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Revamp of the J. R. Simplot Phosphoric Acid Plant

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ABSTRACT

The phosphoric acid plant at J. R. Simplot's Don Plant in Pocatello, Idaho was designed in 1985 to produce 1200 sptd P_2O_5*, using calcined rock. In 1990 a rock slurry pipeline was installed and the plant began using uncalcined rock slurry. There were problems with* P_2O_5 *losses from the flash coolers at high rates and excessive scaling in the flash cooler piping. In 1994 these problems were solved by the installation of a flash cooler pre-condenser, flash cooler piping and pump modifications, and installation of a new vacuum pump system. The cooling limitation on the plant was removed,* P_2O_5 *losses were reduced by 0.5%, and significant energy savings were made. Total annual savings of $1.3m were made for an expenditure of about $2m.*

INTRODUCTION

The phosphoric acid plant at J. R. Simplot's Don Plant in Pocatello, Idaho was expanded in 1985 to produce 1200 stpd of P_2O_5. This expansion involved the replacement of two small dihydrate units by a single Prayon Mark 4 dihydrate reactor with two low-level flash coolers and the addition of the No. 10 evaporator. The plant started using the existing Bird 24C filter and two-65-m^2 Eimco belt filters. In 1990 the Bird filter was replaced by a third 65-m^2 Eimco belt filter and the No. 11 evaporator was added.

As production rates increased it became necessary to blend uncalcined ore with calcined ore. Plant modifications were made throughout the facility to handle increasing amounts of uncalcined ore. In 1990 the calciners were shut down altogether and the phosacid plant was running entirely on uncalcined dry ore, supplied by railcar. During this period an ore slurry pipeline was being constructed. In September of 1991 the pipeline was put into service and the phosacid plant was converted to ore slurry feed from dry rock feed. The conversion to ore slurry and shutting down the calciners significantly reduced the particulate emissions from the Don Plant.

The flash coolers became the limit on plant capacity due to the increased non-condensable loading associated with uncalcined ore. A project to address this bottleneck and several other problems was started in 1992.

PLANT DESCRIPTION

Phosphate rock is supplied to the plant through an 87-mile pipeline. The origin of the pipeline is the J. R. Simplot Co. Smoky Canyon Mine and Mill on the Idaho/Wyoming border. Various grades of ore from the mine are stockpiled at the mill and blended to provide a feed of 25% P_2O_5. Beneficiation at the mill consists of crushing, washing and flotation when necessary to provide 68 BPL (31% P_2O_5) ore. There is a pumping station at Conda, Idaho, just north of Soda Springs and the pipeline ends at the Don Plant in Pocatello, Idaho. At the plant, the ore slurry is thickened from its transport density of 62% solids to 70% solids - the desired phosphoric acid plant feed density. Ore is stored at the Pocatello plant at various densities with a maximum capacity of approximately 40,000 dry tons [(1)].

The phosphoric acid plant was designed to produce 1200 stpd P_2O_5 using calcined rock feed. The reactor is a single concrete tank with nine compartments and a total volume of 1600 m^3. Compartments 1 to 6 comprise the attack section, and 7 to 9 compartments the digestion section. The attack section compartments have center openings in the walls from top to bottom and are agitated by Prochem agitators. A large circulation flow of 65,000 gpm is maintained around the attack section by two axial flow pumps - one feeding each flash cooler.

Slurry overflows from the attack section compartment 6 to compartments 7, 8 and 9 that comprise the digestion section. Here the slurry is allowed to desupersaturate and crystals to grow before the slurry is pumped to the three Eimco belt filters.

Two low-level flash coolers, that are fed the entire reactor circulation flow, provide cooling for the plant. Low-level flash coolers allow a large flow to be pumped with a low head axial flow pump developing only 3.3 ft TDH.

Cooling water is supplied to the flash cooler and evaporator barometric condensers from the cooling tower circuit. Gypsum is slurried, thickened in clarifiers, and pumped to the gypsum stack. Gypsum thickener overflow is returned to the plant as sluice water and, after being heated with steam, is used as cake wash water.

TECHNICAL PROBLEMS

The plant was designed as shown in Figure 1, with the flash cooler pumps pumping **out** of the flash cooler.

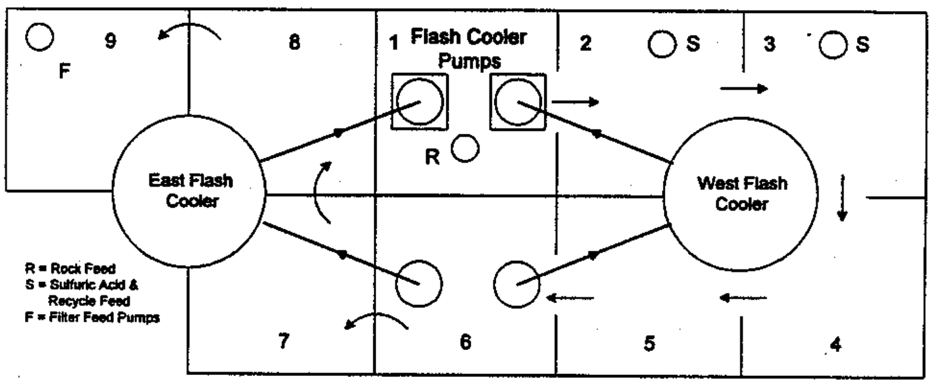

Figure 2 - Original Design

During start-up it was found that the pumps required more NPSH than was expected and could pump only 21,000 gpm each compared with the design flow of 32,500 gpm each. A trial was made by simply reversing the rotation of the pumps, pumping **into** the flash cooler and circulating backwards around the reactor as shown in Figure 2.

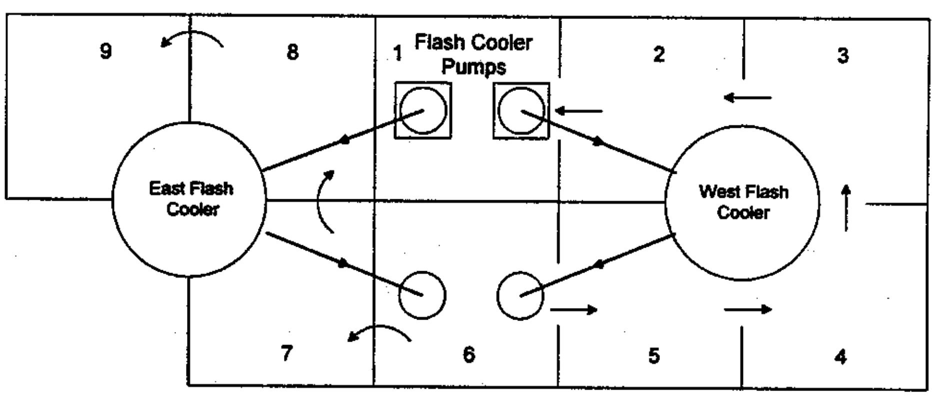

Figure 3 - Trial with Pump Rotation Reversed

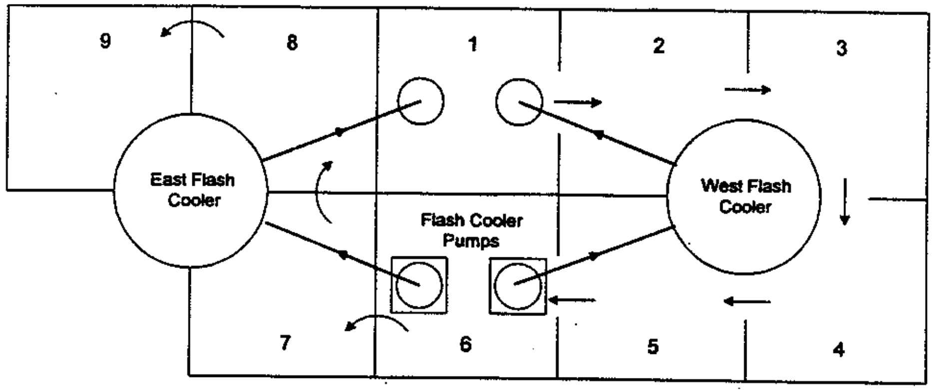

Figure 4 - Final Configuration after Moving Pumps

The pump flow increased considerably in reversed mode which confirmed the NPSH problem. The pumps were moved from compartment 1 to compartment 6 and the original circulation pattern restored, as shown in Figure 3. A flow of 28,000 to 30,000 gpm was achieved with each pump.

The flash coolers and concentration unit were originally designed to be operated without any vacuum source other than the barometric condensers. This worked extremely well on the evaporation unit with pressures as low as 1.6" Hg absolute achieved. All the existing evaporation units were later converted to the "ejector-less" design. The flash cooler system, however, could not operate at design rate and vacuum pumps were added during the plant start up.

Since the change to 100% uncalcined rock the non-condensable load on the cooling system increased and flash cooler control became poor. High P_2O_5 losses occurred when the flash coolers would occasionally boil over. To reduce P_2O_5 losses the flash cooler circulation pumps were slowed. This solved most of the carry-over problems but the lower circulation rate affected plant P_2O_5 recovery and led to higher scaling rates in the flash cooler outlet piping.

The excessive P_2O_5 losses from the flash cooler were caused by a combination of pump performance problems with vacuum control problems. Before the revamp the system was pumping at a high rate into the flash cooler with a partially plugged slurry outlet (the pump speeds had been increased). This caused unstable pump behavior with periods of near-cavitation. This in turn led to strongly reduced recirculation flows. During these periods of reduced flow, level fluctuations and vacuum fluctuations occurred. This in turn created a very unsteady system behavior during which several flash cooler pullovers per hour were common. As the flash cooler level and vacuum fluctuated, superheated slurry was suddenly exposed and eruptive boiling occurred. Once scaling became great enough to restrict slurry flow the flash cooler temperature drop (ΔT) increased. This in turn caused the scaling rate to increase rapidly further compounding the problem.

Plant data for May 1992 showed the East flash cooler pressure varying in a range from 9 to 15" Hg absolute. Good control should restrict this to ± 0.1" Hg. A change in the flash cooler operating pressure from 14" to 10" Hg absolute will increase the flash cooler slurry level by three feet.

DESCRIPTION OF THE REVAMP

Increase Flash Cooler Outlet Piping Diameter and Pump Modifications

A detailed study of the flash cooler system hydraulics was made with the goal of increasing each flash cooler pump flow rate beyond the design rate of 32,500 gpm to reduce flash cooler ΔT and water insoluble (WI) losses.

Increasing circulation generally lowers WI losses, especially at above-design operating rates. This benefit is primarily realized because the sulfate deficiency at the rock addition point is countered by the excess sulfate in the recycle slurry. The maximum practical circulation rate is determined by attack tank hydraulics and the optimum is a function of rock characteristics.

The following conclusions were made from the hydraulic study:

- It is important to keep the flash cooler slurry outlet submerged to reduce boiling in the dip pipe and ensure smooth flow. The top of the original 42" outlet was 11' 4" above the slurry level in compartment 1. The top of a round 54" outlet would probably be at least 12' 4". Hydraulic analyses were made to determine the slurry height in the flash cooler (h_o) with respect to the compartment 1 level.

- In considering possible changes to the large flash cooler slurry piping, we only looked at changing the outlet side. The existing pump comprises most of the inlet pipe and only minor benefit (0.5 ft TDH) is gained by increasing the flash cooler inlet nozzle size.

Table 1 summarizes the results of the hydraulic studies.

TABLE 1

Case	0	1	2a	2b	3a	3b
Pump flow, gpm	32500	26000	32000	32000	50000	50000
Flash Cooler outlet nozzle dia. in	42	42	42	54	42	54
Dip pipe diam., in	42	42	54	54	54	54
Head loss, ft **	3.4	2.4	3.0	2.4	7.4	5.9
Level in Flash Cooler h_o, ft	12.8	12.3	12.4	11.9	13.9	12.5
NPSHa , ft	11.5	11.5	11.5	11.5	10.7	10.7

** including effect of circulation rates on head loss through the attack tank

To derive the values shown in Table 1, the system conditions were checked at 1000 gpm intervals from 32,000 to 50,000 gpm flows. We then compared the derived system curve with the options available for the 42" pump and reached the following conclusions:

- With a 54" outlet nozzle and dip piping the system must pump 45,000 gpm @ 4.9' TDH to maintain full outlet submergence. None of the 42" pump options are capable of this. Thus, the all 54" option was not feasible.

- Considering the 42" outlet with 54" piping option, the various pump configurations available would are listed in Table 2.

TABLE 2

Impeller	Speed, rpm	Flow, gpm	Head, ft	BHP
2-Stage	185	42,500	5.5	144
2-Stage	175	40,500	5.0	124
+10° VAF	185	37,000	4.2	83
+5° VAF	185	33,000	3.4	58

Of these options we selected the +10° VAF impeller running at 185 rpm, since it provides 37,000 gpm flow using the existing 100 HP drive. It also provides a stable pump curve operating near the best efficiency point. The outlet piping and dip pipe were increased to 54 inches diameter, keeping the 42-inch outlet nozzle on the vessel. The revised flash cooler outlet pipes were specially fabricated from Jessop-700. They are easily removable for cleaning at ground level.

Many system problems are attributed to pump performance. When evaluating pump options the effect of pumping a gasified slurry (remember we are pumping into the Flash coolers) must be considered when predicting NPSH requirements. Calculations of critical frequency were done by the pump manufacturer to check the possibility of extending the pump shafts to obtain additional suction head for the pumps. Following confirmation of the absence of a critical frequency problem, it was decided to install a 2-ft longer shaft on each of the flash cooler pumps.

After making the piping and pump modifications a pumping rate of over 35,000 gpm was achieved, and the interval between pipe cleaning has been increased by a factor of three and the frequency of flash cooler cleaning was halved.

Install Flash Cooler Pre-condensers

It was decided to install Flash Cooler Pre-Condensers for four reasons:

- to recover any P_2O_5 losses from the flash cooler and return them to the filter as cake wash

- to save steam for heating cake wash water and eliminate the maintenance associated with the cake wash water heaters
- to reduce the non-condensable load on the new vacuum pump system
- to reduce the cooling load on the barometric condensers and the cooling tower

This system is well proven, and used in most Prayon plants outside the US.

The original plant design had an "ejector-less" flash cooler vacuum system but this never fully worked and vacuum pumps had to be added during start up. Calculations showed that the volume of non-condensables to be removed is greater than can theoretically be completely removed with the design water flow rate and condenser down-leg size. Non-condensable removal is a function of several factors including Froude number, L/D ratio of the condenser down-leg, and water flow rate.

Measurements of CO_2, O_2 and N_2 taken from the combined exhaust of the existing vacuum pumps were used to calculate the vapor flow leaving each existing barometric condenser. Using the gas removal capacity correlations, it was found that the old condensers were removing about 40-45% of the non-condensable load. That is, each condenser receives 2800 acfm; 1200 acfm is removed down the tailpipe; and 1600 acfm passes on to the vacuum pumps.

Using the parameters derived above, we then estimated the probable performance of new "entraining" condensers for an operating rate of 220 stph of rock. Condenser water flow rate is an important variable in this analysis since more water removes more gases and cools them further so that there is less gas volume to remove. The heat load to the new barometric condensers is reduced 20-25% with a pre-condenser system.

TABLE 3

	Rock rate stph	Water to condenser gpm	Down-leg length ft/dia "	Water exit t °F	Gas duty acfm @ Temp, t	Vac Pump acfm @ 90°F
Exist.	190	3000	47'/14"	125	2800	2570
New	220	2700	55'/14"	125	3170	2588
New	220	4000	55'/16"	112	2710	1490
New	220	3500	55'/16"	120	2990	1780

The old barometric condensers were modified and used as pre-condensers and new co-current condensers installed as the main barometric condensers - see Figure 5. Cake wash water is fed to the pre-condensers under flow control and partially condenses the flash cooler vapors. The system is self-regulating and heats the cake wash water to about 162°F - this temperature is determined by the absolute pressure in the pre-condenser. Water from the cooling tower is fed to the barometric condensers. Figure 6 shows the layout of the pre-condenser system.

An additional benefit found from the pre-condenser system was that it acts as a fluorine scrubber and reduces the amount of fluorine reporting to the cooling towers.

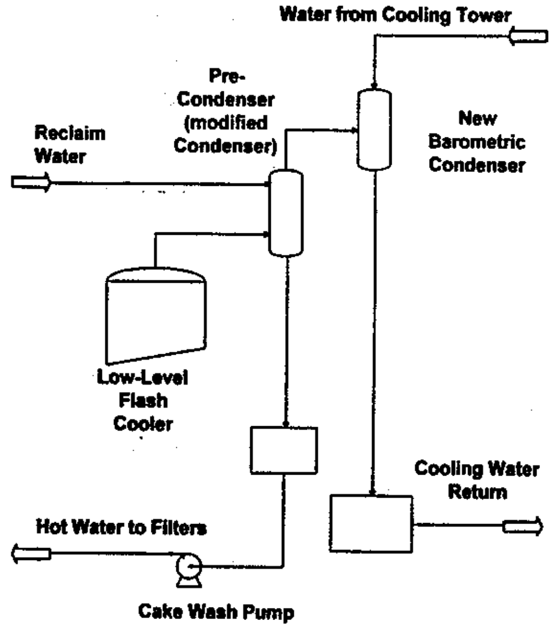

Figure 5 - Pre-Condenser Flowsheet

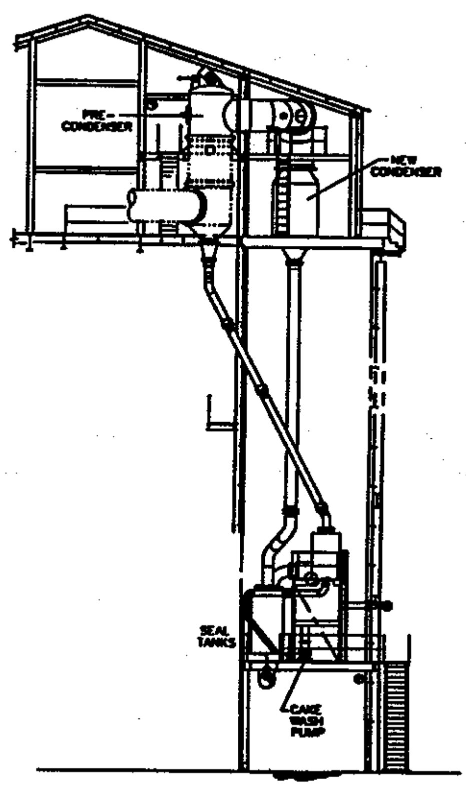

Figure 6 - Pre-Condenser Layout

Improve Cooling Water Supply

The water supply to the original barometric condensers was insufficient. It had originally been planned simply to increase the capacity of the entire cooling system to make more cooling water available. This would have required an additional cooling tower cell, new supply pump, new hotwell return pump and increases in the hotwell size and return piping. This major expense was avoided by adding a booster pump that took suction off the evaporator hot water return line and discharging 115°F water directly to the flash cooler barometric condensers. Some mixing with cold cooling tower water is being done to ensure condenser supply water temperatures are maintained at 105°F or less.

This reuse of hot water has provided a stable supply to the flash cooler barometric condensers and gave significant capital saving compared to adding both hot and cold water pumping capacity and another cooling tower cell.

Vacuum Pump with Closed Circuit Seal Water System

The non-condensable vapor load to the vacuum pumps had increased with the use of 100% uncalcined rock.

The existing pumps were:

West: Nash CL-2002, 1950 cfm @ 15" Hg vacuum
East: Nash CL-3003, 2200 cfm @ 15" Hg vacuum.

It was decided to replace the Nash CL-3003 with a Nash CL-2002, designed specifically for this service. The original pumps were installed due to their availability in the plant. The vacuum systems for both flash coolers are tied together in such a way as to run either vacuum pump on each flash cooler. Two vacuum pumps were chosen instead of one because of operational flexibility in case of vacuum pump failure and flash cooler maintenance. The vacuum pump system is conservatively sized for 3-4000 acfm to allow ample capacity for stable process control at high rock feed rates.

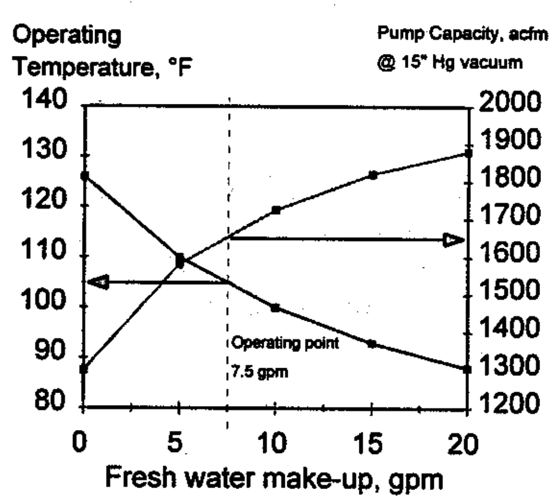

Figure 7 - CL-2002 Vacuum Pump

The vacuum pumps are operated with a closed circuit seal water system. This conserved use of fresh water but slightly reduced the maximum pump capacity (the higher seal water temperature increases the vapor load). Operating the liquid-ring vacuum pump with 110°F seal water compared to 85°F water, is estimated to reduce pump capacity about 10% at 8 to 10" Hg absolute pressure.

Since most flash cooler vacuum pumps are generously oversized, this capacity reduction is usually not significant. The reduction in water consumption can be a very positive aspect in management of the acid water or pond system and fresh water consumption. The same concept can be inexpensively retrofitted to any vacuum pump in the plant including the large units on the phosphoric acid plant vacuum filters.

PERFORMANCE AFTER THE REVAMP AND SAVINGS REALIZED

Circulation Rates

With the enlarged flash cooler outlet piping, changed flash cooler circulation pump impeller and lengthened shaft, the pump capacity increased from 28,000 gpm to 35,000 gpm.

Plant Capacity

Instantaneous plant rates of 225 stph of rock have been achieved for extended periods even during hot summer weather. Before the revamp, plant rates were limited to about 190 stph of rock in the summer because of cooling limitations.

Recovery

Plant P_2O_5 recoveries have increased by 0.5%. Water soluble losses were reduced by 0.3% due to the increased recirculation, and by 0.2% due to capture of entrainment losses from the flash cooler. This does not include the pullover losses estimated to be, at times, more than 1% P_2O_5.

Flash Cooler Cleaning Cycle

The increased circulation flow has reduced the flash cooler temperature drop from 5 to 7 °F to 3 to 5 °F. The number of flash cooler clean outs have been reduced as well, from four per year to two per year. The frequency of flash cooler outlet pipe cleaning also has been reduced from 24 times a year to eight times a year. These improvements have resulted in a increase in the yearly production capability for the plant.

Steam Savings

The elimination of steam to heat cake wash water saved $ 250,000 a year, based on steam savings of 15,000 lb/h and steam valued at $3.50/ 1000 lb.

Process Water Savings

The closed-circuit seal water system on the flash cooler vacuum pump reduced water consumption from 100 gpm to 15 gpm.

Financial Impact of the Project

The cost of the revamp project was about $2.0 million.

The annual savings are estimated to be:

Incremental recovery	$ 500,000
Steam savings	$ 250,000
Incremental production	$ 500,000
Water Savings	$ 50,000
Total	$1,300,000

The return on the project **after depreciation and taxes** is:

IRR (Internal Rate of Return) = 36%
Payback period = 2.2 years

CONCLUSIONS

The revamp project was started to solve problems of P_2O_5 carryover from the flash coolers and a limitation on plant capacity because of insufficient cooling.

Instead of dealing only with the symptoms, a fundamental analysis of the causes of the problems led to a solution with many additional benefits.

- Excessive losses from the flash coolers **were eliminated** and the instantaneous maximum plant capacity was **increased by 15%**.
- More vacuum capacity was provided with a **reduction** in the size of the vacuum pumps and a **reduction** in the quantity of seal water supplied.
- The reactor circulation rate was **increased by 25%** with **no change** in pump size or motor size.
- **More water** was made available to supply the barometric condensers with a **reduction** in the quantity of water pumped from the cooling towers.
- A planned new cooling tower cell and associated pumps and piping installation **were not required**.

REFERENCES

(1) Simplot's Phosphate Slurry Pipeline, Wayne F. Perkins