HERO^{TM} application on high silica gray water for an ACC combined cycle power plant

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Summary: The paper reviews treatment aspects for use of high silica secondary treated sewage as a sole source for the supply of makeup water to the Bajio Power Plant. Brief descriptions of the sewage treatment and water treatment systems are included. Available plant operating data were analyzed. For brevity, representative selected data are presented and discussed.

Central el Bajio is a 600 MW combined cycle power plant located near the town of San Luis de la Paz in central Mexico. Power companies InterGen and AEP Resources jointly own the facility, which achieved commercial operation early in 2002. Approximately 495 MW of the project's power is supplied to Mexico's state owned utility, Comisión Federal de Electricidad (CFE), under a power purchase agreement structured as a build-own-operate contract. The remaining 105 MW of the project's power is supplied to third party industrial customers.

The facility consists of three dual-fuel combustion turbine generators (CTGs), three three-pressure heat recovery steam generators (HRSGs) and one reheat steam turbine generator (STG). Steam from the low-pressure turbine exhaust is condensed in an air-cooled condenser for return to the HRSGs. Perhaps the most unique and challenging feature of this project however, was the source of water available and the treatment required to make it suitable for the various power plant processes.

San Luis de la Paz, a town with a population of approximately 50,000, is located in an arid region of Mexico. Water resources are scarce and priority is given for domestic and agricultural use. The town obtains its water supply via wells. However the government agency, Comision Nacional del Aqua (CNA), responsible for regulating water supplies in Mexico, does not allow the abstraction of groundwater resources for industrial use in this area. Therefore, alternative supplies had to be considered. The Power Purchase Agreement allowed the use of up to 50% of the town's raw sewage as power plant makeup water. It was determined that this was more than sufficient to meet the power plant's requirements including the winter oil-fired case, which was the operating scenario with the greatest water demand. The decision was made to construct a secondary sewage treatment plant to treat up to 125 m^3/hr to supply treated sewage (gray water) to the Bajio Plant.

Typical power plants using gray water depend on treated municipal wastewater from relatively large towns or cities and adequate base line quality data is generally available. The Bajio project had to deal with constructing a sewage treatment plant (STP) in parallel with the power plant. This demanded an aggressive schedule, as treated water was required for power plant construction, commissioning and start-up.

Raw sewage data, which was limited, was compiled and analyzed to establish design characteristics. Additional sampling was carried out to verify or supplement critical parameters. This initial data was used to develop the design sewage analysis included in the specification used to procure a turnkey contract for the design and construction of the STP. In addition, the Owner commissioned a comprehensive 12-month raw sewage sampling and analysis program to be undertaken while the STP was being designed and built. Limited hourly flow data was analyzed to assure that adequate flow could be supplied to the power plant. Development of the design raw sewage characteristics required calculations of flow-weighted values for each parameter. Flow data was also supplemented during the 12-month sampling program to confirm the initial design basis.

San Luis de La Paz had an existing sewer system but had not yet received federal funding to construct their own STP. Sewage was collected in the sewer system and discharged (using land application) at four different points around the community. In addition, a sewer line was constructed out to a plot of land on the outskirts of town, where a future STP could be built.

Sewage Treatment System:

The Project evaluated two options: one based on locating the STP at the town versus one locating it at the power plant. Locating the treatment plant at the source (in town) allowed pumping of gray water instead of raw sewage to the power plant through a long pipeline of approximately 12.6 Km. Risks of leaks and spills associated with pumping raw sewage were considerably higher than those with pumping gray water. A significant STP design issue related to the increased makeup water requirements for the oil-fired case, which can arise at short notice. Biological treatment systems cannot be ramped-up within such a short period of time. Therefore, it was planned to operate the STP at a constant flow close to the design capacity of 125 m^3/hr and to provide the community with the excess treated water for various purposes. Locating the STP within the town boundaries facilitated the transfer of excess gray water to the town. Therefore the owners decided to locate the STP in town (within the plot of land dedicated to the future town STP).

During the design and construction phase of the project, three significant issues arose, two of which affected the design of the STP.
The first involved the discovery of a new wastewater stream being added to the municipal sewer from a local slaughterhouse. BOD measurements on sewage samples taken from the associated interceptor (discharge point) indicated typical values of 1000-2000 mg/l. This resulted in predicted values of 700 – 900 mg/l for the combined raw sewage from all four interceptors. The STP had been designed for an average influent BOD of 400 mg/l with a short-term maximum value of 800 mg/l. Clearly, this would have been a problem. The local sewage authority was contacted and they worked with the slaughterhouse to eliminate the facility's wastewater contribution from the sewage that would flow to the Bajio STP. This was accomplished by rerouting their wastewater discharge to a point in the existing interceptor discharge piping downstream of the branch line that supplies the STP.

The second issue pertained to STP flow control. When the original contract was executed with the town, the local sewage authority committed to closing the existing four discharge interceptors such that the entire sewage flow from San Luis de la Paz would flow out by the STP. The STP equalization basin was hydraulically designed to accept 125 m^3/hr of raw sewage. The excess raw sewage was to be forwarded to a new land-application discharge point. The town had committed to constructing the new excess sewage discharge pipeline and discharge structure. However, during the course of STP construction, the community informed the Owner that they lacked the funds to complete these new facilities. Instead, the town agreed to regulate newly-installed slide gates in each of the four existing discharge lines to ensure sufficient flow to the equalization basin to achieve an equalized flow of 125 m^3/hr. STP influent flow control changed from passive control requiring minimal operator attention to one that requires significant operator attention and communication with the local sewage authority.

The final major issue arising during the construction phase also pertained to the town's inability to construct the new excess sewage pipeline and discharge structure. As previously discussed, excess gray water not required by the power plant was to be given to the town for their own uses. To this end, the STP project included the construction of a 600 m^3 gray water storage tank. The intent was for the town to withdraw the gray water they needed from this tank. Any excess would overflow the tank and be combined with the excess raw sewage in the new pipeline. Since construction of this pipeline was cancelled, the community constructed a large gray water pond adjacent to the STP to collect excess gray water. The town negotiated an arrangement with the local farmers to provide water from this pond to the local irrigation system to prevent the pond from overflowing.

The STP has been operating for more than a year. The system consists of two (2 x 50 percent) sewage treatment trains. The total capacity of the STP is based on water requirements during oil firing in the combustion turbines. However, with one train operational, the STP can provide the gray water for normal operation of the power plant with natural gas firing in the combustion turbines.

An equalization/collection basin receives raw sewage from the town's sewer system. The raw sewage from the collection basin is supplied by lift station to the STP. The sewage treatment system consists of bar screens, fine screening, a degreasing-degritting system, extended aeration activated sludge system with aeration tanks, secondary clarifiers, and sludge recycling. The biological treatment process incorporates nitrification and denitrification steps to remove ammonia (total nitrogen). Excess sludge is digested and dewatered and then disposed of offsite. The treated sewage (gray water) is chlorinated and pumped via a gray water pump station and discharged to a gray water sump inside the power plant boundary.

Water Treatment System:
A simplified water balance with major water flows for a single operating case of the Bajio Power Plant is shown in Figure 1.
Initially, a microfiltration (MF) system with automatic backwash (using an air-water mixture) was considered for pretreatment of the gray water as an alternative process to softening/clarification and filtration. While MF does not remove hardness, silica and other soluble material, it provides significant SDI reduction and removal of bacteria, which could otherwise clog cartridge filters or foul the RO membranes. However, the MF option was dropped from further consideration due to the potential for high variability in gray water quality and lack of time (due to schedule constraints) to run a pilot study with the MF since the gray water source did not exist.

A High Efficiency Reverse Osmosis (HERO™) system (supplied by Aquatech International) was selected in lieu of a conventional RO system with clarifier softening and silica removal based on the following evaluation.

- Removal of silica, barium, and residual TOC within the pre-treatment system was essential for success of a conventional RO process.
- Silica removal by adsorption on magnesium hydroxide precipitate is difficult to control even with conventional water supplies. It is even more difficult to remove from gray water due to the presence of TOC, which can affect sludge settling characteristics and the precipitation process. Previous operating plant data was lacking for high-silica gray water softening requiring a high degree of silica removal.
- Excessive sludge is produced during conventional softening and silica removal, which will require significant handling and disposal operations.
- A conventional softening process could not be completely automated and would require significant operator attention, especially with intermittent operation.
- The HERO™ system had not been previously applied to treat gray water. However, it has demonstrated high tolerance and successful operation on waters with elevated TOC concentrations, waters that are highly fouling to conventional RO systems, and waters with variability in feed water quality. The HERO™ Process was developed specifically for the treatment of high silica waters and biologically active waters.

- High pH RO operation, which is the HERO™ operating mode, keeps silica and organics in soluble form; therefore membrane cleaning frequency is expected to be low. Residual hardness must be removed upstream in the integral WAC exchanger to prevent precipitation of hardness on membrane surfaces.

Description of the Power Plant Makeup Water Treatment System

The gray water from the STP is pumped to a gray water sump located in the power plant. Level in the sump is maintained by a control valve on the supply line. The gray water is treated through a reactor-type clarifier (1) where caustic, coagulant (FeCl3) and a coagulant aid can be added. Clarified effluent is further treated through gravity filters (3) and

pressure filters (2). Filtered water is stored in a tank. Level in the tank is maintained by regulating feed flow from the gray water to the clarifier. The chemicals are metered and paced based on the flow to the clarifier. Sodium hypochlorite is metered into both the gray water sump and inlet to the pressure filters. Clarifier influent & effluent turbidity and pH are monitored. Carbon dioxide is used to adjust clarifier effluent pH, if required. Bisulfite is metered to dechlorinate feed water to the weak acid cation (WAC) units (2). HCl can be used to adjust WAC outlet water pH prior to sending to the decarbonator (1). Hardness and pH of water to and out of WAC are monitored. RO Units (2) feed water pH is adjusted by caustic.
RO feed and permeate conductivities and silica and conductivities of mixed bed (MB) demineralizer units (2) product water are monitored. The WAC & MB regeneration wastes are neutralized and combined with RO reject waste. RO reject is neutralized and passed through a lamella separator to remove precipitated silica prior to combining with demineralizer regeneration wastes.

Demineralized water is utilized for makeup to the steam cycle, NO$_x$ control in combustion turbines (CTs), and washing of CTs. The filtered water is stored in a filtered water storage tank, which also provides water to meet the requirements for the service water system, fire protection system, and domestic (non-potable) water.

POWER PLANT WASTEWATER DISPOSAL OPTIONS

The power plant will generate specific wastewater streams, as mentioned above, which will require discharge from the facility. Following wastewater disposal options were evaluated:

Holding/ Evaporation Ponds: An evaporation pond in a water-short region may not be acceptable and available space was a constraint.

Injection Wells: Quality of the wastewater may be an environmental concern and environmental permitting process may have been the longest (if a hydro-geological study was required).

Brine Concentrator with Small Evaporation Pond or Crystallizer: High O&M cost and trained operators required.

Discharge back to STP: This option entailed returning the high TDS wastewater from the power plant to the sewage treatment plant located at the city in a separate pipeline. To avoid building up a concentration loop, the power plant wastewater is discharged to the effluent side of the sewage treatment plant at the city and mixed with excess gray water. The same trench that is used for makeup supply piping could be used for this discharge piping to minimize the cost of this option. Predicted quality of the blended power plant wastewater and excess gray water was evaluated to ensure the suitability of this water for the uses intended by the community. Discharge back to STP was selected because of low cost and a simpler permitting process.

STP Operation

The STP contractor had agreed to the guaranteed treated water quality listed in Table 1. Summaries of STP operating data are listed in Tables 2 and 3. Prior to turnover of the STP to the Owner, the Contractor performed and passed a seven-day performance test demonstrating that the plant achieved the guaranteed water quality.

TABLE 1, GUARANTEED GRAY WATER QUALITY

Parameter	Weekly Avg.	Daily Max
pH	6-9	6-9
BOD$_5$, mg/l	20	30
TSS, mg/l	20	30
NH3-N, mg/l	5	5
Total Coliform, mpn/100 ml	400	1000
Oil & Grease, mg/l	10	20

Since commissioning, the STP has continued to produce very good quality effluent, with only occasional minor upsets.

Two STP operational issues should be noted. The first is that, at times, the BOD of the raw sewage is much higher than the design average value of 400 mg/l. Based on a historical BOD/COD ratio of 0.58 and an average COD value of 640 mg/l for the first six months of 2002, the average BOD of the raw sewage is estimated to be 370 mg/l. However, based on daily influent COD measurements, influent BOD can be in the range of 400-700 mg/l for extended periods of time. Fortunately, the STP aeration system for the aeration tanks has been conservatively designed and the STP is still able to produce gray water with BOD values less than 20-30 mg/l when influent BOD and COD values are high. However, high raw sewage BOD values result in increased aeration requirements and increased sludge production, both of which add to operating costs.

The other significant operational challenge is related to the issue of raw sewage flow control discussed previously. The reliable flow of raw sewage to satisfy the requirements of the STP and power plant requires frequent intervention on the part of the local sewer authority personnel in adjusting positions of the slide gates in the four existing discharge lines. Early experience indicated that the local sewer authority did not always respond in a timely fashion to STP requests for additional raw sewage. This resulted in times when there was insufficient flow to the STP. However, the Owner has since improved the response time of the sewer authority personnel by providing them with faster means of transportation (bicycles) and cell phones. This has improved response times such that the lack of flow to the STP is no longer a problem.

Operating Experience:

The power plant water treatment system was designed to treat the estimated gray water quality provided at the conceptual stage. This quality was estimated based on the performance expected from a secondary sewage treatment plant with nitrification and denitrification. Alkalinity was estimated by adjusting the raw sewage alkalinity data to account for nitrification/denitrification. Nitrification, which biologically converts Ammonia-N to nitrate, consumes alkalinity, while denitrification returns approximately half of it back.

During initial operation of the WTP, gray water that had been sitting stagnant in the gray water supply line led to startup difficulties. It was difficult to operate the WTP clarifier-softener satisfactorily due to poor settling characteristics of the sludge that allowed the solids to rise and carry over.

TABLE 2- STP PERFORMANCE DATA

	STP Influent		STP Effluent	
Parameter/ 2001	Avg.	Max	Avg.	Max
pH as STU	7.7	8.1	7.7	8.1
Alk. as CaCO3	540	551	341	346
COD	1081	1557	66	146
BOD	649	970	13	45
NH3-N	57	78	4	13
Total-N	84	112	8	18
Total-P	6.8	15	5	14
Total SiO2	105	108	72	78
Reactive SiO2	73	79	56	67
O & G	151	240	4.4	8

Conc. in mg/L, From limited Jan-Feb 2001 data.

TABLE 3- STP PERFORMANCE DATA FROM 2002

Parameter/ 2002	Jan	Feb	Mar	Apr	May
Infl Avg. COD	499	478	684	721	855
Infl max COD	1035	1026	1200	1059	1358
Effl Avg. COD	40	39	44	46	51
Effl Max COD	71	91	108	122	79
Effl Turb. as NTU	5	7	8	6	7
Effl Max Turb. as NTU	10	11	15	12	12
Effl Flow, M2/hr Avg.	65	62	71	66	75
Effl Flow, M2/hr Max	90	100	110	110	100

Summaries of STP operating data are listed in Tables 2 and 3. Gray water data indicates that the STP provides excellent treatment with gray water average effluent BOD of 13 mg/L, COD of 45 mg/l, and turbidity of less than 10 NTU. It is interesting to note that there is some removal of silica in the STP. Removal was about 31% for total silica and 23% for reactive silica. The maximum silica concentration observed in the gray water was 84 mg/l. The STP has achieved excellent removal of oil and grease (O&G). Average gray water O&G concentration is less than 5 mg/l. Similarly, the total-N is being reduced to less than 8 mg/l from 84 mg/l, indicating good nitrification and denitrification.

One surprise is that gray water alkalinity is much higher than what was originally estimated for the WTP original design basis. While the hardness variation in the gray water is small, the alkalinity variation is significant. The supplier of the downstream High Efficiency Reverse Osmosis (HERO™) required an alkalinity: hardness ratio of 1.0 or slightly higher at the inlet to the weak acid cation (WAC) exchangers. Since there was a deficit of alkalinity in the predicted gray water quality, the original plan was to remove total gray water hardness to about 100 mg/l in clarifier-softener using caustic addition. However, operating results indicate that alkalinity is consistently higher than total hardness in the gray water.

Therefore, the clarifier-softener is operated in a clarifier mode and removes additional TSS, phosphate, and organics. Higher hardness load to the WAC reduces throughput between regenerations, but it has not proven to be a significant operational problem or additional expense. CO2, which can be added in the softener effluent to prevent post precipitation of calcium carbonate, is not necessary in the non-softening mode. Neither is supplemental caustic feed, which can be added ahead of the WAC to achieve approximately 1.1 ratio of TA/TH. The WAC effluent pH is lowered by acid addition prior to the decarbonator. As required by the HERO™ process to maintain high solubility of silica in the RO reject, the RO feed pH is adjusted to 10.3 - 10.5.

The weak acid cation exchangers remove hardness associated with alkalinity and replace the hardness with hydrogen ions. This converts much of the carbonate/ bicarbonate alkalinity to carbon dioxide, which is reduced to concentrations of 5-10 mg/l in the decarbonator effluent. Higher alkalinity compared to hardness in the feed to WAC, results in higher alkalinity in the WAC effluent.

The WTP data (not included) shows that 99 % of the time, WAC effluent had negligible hardness. Occasionally, some hardness leakage from WAC takes place. When the differential pressure increase is observed across the RO membranes, on-line acid cleaning of the RO membranes is carried out. To date, the RO membranes have not required off-line cleaning using the supplied clean-in-place (CIP) skid with any other chemical agents. Although provisions for the addition of anti-scalant and a non-oxidizing biocide ahead of the RO system have been included, neither is currently used.

TABLE-4, WTP TA, TH & COND. DATA

Parameter/ 2001	May	June	July	Aug
GWS pH	7.5	7.7	7.8	7.7
GWS TH, mg/l	218	221	212	216
GWS TA, mg/l	337	310	298	271
PF TH, mg/l	203	216	203	151
PF TA, mg/l	329	228	203	376
WAC TA, mg/l	307	247	193	376
WAC effl pH	5.2	4.1	3.6	4.7
GWS Cond., uS/cm	1243	1175	1172	1247
PF Cond.	1352	1351	1509	1829
RO feed Cond.	1945	1863	1858	2289
RO prd Cond	108	130	104	72

GWS=Gray Water Sump, Cond.=Conductivity PF=Press. Filter, TH=Total Hardness as CaCO3, TA= Total Alk. as CaCO3

TABLE-5, WTP SILICA DATA

Parameter/ 2001	May	June	July	Aug
GWS Avg. SiO2, mg/l	65	67	61	59
GWS Max SiO2, mg/l	69	75	84	49
PF Avg. SiO2, mg/l	57	58	53	38
PF Max SiO2, mg/l	57	63	62	49

GWS=Gray Water Sump, Cond.=Conductivity PF=Press. Filter,

Specific conductivity data indicates that conductivity increases from the gray water sump through the pressure filters and to RO feed. This is expected because NaOH, NaOCl, and HCl are added. RO feed conductivity varies significantly with the permeate conductivity averaging between 72 to 130 uS/cm. Total silica removal within the pretreatment system (through the pressure filters) is shown in Table 5.

TABLE-6, REQUIRED Demineralized Water (DM) Quality FROM WTP

Conductivity, uS/cm at 25 deg C	< 0.2
Silica as SiO2, ppb	< 20

TABLE-7, DM QUALITY FROM WTP (Average Monthly Data)

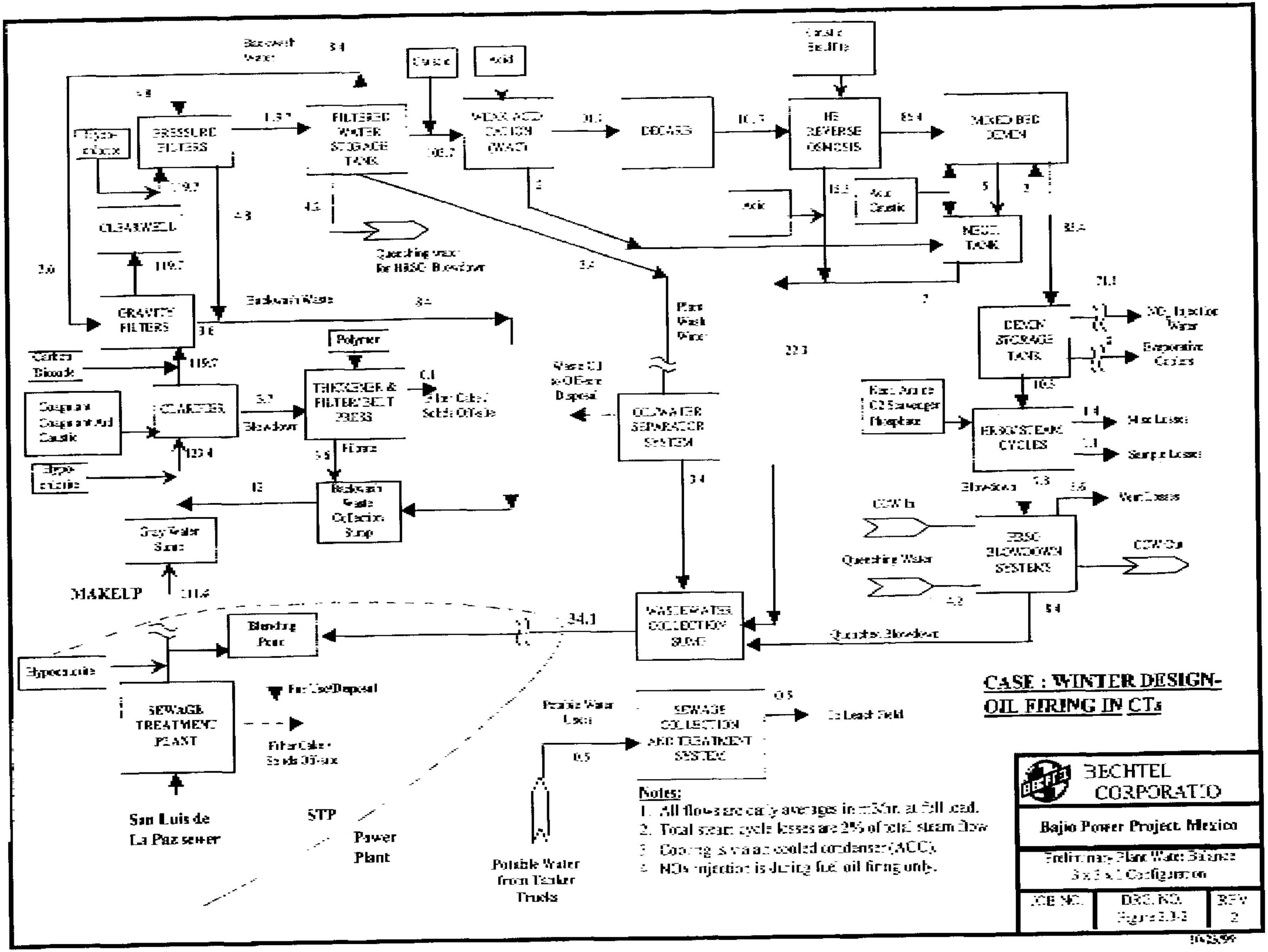
Parameter/ 2002	Feb	Mar	Apr	May	June
MB product, Cond., uS/cm	0.05	0.12	0.09	0.13	0.13
MB Silica as SiO2, ppb	0.2	1.1	2.2	2.8	1.6

The HERO™ system was designed with slightly lower recovery than what the vendor would have recommended (90 to 95%). Presently, the system operates at approximately 85% recovery (60 m3/hr with a reject stream of 9 m3/hr). Demineralized water quality from the mixed beds meets the quality requirements of power plant steam cycle makeup with typical conductivities varying from 0.05 to 0.13 and typical silica concentrations varying from 0.2 to 2.8 ppb.

SUMMARY AND CONCLUSIONS

The Central el Bajio project utilizes raw sewage with high silica concentrations as the sole source of makeup water to the plant. A sewage treatment plant and makeup water treatment system converts the sewage to high quality demineralized water for plant usage. In summary, the following comments and conclusions are presented for plants with similar water sources:

- Raw sewage data in remote areas is likely to be limited. Inorganic, silica and metal data may be even more limited and a supplemental sampling program will most likely be required. This should be planned into project schedule.
- Due to lack of local funding, it may be difficult for local communities in rural areas of many countries to follow through on initial commitments to provide additional infrastructure to support a water supply.
- Alkalinity is significantly affected by the nitrification/denitrification process. In the present case, ammonia-N was removed biologically through nitrification/denitrification. .
- Concentrations of alkalinity relative to hardness impacts both the conventional softener and WAC processes. Caustic softening (for calcium removal) as opposed to lime softening, will remove only a limited amount of alkalinity.
- The water treatment plant clarifier-softener was operated in the softener mode for a very limited time. Gray water that had been sitting stagnant in the gray water supply line during the initial phase of operation resulted in operational problems in the clarifier. Both clarification and softening modes were affected by poor settling sludge.
- Due to higher than expected gray water alkalinity concentrations, the plant operates the clarifier-softener under a clarification-only mode.
- The HERO™ process has proven reliable , providing acceptable results in both clarifier-softener modes on gray water of varying quality. Upstream silica removal was not essential for the successful operation of the HERO™ process.
- Variations in gray water alkalinity impact WTP operation, but with proper monitoring of hardness and pH and chemical feeds, the impact of this variability is mitigated.
- The HERO™ system produces demineralized water of suitable quality and sufficient quantity by treating the gray water supplied. Occasional on-line acid cleaning has been carried out. After a year's operation, and only as a precautionary measure, the plant is currently planning to clean the membranes for the first time using the CIP equipment with a non-oxidizing biocide.



CASE : WINTER DESIGN-
OIL FIRING IN CTs

Notes:
1. All flows are daily averages in m3/hr. at full load.
2. Total steam cycle losses are 2% of total steam flow
3. Cooling is via air cooled condenser (ACC).
4. NOx injection is during fuel oil firing only.

BECHTEL CORPORATIO

Bajio Power Project, Mexico

Preliminary Plant Water Balance
3x3x1 Configuration

JOB NO.	DRG. NO.	REV
	Figure 3.3-2	2

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