COGENERATION'S PLACE IN A MODERN PHOSPHORIC ACID COMPLEX

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This paper will not present new technology or potential economics of a cogeneration facility. Nor is it a selling pitch for any piece of equipment or service capabilities, but it will report actual performance - good and bad. The presentation will be a history of an actual turbo-generator facility which has been integrated into a modern grassroots phosphoric acid complex. Actual operating economics and operational statistics will be examined. With escalating energy costs, the cogeneration plant has not only reduced the complex's overall energy expenses but has also increased the complex's on-stream time by essentially eliminating power interruptions.

This turbo-generator facility is part of Occidental Chemical's Swift Creek Chemical Complex located in White Springs, Florida. This grassroots complex was part of the second phase of Oxy's superphosphoric acid (SPA) expansion. Construction of the complex started in October, 1978, with start-up commencing in November, 1979. With the commissioning of this complex, Occidental's production capacity of SPA was increased to 1,000,000 ST/YR. This production has been committed by a long term, 20 year trade agreement with the U.S.S.R.

Shortly after the complex started production, President Carter placed a trade embargo on phosphate shipments to the U.S.S.R. to protest the invasion of Afghanistan. The complex produced 54%

merchant grade acid (MGA) during the embargo and the SPA facilities were idled. SPA production was resumed in June, 1981, when President Reagan lifted the embargo.

The complex consists of a phosphoric acid plant that utilizes the Oxy hemihydrate process which was developed by the Occidental Research Company. This process can produce 42% P_2O_5 acid directly, which greatly reduces the energy requirements from the traditional dihydrate process. The complex includes facilities that concentrate and purify the product acid. In the purification step, metallic impurities are removed from the acid by an Occidental developed process. Two sulfuric acid trains supply the sulfuric needs of the phosphoric acid plant while supplying the necessary steam required for the concentration step. A power generation facility produces a portion of the complex's power needs by utilizing by-product steam generated by the sulfuric acid plants. The complex's electrical power requirements are normally satisfied from two sources - the Florida Power Corporation (FPC) and the generator. The generator load varys with available steam and the utility load swings as needed.

Many alternatives were evaluated during the SPA project planning stage to improve the overall energy efficiency of SPA production. Among some energy conservation methods incorporated in the complex were:

1. Hemihydrate Phosphoric Acid Process - Producing 42% acid directly greatly reduces the steam requirements in concentrating the product acid up to SPA. The traditional dihydrate process

produces only 28% acid. The hemihydrate process reduces the steam consumption by 107,000 lb/hr over the dihydrate process when operating at a 1,000 STPD rate. This amount of steam can produce 10.7 MWh of power in the turbo-generator unit.

2. In the sulfuric acid plant, pressure drop in the converter system was reduced by decreasing gas velocities and by using a larger size catalyst pellet. The overall pressure drop across the converter was reduced by 50% over the traditional designs, which run 40-45" H_2O. This resulted in a 450 bhp savings in the main air blower for each of the two trains. High pressure steam generated by the process, which is not consumed by driving the air blowers, is made available to the turbo-generator facility. The horsepower savings produce an additional 675 kW of power in the turbo-generator. At 50.0 mils/kWh, this equates to an annual savings of $280,000 per year.

3. All electric drives were used except for the sulfuric acid plant air blowers. This eliminated low-efficiency, low bhp turbines and the associated maintenance costs. Major equipment in the sulfuric plant which typically have been pin-pointed as candidates for steam turbines are BFW pumps, acid circulation pumps, cooling water circulation pumps and cooling tower fans. The approximate bhp of all these drives is 3700 hp. There is an 800 bhp energy savings by eliminating these low bhp turbines. This is based on a turbine efficiency of 65% for the low bhp turbine, 85% for the turbo-generator and an average motors efficiency of 90%.

4. Water reuse methods were integrated into this complex, including a condensate recovery system which has been returning nearly 60% of the water requirements of the steam generated in the complex. Well water is reused after being utilized for once-through cooling requirements as cooling tower makeup water.

The turbo-generator design basis could not be established until the completion of the company's search for the best phosphoric acid process available. At its completion, the delivery schedule became one of the most important criteria used in the machine's selection. A General Electric turbo-generator set, rated at 12.5 MW was the machine selected. The turbine, a single automatic extraction condensing type, is controlled by a mechanical hydraulic governor. The air cooled generator is rated at 18,750 kVA; its output voltage (12,470 V) is automatically controlled by a static excitation system.

The turbo-generator is an integral part of the overall steam system. High pressure (600 psig) steam, not consumed by the sulfuric acid plant blowers or required by the production of SPA, is supplied to the powerhouse. High pressure steam, generated by the sulfuric acid plants or supplemented from an oil fired auxiliary boiler, supplies the three high pressure steam users. The priority of the users is automatically controlled; acid plant blower turbine has first priority, SPA production has second, with the powerhouse third.

The generator's load is regulated by a controller that maintains the turbine's inlet steam header pressure. This controller adjusts the steam flow rate being supplied to the turbine, maintaining the header at a constant pressure through changes in steam production or consumption. The intermediate pressure steam header (100 psig) is automatically controlled by the extraction control of the turbine. As the pressure drops in the header, the machine automatically increases the steam being extracted by decreasing the amount of steam being condensed. The 100 psig header serves the needs of the sulfur handling facilities and supplements demand for 35 psig steam which is consumed by the phosphoric acid (48 and 54%) evaporators.

The instrumentation system provides the operator with complete information to enable him to monitor the cogeneration facility's performance. The inlet steam and extraction headers are monitored for flowrate, pressure, and temperature. Condenser conditions are displayed which include condensate and cooling water flows, and the hotwell's pressure and level. The sulfuric boiler steaming rates are displayed for the operator also. The machine's operating parameters, such as bearing vibration levels, bearing metal temperatures, lube oil temperature, generator air cooler temperature, generator winding temperature, are displayed for the operator. Machinery interlocks provide additional insurance for the safe operation of the unit. The machine will shutdown if one of these events occurs: low inlet steam flow, high condenser pressure, high bearing vibration, excessive rotor axial displacement, low lube oil pressure and the generator circuit breaker opening.

The generator is protected against conditions which could result in major equipment damage caused by overloads. With two power sources in parallel, the loss of one would cause the other to pick up all the load seen on our bus. If the generator is shutdown, the FPC feeder will supply the five complex feeders. If the FPC system was lost and if not disconnected, it would act as a large demand on our bus which would be infinitely greater than our generator's rated output. To prevent the FPC power grid from overloading our generator, the FPC circuit breaker has protective relaying to detect problems on the grid.

The feeders that supply the areas of the complex are all tied to a load shedding system with the exception of the sulfuric acid feeder. The system will drop feeders which have been preselected by the operator anytime the Florida Power breaker is opened for any reason. Plant management has established a priority for each feeder which the operator follows as he preselects the feeders for shedding. He continually monitors the power being purchased from FPC and he selects the appropriate number of feeders necessary to equal or exceed the amount of power being purchased. In this way, the generator would be capable of meeting the unshedded load without overloading.

When FPC service is available, the power distribution system is essentially automatic. But when the service is not available or is curtailed, the operator must correctly distribute the available power from the generator to the complex. There is a substantial penalty for the electric demand pulled during a curtailment. If a demand of 10 MWh was established during a curtailment period, that demand charge would cost $540,000. An operator mistake, misunderstanding or indecision would cost the company severely. To reduce the possibility of these penalties being assessed needlessly, a power curtailment procedure has been enacted. This procedure allows for the systematic curtailment of electric demand that will have the least impact on the overall complex production, and it establishes the maximum demand allowable during a curtailment.

The turbo-generator is a sophisticated piece of machinery that requires skilled operating personnel. To obtain the necessary personnel, a new installation must hire experienced people or train inexperienced operators. Hiring an entire staff of experienced people is for the most part impractical and can be counter productive; but, even with experienced operators, orientation training is necessary. As a grassroots complex is put into operation, there is never enough time to do what is ideally required. The production and construction staffs are under pressure to deliver the plant on time. An effective training plan must be committed to early and be incorporated into the overall construction schedule; time is too precious to use on an ill conceived plan. The plan must commit time and people to training. The program must give the inexperienced and the experienced a broad understanding of the fundamentals of the operation.

Our operating personnel went through a series of formalized classroom, field orientation and on-the-job training sessions. The classroom training consisted of a general operator training course, a sulfuric acid plant orientation course, and a General Electric turbine training program. This formalized turbine training was primarily presented by a trained General Electric instructor, but the standard program was enhanced by the inclusion of representatives of the design contractor and equipment vendors. The course surveyed the fundamentals of a steam turbine-generator and built on those fundamentals to obtain an understanding of its operating characteristics, capabilities and limitations. Included was a discussion of operating principals of the turbine, generator and exciter; then proceeded to describe the major components and auxiliary systems of each. After a thorough understanding of the hardware was obtained, the course centered on how the hardware is controlled, protected and monitored during the operation.

The on-the-job training portions of the program consisted of a line by line P&ID checkout of the plant and hands-on turbine school conducted by the General Electric field erection staff. Also, the operators worked hand and hand with the field staff as the machine went through its preoperational checkout.

The unit went on-line for the first time on January 2, 1980, for one hour fifteen minutes. After General Electric completed preoperational checks, the unit came back on-line on January 11. For the next week, the machine went through a thorough shakedown by General Electric. Functional testing and checking of the protective instrumentation circuitry was completed. Major mechanical problems were encountered during the initial operation. They were: first, a good vacuum could not be maintained because of leaks; second, the condensate pumps were not functioning at design; and finally, severe fluctuation in the turbine governor system and extraction pressure controller were being experienced.

(See Table No. 1 - Next Page)

- TABLE NO. 1 -

MAJOR MACHINE DOWNTIME

During the first year of operation.

January, 1980	Initial operation and testing	15 days
February, 1980	Casing repairs	22 days
March, 1980	Hotwell addition	28 hours
October, 1980	First turnaround	9 days

For the next seven days, the unit's operation was not stable. Vacuum leaks were being identified and repaired. During the search for vacuum leaks, a turbine casing leak was found. The leak was at the low pressure end on the horizontal split of the turbine casing. This lead to a thorough inspection of all turbine casing joints when two more leaks were found at the intermediate pressure region of the machine. General Electric requested the machine to be shutdown and the turbine opened for an inspection. General Electric conceded that there was a manufacturing defect after a factory representative made an inspection of the case.

Scrapers were called in to repair the mating surface of the case. The scrapers trued the faces by hand filing and using cutting stones and hones. Repeated blueing and lifting of the case was done to obtain a good seal. The machine was down from January 24 to February 14 for these repairs. Twenty-two days of downtime eliminated the casing leaks and decreased, but did not eliminate, air in leakage.

The performance of the condensate pump was corrected by increasing the motor horsepower, impeller size and speed, and increasing the NPSH. It was determined that the NPSH required by the pump was only marginally being satisfied. Major downtime occurred when a deep hotwell was added and the piping configuration altered to eliminate pressure drop.

By the second quarter of the year, the operation became reliable. The unit's downtime was almost 95% of the time influenced by steam and cooling water from the sulfuric acid plants. All major mechanical problems were addressed with the exception of the governor fluctuation. All other items on the punchlist were completed or the proposed solution was presented. The outstanding items were postponed to be done during the first turnaround which was to be done after one year of operation. This was done because of the length of downtime required to complete them and certain long delivery of parts required. The turbine fluctuation problem was to become a problem where G.E. could not propose a satisfactory method of repair.

It was decided it would be better to move the turnaround up than to shutdown in the winter. As the cold weather sets in, the electrical demand across the state increases which increases the possibility of a power curtailment. During the first six months of operation, the complex was subjected to numerous power curtailments. During each, the generator was capable of supplying the entire complex through the curtailment. In October, 1980, the unit was taken down for its first turnaround. The machine was thoroughly inspected and all observations were carefully recorded to provide a baseline for further inspections. The machine was generally found to be in good condition. The major item on the punchlist which was not resolved after the turnaround was the governor fluctuations, but the turnaround did eliminate most items on the punchlist.

The persistent fluctuation problem was finally resolved in July, 1981, when the machine was taken down for maintenance. It was suspected that one or more pivot points in the linkage were binding causing its erratic operation. To resolve this condition, the turbine control linkage was removed, cleaned, lubrication cups were added, and the linkage was reassembled. A scored pilot valve in the hydraulic system found during an earlier inspection was also replaced.

The cogeneration facility has increased the complex on-stream time by essentially eliminating electric power interruptions. In the past year and half we have experienced only four power interruptions This includes all reasons for outages, such as: electrical storms, power curtailments, power surges and FPC preventative maintenance. During the numerous power curtailments, the generator facility has been capable of supplying the entire complex without production curtailments. A number of these power curtailments were during the coldest days of the year, which would be the least opportune time to have a complete complex shutdown. FPC performed an 8-hour preventative maintenance inspection of the complex's substation without affecting the production. The generator operated during this period completely isolated from the Florida Power grid, thus enabling FPC to de-energize the station. During isolated operation, the controls for the turbine automatically switch from inlet header pressure control to frequency control. As the complex demand changes, the machine's output changes maintaining the frequency at 60 HERTZ.

The turbo-generator has supplied 81% of the complex power requirement since its start-up. The two main factors that effect the amount of power generated are the sulfuric acid production rate and grade of phosphoric acid being produced. On Table No. 2, the operating statistics are shown listing generator output and complex needs through the first 18 months of operation.

(See Table No. 2 - Next Page)

During the first quarter of 1980, production rates were relatively low and the quarter had some SPA production until the embargo hit in February and the generator experienced major downtime. The generator produced 47.8% of the complex needs. During the second quarter, all the phosphoric acid was manufactured as MGA, production rates were up, and the generator's operation became more stable. The cogeneration facility produced 92.3% of the power consumed.

Beginning in June, 1981, the complex went back to producing SPA after President Reagan lifted the trade embargo. The amount of power generated drops off significantly because high pressure steam

- TABLE NO. 2 -

OPERATING STATISTICS FOR THE COGENERATION FACILITY

PERIOD	COMPLEX USAGE (MWh)	POWER SOLD (MWh)	POWER GENERATED (MWh)	POWER PURCHASED (MWh)	% COMPLEX USAGE GENERATED	AVERAGE SULFURIC PRODUCTION (% DESIGN)	GRADE OF ACID PRODUCED
1980							
1st Quarter	19,900	450	9,970	10,380	47.84	61.31	SPA/MGA
2nd Quarter	24,250	4,380	26,820	1,810	92.25	77.90	MGA
3rd Quarter	23,970	3,220	25,230	1,960	91.82	68.60	MGA
4th Quarter	26,390	3,850	26,280	3,960	84.99	80.20	MGA
1981							
1st Quarter	22,470	1,530	18,240	5,760	74.37	60.93	MGA
2nd Quarter	26,150	1,950	23,830	4,270	83.67	79.10	MGA/SPA

is diverted to the SPA evaporators from the turbine generator. The complex's power demand also increases and therefore the fraction of purchase power increases. This can be seen by examining the monthly statistics for the second quarter of 1981 on Table No. 3.

- TABLE NO. 3 -

MONTHLY OPERATING STATISTICS
FOR THE PERIOD OF APRIL THROUGH JULY, 1981

	APRIL	MAY	JUNE	JULY
Complex Usage (MWh)................	8121	9020	9010	9331
Power Sold (MWh)...................	869	1022	63	36
Power Generated (MWh)..............	7920	9552	6360	6096
Power Purchased (MWh)..............	1070	490	2713	3271
% Complex Usage Generated.........	86.8	94.6	69.9	65.0
% Design of Sulfuric Production...	78.1	85.6	73.6	86.4
P_2O_5 Grade Produced...............	MGA	MGA	SPA	SPA

The turbine-generator facility has demonstrated better than expected economic return, mostly caused by the complex's increased on-stream time and subsequent reduction in production losses. Another factor which has increased the actual rate of return was the sale of power back to FPC. While the capital required for the project was being justified, no credit was given for any power fed into the FPC system. This all changed when new rules from the Federal Energy

Regulatory Commission (FERC) were issued. In February and March, 1980, the FERC issued rules pursuant to the Public Utilities Regulatory Policies Act of 1978 (PURPA) that are intended to encourage the production of electricity from small ($<$80 MW) cogeneration facilities. The rules basically place obligations on the states' public service regulatory agencies to establish rates for the purchase and sale of power to qualifying cogeneration facilities.

In late 1980, Occidental and FPC reached an agreement which set the rate for which FPC will credit Oxy for power sold back to the utility. Under the terms of this agreement, the rate is equal to 95% of the FPC avoided fuel costs. FPC calculated the incremental avoided fuel costs based on a monthly average until recently when additional metering equipment was installed to allow the avoided costs to be continuously calculated.

To demonstrate the economic advantages of the cogeneration facility, actual reported costs were used in the preparation. No cost for steam was considered because no additional operating costs were incurred as a result of the powerhouse. Steam was not produced for the purpose of supplying the powerhouse. The burning of oil supplemented the steam production only when required for the production of phosphoric acid.

From January, 1980, to May, 1981, the turbo-generator has been operated with an actual return on investment of 51%/year. This relates back to a payout time of slightly less than two years. The gross income of the powerhouse, which for this exercise is taken to be the actual complex power consumption, times what the average millage rate would have been if the power was purchased from FPC. During this period, the gross income was $5,600,000. This is based on an average rate of 41.5 mils/kWh and a complex consumption of power - 135,000 MWh. The operating cost for this period was $400,000; this included labor, maintenance and other miscellaneous operating expense costs. Raw material cost is the amount of power purchased from FPC less the credit received from the sales of power to the utility. The complex purchased 26,000 MWh from FPC at an average millage rate of 50.50, and sold 15,000 MWh of power for $400,000 (an average of 26.44 mils/kWh). This equates to a net power cost of $900,000. When fixed costs are added to the other costs, the net operating cost equals $2,100,000. Therefore, the net return, the gross income minus the net operating cost, equals $3,500,000 for the 17 month period. The initial investment in the facility was $4,800,000. Based on the first 17 months of operation, the payout period equals 23 months and the annualized rate of return on investment (ROI) equals 51%. See Table No. 4.

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The cogeneration facility at Occidental has been a successful venture. The capital is being utilized at an acceptable rate of return and the unit is operating reliably. But, in retrospect, there would be several areas where redesign would be advantageous to the overall operability of the plant. The first of these would be the overall power distribution system.

- TABLE NO. 4 -

ECONOMIC SUMMARY OF TURBO-GENERATOR
DURING MGA PRODUCTION
(January 1980 to May 1981)

(All figures expressed in thousands of dollars.)

GROSS INCOME..............	$5,600
OPERATING EXPENSES........	$ 400
POWER PURCHASES...........	1,300
POWER SOLD................	(400)
FIXED COSTS...............	800
NET COSTS............	$2,100

NET RETURN................	$3,500
INITIAL INVESTMENT........	$4,800
RETURN OF INVESTMENT......	51%/Yr
PAY-OUT TIME..............	23 Months

Unlike most plants, a loss of the public utility would mean a complex shutdown, but with the cogenerator facility this is not the case. By the use of load shedding, only the loads which are beyond the current generator output are dropped. All of the feeders have assigned priorities, and the operator "keys" the necessary number of feeders to equal the load being purchased. Then, if the load shedding relay is energized, the "keyed" feeders are dropped. During the design phase, these priorities should be addressed. Essential support facilities, i.e. instrument air and well water, should be preferably placed on the sulfuric feeder or on a separate feeder. The sulfuric feeder must take top priority over all others because without the sulfuric plant there is no steam and therefore no power. The number of feeders and the priority of the users on the feeder will give management more or less flexibility during curtailments. Careful planning at this time will minimize the disruption to production if a portion of the complex must be dropped.

Another area where careful planning can increase the overall energy efficiency is in the development of the complex's steam balance. The balance must consider both average and instantaneous steam rates. In our complex, insufficient turbo-generator condenser capacity has caused available steam to not be fully utilized. In our steam system, steam not condensed by the generator's condenser will be extracted from the turbine at the 100 psig level and condensed in a vent condenser. The steam that enters the turbine and passes through the machine to the turbine's vacuum condenser will produce 1 MW for every 10,000 pounds of steam. If the same 10,000 pounds of steam entered the machine and was extracted, only 0.45 MW of power would be produced. During the first seven months of 1981, 167.2 million pounds of water were condensed by the vent condenser. If we assume that 80% of this steam could have been condensed by the generator's condenser if the capacity were available, an additional 7,300 MWh would have been generated. Annualizing this additional capacity, it would amount to $625,000/year worth of power at 50.0 mils/kWh.

The evaporation area's operating factor must be considered as the steam balance is developed. This is one of the most important factors in determining the design conditions of the turbine's condenser. Maximum and average steam requirements of the evaporators need to be developed taking the scheduling, optimum and realistic, of evaporator downtime into account. The average operating factor experienced in the industry is about 80-85%. Using 85%, each evaporator will be down 25 hours/week. In our complex, we have six evaporators each having approximately a 40,000 lb/hr steaming rate. Therefoie, six evaporators times 25 hours per week, times 40,000 lb/hr equals 6 million pounds of steam per week which is surplus and available to be condensed. If condensed by the turbo-generator, this steam would amount to 600 MWh of power per week. At 5¢/kWh, there would be an annual savings of $1.5 million in avoided power purchase.

Based on the rate of return demonstrated by this facility, I do believe cogeneration has found a place in the modern phosphoric acid complex. The large quantity of energy developed by the sulfuric acid process can no longer be used inefficiently; the overpowering forces of economics will not allow it. The dramatic increase of energy costs and projections of future increases make it imperative for firms to become evermore efficient to stay competitive.