WorleyParsons

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Project Beacon
Evaporation Pond Sizing Calculation

By: Janine Forrest
Cked: J.Foster
Date: 6/15/2009

DESCRIPTION SHEET

General

1) The purpose of this calculation is to estimate the required evaporation pond acreage.
2) Site weather data are based on Cantil, CA. Dry bulb temperature data are from www.wrcc.dri.edu. Monthly average utility and wind speed data are from almanac data found on www.myforecast.com.
3) Site evaporation data are based on Backus Ranch, CA pan evaporation data as found at www.wrcc.dri.edu.
4) Blowdown TDS is based on the site specific mass balance.
5) Blowdown flow rates are based on the site specific water balance.

Instructions

Under the "Inputs" tab:

1) Manually enter the "Pond Design" data required. The Pond Top/Bottom Ratio, Pond Depth for Solids, Water and Freeboard, Annual Operation and Total Operation Duration must all be manually entered. Pond Top/Pond Bottom ratio based on a square pond, therefore must be manually changed if different design.
2) Manually enter all data for "Makeup/Blowdown Water Parameters".If the cooling tower make-up water TDS and the cycles of concentration are known, they should be entered in items 10 and 11. If the make-up TDS concentration is not known or the blowdown TDS concentration is altered due to other wastewater streams, the estimated blowdown TDS concentration should be manually entered in item 13.
3) Manually enter the Max and Min Dry Bulb temperatures, the Morning and Afternoon Relative Humidity and the Wind Speed data under "Site Weather Data".
4) Manually enter the Published Evaporation rate (Class "A" pan), the desired Lake Evaporation Factor, the estimated Pond TDS Concentration and the published Monthly Precipitation for the site under "Evaporation Table". Select which months spray nozzle operation is desired.
5) Manually enter the 24x12 net electricity generation for the facility. This data will have been generated separately by a solar modeling program.

Under the "Pond YEAR 1" tab:

1) Use the "Goalseek" function to set cell C13 to 0 by changing cell C16 on the"Inputs" tab (Inputs!C16).
2) The top and bottom of pond areas are now populated on the "Inputs" tab.

Calculations

Solids

1) Solids were calculated by converting the estimated pond inlet TDS from concentration to total solids through the life of the plant. The concentration is provided in ppm, which is the equivalent to mg/L.
2) The concentration must first be converted into the units of lb/gal.
3) Next the concentration is multiplied by the Spring/Fall Blowdown flow rate thus resulting in the average lb/min entering the ponds.
4) This average value is then multiplied by the estimated Annual Operation hours of the plant and then by the Total Operating Duration (design years of plant) giving the total lbs of TDS generated through the life of the plant.
5) The total mass of solids is converted to volume by using the assumed Dry TDS Solids Density.
6) The final 30 year depth of dry solids is calculated by dividing the volume of solids produced by the Average Bottom of Pond Area. This results in a conservative depth estimate as it does not account for the slope of the pond sides.
7 To determine the depth of solids for a given year the total depth over the life of the pond is scaled per year.
8) A factor of 2X is applied to the dry solids depth in the pond sizing calculations to account for the additional space required for storage of wet solids verse dry solids.

Monthly Blowdown

1) Design blowdown rates are obtained from a water balance for Summer, Spring/Fall and Winter ambient conditions. The flow rate for each season is the equivalent for 100% net electricity production for that given season. The blowdown flow rate will reduce linearly with the electricity

production in times when 100% plant capacity is not attainable (i.e. Summer = 56 gpm design for 250 MW, therefore flow rate would be 28 gpm for 125 MW during summer conditions).

2) The 24x12 net electricity generation for the facility gives an hourly average for each hour of the year thus enabling the estimation of the average blowdown flow rate for each hour of the year. May, June, July and August were chosen for the Summer months; September, October, March and April were chosen for the Spring/Fall months; and November, December, January and February were chosen for the Winter months. Net plant power generation data is estimated by use of Solar Advisor Model (SAM) as released by NREL.
3) The estimated blowdown rate for each season (in gallons per hour) was multiplied by the total electricity (MWh) produced in each appropriate month and divided by 250 MW thus resulting in the total gallons of blowdown entering the evaporation ponds for each month.

Pond Evaporation Rate

1) Published Class "A" pan evaporation rates are used but must converted to pond evaporation rates by the use of the following equations:

$$Evaporation = (PanEvaporationRate - \Pr ecipitation) * LakeFactor * SalinityFactor$$

2) Published daily average precipitation for each month is used.
3) Lake Factor based on information from Membrane Concentrate Disposal: Practices and Regulation, Mikey & Associates, 98-FC
4) The Salinity Factor is calculated by the following equation:

$$SalinityFactor = 1 - 0.0086 * \%TDS$$

However due to the high concentration of TDS water entering the pond, a factor of 0.7 is used, which is industry standard for sat
Reference: Review and Discussion on Evaporation Rate of Brines, December 2000, actis Environmental Services.

5) The Pan Evaporation Rate values are given monthly with a units of inches/acre-month. The pond acreage used to calculate the inches/month of evaporation is at the top of the solids storage section of the pond. This level can be easily maintained throughout the life of the pond and provides a conservative approach in that the water level will always be above the solids level and the smallest possible are for evaporation is chosen by using the top of the solids storage area.

Spray Nozzle Evaporation

1) Evaporation from spray nozzles is based on the following equation as published in the Journal of Applied Sciences 9 (3): 597-600, 2009:

$$E = 4.375 \exp^{0.106u} (e_s - e_o)^{-0.0092} T^{-0.102}$$

where, E = Evaporation Losses (% of nozzle discharge)
u = Wind Speed (mph)
T = Ambient Dry Bulb (°C)
$(e_s - e_o)$ = Vapor Pressure Deficit (mbar)

The Vapor Pressure Deficit is calculated by the following equation:

$$(e_s - e_o) = 0.611 \exp^{\left(\frac{17.27T}{237.3+T}\right)} \left(1 - \frac{RH}{100}\right)$$

where, $(e_s - e_o)$ = Vapor Pressure Deficit (mbar)
T = Ambient Dry Bulb (°C)
RH = Relative Humidity

2) The above equations do not account for drift losses. However, since the nozzles will be centrally located on the evaporation pond with > 100 ft to the nearest pond edge, drift losses are expected to be minimal.
3) Nozzle discharge is the blowdown for each given month.

Pond Sizing

1) The monthly average blowdown (pond inflow), pond evaporation (pond outflow) and spray nozzle evaporation (when chosen) are calculated and the blowdown is subtracted by the pond and spray nozzle evaporation values. In some months this value will result in a negative value showing that more water evaporated. for that month than what has entered the evaporation pond.
2) When the value is greater than zero, the remaining water level is carried over the next month. At no time is overall water volume in the pond permitted to go below zero or greater than the maximum capacity of the designated pond depth for water.
3) The maximum capacity for water is calculated based solely on the depth permitted for water and does not take into account the area below it for solids. This provides a conservative approach in the early years of operation but becomes more accurate in later years of operation.
4) The data is extrapolated over 30 yrs and listed on the Summary Table.

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Pond Design

1) Top of Pond Area	**8**	**acres**	(Rounded up to nearest acre)
2) Pond Top/Bottom Ratio	74%		(Based on square pond design with 3:1 slopes and total pond depth below - will change for different shapes)
3) Avg Bottom of Pond Area	5.9	acres	
4) Pond Depth for Solids	3	ft	(to account for maximum depth of sludge before clean out is required for safety purposes)
5) Pond Depth for Water	3	ft	
6) Pond Freeboard	2	ft	
7) Total Pond Depth	**8**	**ft**	
8) Annual Operation	3,200	hrs/yr	From Solar Advisor Model Hourly Data
9) Total Operating Duration	30	yrs	

Make-up/Blowdown Water Parameters

10) Make-up Water TDS Conc.	1900	ppm	
11) Cycles of Concentration	10		
12) Blowdown TDS Conc. (calc.)	N/A	ppm	
13) Evaporation Pond Feed TDS Co	110,951	ppm	(from "WB Opt 8 using Lake Koehn Chemistry (2009JUN15)"
14) Dry TDS Solids Density	80	lb/ft^3	(estimate for wet sludge)
15) Summer Blowdown	56	gpm	(from Koehn Lake Water balance & email from Scott Stern 06/15/09)
16) Spring/Fall Blowdown	46	gpm	(from Koehn Lake Water balance & email from Scott Stern 06/15/09)
17) Winter Blowdown	36	gpm	(calculated from Summer and Spring/Fall flowrates)

Site Weather Data

Source Data Location Cantil, CA

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max Dry Bulb (^oF)	58.9	65.6	71.5	76.2	86.5	97.7	104.3	102.1	93.1	80.2	64.1	58.0	80.1
Average Min Dry Bulb (^oF)	28.9	33.9	40.8	46.1	55.0	53.8	69.2	67.1	57.1	44.1	34.7	28.2	47.5
Average Dry Bulb (^oF)	43.9	49.8	56.2	61.2	70.8	75.8	86.8	84.6	75.1	62.2	49.4	43.1	63.8
Average RH (morning)	70.0	66.0	66.0	53.0	48.0	39.0	37.0	41.0	49.0	50.0	59.0	63.0	53.0
Average RH (afternoon)	40.0	36.0	36.0	25.0	22.0	17.0	17.0	20.0	22.0	24.0	32.0	40.0	28.0
Average RH (total)	55.0	51.0	51.0	39.0	35.0	28.0	27.0	30.5	35.5	37.0	45.5	51.5	40.5
Average Windspeed (mph)	8.7	10.1	11.1	13.1	13.7	13.8	12.0	10.8	9.6	9.2	8.3	8.2	10.8

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Evaporation Table

Source Data Location Backus Ranch, CA (Evaporation) and Cantil, CA (Precipitation)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Published Evaporation (in)	2.85	3.86	6.77	9.80	12.69	15.93	16.92	15.95	12.19	8.01	4.25	2.98	112.20
Lake Evaporation Factor	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Salinity Factor	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700
Monthly Precipitation (in)	0.71	0.48	0.30	0.09	0.15	0.05	0.10	0.12	0.05	0.03	0.43	0.54	3.05
Monthly Evaporation (in)	1.05	1.66	3.17	4.76	6.14	7.78	8.24	7.76	5.95	3.91	1.87	1.20	53.48
Operate Spray Nozzles (Y/N)	No	No	No	No	No	No	No	No	No	No	No	No	No

Net Plant Power Generation Table

NET OUTPUT TABLE FOR 250 MW SOLAR PROJECT

Hour Starting	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
0	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	24	15	62	94	56	19	2	-	-	-	23
8	20	20	128	123	207	250	220	219	137	14	12	0	112
9	46	60	172	215	250	250	250	250	244	110	62	10	160
10	57	74	164	235	250	250	250	250	250	159	69	10	168
11	52	73	149	231	250	250	250	250	249	157	58	10	165
12	43	69	133	211	250	250	250	250	250	142	50	10	159
13	44	74	134	218	250	250	250	250	250	139	58	10	161
14	58	80	141	207	250	250	250	250	250	149	77	10	164
15	60	86	150	192	250	250	250	250	250	165	79	-	165
16	20	40	115	173	250	250	227	246	250	165	10	-	146
17	-	-	16	139	213	236	193	216	185	95	-	-	108
18	-	-	-	43	119	162	122	100	38	13	-	-	50
19	-	-	-	-	10	19	10	0	-	-	-	-	3
20	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-
Total (MWhr)	401	575	1,326	2,003	2,611	2,761	2,578	2,551	2,356	1,308	475	60	
Days/month	31	28	31	30	31	30	31	31	30	31	30	31	
Monthly Totals (MWhr)	12,442	16,104	41,112	60,094	80,940	82,840	79,904	79,086	70,675	40,560	14,244	1,869	
												Total Annual Energy Generation	579,869

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			Annual			
Year	**Pond Size (ac)**	**Depth of Solids (ft)**	**Inflow - Plant (gal)**	**Outflow - Evap (gal)**	**Net (gal)**	**Margin**
1	8	0.79	7,069,226	9,417,756	-2,348,530	33%
2	8	1.59	7,069,226	9,417,756	-2,348,530	33%
3	8	2.38	7,069,226	9,417,756	-2,348,530	33%
4	8	3.18	7,069,226	9,417,756	-2,348,530	33%
5	8	3.97	7,069,226	9,417,756	-2,348,530	33%
6	8	4.77	7,069,226	9,417,756	-2,348,530	33%
7	8	5.56	7,069,226	9,417,756	-2,348,530	33%
8	8	6.36	7,069,226	9,417,756	-2,348,530	33%
9	8	7.15	7,069,226	9,417,756	-2,348,530	33%
10	8	7.95	7,069,226	9,417,756	-2,348,530	33%
11	8	8.74	7,069,226	9,417,756	-2,348,530	33%
12	8	9.54	7,069,226	9,417,756	-2,348,530	33%
13	8	10.33	7,069,226	9,417,756	-2,348,530	33%
14	8	11.13	7,069,226	9,417,756	-2,348,530	33%
15	8	11.92	7,069,226	9,417,756	-2,348,530	33%
16	8	12.72	7,069,226	9,417,756	-2,348,530	33%
17	8	13.51	7,069,226	9,417,756	-2,348,530	33%
18	8	14.31	7,069,226	9,417,756	-2,348,530	33%
19	8	15.10	7,069,226	9,417,756	-2,348,530	33%
20	8	15.90	7,069,226	9,417,756	-2,348,530	33%
21	8	16.69	7,069,226	9,417,756	-2,348,530	33%
22	8	17.49	7,069,226	9,417,756	-2,348,530	33%
23	8	18.28	7,069,226	9,417,756	-2,348,530	33%
24	8	19.08	7,069,226	9,417,756	-2,348,530	33%
25	8	19.87	7,069,226	9,417,756	-2,348,530	33%
26	8	20.67	7,069,226	9,417,756	-2,348,530	33%
27	8	21.46	7,069,226	9,417,756	-2,348,530	33%
28	8	22.26	7,069,226	9,417,756	-2,348,530	33%
29	8	23.05	7,069,226	9,417,756	-2,348,530	33%
30	8	23.85	7,069,226	9,417,756	-2,348,530	33%

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Year	1													
Top of Pond Area, ac	8													
Solids Depth, ft	0.79													
Pond Depth for Water, ft	3													
Starting Pond Depth for Solids, ft	3													
Available Pond Depth for Solids, ft	2.21													
Year 10 Minus Year 1 Carry Over Volume	0	(Make 0 by changing "Avg Bottom of Pond Area" on "Inputs" page)												
Evaporation (inches/month)	8.2	7.8	5.9	3.9	1.9	1.2	1.0	1.7	3.2	4.8	6.1	7.8	53	Estimated Annual Average Evaporate
Average Dry Bulb (^{o}F)	86.8	84.6	75.1	62.2	49.4	43.1	43.9	49.8	56.2	61.2	70.8	75.8	63.8	
Average Dry Bulb (^{o}C)	30.4	29.2	23.9	16.8	9.7	6.2	6.6	9.9	13.4	16.2	21.5	24.3	17.7	
Average Relative Humidity	27.0	30.5	35.5	37.0	45.5	51.5	55.0	51.0	51.0	39.0	35.0	28.0	40.5	
Windspeed (mph)	12.0	10.8	9.6	9.2	8.3	8.2	8.7	10.1	11.1	13.1	13.7	13.8	10.8	
Hour starting	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total	July to June
Days/month	31	31	30	31	30	31	31	28	31	30	31	30	365	Days per year
gal/month Inflow from Plant	1,073,914	1,062,913	780,253	447,786	123,064	16,150	107,498	139,135	453,879	663,435	1,087,834	1,113,365	7,069,226	Inflow from Plant (gal)
Spray Evaporation (% of Inflow)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
gal/month Outflow (spray evap)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	Outflow - Spray Evap (gal)
gal/month Outflow (pond evap)	1,451,275	1,365,855	1,047,472	688,536	329,600	210,530	184,645	291,635	558,249	837,805	1,081,985	1,370,169	9,417,756	Outflow - Pond Evap (gal)
Net gal/month total	-377,361	-302,942	-267,219	-240,750	-206,536	-194,380	-77,147	-152,501	-104,370	-174,370	5,849	-256,804	-2,348,530	Net (Inflow - Outflow)
Carry over Volume to next month gal	0	0	0	0	0	0	0	0	0	0	5,849	0		
Available Volume gal/month	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,790,275	6,796,124	6,796,124	Available Volume at end of calendar year
Maximum Capacity without freeboard	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	6,796,124	Maximum Capacity without freeboard

reference files:

Rev.	Description	By	Date
A	Original Issue	J.Forrest	06/15/09

Checked By: J.Foster

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Evaporation Pond - Pre-Post Treatment Clarifier (Koehn Lake)

FPLE Solar - Project Beacon

Rev. A