THE SUCCESSFUL USE OF WELDED, GRADE 2 TITANIUM TUBING IN POWER PLANT CONDENSER SERVICE USING TREATED SEWAGE EFFLUENT– A CASE STUDY

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ABSTRACT:

In recent years, concern over the continued use of limited fresh water supplies or similarly, cooling towers and their essential makeup, high maintenance and associated chemical treatment requirements has spawned a crafty, yet dramatic change in power plant surface condenser and heat exchanger cooling. The paradigm shift away from the established and typical toward the unconventional has produced an innovative and non-traditional cooling water source for surface condensers and heat exchangers. Clearly, gray water-cooling has come of age.

Pundits suggest water shortages will increase the amount of water reuse (Chart 1) in the US from a current estimated 1.7 billion gallons to an estimated 12 billion gallons by the year 2015.

![Chart 1: Projected Water Reuse](chart.png)
Given this dramatic prediction, water reuse, or the reclamation and treatment of impaired or gray water will be driven by and emerge as market drivers joined at the hip by emerging effluent discharge standards. Without a clear understanding of the legislative and political landscape, regulative complexities that deal with this type of cooling water could conceivably lead to an unattractive, environmental legacy.

Having duly noted the “trend or aberration” dilemma, this paper will identify the successful efforts by the municipal wastewater treatment plants to economically treat the voluminous unknowns flowing from society by process and transport of a usable product from the municipal host to the ultimate user. A case study will be evaluated where the chosen candidate tube material, Gr. 2 welded titanium, has, since 1986, successfully operated within this dangerous and highly corrosive environment demonstrating that this non-traditional water source can be successfully implemented on a long-term basis within a hostile operating environment.

OVERVIEW

By definition, gray water is cooling water where all or part of the flow stream is made up of either partially or fully treated sewage effluent. As you can well imagine, the use of sewage effluent provokes a plethora of new issues. They are led by the voluminous unknowns that flow from society to the sewage treatment plant and the economics of processing and transporting this impaired water from the municipal host to the ultimate user. The application of this relatively new cooling medium suggests the potential impact of this “water” on plant metallurgy, chemical treatment requirements, corrosion abatement and other physical plant system needs, can become a blueprint for both the speculative and the unproven.

BACKGROUND

Of the 24,000 municipal wastewater treatment plants in the U.S., it is estimated that only about 1,500 employ water reuse facilities. Indeed, more glaring is the fact that only 6% of the total municipal wastewater volume is presently reused. This percentage is even less when applied to power generation facilities. Economic, legislative and logistical impediments to wholesale expansion of water reuse appear to be the high cost associated with medium transport, biological nutrient removal, macro and microfiltration, ultraviolet disinfecting and corrosion abatement activities.

In addition, the “relative” abundant supply of fresh water, be it destined as make-up or once thru, poses even greater challenges to the increased use of impaired water. Even though legislative action, albeit confusing, is currently underway to curtail the use of this “fresh” water, current regulative issues, high transport cost, interruptible shortages, wastewater disposal and inconsistent quality all contribute to any dramatic increase in the use of impaired water. In stark contrast, the relatively stable and predictable cost of fresh water undermines, in many cases, the unpredictability of sourcing to impaired water. Given this operational and economic conundrum, it should be noted that a number of utilities and utility consortiums have successfully made the transition from fresh to impaired. This has been accomplished by maintaining a successful economic return – both within the operating utility itself and the community at large.

Costs

Chart 2 below identifies the comparative raw cost of water worldwide. You will note the United States enjoys a relatively low cost when compared to other locations. One could speculate that this low, first cost poses economic roadblocks to the usage enlargement of impaired water. In many areas of the country, this is a truism. The first or raw cost of the water is not however,
## Chart 2
### Water Cost

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>WATER COST ($/1,000 gal)</th>
<th>Water Cost ($/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>$6.70</td>
<td>$1.78</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>$5.00</td>
<td>$1.32</td>
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<td>Netherlands</td>
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<td>Italy</td>
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<td>Finland</td>
<td>$2.43</td>
<td>$0.64</td>
</tr>
<tr>
<td>Southern California</td>
<td>$2.27</td>
<td>$0.60</td>
</tr>
<tr>
<td>United States *</td>
<td>$2.06</td>
<td>$0.54</td>
</tr>
<tr>
<td>Canada</td>
<td>$1.42</td>
<td>$0.38</td>
</tr>
</tbody>
</table>

Note: Costs west of the Mississippi River can be well above the national average.

The final cost of treated water. The below graphic (Chart 3) will identify the add-on costs to treat a variety of waters using both the "conventional" (chemical) and MF/RO (micro filtration/reverse osmosis) processes.

## Chart 3
### Treated Water Costs

<table>
<thead>
<tr>
<th>BASE COST U.S.</th>
<th>CONVENTIONAL TREATMENT</th>
<th>MF/RO TREATMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2.06/1000 gal</td>
<td>$2.84/1000 gal</td>
<td>$2.68/1000 gal</td>
</tr>
</tbody>
</table>

### The Process

Each day, U.S. industries consume 25 billion gallons of water all while generating about 20 billion gallons of wastewater. Furthermore, each day, thermoelectric plants in the U.S. consume 186 billion gallons of water. Given the voluminous flows and declining resources, gray or impaired water, as an alternate cooling medium, has emerged as a trendy option.

Should sewage effluent be considered as the cooling medium, a first or initial treatment typically takes place at a municipal sewage facility. Here, raw effluent is processed to (1), physically separate solids from liquids and (2), purify the liquid.

**Preliminary Treatment:** Solids, such as wood, rags and plastic are removed by screens. This debris is washed, dried and removed for safe disposal. Grit and sand are similarly removed.
**Primary Treatment**: Remaining solids are separated from the liquid using large, settlement tanks. The settled solids, referred to as sludge, are further treated for use as fertilizers.

**Secondary Treatment**: Biological or percolating filters break down organic material and purify the liquid. The process can be speeded up using aerating tanks. Further separation to isolate sludge is also required during this treatment phase.

At this point, the sewage or gray water is suitable for transport to the user facility. If further or tertiary treatment is required, final “polishing” may be required before the water is returned to the environment.

Photos 1 & 2
Phoenix/Tolleston, Arizona Wastewater Treatment Facility
Note: The use of sewage effluent represents a dramatic departure from the more historically benign water used for cooling in the past. Chart 4 presents an abbreviated water analysis that would typify effluent components that would not present immediate concern to the designer. However, the addition of sewage effluent to the mix dramatically changes not only the water quality but introduces biological considerations tied directly to BOD, COD and TKN requirements. The addition of heavy metals and radioactive materials to the effluent noted in the Chart, further compounds treatment requirements.

Once the effluent arrives at the power plant site, it undergoes a series of further treatments. Initially, trickling filters are employed to reduce ammonia and alkalinity. Additional multi-phase, biochemical treatment processes typically employ clarifiers where phosphates, magnesium, silica and some calcium are removed. A second stage removes much of the calcium-carbonate (CaCO3) using several chemical treatment options. Calcium-carbonate, if not addressed, can be a significant source of scale buildup and corrosion concern. Sulfuric acid may be added at this point to reduce pH and chlorine is added to control biological growth. A final gravity filtration will remove remaining suspended solids.

**Palo Verde Wastewater Treatment Plant**

**Photos 3 & 4**
At this point the treatment is complete and the gray water is transferred to storage reservoirs and used as tower makeup. In other cases, the treated effluent can be used directly as the main cooling water.

Palo Verde Plant Site & Storage Reservoir
Photos 5 & 6

Corrosion Discussion

Calcium-carbonate

The transformation of sewage effluent to gray water – water suitable for use in a power plant surface condenser produces unusual issues that deserve special attention. The first, which was noted previously, is the identification and reduction of phosphates or calcium-carbonate (CaCO₃). The data show⁸ that calcium-carbonate can initiate formation after only 1.5 cycles of concentration. A typical water analysis of gray water would suggest CaCO₃ levels range in the 68 ppm (City of Amarillo, TX) to 71 ppm (Raton, NM). Xcel Energy⁸ has noted that CaCO₃ becomes a problem at levels around 15 ppm. Higher cycles of concentration of the tower or the effluent itself will clearly exceed the 15 ppm threshold and precipitate in the form of deposits on the condenser tube ID surface opening up the potential to underdeposit pitting in susceptible tube materials. To minimize the fouling buildup, several solutions are can be employed.

<table>
<thead>
<tr>
<th>Ferric Sulfate</th>
<th>Lime</th>
<th>Soda ash &amp; carbon dioxide gas</th>
<th>Continuous on-line cleaning</th>
<th>Oligomers (scale inhibitors)</th>
</tr>
</thead>
</table>

In many locations, selection of the lime dosing proved the most economical. Others have selected the soda ash/carbon dioxide treatment. Evaluation of scale inhibitors classified as oligoers show promise as they are chlorine resistant¹. An on-line cleaning system will also prove beneficial if already in place. However, the capitol expenditure of a new unit may prove prohibitive.

Chlorine

A highly effective measure to prevent biocidal growth in all treatment areas typically includes the use of chlorine. This is especially true in pipelines and areas of the treatment that are highly susceptible to the spread of fecal coliform staff infection. Some utilities will use gaseous chlorine sparingly and have eliminated
all forms of chlorine shock due to reasons of safety, regulatory and public relations moving instead to bleach/bromide combinations. The use of chlorine in gray water applications is particularly troubling. If the cooling water contains amines or ammonia, chloroamines are formed which consume chlorine increasing the dosage amount to achieve the desired effectiveness.

**Manganese**

Manganese can also contribute significantly to corrosion concern. Recent research articles identified what they refer to as one of the most interesting and insidious corrosion issues relating to underdeposit pitting in impaired water cooling systems. It has to do with corrosion that is caused by manganese oxide - a phenomena that causes severe pitting on the tubes. The corrosion mechanism is not completely understood, however, it appears that soluble manganese precipitates as manganese dioxide on the condenser tube surface. Indeed, the manganese may be naturally occurring in river or lake water, or in sediments. If sediments become anaerobic, the manganese in them can solubilize. The soluble manganese subsequently oxidizes and precipitates as manganese dioxide on condenser tubes. The austenitic family of stainless steel appears to be particularly susceptible to the phenomenon of manganese induced, underdeposit pitting.

One possible explanation for the corrosion is that oxidizing biocides - such as chlorine - oxidize the manganese oxide to soluble permanganate. This destroys the passive layer on stainless steel and creates cathodic and anodic areas that generate severe pitting. Some researchers also theorize that biofilms themselves can concentrate manganese oxide. When the biofilm contains iron and manganese-oxidizing bacteria then can create manganese-oxide deposits on the tubing. These deposits may work in conjunction with sulfate-reducing bacteria, creating corrosion cells. It would appear this statement is counterproductive in that the use of chloroamines may actually cause corrosion issues. However, since the chlorine must be used in the effluent treatment process, there appears little choice in the matter. This can be a double-edged sword should the cooling water contain amines or ammonia – clearly present in gray water. In this environment, chloroamines are formed which consume chlorine and thus increase the amount of chlorine required to produce the desired results.

An additional problem with manganese is that it induces pitting by changing the potential of the exposed material. In the case of surface condensers, titanium is immune to this type of attack because it has such a very high pitting potential (on the order of +10V). SS, on the other hand, has a pitting potential very close to its rest potential (less than +1V) and can be susceptible to pitting attack when oxidizing compounds are present that raise the potential. Because all stainless materials are susceptible to their own PRE critical pitting temperature number, care must be exercised in the proper material selection when manganese-oxide conditions are present or suspected.

There also appears to be a connection or overlap between impaired or wastewater reuse for cooling and MIC/manganese attack. The case history noted in the reference data identified manganese-induced corrosion of stainless steel piping at the clarified outlet of sewage treatment plants. Higher cycles, waste, mine water reuse, hyper-chlorinization and drought conditions can exacerbate the problem.

**MIC**

Invariably, Microbiologically Influenced Corrosion (MIC) must be addressed when employing impaired or gray water. The bacteria present will predictably, place susceptible materials in harms way. The susceptibility of stainless steels to MIC is well documented. In particular, 304/304L and 316/316L are at risk. Indeed, batch culture tests indicate that all alloys examined at the time (316L, 904L, Al-6X, 254 SMO & 625) are susceptible to MIC attack. Later tests suggest the “N” grade of AL-6X exhibited good resistance to MIC. Considerable testing by the Naval Research Lab suggests titanium is immune to MIC – even at elevated temperatures (55 – 70°C).
Floaters and Sinkers

Effluent water quality can vary a great deal from city to city – from source to source. Plastic materials (floaters) can accompany the effluent water floating on the top of clarifiers potentially plugging heat exchanger equipment. Suspended solids and debris (sinkers) tends to form sludge in the cooling tower basin. Initially, chlorine was used to reduce the biological fouling identified as sulfate reducing bacterial.

However, heavy chlorine dosing can cause damage to system metallurgy – particularly the brass family of condenser and heat exchanger tubing. Other methods may be employed as a result of this damage potential. Similarly, high concentrations of ammonia will cause harm to copper bearing materials. High BOD also tends to exacerbate the problem.

A Case Study

Over the past several years, an increasing number of new generating facilities have employed the use of gray water in some form of cooling – either as tower makeup or, in some cases, direct, once-thru cooling. Delta Energy, Millennium Power, Bosque, The City of Lakeland, Florida, Londenderry and PSE&G are just a few of the subscribers to this latest trend. Indeed, PSE&G – both Bergen & Linden stations replaced their new 316 stainless condenser tubing with titanium principally because of the highly corrosive nature of the cooling medium. Xcel Energy and SWEPCO have employed effluent cooling in some form at their Nichols and Jones Generating stations for almost 40 years.

Historically, the recent spate of impaired water usage has been for small to mid-size generating units. The Arizona Public Service – Palo Verde Generating Station (APS-PV) is the glaring exception in terms of sheer size and historical precedence. Palo Verde is a three-unit, PWR facility generating a total of 3,875 MW and provides electric power to 4 million people in the Southwest. The station has been in operation since 1986 and uses gray water exclusively for cooling. See Chart 5 for plant statistics.

Cooling Water

Raw sewage, received from the greater Phoenix area, is initially treated at the Tolleston, AZ Municipal Sewage plant before transport approximately 45 miles via a 96” diameter line to Palo Verde.
Additional treatment is completed and purified water is pumped to the on-site storage reservoir for use in the closed loop condenser/tower circuit. A nearby CCGT unit – Redhawk also uses a partial flow of the effluent.

Cooling Towers

Three (3), mechanical forced-draft cooling towers service each generating unit. Corrosion of exposed rebar and spalling of the concrete into a gelatinous substance has occurred over the operational years due to the continuous wet/dry cycling. Chlorinating has been used to successfully combat the algae growth. The tower operates at 25 concentration cycles resulting in salinity $\geq$ than seawater. Once this concentration is reached, the water is discharged to evaporation ponds.

Chart 6

| DISTANCE SEWAGE PUMPED | 45 MILES |
| DIAMETER OF PIPE | 96” |
| SEWAGE PLANT FLOW | 58 MILLION GALLONS/DAY |
| APS-PV WATER RECLAMINATION CAP | 90 MILLION GALLONS/DAY |
| STORAGE RESERVOIR | 670 MISSION GALLONS 80 ACRES |
| TOWER EVAPORATION (ave) | 14,000 GAL/MIN/UNIT |
| TOWER BLOWDOWN (ave) | 865 Gal/min/unit |
| EVAPORATION POND | 250 ACRES – 2 PONDS |
| TOWER CONCENTRATION CYCLES | $\geq$ 25 |
Condenser

A Marley, 3-pressure, 3-shell surface condenser was field erected and tubed (see on-site erection photo) at the APS-PV site. In classic multi-pressure, variable tube length configuration, the CIRH20 is series connected in a parallel path (allowing bundle isolation) from the LP to IP to HP shell (see condenser schematic). The cycle is completed with shell C discharging to the cooling tower. Because of the corrodents present in the cooling water, the tube material was changed from stainless steel to titanium. The tube bundles were later staked to prevent the onset of damaging vibration due to the excessively large support plate spacing. The tubesheets are Al. Bronze with mechanically expanded tube joints. The tubesheets are coated at the inlet end but not at the discharge. All 12 water boxes are coated.

It is of keen interest to examine the overall performance and integrity of this condenser given its considerable service life, after-the-fact tube material selection, galvanically dissimilar tubesheet material, tube-tubesheet joint configuration, coating philosophy and above all, the aggressive water chemistry. Let us consider the following after nearly 20 years of service life.

On-site Surface Condenser Erection (1 of 6 shells)

1. No titanium tubing corrosion has taken place.
2. The integrity of the tube-to-tubesheet joint appears to remain viable.
3. Coating the inlet tubesheet has apparently halted some initial erosion of the Al. Bronze material. The initial erosion may have been galvanically induced.
4. Some fatigue failures of the titanium tubes were attributed to excessive support plate spacing. Staking successfully addressed this issue.
5. Several tube failures resulted from poor design of the cold water discharge spargers.
6. Some minor steam erosion has been detected on the tube OD at the top of the bundle.

7. Mechanical scrapers are used to keep the tubes clean. Little to no ID buildup has been observed using this cleaning method.

Conclusion

The remarkable and increasing use of sewage effluent to cool power plant component systems including main surface condensers and ancillary heat exchangers has been successfully demonstrated at many locations where fresh water is unavailable, not usable or too costly. Considering the rather undesirable source, impaired or gray water, given proper treatment, has emerged as an economically viable and highly sustainable resource. As a result, it becomes clear that water reuse will increase dramatically over the next 10 years notwithstanding the invasion of regulatory complexities that could derail this continued growth pattern.

The paper followed the transformation process from effluent to potable water taking on the nuances of multi-phase treatments, attendant corrosion mitigation and metallurgical "red flags". User experience suggested chemical treatments and material selections should be implemented based solely on good engineering practice. Engineers need to take a highly pragmatic view when considering material options, limitations and selection within the operating environment. Considerable dialog was spent on the manganese and chlorine issues – issues that can dramatically impact the operational competency of the system. Finally, a brief case history study of the APS - Palo Verde experience demonstrated that these practices can be successfully implemented on a long-term basis within the operating environment. Proven technologies and good engineering practices, not myopic speculation must be employed when operating in such a volatile system.
References:

3. The grateful contributions of Jer Chin Shih & Frank Francuzik, Arizona Public Service, Palo Verde Nuclear Generating Station
5. **Corrosion 2003** – Paper 03563
6. **Corrosion93** – An Evaluation of Titanium Exposed to Thermophilic & Marine Biofilms, Brenda Little, Patricia Wagner & Richard Ray – Naval Research Laboratory, Stennis Space Center
   **Corrosion93** – An Experimental Evaluation of Titanium’s Resistance to Microbiologically Influenced Corrosion, Brenda Little, Patricia Wagner & Richard Ray – Naval Research Laboratory, Stennis Space Center
7. City of Raton, NM
8. ASME Chemistry Committee, April, 2004 – **Sewage Effluent for Cooling, Xcel Energy’s Two-Score Experience**, Bernie Wieck
11. **Industrial Water Treatment Vol. 28 No 4 & No 6, 1996** – Corrosion Problems and Countermeasures in MSF Desalination Plant Using Titanium Tube, Fukuzuka et al
12. **Vallourec Information on Corrosion**
13. City of Tolleson, AZ Municipal Wastewater Treatment Plant
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## Typical Impaired Condenser Cooling Water Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effluent (mg/l)</th>
<th>Parameter</th>
<th>Effluent (mg/l)</th>
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<tbody>
<tr>
<td>Fecal Coliform</td>
<td>13</td>
<td>Sodium</td>
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<tr>
<td>Fecal Coliform</td>
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<tr>
<td>BOD (Biochemical O² Demand)</td>
<td>5.5</td>
<td>Calcium</td>
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<tr>
<td>TSS (Total Suspended Solids)</td>
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<td>Magnesium</td>
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<tr>
<td>COD (Chemical O² Demand)</td>
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<tr>
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<td>Carbonate</td>
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<tr>
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<td>T Phosphorus</td>
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<td>pH</td>
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### Heavy Metals (total) Effluent (mg/l)

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<thead>
<tr>
<th>Heavy Metals (total)</th>
<th>Effluent (mg/l)</th>
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<th>Effluent (mg/l)</th>
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<tbody>
<tr>
<td>Aluminum</td>
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<tr>
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<td>Arsenic</td>
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<td>Cobalt</td>
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<tr>
<td>Iron</td>
<td>0.1</td>
<td>Vanadium</td>
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<tr>
<td>Lead</td>
<td>&lt;0.001</td>
<td>Zinc</td>
<td>0.07</td>
</tr>
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</table>
Impediments To Using Gray Water...

They may be logistical, economic and/or legislative and include one or more of the following:

1. High cost of medium transport
2. Biological nutrient removal
3. Macro & micro filtration requirements
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4. UV disinfection
5. Corrosion abatement activities
6. Relative abundance of fresh water
7. Legislative & political landscape
24,000 Municipal Wastewater Plants in US

1,500 Employ Water Reuse

Only 6% of Wastewater is Reused

PowerGen use is even less
Projected Water Reuse

Billions gal/day

2001 2003 2005 2007 2009 2011 2013 2015
Object of the Paper

Examine the Process to Achieve a Usable Product
Evaluate Operational Conditions
Identify Emerging Corrosion Issues
Suggest Appropriate Abatement Procedures
Identify Maintenance Issues
Present Actual Case Study
Gray Water or “Impaired Water”

Definition: Flow Stream = Fully or Partially Treated Sewage Effluent

Usage: < 6% Wastewater is Reused

The Good: Readily Available in Untreated Form

The Bad: Economic & legislative impediments + ROI

The Ugly: Potentially Higher Cost
           Medium Transport
           Biological Nutrient Removal
           Macro & Micro Filtration
           UV Disinfecting
           Corrosion Abatement
Gray Water or “Impaired Water”

25 Billion Gallons = US daily Consumption

20 Billion Gallons = US daily wastewater generation

186 Billion Gallons = Thermal Power Plant Consumption
## Untreated Water Cost

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<td>$2.27</td>
<td>$0.60</td>
</tr>
<tr>
<td>United States</td>
<td>$2.06</td>
<td>$0.54</td>
</tr>
<tr>
<td>Canada</td>
<td>$1.42</td>
<td>$0.38</td>
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# Treated Water Cost

<table>
<thead>
<tr>
<th></th>
<th>BASE COST U.S.</th>
<th>CONVENTIONAL TREATMENT</th>
<th>MF/RO TREATMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$2.06/1000 gal</td>
<td>$2.84/1000 gal</td>
<td>$2.68/1000 gal</td>
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</tbody>
</table>
Typical Sewage Treatment Process

What is the Object?

Separate Solids From Liquids.....
or......
“Floaters from Sinkers”
Typical Sewage Treatment Process

What is the Object?

Purify The Liquid
Typical Sewage Treatment Process

Preliminary Treatment
Screens Remove Solid Debris

Primary Treatment
Settlement Tanks Separate Liquid From Solids

Secondary Treatment
Percolating Filters Break Down Organic Matter

Transport to Host or Final Polishing
Typical Sewage Treatment Process

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Primary Treatment
Settlement Tanks Separate Liquid From Solids

Secondary Treatment
Percolating Filters Break Down Organic Matter

Transport from Host or Final Polishing

The liquid may be filtered again using reed beds, filters or grass plots or disinfected with ultra violet light to kill bacteria.

The treated waste water returned to the natural water cycle.
Tolleson Arizona Wastewater Treatment Facility

Aeration Tank

Pumping Station
Palo Verde Wastewater Treatment Plant

Additional Treatment

- Trickling Filters
  Reduce ammonia and alkalinity
Palo Verde Wastewater Treatment Plant

Additional Treatment

• Trickling Filters
  Reduce ammonia and alkalinity
• Clarifiers - Stage 1
  Removes phosphates, magnesium
  silica and calcium
Palo Verde Wastewater Treatment Plant

Additional Treatment

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  Removes calcium carbonate
Palo Verde Wastewater Treatment Plant

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• Trickling Filters
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  • Sulfuric acid controls pH
Palo Verde Wastewater Treatment Plant

Additional Treatment

- **Trickling Filters**
  Reduce ammonia and alkalinity
- **Clarifiers - Stage 1**
  Removes phosphates, magnesium, silica, and calcium
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  Removes calcium carbonate
- **Sulfuric acid controls pH**
- **Chlorine Controls biological growth**
Palo Verde Wastewater Treatment Plant

Additional Treatment

- **Trickling Filters**
  Reduce ammonia and alkalinity
  - **Clarifiers - Stage 1**
  Removes phosphates, magnesium silica and calcium
  - **Clarifiers - Stage 2**
  Removes calcium carbonate
  - **Sulfuric acid controls pH**
  - **Chlorine Controls biological growth**
  - **Gravity Filters remove suspended solids**

Gray Water Treatment is Now Complete!
# Corrosion Considerations

## 1. Calcium - Carbonate (CaCO3)

**Threshold Limits**
- Range 15 - 71 ppm can initiate problems

**Concentration Limits**
- 1.5 to 25 cycles can exceed threshold limits

### Remedial Action Options

<table>
<thead>
<tr>
<th>Ferric Sulfate</th>
<th>Lime</th>
<th>Soda ash &amp; carbon dioxide gas</th>
<th>Continuous on-line cleaning</th>
<th>Oligomers (scale inhibitors)</th>
</tr>
</thead>
</table>
2. Biocidal Growth (fecal coliform/staff)

Treatment Options
- Chlorine
- Bleach/bromide Combinations

Caveat
- Grey water may form chloroamines which will consume chlorine requiring dosage increases
3. Manganese

Manganese Oxide = underdeposit pitting
Chlorine treatment may exacerbate the problem
Grey water may compound the problem
Austenitic stainless is susceptible

Remedial Action Options

Cleaning
Proper material selection
Corrosion Considerations

4. MIC

Gray water bacteria places suspect materials in harms way!

Highest susceptibility
304/304L & 316/316L

Other suspect materials
904L, AL-6X, 254 SMO, 625 (NACE, Naval Research Lab)

Resistant Materials
AL-6XN, UNS 44660, 29-4C

Immune Materials
Gr..2 Titanium (Naval Research Lab)

Remedial Action Options

Proper Material Selection
Chlorinating May or May Not Work?
High Temperature May Be Beneficial
Corrosion Considerations

5. Sinkers & Floaters (Debris)

- Intelligent debris housekeeping
- Sludge removal

Remedial Action Options

- Clarifiers free solid materials
Power Plants Employing Some Form of Gray Water Cooling

(Partial List)

Delta Energy
Millennium Power
PSE&G - Linden & Bergen
Arizona Public Service
XCEL Energy
SWEPCO Nichols & Jones Stations
City of Amarillo
Redhawk
Lincoln Electric - Salt Valley
A Case Study

Arizona Public Service
Palo Verde Nuclear Generating Stations

3-unit PWR
3875 MWe
On-Line Date: 1986

Cooling Source: 100% Treated Sewage Effluent
## Plant Statistics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DISTANCE SEWAGE PUMPED</td>
<td>45 MILES</td>
</tr>
<tr>
<td>DIAMETER OF PIPE</td>
<td>96”</td>
</tr>
<tr>
<td>SEWAGE PLANT FLOW</td>
<td>58 MILLION GALLONS/DAY</td>
</tr>
<tr>
<td>APS-PV WATER RECLAMINATION CAP</td>
<td>90 MILLION GALLONS/DAY</td>
</tr>
<tr>
<td>STORAGE RESERVOIR</td>
<td>670 MISSION GALLONS  80 ACRES</td>
</tr>
<tr>
<td>TOWER EVAPORATION (ave)</td>
<td>14,000 GAL/MIN/UNIT</td>
</tr>
<tr>
<td>TOWER BLOWDOWN (ave)</td>
<td>865 Gal/min/unit</td>
</tr>
<tr>
<td>EVAPORATION POND</td>
<td>250 ACRES – 2 PONDS</td>
</tr>
<tr>
<td>TOWER CONCENTRATION CYCLES</td>
<td>= 25</td>
</tr>
</tbody>
</table>
After Twenty Years of Cooling Tower Service.....

1. Corrosion of tower rebar is apparent
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After Twenty Years of Cooling Tower Service.....

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2. Tower basin concrete is spalling off
3. Chlorinating is successfully combating tower algae
4. 25 tower cycles are high – Chlorides = seawater
After Twenty Years of Condenser Service.....

1. No titanium tubing corrosion has taken place
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2. The integrity of the rolled-only tube-to-tubesheet joint remains intact and in excellent condition.
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2. The integrity of the rolled-only tube-to-tubesheet joint remains intact and in excellent condition.
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4. Some fatigue failures of the titanium tubing were attributed to excessive support plate spacing. Subsequent “staking” successfully addressed the issue.
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5. Several tube failures resulted from poor design of the cold water spargers.
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6. Minor tube erosion has been detected on tube bundle impingement tubes attributable to choke flow conditions in winter months.

7. Mechanical scrapers are employed to keep the tubes clean. Little to no I.D. buildup has been observed using this cleaning method.
1. Sewage Effluent Cooling is on the rise
2. Proper treatment is vital
3. Regulatory issues do not appear to be a factor.
4. Metallurgical ‘Red Flags”
5. Proper chemical treatments & material selections are imperative
6. Palo Verde case history
References:


3. The grateful contributions of Jer Chin Shih & Frank Francuzik, Arizona Public Service, Palo Verde Nuclear Generating Station


5. **Corrosion 2003** – Paper 03563

6. **Corrosion93** – An Evaluation of Titanium Exposed to Thermophilic & Marine Biofilms, Brenda Little, Patricia Wagner & Richard Ray – Naval Research Laboratory, Stennis Space Center

    **Corrosion93** – An Experimental Evaluation of Titanium’s Resistance to Microbiologically Influenced Corrosion, Brenda Little, Patricia Wagner & Richard Ray – Naval Research Laboratory, Stennis Space Center

7. City of Raton, NM

8. ASME Chemistry Committee, April, 2004 – *Sewage Effluent for Cooling, Xcel Energy’s Two-Score Experience*, Bernie Wieck


11. **Industrial Water Treatment Vol. 28 No 4 & No 6, 1996** – Corrosion Problems and Countermeasures in MSF Desalination Plant Using Titanium Tube, Fukuzuka et al

12. **Vallourec Information on Corrosion**

13. City of Tolleson, AZ Municipal Wastewater Treatment Plant