DOUBLE EFFECT EVAPORATION OF CRUDE PHOSPHORIC ACID

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ABSTRACT

Traditionally, weak phosphoric acid produced by the wet process has been concentrated in single effect evaporators which require approximately 1.25 pounds of steam per pound of water evaporated. Recent modifications in materials of construction now make it possible for at least a part of the evaporation load to be handled in double effect evaporators where the energy requirement is approximately 0.760 pounds of steam per pound of water evaporated.

With the current trend to much higher steam costs, double effect evaporators can now be economically justified. Calculations will be presented comparing the steam consumption savings possible in a typical plant versus the capital cost of the equipment involved.

There are many equipment arrangements available to accomplish the unit operation of evaporation. The evaporators may be arranged as single stage single effect, multiple effect, or compounded in combinations. Physical and chemical properties of the process material dictate the proper arrangement of the equipment. For the purpose of this paper, a staged evaporator is defined as one that concentrates a feed solution to a predetermined discharge concentration by means of two or more single effect evaporators operating in series. For the purpose of this paper, effected evaporators are defined as those whose generated vapors are the heating medium in subsequent evaporators.

There are many applications of the principle of multiple effect evaporation in the chemical industries. Classic examples are the sextuple and septuple effect spent liquor evaporators of the paper industry, as illustrated in Figure I. Another example is the triple (Figure II) and, more recent, quadruple effect electrolytic caustic evaporators. These units are fabricated of relatively more expensive materials and require correspondingly higher steam costs to justify the additional effects. The recent installation of quadruple effect evaporators and conversion of triples to quadruples is dictated by the ever-increasing cost of energy.

Traditionally, weak phosphoric acid produced by the wet process has been concentrated in single effect staged evaporators (Figure III). There are two basic reasons for single effect concentration of wet process phosphoric acid. First, steam consumption in these evaporators has not been a concern because of a plentiful supply of relatively low cost steam in the phosphate fertilizer complex. Second, temperature limitations on proven materials of construction have prevented consideration of the higher pressures and temperatures required for multiple effect evaporation and to overcome the relatively high boiling point elevations encountered in the concentration of phosphoric acid.

Recent modifications in materials of construction now make it possible for at least a part of the evaporation load to be handled in a double effect evaporator where the energy requirement is approximately 0.760 pounds of steam per pound of water evaporated, as compared to approximately 1.25 pounds of steam per pound of water evaporated in a single effect evaporator.

The current trend to much higher costs and possible utilization of an imbalance in plant complex steam in alternate operations, such as power generation, requires serious consideration of the economics of double effect evaporators. In addition, improved recovery efficiencies in the wet process phosphoric acid operation are possible through increased filter cake wash, providing there is steam available to remove the additional water. Double effect evaporation would assist in accomplishing these improved recovery efficiencies with basically the same steam consumption.

The modified materials of construction permit, for the present, double effecting only part of the traditional evaporator load, that is, weak feed acid in the 28 to 29% P_2O_5 range to a product 42% P_2O_5. Acceptable materials of construction would limit the product temperature from the double effect to 225°F (107.2°C), for an average product concentration of approximately 42% P_2O_5.

Figure IV shows a temperature frame for a 100 ton per day single effect phosphoric acid evaporator system concentrating from a feed of 28% P_2O_5 at 125°F (51.7°C) to a product of 42% P_2O_5. Steam consumption for this unit would be 12,520 pounds per hour, including a 3% allowance for radiation and convection heat losses. Condenser water consumption would be approximately 424 gallons per minute of 90°F water.

Figure V shows a temperature frame for a 100 tons per day double effect phosphoric acid evaporator system. The liquor temperature in the first effect is at 225°F, within the limit for chlorobutyl rubber. The steam temperature at 290°F is below the 335°F operating limit for impervious graphite.

Figure VI shows a temperature frame for a triple effect system to produce 54% P_2O_5 from a 28% P_2O_5 feed. This illustrates how the liquor and steam temperatures in the first effect exceed the temperatures allowed for the accepted materials of construction. New alloys under test may permit operation of phosphoric acid evaporators under these temperatures in the future if steam costs justify the cost of the additional effect. In this case, the steam requirement would be approximately 0.510 pounds of steam per pound of water evaporated. Approximately the same steam requirement is necessary to concentrate from 28% P_2O_5 to 42% P_2O_5 in a triple effect.

A return to Figure V shows a temperature frame for a 100 ton per day double effect phosphoric acid system concentrating from a feed of 28% P_2O_5 at 125°F (51.7°C) to a product concentration of 42% P_2O_5. Steam consumption for the double effect would be 7,540 pounds per hour including a 3% allowance for radiation and convection heat losses. Condenser water consumption would be 806 gallons per minute of 90°F water.

The steam requirement for the single effect is 1.26 pounds of steam per pound of water evaporated. The steam requirement for the double effect is 0.760 pounds of steam per pound of water evaporated. This is a reduction in steam consumption of approximately 4,985 pounds per hour, or 40%. In many areas, steam costs are close to $4 per 1000 pounds. On the basis of an 8000 hour year, steam savings in this case would be approximately $159,520.00 per year.

Figure VII illustrates the utilities consumption and equipment size differences for various production rates, all based as before on feed acid at 28% P_2O_5 and a product acid at 42% P_2O_5. The 600 ton per day production rate will be considered as an example for a double effect system. A maximum liquor temperature of 225°F is selected for the first effect. This temperautre would be accomodated by using chloro-butyl rubber in the first effect. The vapor from this effect would be at 188°F and would be the heating medium in the second effect. The liquor temperature in the second effect would be 136°F.

The comparison is based on about the largest single effect heating element (600 tons per day) versus the double effect. The single effect would have a 17'-6" diameter vapor head (with single circulating loop) and require 75,143 pounds per hour of steam and 2,546 gallons per minute of water at 90°F maximum. The approximate price for this unit would be <u>$456,000.00</u>.

This capacity in a double effect would require an 11'-0" diameter and 17'-6" diameter vapor head for the first and second effect respectively (each with a single circulating loop) and would require 45,252 pounds per hour of steam and 4,837 gallons per minute of water. In actual practice, one might prefer that both vapor heads be 17'-6" in diameter to permit single effect operation in the event one unit was out for service (cleaning, maintenance, etc.). Vapor piping would be such that either unit could be run off one condenser or a stand-by condenser could be provided to permit conventional two-stage operation.

In order for a multiple effect evaporator to operate with reasonable cycles, the vapors from the boiling liquors must be relatively low in impurities that might foul the vapor side of the heat exchanger. In the concentration range 33% P_2O_5 to 42% P_2O_5, approximately 40 pounds of fluorine per ton of P_2O_5 are evolved from the boiling solution at 185°F.[2,3] For this case, then, approximately 1000 pounds per hour of fluorine would be evolved in the first effect with (5,214 x 6) pounds per hour of vapor in the form of hydrogen fluoride and silica tetra fluoride. Fortunately, these compounds are readily soluble in water to form fluosilicic acid.[4] In this case, with backward feed, there is a probability that fouling of the outside of the second effect heater tubes could be a problem if the vapors were not scrubbed. We have had indications that silica can be deposited on these tubes from silica tetra fluoride in the vapors.

If fluorine recovery was practiced in the first effect vapor head, it appears there would not be much of a problem as the bulk of the silica tetra fluoride would be removed in the fluorine recovery tower. If fluorine recovery was not used, then the vapors would be passed through a scrubbing tower to remove the bulk of the silica tetra fluoride and hydrogen fluoride. The pounds of fluorine per pound of water vapor from the scrubbing solution at a 10% concentration of fluosilicic acid at 167°F is approximately 0.00125 pounds of fluorine per pound of water[2] vapor which translates to ~~6.51~~ 39 pounds per hour of fluorine in vapors to the second effect heating element. The vapors may also be scrubbed with various solutions that would form soluble fluosilicates. Finally, sprays could be installed in the vapor side of the heating element to wash the outside of the tubes with condensate as has been done on surface condensers in this same type of service.[6]

A double effect evaporator temperature frame for forward feed is shown in Figure VIII. The steam requirement for forward feed is 0.714 pounds per pound of water evaporated, which is about 6-1/2% lower than backward feed. However, in those operations concentrating to 54% P_2O_5 as final product, the liquor from the second effect would be at 147°F and the sensible heat load on the 54% unit would cancel out any economy advantage of the forward feed over the backward feed.

The big advantage of the forward feed is that the vapors from the first effect are evolved from 33.3% P_2O_5 which are reported to contain very little, if any, fluorine.[2,5] Because of the variations in the composition of crude wet process phosphoric acid evaporator feeds, it is recommended that the vapors from the first effect be scrubbed to minimize fouling of the vapor side of the heating element.

The approximate selling price for the double effect 600 ton per day unit including the scrubbing tower would be $760,000.00.

The steam savings of 29,890 pounds per hour for the double effect on the basis of an 8000 hour year and $4 per 1000 pounds steam would have a value of approximately $956,480.00 per year. Thus, the steam savings of the double effect could pay for the additional equipment in approximately four months and approximately nine months on an installed basis.

The materials of construction for the double effect evaporator would be chlorobutyl rubber in the first effect vapor head, top and bottom liquor chamber, liquor circulating piping, and vapor piping, with standard three ply rubber lining in the second effect evaporator. The second effect heating element would have a 317L stainless steel shell and internal baffles with impervious graphite tubes. Alternately, the heating element might be of the multiple or stacked carbon block type with alloy or chlorobutyl lined shell.

Each phosphate fertilizer operation has to make its own evaluation. New plants are considering electric power generation from their plant complex steam source and, to maximize the available steam, are considering electrically driven motor power for operations formerly using steam, for example, mechanical vacuum pumps.

Existing plants should consider the possibilities of double effect evaporation as they operate to improve recovery efficiencies with a weaker feed to the evaporator section and resultant greater steam requirement.

Finally, there appears to be an increasing demand for P/F ratio over 100. These can be achieved by steam stripping the fluorine from the acid. If these defluorinated products required additional steam from fossil fuel fired boilers, double effect evaporation appears attractive in the initial concentration operation, and the steam saved would be available for the defluorination step.

1. "Upgrading Existing Evaporators to Reduce Energy Consumption", E.R.D.A., COO/2870-2.

2. Parrish & Sanders, "Fluorine Recovery from Wet Process Phosphoric Acid", Swift and Company, et al.

3. Kleinman, G., "Fluorine Recovery" Symposium on Wet Process Phosphoric Acid, 1965. Swenson Division, Whiting Corporation.

4. Kohl, A. J., "Gas Purification", pg. 172, Fig. 6-10 (Data Brosher, Lenfesty and Elmore).

5. Rushton, W. E., Internal Correspondence, Swenson Division, Whiting Corporation.

6. Khritunov, N. F., A. Ya Abramovitch, B. A. Kopylov, Soviet Chemical Industries, pg. 8900.

FIG. I

Eight body sextuple effect evaporator with forced-circulation concentrators at American Can Company, Halsey, Oregon. ▼

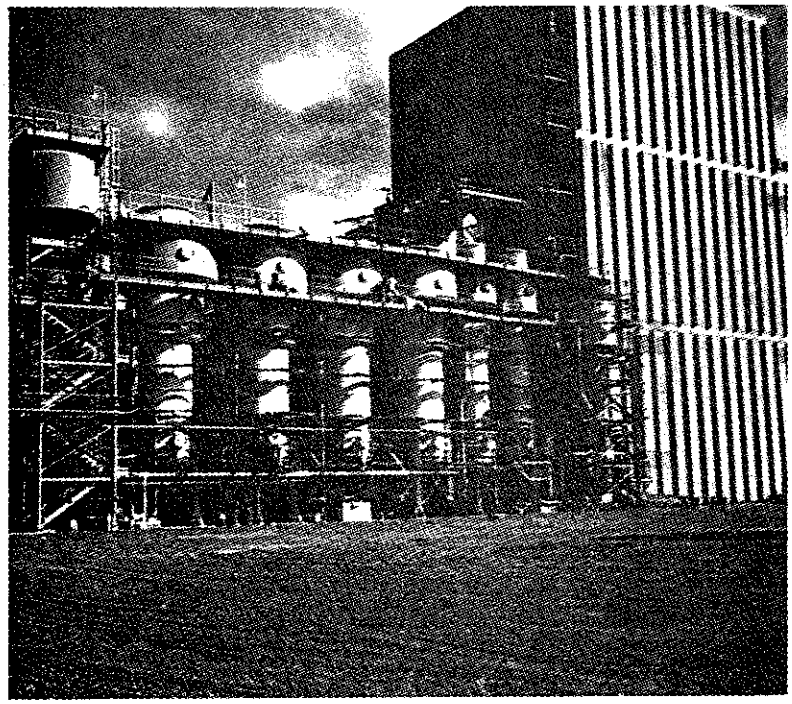

FIG. II

Swenson 440 ton per day, triple-effect caustic soda evaporator at Weyerhaeuser's plant in Longview, Washington.

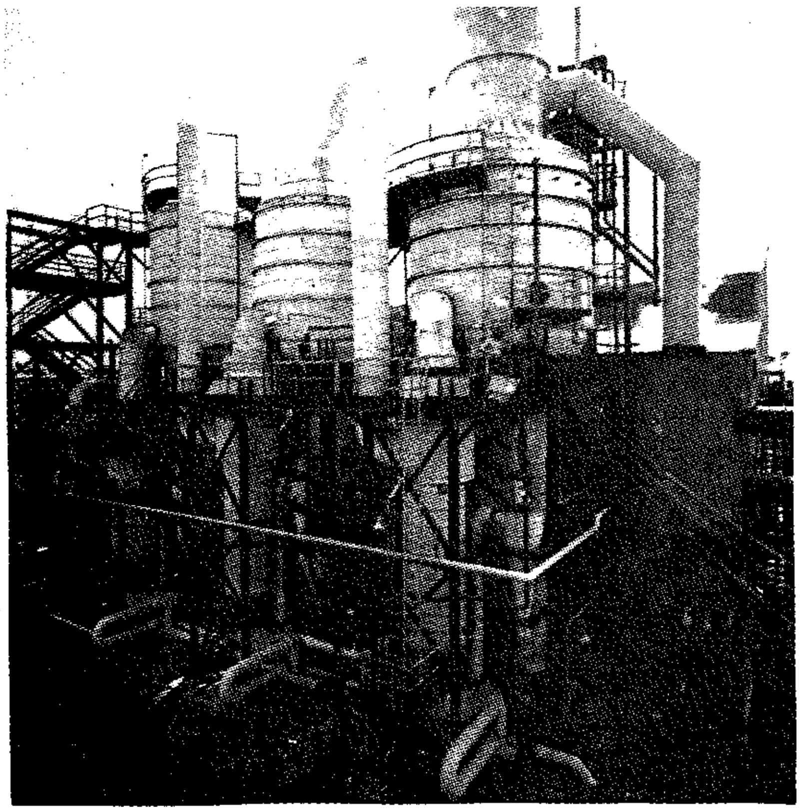

FIG. III

SWENSON FORCED CIRCULATION EVAPORATOR

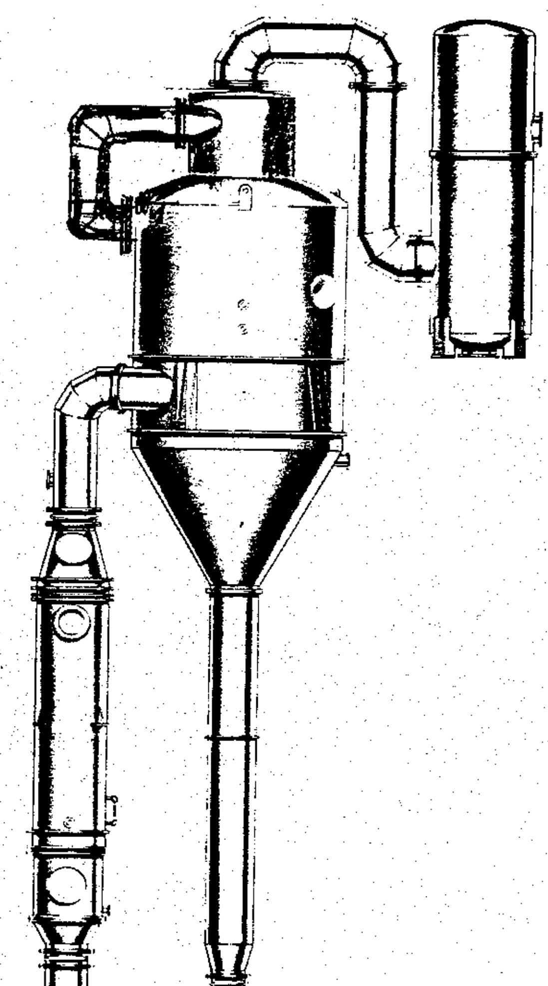

FIG. IV

SINGLE EFFECT

Basis: 100 T/D P_2O_5

Feed:	29,761 lbs/hr @ 28% P_2O_5
Disch:	19,841 lbs/hr
Evap:	9,920

Effect	I
Steam Pressure	27.5 psia
Steam Temperature, °F	245
T, °F	60
Liquid Temperature, °F	185
B.P.E., °F	37
Vapor Temperature, °F	148
Vapor Pressure, " Hg. Abs.	7.2
Vapor Head Diameter, Ft.	8'-0"
Steam, lbs/hr	12,520
Cond. Water, gpm	424 @ 90°F

FIG. V

DOUBLE EFFECT (BACKWARD FEED)

Basis: 100 T/D P_2O_5

Feed:	29,761 lbs/hr @ 28% P_2O_5	
Disch:	19,841 lbs/hr	
Evap:	9,920	

Effect	I	II
Steam Pressure	57.5 psia	17.7" Hg. Abs.
Steam Temperature, °F	290	186
T, °F	65	50
Liquid Temperature, °F	225	136
B.P.E., °F	37	22
Vapor Temperature, °F	188	114
Vapor Pressure, " Hg. Abs.	18.2	2.9
Vapor Head Diameter, Ft.	4'-6"	7'-0"
% P_2O_5	42.0	33.0
Lbs/hr Evaporation	5210	4710
Steam, lbs/hr	7540	----
Cond. Water, gpm	----	806 @ 90°F

FIG. VI

TRIPLE EFFECT

Basis: 100 T/D P_2O_5

Feed:	29,761 lbs/hr @ 28% P_2O_5	
Disch:	19,841 lbs/hr	
Evap:	9,920	

Effect	I	II	III
Steam Pressure	335 psia	57.5 psia	17.7" Hg. Abs.
Steam Temperature, °F	427	290	186
T, °F	60	65	50
Liquid Temperature, °F	367	225	136
B.P.E., °F	75	37	22
Vapor Temperature, °F	292	188	114
Vapor Pressure	59.4 psia	18.2" Hg. Abs.	2.9" Hg. Abs.
% P_2O_5	54.0	42.0	33.0
Steam, lbs/hr	5059	----	----
Cond. Water, gpm	----	----	492 @ 90°F

FIG. VII

SINGLE EFFECT VS. DOUBLE EFFECT

Production Rate T/D P_2O_5 28% to 42%	Utilities				Equipment Sizes	
	Steam, lbs/hr		Water, gpm		Vapor Heads	
	S. E.	D. E.	S. E.	D. E.	S. E.	D. E.
100	12,520	7,540	424	806	8'-0"	4'-6" & 7'-0"
500	62,619	37,710	2,122	4,031	16'-0"	10'-0" & 16'-0"
600*	75,143	45,252	2,546	4,837	17'-6"	11'-0" & 17'-6"
700	87,667	52,794	2,971	5,643	19'-0"	12'-0" & 19'-0"
800	100,191	60,336	3,395	6,450	20'-6"	13'-0" & 20'-0"
900	112,745	67,878	3,820	7,256	21'-6"	13'-6" & 21'-6"
1000	125,239	75,420	4,244	8,062	23'-5"	14'-6" & 22'-6"

* Used as example in text

FIG. VIII

DOUBLE EFFECT (FORWARD FEED)

Basis: 100 T/D P_2O_5

Feed:	29,761 lbs/hr @ 28% P_2O_5
Disch:	19,841 lbs/hr
Evap:	9,920

Effect	I	II
Steam Pressure	54.1 psia	22.98 Hg. Abs.
Steam Temperature, °F	286	199
T, °F	61	52
Liquid Temperature, °F	225	147
B.P.E., °F	22	37
Vapor Temperature, °F	203	110
Vapor Pressure, " Hg. Abs.	23.9	2.6
% P_2O_5	33.3	42.0
Steam, lbs/hr	7080	----
Cond. Water, gpm	----	860 @ 90°F