Calculation of Effect of Cycles of Concentration on Amount of Makeup Water Necessary for Seawater Cooling Towers at Diablo Canyon Power Plant

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It is necessary to continuously replace the evaporative loss in a cooling tower. If only evaporative loss is replaced, then the dissolved solids that were in the evaporated water to begin with start to build up in the circulating cooling water. This can cause problems with scaling, fouling, etc. It is therefore necessary to continuously discharge some amount of the circulating water to prevent the dissolved solids from building up too high in the circulating water. This discharge is known as "blowdown." In a freshwater cooling tower, the amount of blowdown is substantially less than the amount of water evaporated. However, in a cooling tower circulating seawater, which has a dissolved solid content of about 35,000 ppm, the blowdown rate is typically maintained at about double the evaporation rate in order to maintain the circulating water dissolved solids concentration around 50,000 ppm.

Cooling tower evaporative cooling is achieved by the evaporation of a small fraction , about 1 to 2%, of the recirculating water flow.[1] The cooling tower water ("w") balance consists of water lost to evaporation, water lost in blowdown, and water lost as aerosol drift:

$$w_{make\text{-}up} = w_{evaporation} + w_{blowdown} + w_{drift}$$

f_{latent} = fraction of total heat rejected by latent heat transfer (0.9 is used here, but it can be lower depending on ambient conditions and design choice), and h_{fg} = latent heat of vaporization in British thermal units per pound of salt water at 50,000 ppm, 60 ^oF (Btu/lb_m); ~1,010 Btu/lbm.[2]

The existing once through cooling systems at Diablo Canyon Units 1 and 2 are each designed to reject 7,764 x 10^6 Btu/hr at a circulating water flowrate of 862,690 gallons per minute (gpm) at a design net output of 1,100 MW.[3] The heat duty for the cooling system would be approximately 7,000,000 Btu/hr per MW of electric power generated.

1. Seawater Cooling Tower Evaporation Rate

Q = heat load, w = water balance

$Q_{tower} = 7 \times 10^6$ Btu/hr per MW_e

$w_{evaporation} = 7 \times 10^6 \times 0.9/1{,}010 = \sim 6{,}200$ lbm/hr per MW_e, or

[1] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers – PIER Final Consultant Report*, prepared for California Energy Commission, January 2010, Table 4-1, Salt Water Tower Installations, pp. 8-10.

[2] M. Sharqawy, et al – MIT, The thermophysical properties of seawater: A review of existing correlations and data." Desalination and Water Treatment, 16 (April 2010) 354–380, Figure 12, p. 64, 50 g/kg salt, 16 oF, latent heat = 2,350 kJ/kg (1,010 Btu/lb_m).

[3] TetraTech, *California's Coastal Power Plants: Alternative Cooling System Analysis*, February 2008, Chapter C – Diablo Canyon Power Plant, Table C-5, p. C-10. Heat rejection per unit = 7,764 million Btu/hr. Cooling water flowrate per unit = 862,690 gpm.

$w_{evaporation}$ = (6,200 lbm/hr per MW_e)(1 hr/60 min)(1 gal/8.54 lb)

$w_{evaporation} \simeq$ 12 gpm/MW_e

2. *Seawater Cooling Tower Blowdown Rate*

Blowdown rates are set to control scaling, fouling, and corrosion by limiting the buildup of impurities in the circulating water. This criterion is normally expressed in terms of maximum allowable cycles of concentration ("n"). A typical number of cycles of concentration for a seawater cooling tower is approximately 1.5.[4] Therefore, the blowdown rate for a seawater cooling tower would be:

$w_{blowdown} = [1/(n - 1)] \times w_{evaporation} = [1/(1.5 - 1)] \times (12\ gpm/MW_e) = 24\ gpm/MW_e$

3. *Seawater Cooling Tower Drift Rate*

The drift rate for a new cooling tower equipped with best available drift eliminators would be 0.0005%. Therefore, the cooling tower drift rate assuming 862,690 gpm circulating water rate would be:

$$w_{drift} = 0.000005 \times (862{,}690\ gpm/1{,}100\ MW_e) = 0.0039\ gpm/MW_e$$

4. *Example: Total Seawater Cooling Towers Makeup Water Requirement*

Diablo Canyon Unit 1 is used as the case study in the following example to determine the quantity of makeup water necessary assuming the once-through cooling flowrate of 862,690 gpm and 1.5 cycles of concentration.

$$w_{evaporation} \simeq 12\ gpm/MW_e$$

$$w_{blowdown} = 24\ gpm/MW_e$$

$$w_{drift} = 0.0039\ gpm/MW_e$$

Therefore, total unit cooling tower make-up water flow rate would be =

$$12\ gpm/MW_e + 24\ gpm / MW_e + \sim 0\ gpm/ MW_e = 36\ gpm/ MW_e$$

The seawater makeup requirement for 1,100 MWe Diablo Canyon Unit 1 (or Unit 2) would be:

$$36\ gpm/ MW_e \times 1{,}100\ MW_e = 39{,}600\ gpm$$

[4] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers – PIER Final Consultant Report*, prepared for California Energy Commission, January 2010, Table 4-1, Salt Water Tower Installations, p. 17. "Typically towers with high-salinity makeup (approaching seawater salt content) are operated at low cycles of concentration in the range of x 1.5 to x 2. In the case of seawater this results in a circulating water concentration of 50,000 to 70,000 ppm."

5. *Percentage Reduction in Cooling System Seawater Withdrawals Using Seawater Cooling Tower, 95.4%*

The percentage of makeup water flow to total circulating water flow is:

39,600 gpm ÷ 862,690 gpm = 0.046 (4.6%)

The reduction in cooling system ocean water withdrawals using a seawater cooling tower on Unit 1 (or Unit 2) would be:

Reduction in seawater usage = 1 – 0.046 = 0.0954 (95.4%)

6. *TetraTech Makeup Water Estimate for Diablo Canyon Units 1 and 2, 95.7%*

The total make-up water calculated for seawater cooling towers at Diablo Canyon give a similar result to the total makeup water estimate in the 2008 TetraTech report for Diablo Canyon:[5]

Table C-10. Makeup Water Demand

	Tower circulating flow (gpm)	Evaporation (gpm)	Blowdown (gpm)	Total makeup water (gpm)
Tower 1	862,690	12,600	25,000	37,400
Tower 2	862,690	12,600	25,000	37,400
Total DCPP makeup water demand	**1,725,380**	**25,200**	**50,000**	**74,800**

Using TetraTech values, the reduction in seawater cooling water withdrawal at Diablo Canyon for Unit 1 (or Unit 2) would be:

37,400 gpm ÷ 862,690 gpm = 0.043 (4.3%)

The reduction in cooling system ocean water withdrawals using a seawater cooling tower on Unit 1 (or Unit 2) would be:

Reduction in seawater usage = 1 – 0.043 = 0.957 (95.7%)

[5] Ibid, Table C-10, p. C-17.