

## Technical Memorandum

---

Date: April 21, 2017  
To: Sylvan Source  
From: Michael DiFilippo  
Subject: Equipment Cost Analysis for FGD Wastewater Treatment Systems

Treatment of FGD wastewater was evaluated to compare OPEX and CAPEX of the Sylvan Core against three common volume reduction technologies – RO+VCE, MED and VCE. This analysis is an adjunct to the industrial report dated March 10, 2016. The case evaluated is a coal-fired power plant with 1 MGD of FGD wastewater. The treatment scenario for this plant is that it requires a ZLD system to treat all FGD wastewater to dryness (moist solids with no free water). Because of its location, evaporation ponds are not an option. Other in-plant waste streams (e.g. contact storm water, boiler blowdown, maintenance wash down, etc.) are stored and routed to the FGD towers. Water recovered by ZLD treatment (distillate and permeate) will be reused in the FGD system. A crystallization process to achieve ZLD, which would be common to all of the alternatives, was not included in the cost evaluation. The capacity of the crystallizer would vary somewhat for each alternative (except RO+VCE), but for this analysis there are considered equivalent. Pretreatment is required by all of the evaporative processes to reduce magnesium<sup>1</sup> concentrations to enable crystallization (MgCl<sub>2</sub> and MgSO<sub>4</sub> are highly soluble). The RO process requires complete hardness removal so pretreatment includes WAC softening. The RO system is coupled with a VCE to achieve comparable volume reduction to the evaporative processes. FGD chemistry can be highly variable depending on the source(s) of coal,<sup>2</sup> plant operating chemistry targets for the FGD, and day-to-day changes in FGD system chemistry. The FGD chemistry used in this analysis is from a power plant in the US.

Table 1 summarizes the pretreatment requirements for each wastewater; FGD wastewater (feed to the treatment system) and pretreatment chemistry are found in Table 2. Note that only major ions are shown; heavy metals are prominent in FGD wastewater (ppb levels), but usually do not impact pretreatment chemistry. Pretreatment chemistry is slightly different for the RO alternative; total hardness would be less than 1 mg/L<sub>CaCO<sub>3</sub></sub>.

---

<sup>1</sup> High levels of magnesium are common in FGD wastewater. It is an impurity in many sources of limestone, and because it is so soluble, it tends to accumulate in the FGD system.

<sup>2</sup> Many plants have two or more sources of coal because they shop the market to minimized plant fuel costs.

**Table 1**

	FGD Wastewater			
	Core	RO	MED	VCE
Precip Softening	X	X	X	X
WAC Polishing	---	X	---	---

*Notes...*

1. ZLD assumes complete recovery of wastewater. Evaporator brine sent to crystallizer.
2. Crystallizer not included in analysis since common to all alternatives and similarly sized.
3. Permeate and distillate recovered for FGD makeup.

**Table 2**

	Pre-Treated	
	FGD Blowdown	FGD Blowdown
Flow Rate, gpm	694.4	676.5
Na, mg/L	330	5,916
K, mg/L	35	35
Ca, mg/L	710	12
Mg, mg/L	3,300	607
HCO <sub>3</sub> , mg/L	769	37
Cl, mg/L	4,926	4,926
F, mg/L	50	5
NO <sub>2</sub> /NO <sub>3</sub> , mg/L-N	0	0
SO <sub>4</sub> , mg/L	8,100	8,100
SiO <sub>2</sub> , mg/L	87	9
B, mg/L-B	590	590
TDS, mg/L	21,681	23,021
TSS, mg/L	420	10

Table 3 shows operating and capital costs for all of the alternatives. None of the alternatives were optimized for size, power usage, or chemical utilization for this level of analysis. Because the RO system has relatively low recovery for both wastewater sources, its reject is treated with VCE to further reduce wastewater volume and thus the cost of the crystallizer. Pretreatment costs for FGD wastewater are significant; almost solely due to the high levels of magnesium that must be removed. Extensive pretreatment also affects handling/disposal costs associated with dewatered solids which were assumed to be stored onsite along with ash and FGD solids.

**Table 3**

	FGD Wastewater			
	Core	RO + VCE	MED	VCE
Feed Rate, MGD	1.00	1.00	1.00	1.00
Feed Rate, gpm	694.4	694.4	694.4	694.4
Pretreatment (YES/NO)	YES	YES	YES	YES
Net Feed Rate, gpm	676.5	676.5	676.5	676.5
Overall Recovery	88.5%	64.6%	88.5%	88.5%
Distillate (or Permeate), gpm	622.7	436.9	622.7	622.7
Wastewater, gpm	53.8	239.6	53.8	53.8
Wastewater TDS, mg/L	205,022	65,000	205,022	205,022
Recovery (VCE <sub>RO</sub> )	---	67.5%	---	---
Overall Recovery (VCE <sub>RO</sub> )	---	86.2%	---	---
VCE <sub>RO</sub> Distillate, gpm	---	161.7	---	---
Wastewater, gpm	---	77.9	---	---
Wastewater TDS, mg/L	---	200,000	---	---
Operator Staffing	10	14	10	10
Steam Requirement, #/hr	36,000	---	77,900	---
Power Requirement, kWh/day	3,000	33,400	19,900	81,000
<i>Operating Costs...</i>				
Pretreatment Chemicals	\$11,811,000	\$11,905,000	\$11,811,000	\$11,811,000
RO Chemicals	---	\$117,000	---	---
Evap Chemicals	\$148,000	\$51,000	\$148,000	\$148,000
Labor	\$843,000	\$1,180,000	\$843,000	\$843,000
Solids Disposal	\$2,080,000	\$2,080,000	\$2,080,000	\$2,080,000
Power	\$131,000	\$1,463,000	\$872,000	\$3,548,000
Steam	\$1,484,000	---	\$3,211,000	---
Maintenance	\$230,000	\$241,000	\$418,000	\$364,000
Disposables	---	\$74,000	---	---
Total Operating Cost	\$16,727,000	\$17,111,000	\$19,383,000	\$18,794,000
Unit OPEX, \$/kgal-Feed	\$45.83	\$46.88	\$53.10	\$51.49
Unit OPEX, \$/kgal-Distillate	\$51.79	\$54.38	\$60.01	\$58.19
<i>Installed Costs...</i>				
Feed Rate, MGD	1.00	1.00	1.00	1.00
Feed Rate, gpm	694.4	694.4	694.4	694.4
Pretreatment	\$9,280,000	\$14,680,000	\$9,280,000	\$9,280,000
Equipment	\$17,700,000	\$21,420,000	\$44,500,000	\$36,300,000
Total Equipment	\$26,980,000	\$36,100,000	\$53,780,000	\$45,580,000

Refer to Table 4 for generalized equipment lists for the RO and evaporative processes. Table 5 includes equipment for pretreatment.

**Table 4**

<u>Sylvan Core</u>		<u>Vapor Compressor Evaporator</u>	
SSI Cores	10	VCE Body & Sump	1
Brine Transfer Pumps	10	Recirculation Pump	1
Deaerator	1	Deaerator	1
Feedwater Heater	1	Compressor	1
Distillate Transfer Tank	1	Feedwater Heater	1
Feed Tank	1	Distillate Transfer Tank	1
Core System Feed Pumps	2	Feed Tank	1
Distillate Take-Away Pumps	2	VCE Feed Pumps	2
		Distillate Take-Away Pumps	2
<u>RO System</u>		<u>MED System</u>	
Chlor/De-Chlor System	1	Evaporator Effects (falling film)	5
UF Feed Tank	1	Recirculation Pumps	5
UF System	1	Deaerator	1
UF CIP System (including pumps)	1	Surface Condenser w/Steam Eject	1
RO System	1	Cooling Tower	1
RO CIP System (including pumps)	1	Circulating Water Pumps	2
UF Feed Pumps	2	Feedwater Heater	1
RO Feed Pumps	2	Distillate Transfer Tank	1
RO Booster Pumps	2	Feed Tank	1
RO Building	1	VCE Feed Pumps	2
		Distillate Take-Away Pumps	2

**Table 5**

<u>Pretreatment System for Evaporators &amp; RO</u>		<u>Additional Equipment for RO Pretreatment</u>	
Lime Softener (Reactor Clarifier)	1	WAC BW Pumps	2
Clearwell	1	35% HCl Feed Pumps	2
Sludge Thickener	1	50% NaOH Feed Pumps	2
Filter Presses	2	WAC Dil/Disp Water Pumps	2
Media Filters	3	Neutralization Tank Recirc Pumps	2
WACs	2	35% HCl Neutralization Pumps	2
Lime Softener Feed Pumps	2	50% NaOH Neutralization Pumps	2
Media Filter Feed Pumps (at Clearwell)	2	35% HCl Tank (vertical)	1
Hydrated Lime Silo, Soda Ash Silo	2	50% NaOH Tank (vertical)	1
Lime, Soda Ash Recirc Pumps, Soda Ash	4	Neutralization Tank	1
Polymer Feed Pumps	2		
Lime Softener Underflow Pumps	2		
Filter Press Feed Pumps	2		
Overflow/Filtrate Transfer Pumps	2		

Budgetary equipment costs for a 1 MGD (feed basis) Core, RO+VCE, MED, and VCE are found in Table 6. The installation factor for RO+VCE is a blended number; 3.0 factor for RO and 2.4 for VCE. Table 7 shows pretreatment equipment costs by system. The installation factor is 3.0 for all equipment except for the Precipitation Softener. The softener cost is on an installed basis so the installation factor for this item is 1.30 to account for piping, electrical, painting, etc.

**Table 6**

	Equipment Costs		
	Equip Only	Installed	Install Factor
SSI Core	\$8,300,000	\$17,700,000	2.1
RO+VCE	\$8,400,000	\$21,400,000	2.5
MED	\$17,900,000	\$44,500,000	2.5
VCE	\$15,300,000	\$36,300,000	2.4

**Table 7**

	Pretreatment Equipment Costs	
	Equipment	Installed
Precipitation Softener System	\$3,320,000	\$7,240,000
Media Filter System	\$680,000	\$2,040,000
WAC Softening System	\$1,800,000	\$5,400,000
Total	\$5,800,000	\$14,680,000