

# Technical Memorandum

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Date: May 8, 2017  
 To: Sylvan Source  
 From: Michael DiFilippo  
 Subject: Equipment Cost Analysis for Cooling Tower Blowdown Treatment Systems

Treatment of cooling tower blowdown 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 cooling tower blowdown. The treatment scenario for this plant is that it requires a ZLD system to treat all blowdown 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 typically routed to the cooling towers at ZLD plants. Water recovered by ZLD treatment (distillate and permeate) will be reused in the cooling tower. 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 ranged from 72.4 to 74.8 gpm, and for this analysis, they are considered equivalent. 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. Blowdown chemistry used in this analysis is from a US power plant.

Table 1 summarizes the pretreatment requirements for each system; cooling tower blowdown (feed to the treatment system) and pretreatment chemistry are found in Table 2 (note that only major ions are shown). Pretreatment chemistry is slightly different for the RO alternative; total hardness would be less than 1 mg/L<sub>CaCO3</sub>.

**Table 1**

	Cooling Tower Blowdown Pretreatment Requirements			
	In-Line Clean Core	RO	MED	VCE
No Pretreatment	<b>X</b>			<b>X</b>
Precip Softening	---	<b>X</b>	<b>X</b>	---
WAC Polishing	---	<b>X</b>	---	---

*Notes...*

1. Crystallizer not included in analysis since common to all alternatives and similarly sized.
2. Permeate and distillate recovered to cooling tower.

Note that the Sylvan In-Line Clean Core alternative will not require pretreatment. This process is currently in development and has not been demonstrated on a live stream. The In-Line Clean Core configuration enables the Core to be cleaned while operating. One unique feature is a dual bottom stage. The bottom stage is most susceptible to fouling from mineral scale because it operates at the highest temperature. When scale starts to impair this stage the other stage, which is on stand-by mode, is put in line, while the fouled stage is cleaned. These stages will be designed to rotate duty. There are also provisions to clean the entire system as required but this is expected to occur much less frequently

**Table 2**

	Pre-Treated	
	Cooling Tower	Cooling Tower
	Blowdown	Blowdown
Flow Rate, gpm	694.4	692.1
Na, mg/L	6,368	7,189
K, mg/L	276	276
Ca, mg/L	400	12
Mg, mg/L	236	24
HCO <sub>3</sub> , mg/L	46	37
Cl, mg/L	4,160	4,160
F, mg/L	21	2
NO <sub>2</sub> /NO <sub>3</sub> , mg/L-N	0	0
SO <sub>4</sub> , mg/L	9,791	9,791
SiO <sub>2</sub> , mg/L	176	18
B, mg/L-B	4	4
TDS, mg/L	21,494	21,531
TSS, mg/L	5	10

**Notes...**

1. Only major ions shown.

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 hardness and silica removal are significant. Extensive pretreatment also affects handling/disposal costs associated with dewatered solids which were assumed to be stored onsite with combustion residuals. A natural gas combined cycle plant would have to have the solids transported offsite or stored onsite in a designated disposal area.

**Table 3**

	Cooling Tower Blowdown			
	In-Line Clean			
	Sylvan 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)	NO	YES	YES	NO
Net Feed Rate, gpm	694.4	692.1	692.1	694.4
Overall Recovery	89.2%	66.9%	89.2%	89.2%
Distillate (or Permeate), gpm	619.7	462.8	619.7	619.7
Wastewater, gpm	74.8	229.3	72.4	74.8
Wastewater TDS, mg/L	199,774	65,000	199,774	199,774
Recovery (VCE <sub>RO</sub> )	---	67.5%	---	---
O'all Recovery (VCE <sub>RO</sub> )	---	88.9%	---	---
VCE <sub>RO</sub> Distillate, gpm	---	154.8	---	---
Wastewater, gpm	---	74.5	---	---
Wastewater TDS, mg/L	---	200,000	---	---
Operator Staffing	4	14	10	4
Steam Requirement, #/hr	36,900	---	79,700	---
Power Requirement, kWh/day	3,000	32,600	19,900	79,600
<i>Operating Costs...</i>				
Pretreatment Chemicals	---	\$1,643,000	\$1,545,000	---
RO Chemicals	---	\$120,000	---	---
Evap Chemicals	\$222,000	\$50,000	\$151,000	\$153,000
Labor	\$436,000	\$1,180,000	\$843,000	\$337,000
Solids Disposal	\$139,000	\$280,000	\$280,000	\$139,000
Power	\$131,000	\$1,428,000	\$872,000	\$3,486,000
Steam	\$1,521,000	---	\$3,286,000	---
Maintenance	\$192,000	\$238,000	\$418,000	\$303,000
Disposables	---	\$74,000	---	---
Total Operating Cost	\$2,641,000	\$5,013,000	\$7,395,000	\$4,418,000
Unit OPEX, \$/kgal-Feed	\$7.24	\$13.73	\$20.26	\$12.10
Unit OPEX, \$/kgal-Distillate	\$8.11	\$15.44	\$22.70	\$13.56
<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	---	\$14,680,000	\$9,280,000	---
Equipment	\$20,200,000	\$21,040,000	\$44,500,000	\$36,300,000
Total Equipment	\$20,200,000	\$35,720,000	\$53,780,000	\$36,300,000

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
Chemical 1 Tank & Pumps	1	Distillate Take-Away Pumps	2
Chemical 2 Tank & Pumps	1		
Chemical Cleaning Recirc 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</u>		<u>Additional Pretreatment Equipment for RO</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**

	Installed Equipment	Install Factor
In-line Clean Core	\$20,200,000	2.1
RO+VCE	\$35,720,000	2.5
MED	\$53,780,000	2.5
VCE	\$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