capital and service contract for reverse osmosis systems at TVA’s fossil plants

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summary
Outsourcing water treatment is an important option to be considered in today’s competitive environment. It allows industrial plants that rely on treated water to control cost and return focus to their core business. The water treatment service industry has grown beyond ‘demineralizers on wheels’ and can offer many options for treating your water. Those options are discussed here, including a hybrid concept being utilized at TVA.

challenge
When faced with a make-up demineralizer system that no longer meets the needs of a plant, numerous factors must be evaluated in the decision on how and when to upgrade or replace the system. Those factors can include collecting and analyzing data from every facet of the operation, running detailed financial cost/benefit models, and implementing corporate goals. In the case of the Tennessee Valley Authority’s Fossil Operations Power Division, both ends of the spectrum have been and are being utilized to replace the existing make-up demineralizer systems at its eleven fossil plants.

The commercial dates for TVA’s eleven fossil plants range from the early 1950’s to the early 1970’s. The original make-up systems included submerged tube evaporators, flash evaporators, and in a few cases, conventional ion exchange demineralizers. Over the years, many of the evaporator systems were replaced with conventional ion exchange demineralizer systems.

solution
In 1988, TVA’s Fossil and Hydro Department installed its first reverse osmosis (RO) system. Since the technology was new to TVA and the system was needed quickly, a service company was contracted to supply and operate the system. Shortly thereafter, a second RO system was installed by the service company. By 1993, TVA’s Fossil and Hydro Department had three RO systems operating under service contracts.

In 1993, TVA’s Board of Directors established “Environmental Leadership” as one of the company’s primary corporate goals. In support, a decision was made to eliminate all acid and caustic from the fossil plants. On the basis of this decision and the success experienced at previous locations, RO technology was embraced as key to achieving this goal.

After technical and economic evaluation, a decision was made to install new TVA owned make-up systems utilizing RO technology rather than use contract services. This decision was made to reduce operating and maintenance (O&M) costs. Capital funds were budgeted for the design and installation of all eleven systems. Two-pass RO with softening pretreatment was determined to have the lowest evaluated cost. Final polishing of the RO permeate would be accomplished utilizing mobile ion exchange demineralizers regenerated at a centralized location.

This paper reviews the process utilized to reach the decision to design, build and operate these capital systems in-house as compared to using full-service contract systems. This paper also reviews the criteria used to decide upon the system designs. Lastly, this paper discusses pros and cons of these systems, challenges to their installation, and successes and problems encountered thus far.
There are several published papers describing the water treatment by service contract concept.\textsuperscript{1,2,3,4} Essentially, these papers identify three basic service categories, all of which are utilized by TVA:

1. Emergency Service
2. Interim Service
3. Extended Service

A fourth category will be presented here, describing a hybrid service option.

**Emergency Service**

This segment includes emergency response by a service company due to an unexpected shortfall or lack of treated water. The need for such service could develop due to several conditions.\textsuperscript{1,2}

1. Water treatment system mechanical problems
2. Ion exchange resin problems
3. Increase in raw water TDS
4. Regenerant chemical or system problems
5. New system start-up problems
6. Support boiler or condenser tube leak resulting in high boiler blowdown rate

**Interim Service**

This type of service arrangement involves preplanning. The treatment systems provided under this service category are optimized to efficiently produce the desired water quality and quantity at a competitive price. These systems can be temporary or long term to support planned plant outages or supplemental to support increased treated water needs. Specific reasons for interim service\textsuperscript{1} might include:

1. Change in effluent quality requirements
2. Increased need in flow (quantity) requirements
3. Waste discharge limitations
4. Test make-up water quality on product/production
5. Bridge during upgrades or new construction
6. Planned maintenance of existing system

**Extended Service**

Extended service is a long-term water treatment contract, generally one to five years or longer. These systems involve reliance on an outside contractor for daily make-up water treatment needs. In today’s business environment, this is sometimes referred to as outsourcing. Outsourcing service is a major ingredient in many business operations and can allow a company to work more efficiently while streamlining. Outsourcing services include small contracts for office copier service to large steam contracts for the cogeneration market.

Popularity for outsourcing water treatment needs is developing for many reasons,\textsuperscript{1,2} including:

1. Optimizing operations to focus on core business purpose
2. Capital funds not available for new equipment purchase
3. Service contract has lower evaluated cost.
4. Uncertain time, volume and quality requirements
5. Environmental restrictions
6. Fast track project
7. High maintenance cost on current system
8. Inexperience with technology

Outsourcing water treatment needs simplifies cost accounting and minimizes budget overruns by eliminating unexpected O&M cost. Furthermore, outsourcing provides accountability for meeting water quality specifications through contract guarantees.

A major advantage outsourcing brings to the end user is competitive pricing. Competition requires service companies to increase efficiencies and optimize designs to provide the highest quality product at the best possible price. This is a major business principle that you can’t fully apply if you own your own system, since there is little internal competition.

**Hybrid Service**

The hybrid concept is a service option not yet identified. This service option is actually a subcategory to those previously discussed, but is normally associated with extended service needs. Specifically, this service option involves customer owned equipment working symbiotically with a service company’s equipment. For instance, the customer may own the clarifier pretreatment and reverse osmosis system feeding the service company’s mobile demineralizers. In each case the system is designed to work together in part as a whole. The advantages of this arrangement are:

1. Reduced initial up-front capital
2. Minimize unexpected costs
3. Share in the responsibility to make treated water
4. Additional resources available: technical, parts inventory and supplies
5. Emergency back-up available
6. Option to remove regenerant chemicals off site to meet environmental objectives
7. Lower monthly service bill
8. Service company guarantees final water quality

In summary, TVA successfully utilizes the four service options mentioned here. This is made possible by a strong partnering relationship with its service company. Both have benefited over the years from sharing the responsibility for make-up water treatment.

The three make-up water treatment systems described in this paper involve hybrid systems. In August 1995, the first of these new systems was completed and put into operation at Johnsonville Fossil Plant in New Johnsonville, TN. In September 1995, the second system was completed and put into operation at Colbert Fossil Plant in Tuscumbia, AL. The next system to be installed is at Cumberland Plant in Cumberland, TN.

**the decision process**

The decision process that ended with Johnsonville Fossil, Colbert Fossil, and Cumberland Fossil Stations installing a hybrid system, dates back to the late 80s. In 1988, TVA’s Widows Creek Fossil Station in Stevenson, AL had a water treatment system needing major upgrades to support increases in quantity and improved quality in demineralized water production. The most expedient and cost-effective choice at the time was a service contract utilizing RO followed by a mobile demineralizer. The plant made major operational improvements to their filtration system to support the more stringent RO pretreatment requirements, and realized immediate improvements in boiler chemistry stemming from the higher quality DI water being processed by the interim mobile system. Bull Run Fossil Station in Clinton, TN followed soon thereafter, replacing an evaporator make-up system with a reverse osmosis, ion exchange demineralizer system supplied under a service contract.

In 1993, TVA entered into a long-term partnering agreement with SUEZ to provide a wide variety of water treatment services and products for all their plants. At about this time TVA’s corporate management was formulating concepts to resolve the immediate and long-term water treatment needs for all TVA plants. Several water treatment problems occurring at different power plants within the TVA network initiated management’s concerns:

1. Super critical boilers operating on old and failing evaporators
2. Improved water quality requirements
3. Eliminate regenerant chemicals as a boiler feed contaminant source
4. Eliminate regenerant chemicals for safety and environmental reasons
5. Address the individual water treatment needs and problems at each plant with a company-wide approach

Three solutions were being studied to answer these concerns:

1. Upgrade all make-up systems with TVA purchased equipment
2. Employ various SUEZ services
3. Install ROs at each plant and build TVA’s own centralized regeneration facility for DI polishing resins

Solution one, upgrading the current on-site make-up treatment system at each power plant was given little consideration since it did not alleviate concerns number three and four, to eliminate regenerant chemicals as a boiler feed contaminant source, and for safety/environmental reasons.

Solution two, to employ various SUEZ services, economically represented low capital cost but high operating and maintenance cost (O&M). This was a favorable option, however if possible, TVA preferred an opposite budget reflecting higher capital spending and lower O&M cost.

Solution three was also viable. However, TVA lacked experience in this area to determine precise costs for this option.

In the summer of 1995, midway through the evaluation process, Johnsonville Fossil Station’s evaporators developed problems requiring immediate attention. SUEZ installed a 300 gpm RO/DI System to meet the plant’s long-term need. Shortly after this, TVA was approached by a neighboring manufacturing plant with a business offer to provide approximately 500,000 lbs./hr of low pressure steam for process needs. Entertaining this proposition, TVA reevaluated the long-term make-up needs for Johnsonville Fossil Station.
The cogeneration project increased Johnsonville Fossil’s make-up requirement from 300 gpm to 1,600 gpm. This became the catalyst that motivated TVA to move forward with the system wide upgrade project. With primary consideration going to Johnsonville’s cogeneration proposition, TVA revisited their options:

1. Install a complete 1600 gpm on site make-up system
2. Contract with SUEZ for a complete make-up service package
3. Install an on-site capital RO system and build a TVA owned and operated central regeneration facility for downstream mobile demineralizers
4. Install an on-site capital RO system and contract downstream mobile demineralizers and regeneration services through SUEZ

Option one failed TVA’s long-term goal to remove regenerant chemicals from plant sites and was therefore abandoned. Consideration for the remaining options centered on budgetary issues involving O&M costs versus capital expenditures.

Contracting with SUEZ for a complete make-up service package was seriously considered for the following advantages:

1. Regenerant chemicals removed from plant sites
2. Successful experience treating the raw water supply
3. Quick equipment availability and project start-up
4. Design and quote expedience.
5. Firm pricing

Full-scale design and pricing based on a service contract were offered to TVA. Although this option was given serious consideration, TVA’s internal budgets favored higher capital spending and reduced O&M cost.

After completing a fiscal analysis, TVA decided to proceed with the option that involved building TVA owned ROs at each power plant to support mobile demineralizers regenerated at a central location. At this point, TVA was undecided on whether to install their own central regeneration facility or utilize SUEZ’s mobile demineralizer systems and regeneration services.

Additional studies were commissioned to determine the feasibility for TVA to build, own, and operate a regeneration facility. TVA solicited SUEZ and hired a private consultant to formulate designs and develop costs for mobile demineralizers and a central regeneration facility. In the meantime, TVA relied on SUEZ to supply mobile demineralizers at Johnsonville Fossil and subsequent installations. Based on the information gathered, changes in business philosophies and budgets, TVA elected to shelve the central regeneration facility project in the near term.

In the fall of 1995, a contract was awarded to an architectural and engineering (A&E) firm to build and install the capital RO system at Johnsonville Fossil Station. Because a major component of the system is mobile demineralizer service by SUEZ, they participated in review of the system design. The final process flow scheme approved for Johnsonville Fossil Station was based on the initial SUEZ design offered as a service option.

For the Colbert and Cumberland Fossil Station projects, TVA extrapolated the Johnsonville decision process. These systems are slightly different from Johnsonville’s make-up treatment plant, but are basically the same.

**system design**

**Johnsonville Make-Up System Design**

The system was designed to optimize mobile demineralizer flow rate and capacity to achieve operating economy. The feed to the system is the Tennessee River, which averages 120 TDS. Key features of the Johnsonville design include:

1. Inclined plate Lamella clarifier with pre-flocculation
2. Dual media filters, anthracite and activated carbon, to prevent membrane oxidation damage due to chlorine
3. Packed bed ion exchange softening with external backwash tank
4. Two-pass polyamide membrane, reverse osmosis design to maximize downstream mobile demineralizers through put
5. Forced draft aeration followed by vacuum de-aeration to minimize carbon dioxide loading on the mobile demineralizers and reduce boiler feed water dissolved oxygen levels
6. Specially designed header system to facilitate easy mobile demineralizer installation and removal
7. Specially designed mobile demineralizers designed specifically for the RO permeate quality and upstream treatment process

The system, which went on line in March 1996, is illustrated in Figure 1.
Since the system began operation, there have been relatively few problems. The difficulties encountered have been attributed to new system start-up pains. The inclined plate settler was operated outside flow rate guidelines causing the plates to shift. Special clips were installed to prevent this in the future. The packed bed ion exchange softening system requires excessive backwashing when filter pretreatment is performing less than perfect. Better coagulant control is being investigated to improve this situation.

After the first few months of operation, the two-pass RO required membrane cleaning due to a coagulant polymer overfeed. Only the first pass membranes were fouled. Initial membrane cleaning proved ineffective, suggesting two improvements to the cleaning-in-place skid. One, a larger pump was installed to reach higher cleaning velocities. Two, a heater was installed for higher temperature cleanings. In the meantime, an off-site membrane cleaning service was utilized to restore membrane performance.

The vacuum degasifier has experienced minor problems meeting dissolved oxygen performance guarantees, and improvements are being worked on by the A&E firm.

The first mobile demineralizers were overrun to complete exhaustion. This caused slight regeneration problems due to silica polymerization. The mobile DI unit is a two-step design utilizing strong base anion followed by polishing mixed bed. This is considered the optimum design resin loading since the RO permeate contains primarily silica and carbon dioxide. These ionic species are exchanged exclusively on strong base anion resin. When the overrun trailer was regenerated, the silica polymerized causing minor problems. Since trailers have been exchanged based on throughput to alleviate this problem.

In light of these problems, the two-pass RO design and the mobile demineralizers are performing exceptionally well. Permeate conductivity is typically less than 1 µmho. The customized mobile demineralizers, designed to process thirty million gallons at 450 gpm (1.7 m³/h) with a 40-psi pressure drop, are producing fifty to sixty million gallons at 500 gpm with an 18-psi pressure drop.

**Colbert Make-Up System Design**

Colbert Fossil Station is located in Tuscumbia, AL. Although this upgrade did not include a cogeneration steam host, its make-up system needed major attention. Had Johnsonville not required an upgrade to meet the immediate steam host demands, Colbert Station would have been first in line for a new make-up system. Colbert’s financial and design work was a natural extension of the work already performed for the Johnsonville project. The two systems are almost identical, treating the same Tennessee River raw water supply. However, the Colbert project had some unique features not found in Johnsonville’s make-up system, such as:

1. The existing clarifier pretreatment is being utilized
2. The system is designed to produce a much smaller make-up requirement
3. The RO can operate in double pass or single pass mode.

4. It utilizes a standard configured mobile demineralizers.

Slight modifications to the existing clarifier pretreatment had to be made to accommodate for the additional RO reject flow to waste. The RO normally operates in two-pass mode producing 250 gpm (0.95 m³/h). During peak flow rate demand, the system can operate in one-pass mode to produce 450 gpm (1.7 m³/h). Therefore, any downstream mobile demineralizer design would have to perform equally well at varying flow rate and permeate quality. The optimum design chosen was a chemically balanced cation to anion standard mobile demineralizer. The basic make-up system design is illustrated in Figure 2.

**Figure 2: Colbert & Cumberland Fossil’s Make-up Water Treatment System**

Colbert’s new make-up system has been running smoothly since September 1995. Only minor piping modifications have been made since start-up. Mobile demineralizer capacity when processing two-pass permeate has yielded twenty million gallons as designed. All in all, the system has experienced trouble-free installation and operation.

**Cumberland Make-Up System Design**

Cumberland Fossil Station is located in Cumberland City, TN. The raw make-up supply to the plant is the Cumberland River that averages 160 to 170 ppm (mg/L) TDS. This make-up system is scheduled to come on-line in December 1996. As with Colbert, Cumberland’s basic system design and decision process was based on the information gathered on the Johnsonville project.

The system design is identical to Colbert’s with a minor difference in equipment employed and maximum peak flow rate. For normal two-pass operation the system will produce 250 gpm (0.95 m³/h). In single pass operation, the system is designed to produce a maximum 500 gpm (1.9 m³/h). In order to achieve this flow rate with the exact same RO design as Colbert’s, the new, larger 400 ft² (37 m²) membrane elements now offered by membrane manufacturers will be employed. Additional equipment, not part of Colbert’s make-up system, includes clarifier pretreatment and a vacuum degasator after the second pass RO.
Cost Comparisons

Accurate cost comparisons between capital installations and service contracts are not as straightforward as they may seem. There is the obvious equipment, chemical, and dedicated labor cost, but the less obvious, and still important considerations, include:

1. Maintenance support
2. Non-dedicated trade labor
3. Inventory and warehouse cost
4. Segregated utility cost
5. Technical and engineering support services
6. Finance cost
7. Amortization schedules

The main cost difference between owning a system and a service contract is fixed pricing. A service contract eliminates unexpected maintenance and repair costs, including required support services that affect annual budgets. The “Year-to-Date” data shown in Figure 3 is representative of unexpected costs. The numbers are reported in cost per thousand gallons produced. The cost figures shown for SUEZ are based on actual quotations, that may have varied slightly due to monthly water usage.

TVA’s “Year-to-Date” numbers, shown in Figure 3, are slightly misleading. The costs figures include one-time unexpected O&M cost. It is anticipated that these costs will average out by year’s end and that the final water treatment cost for the three plants will be at or near initial estimates. The TVA numbers also include the capitalization cost to build the three make-up water treatment systems spread out over ten years.

Figure 3: Water Treatment Cost

TVA’s present demineralized water treatment cost is higher than initial estimates for a number of reasons. At Johnsonville, membrane cleaning and filtration pretreatment support by SUEZ drove the cost to produce water unexpectedly higher during the first and second quarter. However, Colbert’s higher “Year-to-Date” cost is attributed to system changes prior to and during start-up that were not in the A&E’s original scope. The “Year-to-Date” cost for Cumberland’s make-up system, currently under construction, is a projected increase above the original budget. These increases are due to system modifications, implemented after the initial cost analysis, based on several things learned from the Johnsonville and Colbert project.

This comparison is made difficult by the many options to consider when adding up true cost. In response to uncertainties and preparing itself for future competition in the power industry, TVA is working to perfect true cost accounting. The numbers presented here are made possible by TVA’s new accounting system. In the future, this system will allow TVA to streamline operations by providing quick cost analysis for any function within TVA.

Since the upgrade project inception, beginning with Johnsonville Fossil Station, business philosophies, budgets and individual plant needs have changed. There is no longer an emphasis to build a TVA owned and operated central regeneration facility. Business philosophies and trends shifted within TVA making the central regeneration facility less attractive. Also, it was determined that several million dollars would be required for startup capital on this project. Furthermore, SUEZ’s service cost is comparable to TVA’s estimated cost to provide the same service.

The water treatment service industry has grown over the years, and is competitive with traditions capital installations and operations. Options are now available to end users that include capital equipment, service contracts or a combination of both. You must weigh all factors when making a decision on a new water treatment system.

Owning and operating your own water treatment system entails some risk. The water treatment service industry owes their primary existence to emergency water treatment problems. They now offer us a way to eliminate the unexpected problems
and the associated cost by providing fixed contractual pricing and quality guarantees. They can afford to take this risk because they are extremely focused in producing treated water to meet our needs.

references