully for over 3 years as a hemihydrate process. Overall P_2O_5 recovery was below the goal for a double crystallization process because recrystallization was incomplete due to the rare earths contained in Kola rock. Hemihydrate filtration was excellent. However, scaling was severe and filterability of the recrystallized gypsum was poor. Attempts were made to improve the yield and to reduce the hemihydrate insoluble P_2O_5. Ultimately the solid solution P_2O_5 was reduced from 1.5% to 1.6% P_2O_5 dry basis in the hemi to 1.1% to 1.2%. After a partial recrystallization of this hemi and a normal water soluble loss, only about 96% P_2O_5 recovery was achieved, below the goal of 98% recovery. This, coupled with several other factors including an immediate need for expanded output and equipment delivery time problems, resulted in the plant reverting to dihydrate operation with evaporation, and it is now running as a 400 t/d P_2O_5 dihydrate plant.

Substantial experience was gained in both pilot plant and commercial operation of hemihydrate from several varieties of rock including Florida rock. We believe there is a real potential for energy and capital cost savings in the hemi route. However, the operating factor for such an operation versus a dihydrate process is something that cannot be established except by extended operation at commercial plant scale. Therefore we believe it makes sense to consider a convertible type plant.

Figure 10 shows the alterations required to allow the Jacobs-Dorrco Single Tank Reactor System to operate as a hemihydrate system. A launder splitting the cooler return slurry flow is required as shown. This will make it possible to have a low sulfate zone in the annulus of the reactor and a higher sulfate level in the cooler feed compartment, cooler and seal tank zone. Digestion operation, as in Finland, would be about 80°C to 85°C.

FIGURE 10
JACOBS-DORRCO HEMIHYDRATE PHOSPHORIC REACTOR SYSTEM



In one version of the process the hemi can be filtered preferably in a filter providing for both cloth and filter grid washing, recrystallized to gypsum in recycled pond water in one or more stages and pumped to a pond where the gypsum is settled out of the weak P_2O_5 solution. We expect the insoluble P_2O_5 in the hemi from Florida rock to be 1.3% to 1.8% P_2O_5 on a dry basis depending on the rock particle size, and that about 30% to 40% of this P_2O_5 will be recovered from the recrystallization and pond separation. The process proposed is similar to the Dorrco HYS process(7) except the pond is substituted for the second stage filtration step. Overall recovery is about comparable to present dihydrate process plants and the conversion to high strength acid production at reasonable yields does not require a second filter.

We believe the savings via the hemi route warrant serious consideration for the hemi process. But we also believe the prudent route is by a convertible plant.

3. Uranium Recovery

Several uranium extraction plants are now in the process of initial operation, construction or design. The extraction of uranium is generally considered to be potentially able to add revenues of from \$25 to \$40 per ton of P_2O_5 for those acids yielding about a pound of U_3O_8 per ton of P_2O_5. This is based on a sell price of \$25 to \$40 per pound of U_3O_8.

If uranium can be recovered from phosphoric acid at a cost of \$15 to \$20 per pound of U_3O_8, then the net revenues compare very favorably with the potential process savings listed previously and summarized below.

	Potential Savings \$ per ton of P_2O_5
Uranium Recovery	10 - 20
Wet rock slurry feed	5 - 6
"Unground" rock use	3 - 4
Hemihydrate	15

Table 6 lists uranium contents for a variety of commercial phosphate rocks. These analyses were compiled over a number of years by the U.S. Department of Agriculture(8), but do not necessarily represent values for rock presently being mined and beneficiated. However, the table does indicate that many phosphate rocks are likely to yield uranium profitably.

TABLE 6

URANIUM IN PHOSPHATE ROCK

	Uranium mg/kg*
Florida Pebble	127-222
Morocco	141-300
North Carolina	79
Tennessee	11-16
Western U.S.A.	114-183
South Carolina	399
Algeria	104
Tunesia	48

*Median, 3 to 17 samples(8)

REFERENCES

1) "Manufacture of Phosphoric Acid from A.A.C. Black Rock Using the Dorr-Oliver Single Tank Reactor"
Kronseder, Kulp, Leyshon and Jaeggi
Fertilizer Industry Round Table, 1965 - Washington, D.C.

2) "Wet Grinding of Phosphate Rock"
Gregory D. Loughrie, CF Industries
A.I.Ch.E., May 1976 - Daytona Beach, Florida

3) "The Isothermal Process for Producing Wet Process Phosphoric Acid"
Q. D. Bowers
A.I.Ch.E., May 1975 - Daytona Beach, Florida

4) "Landskrona Travelling Belt Filter for Wet Process Phosphoric Acid Filtration"
R. Nordengren
A.C.S., August 1973 - Chicago, Illinois

5) "Continuous Pilot Plant for the Manufacture of Phosphoric Acid"
D. W. Leyshon and W. A. Lutz
I. & E.C., September 1961

6) "Dorr-Oliver HYS Phosphoric Acid Process"
Weber, Roberts, Mangat, and Uusitalo
Fertilizer Society, December 1969 - London, England

7) U.S. Patent No. 3,552,918 - Process for the Production of Phosphoric Acid; Fitch and Roberts
January 5, 1971

8) "Uranium, Radium and Thorium Content in Phosphate Rocks and Their Possible Radiation Hazard"
R. G. Menzel
J. Agr. and Food Chemistry, Vol. 16, No. 2, Mar.-Apr. 1968