Technical Memorandum

Date: October 24, 2023

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 two common volume reduction technologies: RO+VCE, VCE (standalone). This analysis is an update a previous version dated May 8, 2017. 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_{CaCO3}.

Table 1

Cooling Tower Blowdown Pretreatment Requirements

	In-Line Clean Core	RO	VCE
No Pretreatment	**X**		**X**
Precip Softening	---	**X**	---
WAC Polishing	---	**X**	---

Notes...

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

The number of stages selected for the Core depends on feedwater chemistry, available steam characteristics, and tradeoffs between number of stages and energy used (CAPEX vs OPEX). In the original 2017 analysis, a 10-stage Core was assumed; in this analysis a more typical 5-stage Core is recommended. The 5-stage Core offers a slightly higher steam use for a lower capital cost, either configuration can be used.

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 and brine concentration. When scale starts to impair this stage, the other (standby) stage is put in line, allowing the fouled stage to be 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

	Cooling Tower Blowdown	Pre-Treated Cooling Tower 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
HCO3, mg/L	46	37
Cl, mg/L	4,160	4,160
F, mg/L	21	2
NO2/NO3, mg/L-N	0	0
SO4, mg/L	9,791	9,791
SiO2, 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	VCE
Feed Rate, MGD	1.00	1.00	1.00
Feed Rate, gpm	694.4	694.4	694.4
Pretreatment (YES/NO)	NO	YES	NO
Net Feed Rate, gpm	694.4	692.1	694.4
Overall Recovery	89.2%	66.9%	89.2%
Distillate (or Permeate), gpm	619.7	462.8	619.7
Wastewater, gpm	74.8	229.3	74.8
Wastewater TDS, mg/L	199,774	65,000	199,774
Recovery (VCE_{RO})	---	67.5%	---
O'all Recovery (VCE_{RO})	---	88.9%	---
VCE_{RO} Distillate, gpm	---	154.8	---
Wastewater, gpm	---	74.5	---
Wastewater TDS, mg/L	---	200,000	---
Operator Staffing	4	14	4
Steam Requirement, #/hr	73,845	---	---
Power Requirement, kWh/day	3,000	33,600	80,400
Operating Costs…			
Pretreatment Chemicals	---	$2,793,000	---
RO Chemicals	---	$264,000	---
Evap Chemicals	$49,000	$52,000.00	$156,000
Labor	$531,000	$1,437,000	$411,000
Solids Disposal	$228,000	$458,000	$228,000
Power	$160,000	$1,739,000	$4,246,000
Steam	$3,707,000	---	---
Maintenance	$302,000	$376,000	$442,000
Disposables	---	$318,000	---
Total Operating Cost	$4,977,000	$7,437,000	$5,483,000
Unit OPEX, $/kgal-Feed	$13.64	$20.38	$15.02
Unit OPEX, $/kgal-Distillate	$15.28	$22.91	$16.83
Installed Costs…			
Feed Rate, MGD	1.00	1.00	1.00
Feed Rate, gpm	694.4	694.4	694.4
Pretreatment	---	$25,440,000	---
Equipment	$37,750,000	$25,640,000	$55,250,000
Total Equipment	$37,750,000	$51,080,000	$55,250,000

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

Table 4

Sylvan Core	
SSI Cores	6
Brine Transfer Pumps	6
Deaerator	1
Feedwater Heater	1
Distillate Transfer Tank	1
Feed Tank	1
Core System Feed Pumps	2
Distillate Take-Away Pumps	2
Chemical 1 Tank & Pumps	1
Chemical 2 Tank & Pumps	1
Chemical Cleaning Recirc Pumps	2
Soda Ash Tank & Pumps	1
Citric Acid Tank & Pumps	1

RO System	
Chlor/De-Chlor System	1
UF Feed Tank	1
UF System	1
UF CIP System (including pumps)	1
RO System	1
RO CIP System (including pumps)	1
UF Feed Pumps	2
RO Feed Pumps	2
RO Booster Pumps	2
RO Building	1

Vapor Compressor Evaporator	
VCE Body & Sump	1
Recirculation Pump	1
Deaerator	1
Compressor	1
Feedwater Heater	1
Distillate Transfer Tank	1
Feed Tank	1
VCE Feed Pumps	2
Distillate Take-Away Pumps	2
93% H_2SO_4 Tank & Pumps	1
Defoamer Feed Tank & Pumps	1

Table 5

Pretreatment System	
Lime Softener (Reactor Clarifier)	1
Clearwell	1
Sludge Thickener	1
Filter Presses	2
Media Filters	3
WACs	2
Lime Softener Feed Pumps	2
Media Filter Feed Pumps (at Clearwell)	2
Hydrated Lime Silo, Soda Ash Silo	2
Lime, Soda Ash Recirc Pumps, Soda Ash	4
Polymer Feed Pumps	2
Lime Softener Underflow Pumps	2
Filter Press Feed Pumps	2
Overflow/Filtrate Transfer Pumps	2

Additional Pretreatment Equipment for RO	
WAC BW Pumps	2
35% HCl Feed Pumps	2
50% NaOH Feed Pumps	2
WAC Dil/Disp Water Pumps	2
Neutralization Tank Recirc Pumps	2
35% HCl Neutralization Pumps	2
50% NaOH Neutralization Pumps	2
35% HCl Tank (vertical)	1
50% NaOH Tank (vertical)	1
Neutralization Tank	1

Budgetary equipment costs for a 1 MGD (feed basis) Core, RO+VCE and VCE are found in Table 6. The installation factor for RO+VCE (2.77) is a blended number; 3.0 factor for RO and 2.5 for the Core and 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
Core	$37,750,000	2.5
RO+VCE	$51,080,000	2.77
VCE	$55,250,000	2.5

Table 7

	Equipment	Installed
Precipitation Softener System	$4,850,000	$14,550,000
Media Filter System	$1,000,000	$3,000,000
WAC Softening System	$2,630,000	$7,890,000
Total	$8,480,000	$25,440,000