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ECONOMIC BENEFITS AND PRACTICAL ASPECTS OF CONVERTING
TO THE HEMIHYDRATE ROUTE FOR PHOSPHORIC ACID.

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SUMMARY

There is a trend in the fertilizer industry to convert existing dihydrate phosphoric acid plants to hemihydrate technology. This results in improved ease of operation, energy savings and increased P_2O_5 recovery for a relatively low capital investment. Most converted plants utilise Norsk Hydro technology and three recent examples are examined in this paper. Details of the conversions of the full-scale commercial plants by the Royster Company, USA, Supra AB, Sweden and Belle-dune Fertilizers, Canada are provided. Operating data where available are also given.

Following from the details of the conversion, a review of capital cost is presented. In addition, a production cost comparison for the hemihydrate, hemidihydrate and dihydrate process is provided. This shows a saving of between US \$24-35 per tonne P_2O_5 when using the hemihydrate processes. The achievement of these economic benefits is explained.

HEMIHYDRATE TECHNOLOGY: COMMERCIAL PLANT OPERATION

The production of phosphoric acid by the hemihydrate route is no longer experimental. Hemihydrate plants have been in fullscale commercial operation since 1970, (1, 2). Whereas Norsk Hydro continues to develop and improve its hemihydrate technology, it is clear that the process has been established in commercial production worldwide. Tables 1 and 2 show the operating companies and the different phosphate rock feed stocks which have been used. In addition, a considerable number of other phosphates have been tested in our hemihydrate pilot plant facilities, these are shown in Table 3, (3).

Table 1NHL Hemihydrate Technology: Commercial Plants

Client	Country	Start-up	Process
Windmill	Holland	1970	HH
RMHK Trepca	Yugoslavia	1974	HDH
A & W	UK	1980	HDH
CSBP	Australia	1981	HDH
Pivot	Australia	1981	HDH
HCI	Cyprus	1982	HH
Windmill*	Holland	1983	HH
Royster*	USA	1985	HH
Belledune*	Canada	1986	HH
Supra*	Sweden	1986	HDH
NFC	Thailand	1987	HDH

* Plant conversion from dihydrate unit.

Table 2
NHL Hemihydrate Technology: Commercial Plants

Client	Country	Capacity tpd P ₂ O ₅	Rock Feed
Windmill	Holland	610	Togo
RMHK Trepca	Yugoslavia	160	Jordan
A & W	UK	500	Morocco
CSBP	Australia	500	68 Florida
Pivot	Australia	100	68 Florida
HCI	Cyprus	130	Algeria
Windmill*	Holland	330	72 Florida
Royster*	USA	586	66 Florida
Belledune*	Canada	500	68 Florida
Supra*	Sweden	360	Florida/Morocco/ Jordan
NFC	Thailand	810	Florida/Morocco/ Jordan

* Plant conversion from dihydrate unit.

Table 3NHL Hemihydrate Technology:
Phosphates tested in Laboratory and Pilot Plant

Phosphate Rock	
Florida	various grades
Khouribga	various grades
Calcined North Carolina	
Uncalcined North Carolina	
Langebaan	
Sahara	
Araxa	
Jordan	
Nauru	
Syrian	
Taiba	
Vernal	
Wooley Valley	
Phalaborwa	
Duchess	
Gafsa	
Calcined Idaho	
Togo	
Kola	
China	
Nauru	

Many representatives from the world fertilizer industry have visited these plants over recent years. Consequently the features and benefits of the technology have become well known. This has led to subsequent conversion of existing dihydrate plants to the hemihydrate processes.

This trend is particularly relevant at the present time because of the limitation on capital spending. Plant conversions can usually be achieved at low cost compared to the capital requirement for a new plant installation. The cost of a plant conversion will depend on the compatibility of the hemihydrate technology with the existing dihydrate plant equipment, (4). In order to demonstrate how full-scale commercial plants can be converted, details of the conversion projects at Royster, USA; Belledune, Canada; and Supra, Sweden are provided.

PRINCIPLES OF PLANT CONVERSION

Before undertaking a plant conversion it is necessary to define the process operations which are to be achieved. The main points of the single stage hemihydrate (HH) process and the two stage hemidihydrate (HDH) process are given below:

HH Process

Figure 1 shows the major operations involved in the HH process. Reaction and filtration are the key process steps. The hemihydrate reaction proceeds in two distinct zones. It is therefore necessary to provide at least two vessels or compartments with a volumetric ratio of approximately 2:1. Some filter feed buffer capacity is desirable between zone 2 and the filter.

Phosphate rock is fed to zone 1; sulphuric acid and dilute phosphoric acid ("return acid" from the filter) are fed to zone 2. Slurry from zone 2 is recycled to zone 1, thus exposing the phosphate rock to sulphate ions under controlled conditions to promote the reaction.

Heat is removed to maintain the reaction slurry temperature between 98-100°C. Both air and flash cooling are satisfactory.

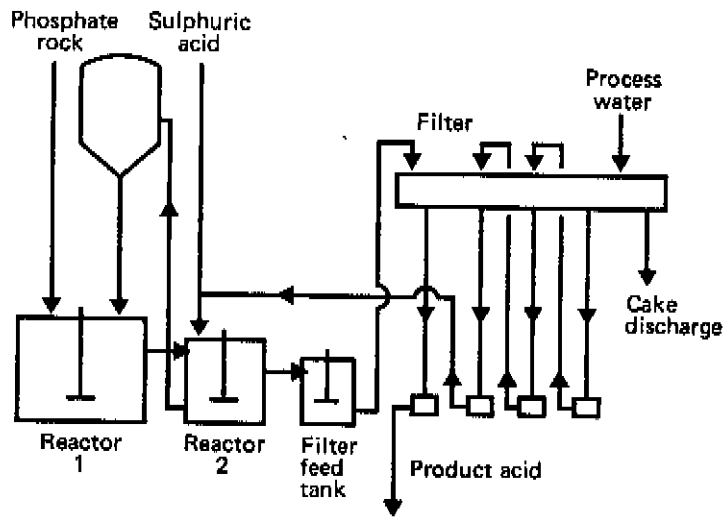
The product acid and hemihydrate are separated by a horizontal vacuum filter with counter current wash stages. Product acid from the filter passes directly to storage. It does not require clarification or solids removal. More details can be found in (1).

HDH Process

The HDH process is a development of the HH route whereby the P_2O_5 recovery efficiency is increased to around 98.5%, (5). This is achieved by adding a second process stage in which hemihydrate is converted to dihydrate under controlled conditions thus releasing P_2O_5 into solution which can be recovered and returned to the process. A simplified flowsheet is shown in Figure 2.

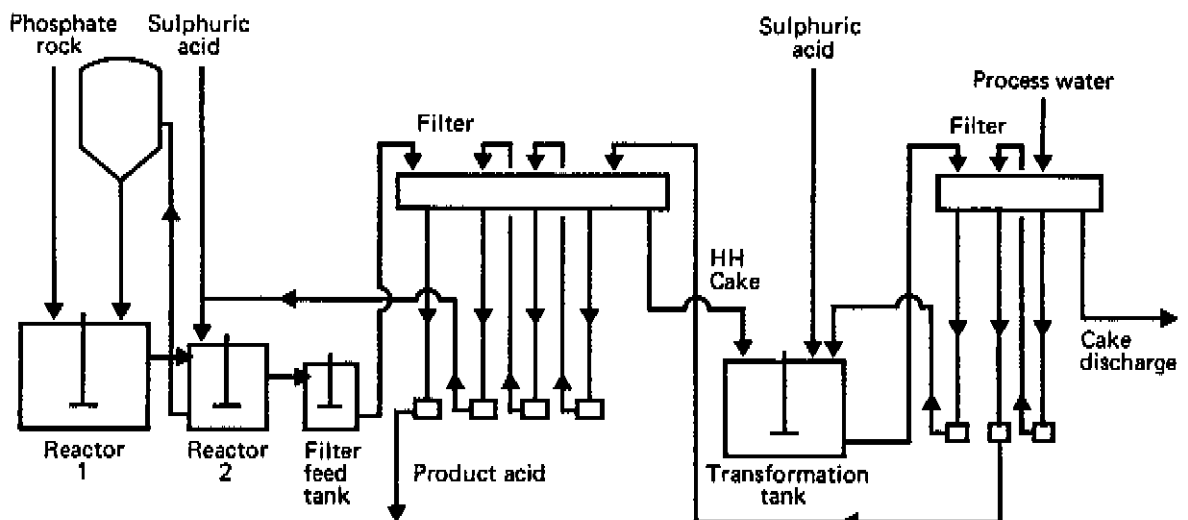
The first stage of the process is almost identical to the hemihydrate section previously described.

Figure 1



Hemihydrate Process

Figure 2



Hemidihydrate Process

The hemihydrate cake is discharged from the first stage filter into an agitated transformation tank. In this tank the operating conditions are controlled to ensure complete transformation of hemihydrate to dihydrate and to allow sufficient time for the dihydrate crystals to grow. The rate of transformation is increased by the addition at this stage of a small proportion of the sulphuric acid feed. Nearly all the lattice P_2O_5 co-precipitated with the hemihydrate is released into the liquid phase.

The dihydrate slurry is then filtered and the cake washed with process or pond water before being discharged. The filtrate containing the released P_2O_5 is returned to the hemihydrate reaction stage as the last wash on the hemihydrate filter.

Unit Operations

The main unit operations to be considered in a conversion project are:-

Phosphate Rock Feed

The hemihydrate process can normally accept a coarser particle size analysis of phosphate rock than the dihydrate process (see Table 4). Therefore a plant converted to hemihydrate technology can utilise the existing rock feed and preparation system with minimal modifications.

Table 4
Comparison of Rock Grind Requirements
for HH/HDH and DH Processes

Aperture (Microns)	Particle Size % Through	
	HH/HDH	DH
1700	100	100
500	75	95
250	25	60
150		30
75		

Reaction

Although hemihydrate operation requires two reaction zones, these can take place in a number of compartments or vessels. The reactor residence time is of a similar order to conventional dihydrate processes. Therefore it is generally possible to operate the hemihydrate process utilising dihydrate reactors with the minimum of disruption and minimum investment. Materials of construction of dihydrate reactors are normally satisfactory for hemihydrate duty.

Agitation

Following developments in agitator and reactor design, the agitator power requirement in the hemihydrate stage of the process is not significantly different from that of the dihydrate process. However because of the higher P_2O_5 in the liquid phase, the hemihydrate reaction slurry normally has a higher viscosity and higher specific gravity than dihydrate slurry. The effect of this needs to be examined and can be compensated for if necessary by reducing the speed of rotation or diameter of the agitators to the level where the absorbed power matches the installed power of the motor and gearbox.

Cooling

NHL normally designs hemihydrate plants to utilise a flash cooling system, however air cooling can be used and is easily adapted to the hemihydrate system.

The heat of reaction when producing calcium sulphate hemihydrate is approximately 20% lower than when producing the dihydrate form. Furthermore the hemihydrate reaction slurry is cooled to $100^\circ C$ whereas the dihydrate slurry is cooled to $80^\circ C$ requiring extra cooling capacity. As a result the reaction cooling load in the hemihydrate process is lower than in the dihydrate process. The acceptable temperature differential across a flash cooler in a hemihydrate system is larger than in a dihydrate plant therefore the cooling capacity of an existing flash cooler can be increased. Scaling in the flash cooler in a HH/HDH plant does not occur.

Gas Scrubbing

Because the operation of a hemihydrate process is at a higher temperature than a dihydrate plant it results in increased fluorine evolution mainly as SiF_4 , in the exhaust system. The degree of fluorine evolution is dependent on the level of impurities (for example, silica, aluminium) in the phosphate rock being processed. It is therefore necessary to examine an existing gas scrubber system to assess whether it can cope with the increased fluorine levels in the reaction exhaust gases.

Filtration

Although the filtration rate of hemihydrate slurry can be lower than that of dihydrate slurry, because of hemihydrate permeability and acid viscosity, with many widely used phosphates such as Togo and Florida there is little if any penalty on filtration when producing acid below 45% P_2O_5 .

Commercial hemihydrate plants have used belt, table and tilting pan filters, each of which has been satisfactory. Therefore the use of an existing filter of these types is not expected to present a problem.

Transformation

The rate of transformation of hemihydrate to dihydrate can vary with different phosphate rocks. Normally it is sufficient to provide a residence time of 2-3 hours and a small flow of sulphuric acid.

However the transformation rate can be increased if necessary, by chemical additives.

Agitation in the transformation stage though important is not critical and a simple mixing system will suffice.

THE ROYSTER PROJECT (6)

The Royster Company is a part of the Superfos Denmark group. Its fertilizer complex in Mulberry, Florida, USA incorporates a 600 tpd P_2O_5 phosphoric acid plant, 1100 tpd DAP plant and 1500 tpd sulphuric acid plant.

The phosphoric acid plant was originally a Prayon unit which in 1982 underwent a capacity boost with installation of additional equipment. In 1986 the plant was converted to the Norsk Hydro HH process. The main features of the HH conversion are that:

- wet rock grinding is eliminated
- cooling duty is satisfied with only one of the two existing flash coolers
- production rate is achieved with only one of the two existing filters
- acid for DAP is produced directly from the filter and the concentration step avoided.

Royster decided to convert to the HH process "based on current economies with provisions for future conversion to HDH"(6).

The justification for the conversion was the savings in production costs. "The economies appeared extremely favourable and included increased energy recovery by elimination of wet rock grinding, reduced steam requirements for phosphoric acid evaporation (producing more electric power), and for the hemihydrate process, a 4% to 5% increase in rock recovery"(6).

In order to convert the Royster plant to the HH process the following modifications were made to the unit operations:

Rock Handling

Because the HH route accepts a coarser phosphate than the DH process, it was possible to use a Florida spiral concentrate thus avoid rock grinding. As a result some of the existing rock intake and grinding system were bypassed, and the 65 BPL Florida rock fed as received to the plant. A chemical analysis of the rock is given in Table 5 and a size analysis in Table 6.

Reaction System

The original Royster plant was a Prayon unit with 12 compartments; a simplified flowsheet is given in Figure 3.

In order to convert to a hemihydrate unit the system was arranged as follows:

Compartments 1 - 6A	=	HH Zone 1
Compartments 7, 7A, 8	=	HH Zone 2
Compartments 9, 10	=	HH Filter.

A simplified flowsheet is shown in Figure 4.

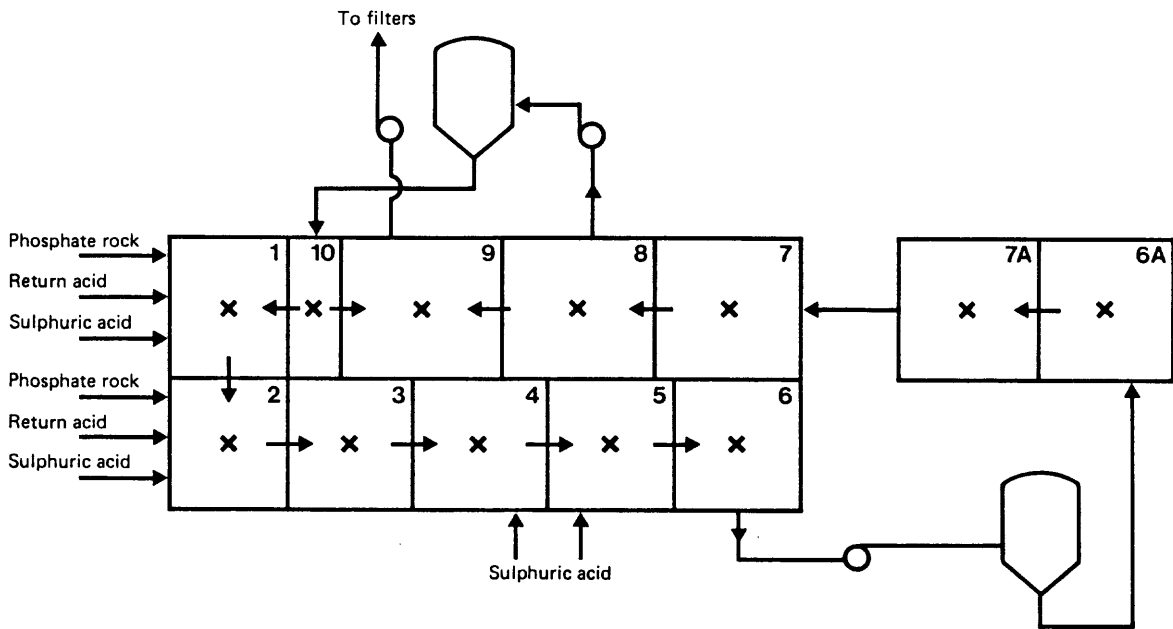
Table 5Florida Phosphate Used by Royster: Chemical Composition

Component	% w/w d.b.
P ₂ O ₅	30.5
CaO	44.9
SO ₃	0.93
F	3.43
Cl	0.0048
SiO ₂	8.46
Na ₂ O	0.57
K ₂ O	0.08
MgO	0.40
Al ₂ O ₃	1.97
Fe ₂ O ₃	1.49
CO ₂	3.74
Organic	0.40
Combined H ₂ O	2.67
Free H ₂ O	12.0

Table 6Florida Phosphate Used by Royster: Size Analysis

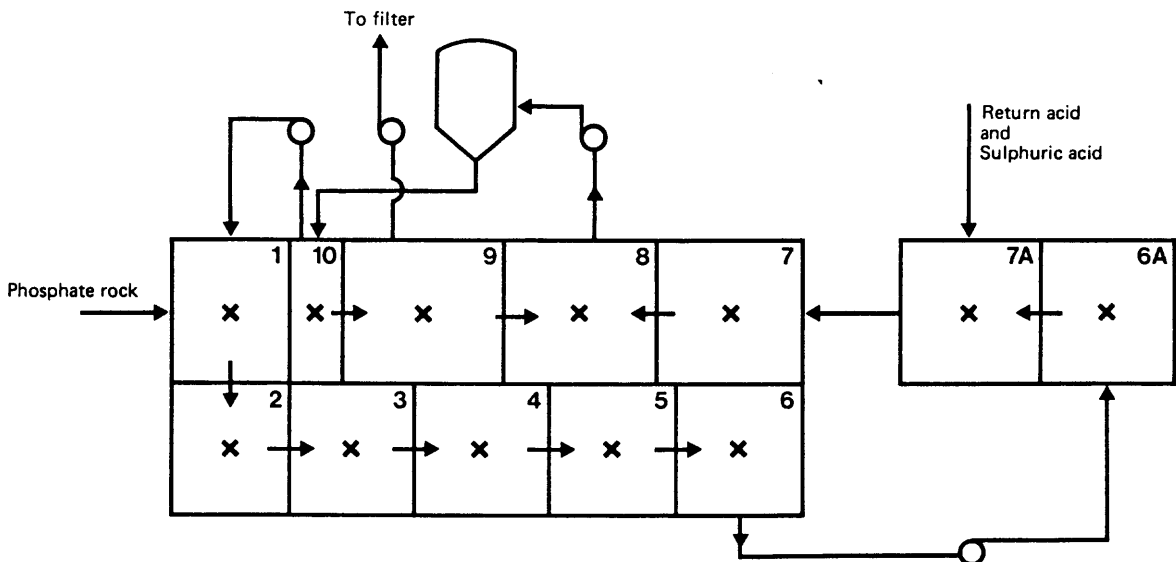
Aperture (mm)	Cumulative % Through
1.67	99.7
1.40	98.0
1.00	82.0
0.60	44.2
0.50	33.6
0.421	27.7
0.355	22.9
0.300	18.4
0.250	14.1
0.212	10.5
0.180	7.7
0.150	4.6
0.125	2.8
0.105	1.9
0.088	1.4
0.076	0.8

Figure 3



Royster's Original Prayon Reaction System

Figure 4



**Royster's Converted Plant:
Hemihydrate Reaction System**

The internal reactor walls remained intact except that an overflow weir from compartment 1 to compartment 2 was created.

The cooling duty was satisfied by only one of the two existing flash coolers thus reducing operating costs.

A new slurry recycle pump was installed in compartment 10 to provide a controlled flow of slurry into compartment 1. This slurry recycle rate is lower than when operating in the dihydrate mode, so again costs were reduced.

Agitation

The existing agitators, most of which are constructed from 317 stainless steel, were used and proved to be satisfactory.

Filtration

There were two existing filters at Royster, a Bird 24B and 24D. In order to achieve the design production rate it was necessary to use only the 24D filter. In fact during the first six months of operation capacities exceeding design were achieved with only one filter. The material of construction of the filter pans is 316L stainless steel and is satisfactory.

The hemihydrate crystals produced are typical in shape and size and are shown in Figure 5.

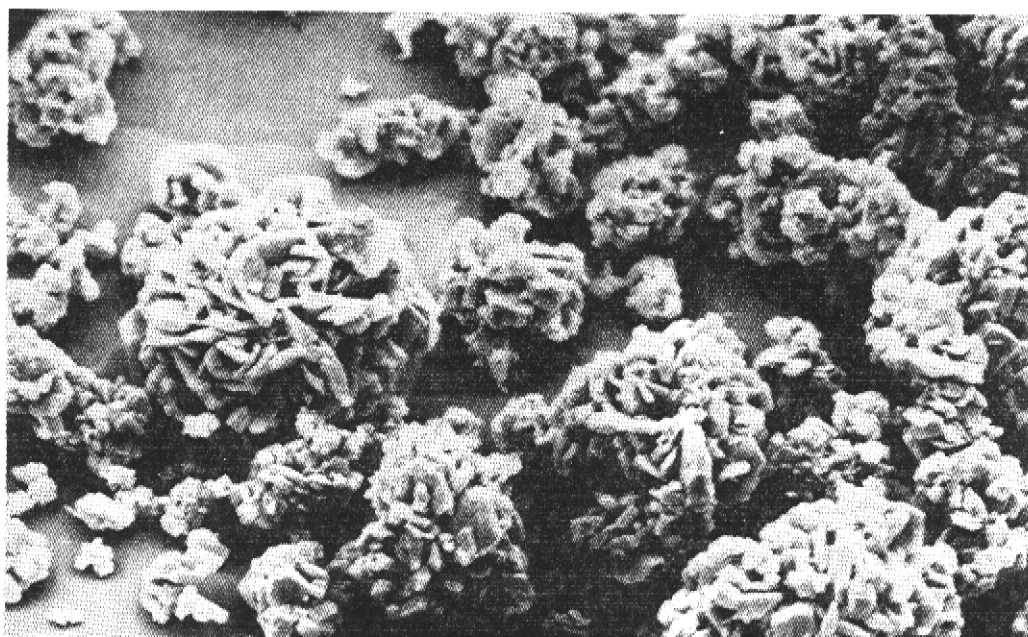


Figure 5 Royster Hemihydrate Crystals

Gas Scrubbing

A supplementary gas scrubbing system was added, to accept part of the off-gases from the reactor and filter hood. It operated without problem. The exit gas contained 0.0063 lbsF/t P_2O_5 which was within guarantee.

Commissioning

The commissioning proceeded smoothly with only two areas requiring special attention. These were slurry gasification and hemihydrate disposal.

Gasification

As with all processes using Florida rock, foaming or gasification occurs in the reaction slurry. At Royster this caused cavitation in the transfer pump from compartment 6 to 6A. However a change in the defoamer used and a modification to the pump soon overcame the problem.

Hemihydrate Disposal

In order to avoid problems by hemihydrate hydration, Norsk Hydro specify the use of an anti-scale additive in their HH plants. However Royster decided to start the plant without using the additive. Consequently it ran into problems with the stacking of the hemihydrate in the conventional pond system. An alternative additive was then used and found to be ineffective. So the originally specified anti-scale additive was eventually used and the problem disappeared. The hemihydrate is well suited to the pond disposal system as can be seen in Figure 6.



Figure 6 Disposal Pond at Royster, Florida

The cost of the additive is approximately US \$0.7/t P_2O_5 produced.

Plant performance

A comparison of achieved and guaranteed performance is shown in Table 7.

Table 7
Royster HH Plant Performance

Item	Guaranteed Value	Achieved Value
Production Rate	586 tpd P ₂ O ₅	600 tpd P ₂ O ₅
P ₂ O ₅ Recovery	92.5%	93.8%
P ₂ O ₅ in Product Acid	42% P ₂ O ₅	42% P ₂ O ₅
SO ₄ in Product Acid	1.7%	1.7%
Solids in Product Acid	1.0%	1.0%

THE SUPRA PROJECT

The original phosphoric acid unit at Supra was a Dorr Oliver dihydrate plant with a production capacity of 240 tpd P₂O₅. Supra decided to convert to the HDH process and boost the production capacity to 360 tpd P₂O₅, producing 42% P₂O₅ acid directly from the filter.

The main features of the conversion are that:

- P₂O₅ recovery efficiency is increased to over 98%.
- 42% P₂O₅ acid produced thus eliminating the concentration step and so achieving substantial energy savings.

The combination of reduced raw material costs, energy savings and increased P₂O₅ production has ensured a satisfactory return on investment and justified the conversion.

The conversion required the following changes to the unit operations:

Rock Handling

The HDH plant is designed to operate with Khouribga, Florida and Jordan phosphates. Because the process accepts a coarser particle size than the DH route, Supra have bypassed the rock grinding mill, and the rock is fed to the plant as received.

Thus savings in rock grinding costs have been made.

Reaction System

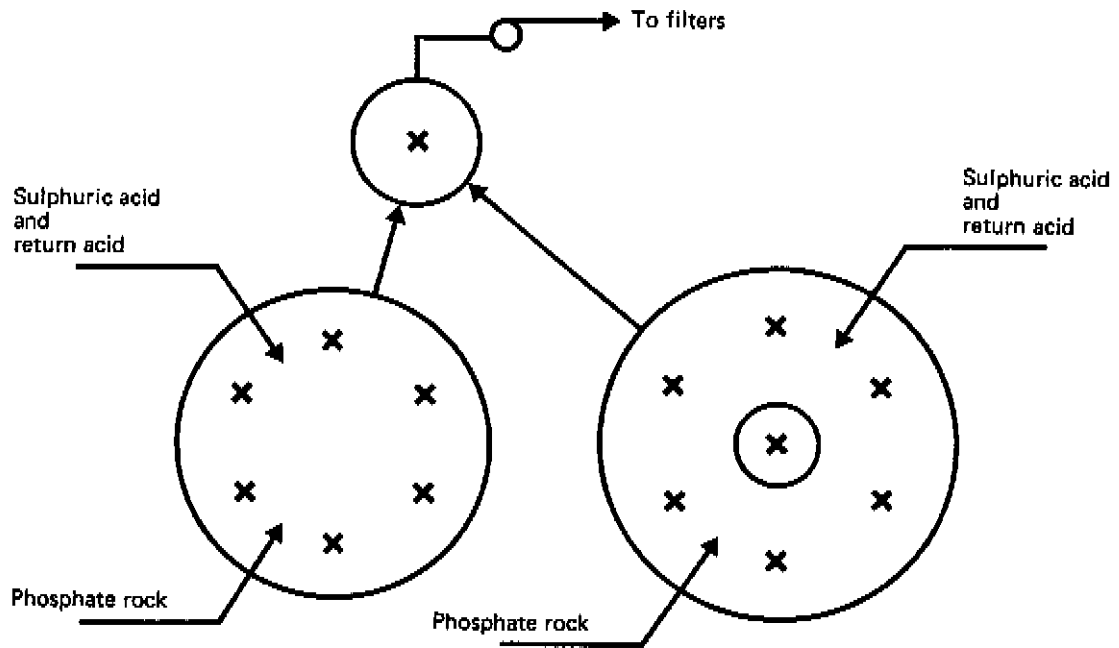
The original Supra plant was a two reactor Dorr Oliver unit. A sketch is shown in Figure 7.

In order to meet the increased production rate, supplementary reaction volume was added. A sketch of the hemihydrate stage of the system is shown in Figure 8.

The existing air cooling system was in need of extensive maintenance and therefore was replaced by flash cooling.

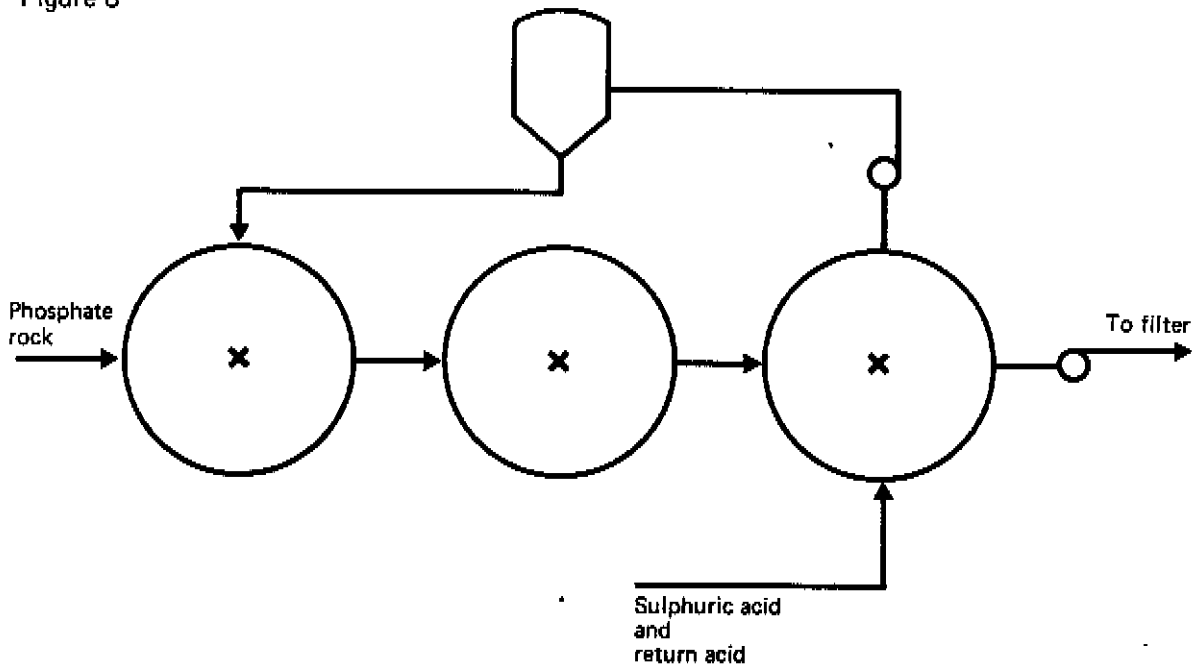
A new slurry recycle pump was installed for the slurry flow from zone 2 to zone 1.

Figure 7



Supra's Original Dorr-Oliver Reaction System

Figure 8



Supra's Converted Plant: Hemihydrate Stage Reaction System

HH Filtration

The existing plant incorporated three belt filters of 15 m² effective area each. These will be used for dihydrate filtration in the transformation stage of the HDH plant. Hemihydrate filtration takes place on a new belt filter supplied by Delfilt. A chute has been fitted at the cake discharge end to direct the hemihydrate cake into the transformation tank.

Gas Scrubbing

The gas scrubbing system was revamped by Supra.

Transformation

Hemihydrate filter cake passes into a new transformation tank where it converts to gypsum and is filtered on the existing belt filters. The first filtrate is returned as hemihydrate cake wash. The second filtrate is returned to the hemihydrate stage as filter cloth and chute wash. Thus the P₂O₅ recovered in the transformation stage is retained in the system and the P₂O₅ recovery is improved.

THE BELLEDUNE PROJECT

Belledune Fertilizer is a Division of Brunswick Mining and Smelting Corp., Ltd. in New Brunswick, Canada. The phosphoric acid plant was originally a Prayon unit before it was converted to the Norsk Hydro hemihydrate process. The phosphoric acid plant receives sulphuric acid from a nearby smelter, the product is used exclusively for DAP manufacture. The main features of the converted plant are:

- simplified plant operation
- sulphuric acid dilution cooling eliminated
- 42% P₂O₅ acid produced from filter thus avoiding concentration step and achieving energy savings
- plant capacity maintained with existing reactor and filter.

The simplified plant operation and savings in fuel costs has ensured a satisfactory return on investment and justified the conversion.

To convert to the hemihydrate route the following modifications were made to the plant.

Rock Handling

The rock intake system is to be used without modification. Although the grinding mill remains in the circuit, the duty is reduced as the HH unit will accept a coarser rock than the DH process. Therefore savings in grinding costs have been made.

Reaction System

The original Belledune reaction system was a Prayon unit with nine compartments, a simplified flowsheet is shown in Figure 9. In order to convert to hemihydrate operation the system was arranged as follows:

- | | | |
|--------------------|---|------------------|
| Compartments 1 - 6 | = | HH zone 1 |
| Compartments 7, 8 | = | HH zone 2 |
| Compartment 9 | = | Filter Feed Tank |

A simplified flowsheet of the converted reactor is shown in Figure 10.

The internal walls remained intact except that an overflow weir from compartment 1 to compartment 2 was installed, and an underflow from 8 to 9.

The cooling duty was satisfied by the existing flash cooler such that the existing sulphuric acid dilution cooling could be removed. This reduced maintenance and down-time costs.

A new slurry recycle pump was installed to provide a controlled flow from compartment 8 to 1.

Agitation

The agitators in compartments 1, 2, 7 and 8 have been replaced to improve agitation whilst reducing power consumption thus saving on operating costs. The remaining agitators are used without modification.

Filtration

The existing filter is used with no loss of production capacity. Modifications have taken place to improve drainage thus reduce water soluble P_2O_5 losses. New systems to reduce scaling in the filter circuit have been installed.

Gas Scrubbing

A supplementary gas scrubbing system was added to act in series with the existing scrubber and thus ensure adequate fluorine removal.

Hemihydrate Disposal

Apart from the use of an anti-scale additive to prevent hemihydrate hydration in the pipeline, the disposal system remains the same as it was for dihydrate duty.

PRODUCTION COSTS

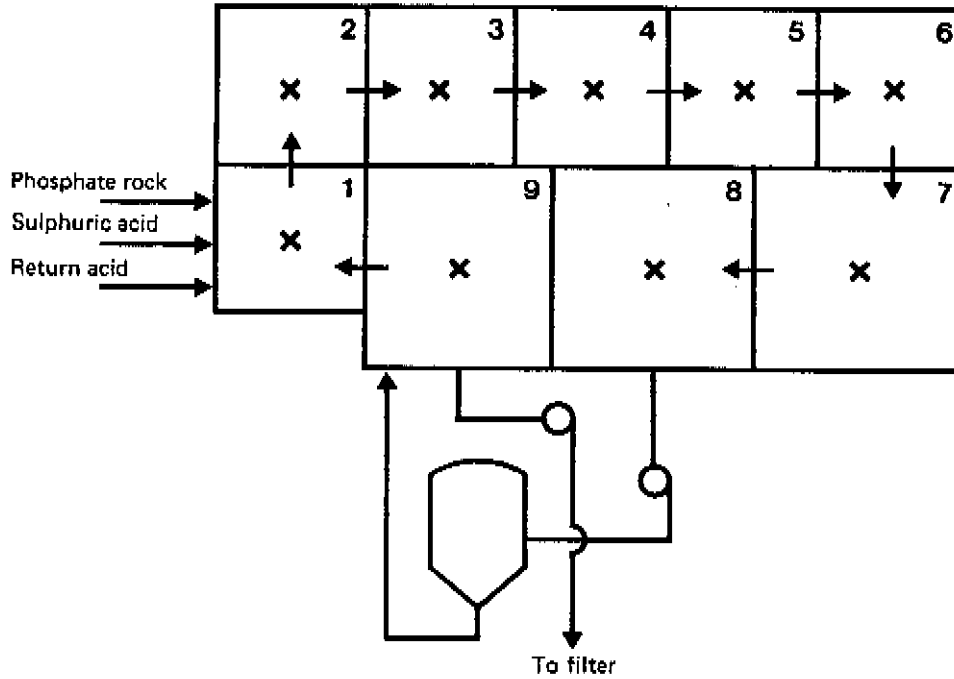
Since a hemihydrate phosphoric acid plant converted from an existing dihydrate plant incorporates the principal process features of a purpose-built hemihydrate unit, it also enjoys a similar operating cost benefit. Because this can be achieved with a capital expenditure of a fraction of that required for a new plant, the return on investment is attractive and can be over 100%.

The factors affecting production cost include raw materials consumptions, utility consumptions and the usage of other chemicals. All these factors, the most significant of which are phosphate rock, sulphuric acid and steam, are considered in more detail below.

Phosphate Rock

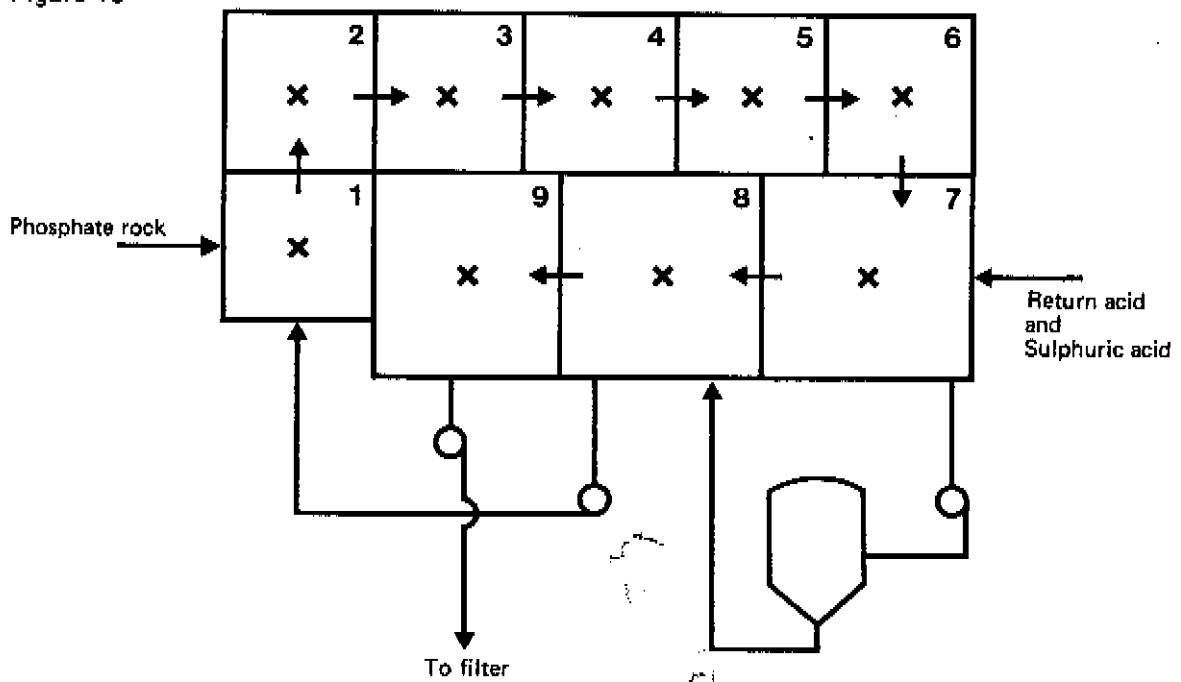
The consumption of phosphate rock is determined by the overall efficiency of the phosphoric acid production process. The single stage hemihydrate has a recovery similar to dihydrate, whilst that of the two-stage hemidihydrate is significantly higher. In both hemihydrate cases the losses associated with intermediate storage, evaporation and clarification are avoided.

Figure 9



Belledune's Original Prayon Reaction System

Figure 10



Belledune's Converted Plant: Hemihydrate Reaction System

Effective costs of phosphate rock are sensitive to freight charges. Thus the potential savings of the HDH route are of greatest interest when freight costs are high, for example in Western Europe or the Far East.

Sulphuric Acid

The consumption of sulphuric acid per unit of phosphoric acid produced depends on the analysis of the phosphate rock and the overall P_2O_5 recovery. Thus comments made above in relation to rock consumption also apply here.

In addition, the sulphuric acid consumption is affected by the free SO_4 in the product. Since 40-50% P_2O_5 hemihydrate acid contains 2% SO_4 compared to 4-5% SO_4 in concentrated dihydrate acid, the usage of sulphuric acid is reduced.

Electricity

Power consumed in the hemihydrate process is almost identical to that consumed by the dihydrate route including concentration, and amounts to about 100 kWh/t P_2O_5 . However the ability of the hemihydrate process to consume coarse phosphate rock avoids the usual grinding operation. This allows an important saving of electricity to be made amounting to about 30 kWh/t P_2O_5 .

Steam

In the dihydrate route the concentration stage is a major consumer of steam. When producing 45% P_2O_5 acid from 28% P_2O_5 filter acid this amounts to nearly 2 tonnes steam/tonne P_2O_5 . Apart from a small consumption for heating filter cake washing water, the hemihydrate process totally avoids the need for this steam, thus offering a major potential saving.

In the case where steam has to be generated deliberately by the combustion of hydrocarbon fuel, a saving representing the full value of the fuel is possible. Furthermore the operating and maintenance costs of the boiler can also be avoided.

Alternatively in the case where steam is available as a by-product, e.g. from an adjacent sulphuric acid plant, another use for the surplus steam can be considered. Of increasing interest is its utilisation for generation of electricity. Our information suggests that electricity generation can be increased by approximately 60% when using a condensing set turbo-alternator following a HH/HDH operation compared to a back-pressure set which is required with DH operation. The value of the electricity can range from the fuel cost avoided by the utility company to the full commercial price of power to the consumer. This will depend on local circumstances, however there is considerable current interest in co-generation projects.

Process Water

Considering the water balance for the hemihydrate route it is evident that less process water is called for (as filter cake washing water eventually being recycled to the reactor) because of the higher product strength.

This is even further reduced for the single stage process since less water of crystallisation is rejected with the hemihydrate filter cake.

A saving in process water can be an important consideration when it is in short supply.

Cooling Water

The cooling load of a hemihydrate unit is less by 20-40% than the equivalent dihydrate plant. This results from the lower heat of reaction and the greater natural losses by operating at a higher temperature. Consequently the load on a vacuum cooler condenser is reduced leading to lower cooling water consumption.

Avoiding the consumption of cooling water in the dihydrate concentration unit condenser permits a further substantial saving.

Defoamer

Because of the higher density and viscosity of a hemihydrate reaction slurry there is a tendency for gasification to occur. This is controlled to avoid reducing the reactor retention time and other operational difficulties by use of defoaming agents. The usage for hemihydrate, whilst not being excessive, is slightly higher than usual for the dihydrate route.

Chemicals

As explained earlier it is sometimes necessary with certain rocks to introduce a chemical additive to the filter system to avoid premature hydration of hemihydrate crystals.

The chemical is widely available and is of modest cost.

Operating Cost Tables

Tables 8 and 9 illustrate the comparative operating costs for producing 45% P_2O_5 acid by the single stage hemihydrate (HH) process, the two-stage hemidihydrate (HDH) process and the dihydrate route. Florida 68 BPL rock is assumed in each case. Table 8 refers to a rock-mine location where the freight cost element for rock is low. Table 9 refers to a Western European location where rock is costed in at a higher price.

It can be seen that at either location the single stage hemihydrate process shows a cost advantage of over US \$24/tonne P_2O_5 . When using the two-stage HDH process, this increased to over US \$31/tonne P_2O_5 at a rock-mine location and even more - nearly US \$36/tonne - for a Western European site.

These figures have been calculated using a steam value equivalent to burning hydrocarbon fuel for its generation, namely US \$11/tonne. For by-product steam from a sulphuric acid plant it is usual to allocate a value of about US \$6/tonne.

Table 8
Typical Raw Material and Utility Costs in US Dollars per tonne P₂O₅
Producing 45% P₂O₅ Phosphoric Acid at a Rock Mine Location From
Florida 68 BPL Rock

Item	Units	Price (US \$)	Hemihydrate (HH)		Hemidihydrate (HDH)		Dihydrate (DH)	
			Consumption per tonne P ₂ O ₅	Cost (US \$)	Consumption per tonne P ₂ O ₅	Cost (US \$)	Consumption per tonne P ₂ O ₅	Cost (US \$)
Phosphate Rock	tonnes	20	3.41	68.20	3.26	65.20	3.41	68.20
Sulphuric Acid	tonnes	45	2.70	121.50	2.60	117.00	2.80	126.00
Steam	tonnes	11	0.18	1.98	0.18	1.98	1.90	20.90
Electricity	kWh	0.05	100	5.00	110	5.50	136	6.80
Process Water	m ³	0.02	6	0.12	6.5	0.13	7	0.14
Cooling Water	m ³	0.005	27	0.13	30	0.15	70	0.35
Defoamer	kg	1.50	1.0	1.50	1.0	1.50	0.7	1.05
Chemical	kg	0.80	1.0	0.80	1.0	0.80	-	-
TOTALS				199.23		192.26		223.44

Table 9

Typical Raw Material and Utility Costs in US Dollars per tonne P₂O₅
Producing 45% P₂O₅ Phosphoric Acid at a Western European Location From
Florida 68 BPL Rock

Item	Units	Price (US \$)	Hemihydrate (HH)		Hemidihydrate (HDH)		Dihydrate (DH)	
			Consumption per tonne P ₂ O ₅	Cost (US \$)	Consumption per tonne P ₂ O ₅	Cost (US \$)	Consumption per tonne P ₂ O ₅	Cost (US \$)
Phosphate Rock	tonnes	50	3.41	170.50	3.26	163.00	3.41	170.50
Sulphuric Acid	tonnes	45	2.70	121.50	2.60	117.00	2.80	126.00
Steam	tonnes	11	0.18	1.98	0.18	1.98	1.90	20.90
Electricity	kWh	0.05	100	5.00	110	5.50	136	6.80
Process Water	m ³	0.02	6	0.12	6.5	0.13	7	0.14
Cooling Water	m ³	0.005	27	0.13	30	0.15	70	0.35
Defoamer	kg	1.50	1.0	1.50	1.0	1.50	0.7	1.05
Chemical	kg	0.80	1.0	0.80	1.0	0.80	-	-
TOTALS				301.53		290.06		325.74

Even at this reduced steam value the savings are attractive - over US \$15/tonne P₂O₅ for the HH process and over US \$22 and US \$27/tonne P₂O₅ for the HDH route at rock-mine and Western European locations respectively.

Individual producers' costs are unlikely to coincide exactly with the examples given, but insertion of the specific figures will give a similar outcome.

Production of 50% P₂O₅ acid is possible with the HH process but at the penalty of reduced recovery of P₂O₅. As a result it is common for best economics to produce filter acid at 45% P₂O₅ and evaporate to the required higher concentration. In this case the production cost benefit quantified above will be retained.

No recovery penalty results in the production of 50% P₂O₅ acid by the HDH process. In this case further savings in steam consumption and cost benefits can be achieved.

Summary of Cost Savings

The savings shown in Tables 8 and 9 are summarised below and translated to annual savings for two typical production capacities.

Table 10

Location	Process	Saving (US\$) per tonne P ₂ O ₅	Annual Saving (million US\$)	
			300 t P ₂ O ₅ /day	600 t P ₂ O ₅ /day
Rock-Mine	HH	24.21	2.2	4.5
	HDH	31.18	2.9	5.8
Western Europe	HH	24.21	2.2	4.5
	HDH	35.68	3.3	6.6

Capital Cost of Conversion

The actual capital cost (including new equipment, modifications to existing equipment, instruments, electrics, engineering, construction and licence fees) will clearly vary from plant to plant. It will also be affected by equipment already requiring replacement or modification as a result of wear and tear or external changes, such as emission controls. However studies carried out by Norsk Hydro and conversions already completed indicate a range of costs from US \$0.75 million to US \$2.5 million.

The return on investment (ROI) on all projects studies has been extremely attractive, in some cases approaching 200%. The minimum has been about 50%. Few companies in the phosphates business would find such potential unattractive.

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TA/86/2 Economic benefits and practical aspects of converting to the hemihydrate route for phosphoric acid by B.T. Crozier & J.D. Crerar, Norsk Hydro Fertilizers Limited, United Kingdom

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

Q - Mr. N. LOUIZOS, Hellenic Fertilizers, Greece

Influence on the economy of hot water recovered from H₂SO₄ plant.

A - Even with the use of low grade recovered heat, the HH process still achieves production cost savings with the reduction in phosphate rock grinding and fewer unit operations. In the HH process it is not necessary to operate sulphuric acid dilution, intermediate storage and acid clarification as well as concentration and thus production and maintenance costs are reduced.

Q - Mr. A. BOURGOT, Prayon-Hupel, Belgium

1. Differences of P₂O₅ efficiency between DH and HH processes
2. Steam consumption in DH process
3. Operating time.

A - 1. The figures given in table 8 were obtained from an actual plant study. The recovery of 94% based on cake losses can be achieved in practice and has been reported by N. Kolmeijer in a paper "Hemihydrate Performance of Florida Rock in a Converted Phosphoric Acid Plant" presented to the Fertilizer Industry Round Table in October 1985.

It is also the case that when you consider all the unit operations in a dihydrate plant, for example rock grinding, reaction, filtration, intermediate storage, two stages of acid concentration, acid clarification, then the P₂O₅ efficiency is much lower than 95%. In our experience in the USA, many DH plant operators report an overall recovery of 90-91%.

2. The steam consumption in acid concentration depends on steam quality (temperature and pressure) and filter acid strength which is often 27-28% P₂O₅, therefore the figure of 1.9 t steam/t P₂O₅ is realistic.
3. Again if you consider all the unit operations in a DH plant then the on-stream time is typically 310 dpy, because of such factors as washing of concentration plant heat exchangers, removing sludge from intermediate storage, maintenance on grinding mills, etc...

It was also reported by N. Kolmeijer at the British Sulphur Conference in November 1983 (see Proceedings page 579) that in real life the on-stream time of a HH plant is the same or better than a DH unit.

Q - Mr. L.K. RASMUSSEN, Royster, USA

Is the HH process only attractive for plants burning fossil fuel?

A - The benefits of the HH process are lower production costs due to reduced rock grinding, simplified operation, improved acid quality and avoiding acid concentration. These benefits can be applied to most phosphoric acid producers not just those which employ fossil fuel to produce steam.

Q - Mr. P. ORPHANIDES, Duetag, France

Is it expected that all the DH plants of Norsk Hydro will be converted in HH?

A - During the present poor P2O5 market conditions, fertilizer producers are examining ways of reducing costs. This includes the conversion to the HH/HDH route. Factors such as potential savings, capital cost, availability of funds, return on investment, use of steam, etc..., need to be evaluated. In most cases the results of this evaluation show that conversion to HH/HDH is profitable. This has led to the increasing trend to use HH/HDH technology, throughout the industry worldwide.

Q - Mr. N.A. HUMMADI, JPMC, Jordan

Impact of high operation temperatures on:

- 1 - Materials of construction
- 2 - Scaling, foaming and other operating problems.

A - 1. The materials of construction are affected more by the level of impurities, such as chlorine and fluorine, than by temperature. Most stainless steels which are suitable for use in a DH plant are also suitable in a HH/HDH plant using the same phosphate rock.

As for other materials, polypropylene, FRP, etc..., they are suitable at 1000° C and butyl and neoprene rubber can also be used.

2. Other performance factors:

Scaling: the deposition of fluosilicate scale is the same in the HH/HDH process as it is in the DH route. However, Norsk Hydro have developed know-how to reduce the rate of scale deposition and therefore extend the period of operation between washes.

Foaming: in a HH/HDH process the CO2 in a phosphate rock manifests itself by gassing the reaction slurry whereas in the DH plant it appears as foam on the surface of the slurry. However, both can be overcome by the use of conventional anti-foam agents.

Cooling: the heat of reaction in the HH process is approximately 20% lower than in the DH route; therefore the cooling load is reduced.

Rock grinding: the HH/HDH process will accept a coarser particle size phosphate rock than the DH plant; therefore the grinding load is reduced.

Q - Mr. P. SUPPANEN, Kemira Oy, Finland

Experience with hard magmatic rocks.

A - We have tested Kola and Phalaborwa phosphate rock and found exceptionally good performance in the HH process. For example, in producing 42% P₂O₅ acid directly from Phalaborwa rock, the HH process achieves a filtration rate of 9 tpd/m³ with a recovery efficiency between 94-95%.

however, in each case, the hemihydrate from these phosphate rocks is very stable and slow to convert to dihydrate. Therefore, a larger transformation volume is required than for sedimentary rocks.

Q - Mr. M. BARLOY, SCPA, France

Sensitivity of HH process to mal-operation.

A - The HH process is more tolerant of mal-operation than the DH route, for example poor sulphate control will not cause inhibition of the reaction in a HH plant whereas it would be in the DH process.

Q - Mr. W.H. PAULSON, Royster, USA

Determination of the P₂O₅ efficiency at BELLEDUNE.

A - The P₂O₅ efficiency at the Belledune phosphoric acid plant is based on the analysis of the (hemi) gypsum slurry discharge.

Q - Mr. A. HORNSHOJ-MOLLER, Kenobel, Sweden

1. Names of ineffective and effective defoamers
2. Improvement to slurry pumping due to change of defoamer or pump modification?
3. Names of anti-scale additives.

A - 1. The defoamer which was found to be ineffective was called Defoamer 2902L from SSC Industries Inc., Georgia, USA. Those which were found to be effective include Defoamer AZS23 from AZS Corporation, USA ; Surex 64A-3 from Basso Chemicals Inc., Florida, USA.

The modifications to the slurry pump included increasing the size of the impellor and modifying the suction line inlet.

2. The improvement in operation was mainly due to the effectiveness of the defoamer.
3. The name and type of anti-scale additive are confidential; however it is readily available throughout the world.

Q - Mr. S. SAIDI, ICM, Tunisia

Are both HH and HDH processes convenient for low grade phosphates, and what are the performances.

A - We have treated a number of low grade rocks in our processes. The product acid strength is normally 42% P2O5 with reaction volume in the range 1-3 m3/tpd P2O5.

Here are two examples:

(a) Rock analysis:

	28.4% P2O5
	48.7% CaO
	7.9% CO2
P2O5 Reaction Efficiency =	93.0%
H2SO4 Consumption =	2.75 t 100% H2SO4/t P2O5
Product Acid =	42% P2O5
Filtration Rate =	5.4 tpd P2O5/m2 effective

(b) Rock analysis:

	23.1% P2O5
	32.9% CaO
	34.7% SiO2
P2O5 Reaction Efficiency =	93.0%
Product Acid =	43% P2O5
Filtration Rate =	6.9 tpd P2O5/m2 effective

In both cases if the HDH process is used the P2O5 recovery is expected to increase to 98.5%.

Q - Mr. L. RAHAOUI, SAEPA, Tunisia

In relation of the high slurry temperature, what are:
 - the materials of construction
 - the limits of chlorine and fluorine
 - the frequency of shutdown for cleaning the circuits.

A - The materials of construction are:

Reactor: Concrete or mild steel lined with rubber and carbon bricks.

Reactor roofs: Rubber covered mild steel or concrete. Wood.

Agitator:

- Stainless steel such as 317 or UB6.
- Mild steel rubber covered.
- Polypropylene.

Pumps:

- Stainless steel such as 317 or UB6.
- Mild steel rubber covered.
- Plastic.

There are no limits on fluorine or chlorine for the HH/HDH process but the correct materials of construction are required for each case.

The typical washing routing is once per ten days. However, it can vary from rock to rock.

Q - Mr. A. CHARFI, ICM, Tunisia

Name of the anti-scaling agents.

A - The name of the anti-scaling agent is part of our know-how and as such is confidential. However, it is a simple chemical available worldwide.

Q - Mr. S. SAIDI, ICM, Tunisia

Crystallization of HH compared to DH.

A - In our tests to produce 43% P2O5 acid from Gafsa rock directly from the filter the HH process achieved a P2O5 recovery of between 95-96%. This is equivalent to, or even better than, that achieved in the conventional dihydrate route. The filtration rate was equivalent to that obtained in the DH process.

Q - Mr. Y. LOUIZI, SIAPE, Tunisia

1. Differences of P2O5 efficiency between DH and HH processes.
2. Influence of CO2 and organic substances in phosphate on HH process.
3. Reasons for capacity increase when converting a unit from DH to HH.
4. Influence of the raw materials cost in the savings.
5. Experience with GAFSA.

A - 1. In the HH process the overall P2O5 recovery is normally the same as in the DH route including acid concentration and clarification, etc... Therefore the phosphate rock consumption is the same in each case.

Because the product acid from the HH process contains a lower SO4 level than DH product acid, then the sulphuric acid consumption in the HH process is lower than in the DH.

In the HDH process, the P2O5 recovery efficiency is 98.5% which is higher than that achieved in the classic DH route; therefore the phosphate rock consumption in the HDH process is lower than the DH.

2. We have processed phosphates containing 7.9% CO2 and 0.4% organic and have achieved a hemihydrate filtration rate of 5.4 tpd P2O5/m2 when producing 42% P2O5 acid. The efficiency was 93%. This could be increased if the HDH process were used.
3. The increase in production capacity in existing plants which adopt our hemihydrate technology is achieved because our technology allows the existing plants to be de-bottlenecked. For example, the HH/HDH process requires less rock grinding, less cooling capacity, no sulphuric acid dilution, lower steam and cooling water consumption. In addition, existing reaction volume is often more than is necessary for the hemihydrate system.

A - 4. Table 9 in the paper is based on the actual costs of raw materials and utilities at a site in Western Europe, where we carried out a study. The same costs were used in each of the three cases compared in the table.

5. When we processed Gafsa rock in the HH plant, the product acid concentration was 43% P2O5 and the P2O5 recovery efficiency was between 95-96%.

The main difficulty in processing this rock was caused by the high CO2 level. It was necessary to control the gasification of the slurry with the use of an anti-foam agent.

Q - Mr. L.K. RASMUSSEN, Royster, USA

The table on page 2-22 shows the same rock usage for HH and DH. Normally HH has an inherently higher loss for 2 reasons (1) Higher lattice loss due to co-precipitated P2O5 and (2) less wash water can be applied to the filter. Can you explain?

A - In the production of 42% P2O5 acid the HH process does not necessarily have an inherently higher P2O5 loss. Although the lattice loss can be higher, it is normally near to the level obtained in dihydrate. However, significantly higher lattice losses have been reported when producing 50% P2O5.

Again, although the production of 42% P2O5 acid would require less water than a DH process producing 28% P2O5, often in the DH process a wet rock grinding plant is used and the rock is fed to the plant as a slurry containing 60% water. This reduces the water available to add to the DH filter. Sulphuric acid dilution cooling is another factor which reduces the cake wash water available in a DH plant.

Also in a HH plant we avoid P2O5 losses from the grinding plant, weak acid storage, sludge removal, acid concentration.

It has been reported by N. Kolmeijer in his paper "Hemihydrate Performance of Florida Rock in a Converted Phosphoric Acid Plant" to the Fertilizer Industry Round Table, October 1985, that the overall recovery of the HH and DH processes can be the same.

