Questions and Confirmations, September 2013 Bechtel Report

Powers Engineering, November 25, 2013

Basic Questions

1. Is it Bechtel's contention that use of fine traveling screens and/or wedge-wire screens used at Diablo Canyon will achieve:
    - a. a minimum 93 percent reduction in intake flow rate for each unit
    - b. at least a 90 percent reduction in impingement mortality

2. Is it Bechtel's contention that cooling towers can meet these flow rate and impingement mortality rates?

3. Is it Bechtel's contention that it is infeasible to construct cooling towers in the area of the parking lots and associated structures identified by Tetra Tech, PG&E and Powers Engineering?

4. Please provide a detailed and itemized cost estimate for construction of cooling towers on the parking lot site described in Question 3 (see also Detail Questions 4 and 5 below).

5. Please provide an itemized, detailed budget, with justification of costs, for the line items in the cost estimates for the cooling tower options currently provided in the September 20, Bechtel report (see also Detail Question 22 below).

Detail Questions

1. Confirm the steam turbine backpressure alarm level on Unit 1 and 2 steam turbines is 9.0 inches mercury and the high backpressure trip point is 10.5 inches mercury (Bechtel report, p. 6).
2. Identify the highest actual steam turbine backpressure level reached on Units 1 and 2, and state why the reason these peak backpressure levels occurred.
3. Confirm that Bechtel has reviewed all the historical Diablo Canyon closed cycle cooling studies included in the "*Scope of Work Report*, by the Review Committee to Oversee Special Studies for the Nuclear-fueled Power Plants Using Once-through Cooling," November 7, 2011, Appendix B, Diablo Canyon Power Plant (DCPP) Reference Documents.
4. For a back-to-back plume-abated cooling tower configuration located in warehouse/ parking lot area and built to meet 9.0 inches mercury backpressure at design condition of 61 ^{o}F wet bulb temperature or 64.5 ^{o}F wet bulb temperature, identify the size, approach temperature, range, and circulating water flow rate per unit.
5. Confirm that any cooling tower design that maintains steam turbine backpressure at or below 9.0 inches mercury is a technically feasible cooling tower alternative.
6. Confirm that the hybrid wet/dry mechanical draft cooling tower design proposed by Bechtel results in a maximum monthly average steam turbine backpressure of 2.5 inches mercury at design conditions (Bechtel report, Figure 4.3-2, p. 74).

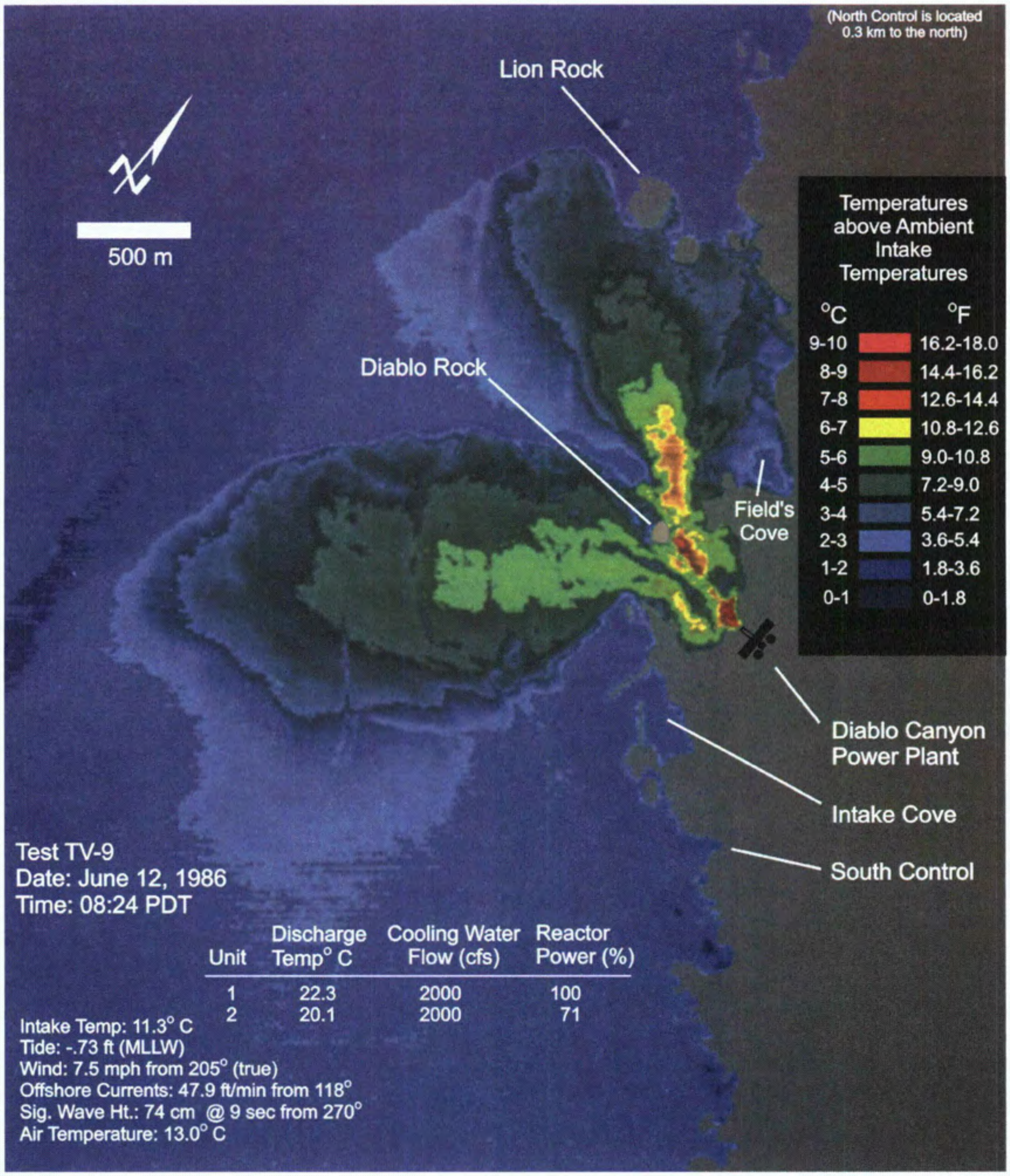
7. Confirm that Bechtel includes the cost of condenser upgrades in each of its closed cycle cooling alternatives (Bechtel report, p. 189).
8. Explain why Bechtel shows a backpressure of 2.25 inches mercury for 70 ^{o}F cold water inlet temperature for mechanical draft and round hybrid cooling towers (Bechtel, Figures 4.3-1 and 4.3-2, p. 74), while TetraTech states a backpressure of 1.89 inches mercury for the same 70 ^{o}F cold water inlet temperature condition assuming a condenser upgrade consisting of replacement surface condenser tube bundles (TetraTech 2002, p. 16).
9. Confirm that TetraTech states that the steam turbine efficiency loss at 1.89 inches mercury, relative to the design once-through cooling backpressure of 1.5 inches mercury, is 10.5 MW per unit and 21 MW for both units (TetraTech 2002, p. 16).
10. Confirm that the size of the retrofit cooling tower selected is inherently a balance between the capital cost of the retrofit cooling tower and the performance penalty imposed on Diablo Canyon.
11. Confirm that Bechtel assumed a design wet bulb temperature of 64.5 ^{o}F (Bechtel, Table 4.3-2, p. 73) and a design approach temperature of 12.5 ^{o}F for the mechanical draft cooling tower and round hybrid cooling tower (Bechtel, Table 4.3-2, p. 73).
12. Confirm that the Tera 1982 study used an approach temperature of 14 ^{o}F and TetraTech 2008 used an approach temperature of 17 ^{o}F (TetraTech 2008, p. C-10).
13. Provide the design approach temperature used by Enercon in its 2009 report prepared for PG&E to select 40-cell back-to-back mechanical draft cooling towers for Units 1 and 2 at Diablo Canyon.
14. Confirm that Bechtel did not evaluate any other approach temperature than 12. 5 ^{o}F for the mechanical draft or round hybrid cooling tower alternatives in the report.
15. Confirm Bechtel indicates a cold water inlet temperature for once-through cooling of no greater than 58 oF (Bechtel, Figure 4.3-1, p. 74).
16. Confirm that the TetraTech 2002 closed cycle cooling study for Diablo Canyon stated that maximum seawater temperature in 1972-1982 period was 64 ^{o}F. (TetraTech revised draft, November 2002, p. 3).
17. Confirm the temperature at the existing Diablo Canyon intake structure have not exceeded 64 ^{o}F.
18. Confirm that the hot water plume graphic for Diablo Canyon provided as **Attachment 1** is representative for the low tide condition.
19. If the intake structure water temperatures have exceeded 64 ^{o}F, identify the day, hour and temperature of each inlet water temperature greater than 64 ^{o}F.
20. Confirm Bechtel has commissioned two salt water cooling towers within the last 15 years per 2010 CEC evaluation of the performance of salt water cooling towers (CEC 2010, Table 4-1, pp. 18-21).
21. Confirm that Bechtel co-authored the 2003 Cooling Technologies Institute paper titled "*Feasibility of Seawater Cooling Towers for Large-Scale Petrochemical Development*" provided as **Attachment 2**.
22. Provide detail drawing of in-ground structures in front of the turbine building where TetraTech 2008 and Tera 1982 (referenced in TetraTech 2008 at p. C-14) proposed the location of the closed cycle cooling pump house for Unit 1 and 2 cooling towers (Powers Engineering could not locate any online drawings associated with the Bechtel report that provide this detail).

23. Confirm that the construction of a closed cycle cooling pump house on either side of the Diablo Canyon once-through cooling intake pipes shown in **Attachment 3** would not require a plant outage.
24. Provide location, number & type of cells, design approach temperature, design range, and circulating water flowrate of the two salt water cooling towers commissioned by Bechtel that are identified in the California Energy Commission consultant report titled, "*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.
25. Provide supporting detail about the nature of the costs and expected labor hours and equipment or insurance/warranty rates for each of the following costs listed for the wet natural draft cooling tower option evaluated by Bechtel (Bechtel report, p. 177). Explain what component of each of these costs is directly or proportionately related to 1) the excavation of 317 million cubic yards of material and associated site preparation the cooling tower location, and 2) the desalination plant and all associated hardware (piping, etc.).

Cost Element	**Cost Estimate ($, millions)**
Field indirect costs	641
Field costs	959
Home office costs	56
Other costs (securities, insurances, warranties, taxes and permits)	370
Contingency	1,136
Fee	688
Total:	3,850

Attachment 1

Technical Data Report – Heat Shock



Test TV-9
Date: June 12, 1986
Time: 08:24 PDT

Unit	Discharge Temp° C	Cooling Water Flow (cfs)	Reactor Power (%)
1	22.3	2000	100
2	20.1	2000	71

Intake Temp: 11.3° C
Tide: -.73 ft (MLLW)
Wind: 7.5 mph from 205° (true)
Offshore Currents: 47.9 ft/min from 118°
Sig. Wave Ht.: 74 cm @ 9 sec from 270°
Air Temperature: 13.0° C

Environmental Report Technical Data Report
Diablo Canyon Power Plant

Figure 3
Surface Infra-Red Aerial Survey of DCPP Thermal Plume on June 12, 1986 During Low Tide Conditions

source: (PG&E) Diablo Canyon License Renewal Feasibility Study Environmental Report, Technical Data Report, HEAT SHOCK, Revision 0, 2008.

Attachment 2

PAPER NO: **TP03-17**
CATEGORY: **MECHANICAL DRAFT TOWERS**

COOLING TECHNOLOGY INSTITUTE

FEASIBILITY OF SEAWATER COOLING TOWERS FOR LARGE-SCALE PETROCHEMICAL DEVELOPMENT

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PAUL LINDAHL, JR.
MARLEY COOLING TECHNOLOGIES

Presented at the 2003 Cooling Technology Institute Annual Conference
San Antonio, Texas – February 10-13, 2003

Attachment 2

Feasibility of Seawater Cooling Towers for Large-Scale Petrochemical Development

Shahriar Eftekharzadeh [1], Muin M. Baasiri [2], and Paul A. Lindahl Jr. [3]

ABSTRACT

The major feasibility issues concerning the applicability of Mechanical Draft Seawater Cooling Towers for a large-scale petrochemical development in the hot-humid Arabian Peninsula (Gulf) region were investigated.

The main issue addressed was the impact of salts in the cooling water as it affects the thermal performance, permissible salts concentration, salts emission (drift) and potential impacts upon the environment. Also addressed were tower system design modifications to suit the Gulf region extreme weather conditions, the operation & maintenance concerns, and life-cycle costs.

It was found that seawater cooling towers, when properly designed and managed, could satisfy the cooling needs of large-scale petrochemical development in the Gulf region, without significant problems. Cost of cooling was found to be less than the conventional once-through system normally used.

Based on the findings of this study, plans are underway to double the size of one of the largest petrochemical complexes in the world, located in the region.

Introduction

Petrochemical industries generate large quantities of waste heat. Therefore, cooling system considerations constitute an important aspect of petrochemical development schemes. Technically feasible and economically favorable industrial cooling solutions are essential.

This study was performed for a major petrochemical complex located on the North-Eastern shores of the Arabian Peninsula. The complex has been operating a successful “Once-Through” central seawater cooling system since 1982. Currently, an average flow of about 650,000 m^3/hr of seawater is supplied to 17 primary petrochemical industries, and returned to the Gulf with a maximum temperature rise of 10 ^oC. Industries are charged a flat rate of $13.6 per 1000 m^3 of seawater use for this service. The existing system has an ultimate capacity of 1,040,000 m^3/hr, which is expected to be reached by the year 2006.

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Currently a seawater demand of 1,300,000 m^3/hr in the existing City is projected by year 2010. In addition, a second adjacent industrial park, with a projected heat load comparable to the existing City is being developed. To enable such expansion, a technically and economically feasible industrial cooling scheme had to be identified. Economic and technical studies were conducted on the feasibility of various cooling alternatives were undertaken. It was concluded that Mechanical Draft Seawater Cooling Towers were the most feasible alternative.

This paper summarizes the major feasibility aspects of seawater cooling towers that were investigated for this petrochemical complex. Its findings are applicable to petrochemical units and other major waste heat producing plants in the Gulf region.

Once-Through Versus Recirculating System

Cooling systems are either "Once-through" or "Recirculating". A Once-through system uses the cooling water only once before it is discharged. A Recirculating system recycles the cooling water after it has been cooled at a heat sink.

Cooling systems are also classified as "Closed" or "Open". In a Closed system, the sink is a heat exchanger, and the system is not exposed to the atmosphere. In an Open system, the sink is either an evaporative cooling facility (such as a pond or a cooling tower), or a free water body (such as a lake, river, or sea), such that the system is open to the atmosphere.

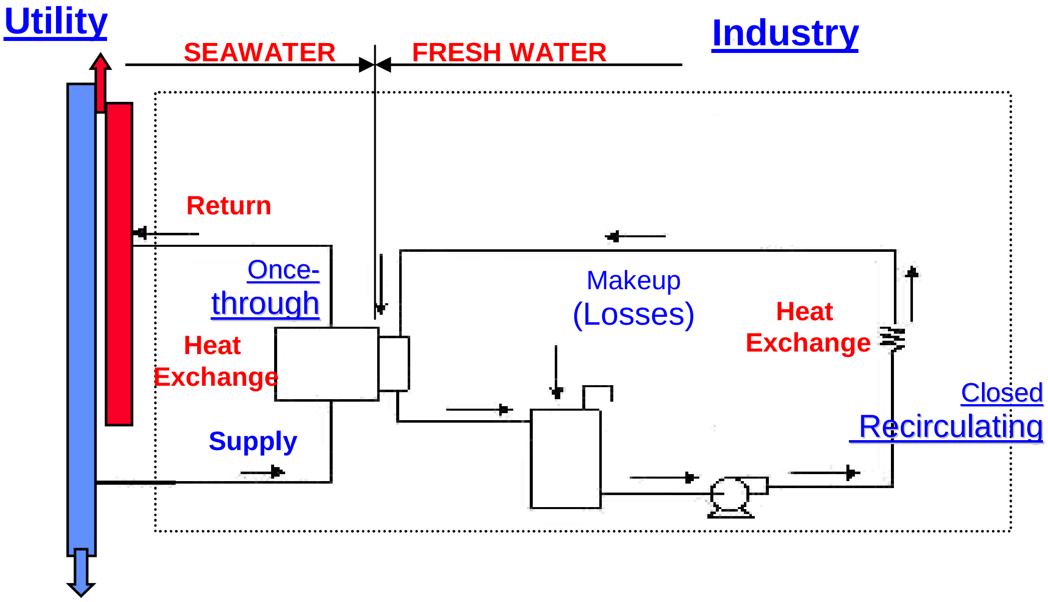


Figure 1: Typical "Once-through" system

Figure 1 represents the seawater cooling arrangement used in the petrochemical complex of this study. It is an arrangement commonly used in the Petrochemical complexes in the Gulf region. It is a Once-through system (operated by the utility company), coupled with a fresh-water Closed Recirculating system (operated by individual industries). The utility department distributes the entire cooling flow to individual industries and receives the return flow for discharge.

The Once-through portion of the above arrangement may be replaced by cooling towers in an Open Recirculating system. The industry portion (Closed Recirculating part) would remain mostly unchanged. Figure 2 shows the proposed system with cooling towers.

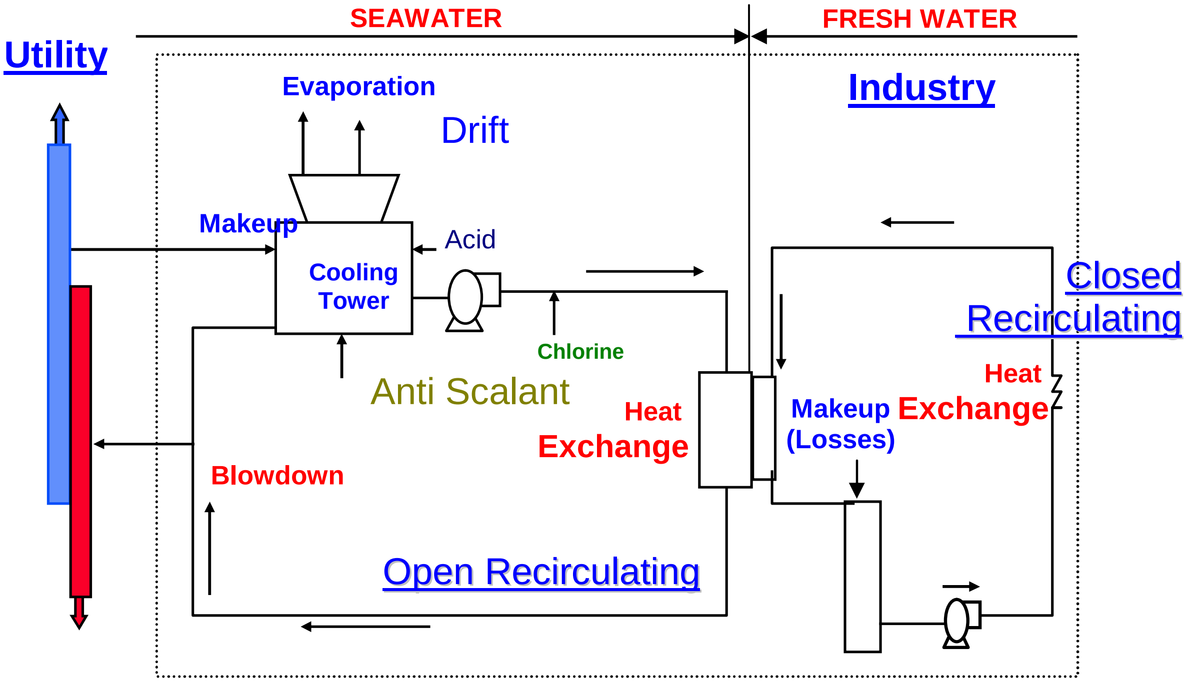


Figure 2: Proposed system with cooling towers

Both the Open Recirculating (Cooling Towers), and the Closed Recirculating systems would be operated by the industry. The role of the utility company would be to provide the Makeup water required, and to receive the Blowdown from the towers. This means significant reductions in the scope and cost of the water Supply infrastructure (normally a major seawater pumpstation), as well as the Distribution and the Return systems (canals or large-diameter piping) that must be furnished by the utility company. This is because Makeup flow is only about 6%, and Blowdown is only about 4% of the cooling water flow. This constitutes a major advantage of this system over the Once-through system as it impacts the first investment costs, and future expansion possibilities.

For a petrochemical complex already using the Once-through system, industries can use the above cooling tower arrangement either as a substitute or as a supplement to the Once-through system, since it does not impact their closed loop system.

One alternative with existing Once-through systems is to use cooling towers on the Return line as “helper” towers. This can nearly double the availability of seawater. No makeup or blowdown is necessary as the system is not Recirculating.

Salts in the Cooling Water

What differentiates seawater cooling towers from fresh water towers is the existence of dissolved minerals (salts) in the cooling water. Therefore, establishing the impact of salts in the cooling water is the single most important technical feasibility concern. The areas of concern were identified as thermal performance, salts concentration, salts emission (Drift) and environmental impacts, and O&M.

Thermal Performance

Salt in the water has four basic effects on its use as a coolant, only one of which is major. Salt lowers the vapor pressure of water, thus the water does not evaporate as readily. This makes it less as a effective coolant and reduces tower performance (1). Table 1 shows an example of the effect of salts in water upon vapor pressure (4).

Table 1: Impact of salts in water upon vapor pressure (4)

Physical property	Fresh Water	Seawater 1)
Water Temp (°C)	35	35
Air Temp (°C)	30.6	30.6
Air Relative Humidity (%)	60	60
Liquid Vapor Pressure (kPa)	5.62	5.42
Air Vapor Pressure (kPa)	2.63	2.63
Liquid-Air Vapor Pressure Difference (kPa)	2.99	2.79
Liquid-Air Vapor Pressure Difference (% of Fresh Water Condition)	100	93.2
Performance loss (%) 2)	-	5.4

1) At salts concentration of 50,000 ppm

2) Performance loss (approximated as 80% of change in VP difference) = 0.8 x (1-0.932)

The Research and Development Division of Fluor Corporation (11) summarized corrosion and thermal performance results conducted on fresh water, and water with salt levels of 34,000 and 62,000 ppm. Their conclusion was that increasing the design wet bulb temperature by 0.055 °C per 4,000 ppm TDS was a satisfactory compensation for the salt effect on cooling tower performance (1).

Cooling tower vendors recommend degrading the tower performance by approximately 1.1% for every 10,000 ppm of salts in the cooling water. In practice, most engineering contractors specify a 0.55-1.1 °C margin on the wet bulb temperature to account for salts in the cooling water (2).

Salts also increase density and surface tension, while decreasing specific heat capacity. The increase in density has a small positive effects on performance, while lower heat capacity and the higher surface tension have a negative effect. The net impact is a small negative effect. Table 2 compares the density and specific heat capacity of fresh water and seawater at 50,000 ppm salts concentration.

Table 2: Effect of salts on water density and specific heat capacity (4)

Physical property [1]	**Fresh Water**	**Seawater [2]**	**Difference (%)**
Density (kg/m^3)	989.9	1026.8	+ 3.7
Specific Heat Capacity (kJ/kg-°C)	4.178	3.952	- 5.4

1) Corresponding to temperature at 49 °C
2) At salts concentration of 50,000 ppm

Therefore, the heat capacity decreases more than the density increases. Since heat transfer is proportional to the product of Density and Specific Heat capacity, the net effect is slightly less heat absorbing capacity of seawater as compared with fresh water. However, this effect is minor as compared with the vapor pressure effect.

It follows that the net impact of salts in the cooling water is that it reduces the effective "Approach" (defined as the difference between wet bulb temperature and cold water temperature). For design purposes, a maximum value of 1.1 °C reduction in Approach would be used. This impacts the tower size required to achieve the same cold water temperature. The impact of Approach upon tower size using fresh water is shown in Figure 3 (3).

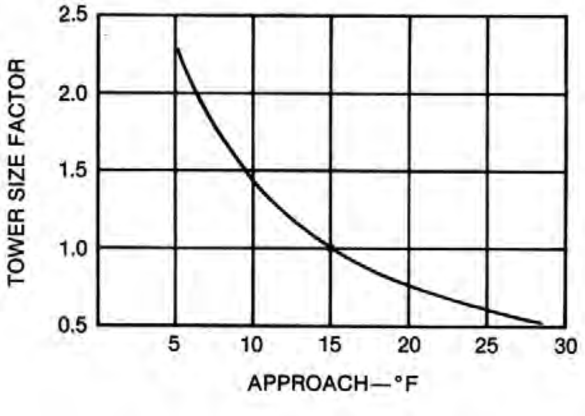


Figure 3: Impact of "Approach" on tower size using fresh water (3)

The shape of the curve in Figure 3 means that the impact of reduced Approach upon tower size is more pronounced at the lower end of the Approach scale. With 2.8 ^oC (5.0 ^oF) being considered as the lowest practical Approach for fresh water, the corresponding minimum Approach for salt water could shift to as high as 3.9 ^oC (2.8 ^oC limit + 1.1 ^oC allowance for salts). Consequently, the tower size could be up to 20% higher i.e. the worst practical impact of salts in the cooling water is to require 20% more tower size (20% more cells). In practice, the actual impact depends on the TDS in the seawater source and the concentration cycle (factor by which that water is permitted to concentrate). This is elaborated upon below.

Salts Concentration

Salts in the cooling water provide the potential for scaling i.e. deposition of salts in the cooling system. The potential for scaling increases with salts concentration and is affected by the composition of the salts and the water chemistry.

The permissible concentration of salts in the cooling water is determined from the results of the water chemical and physical analysis. For scaling potential, the concentration of Ca^{++} and Mg^{++}, and levels of pH and the alkalinity are particularly important. Table 3 shows the seawater composition for this study.

Table 3: Seawater analysis results for this study

Temperature	15 ^oC – 35 ^oC
Density	1.027 kg/l at 25 ^oC
Turbidity	1.0 – 2.5 NTU
Total Suspended Solids	10 – 30 mg/l
Conductivity	59,000-61,000 umho/cm
TDS	41,654-43,066 mg/l
pH at 25 ^oC	8.1 – 8.3
M - Alkalinity	130 - 135 mg/l as $CaCO_3$
Total Hardness	7625 - 7750 mg/l as $CaCO_3$
Ca^{++}	470-500 mg/l
Mg^{++}	1563 - 1585 mg/l
Na^+	13000 - 13165 mg/l
K^+	458 - 473 mg/l
Cl^-	23,000 – 24,500 mg/l
$SO4^{--}$	3300 – 3500 mg/l
Total Fe^{---}	10- 12 ppb
Cu^{--}	6 ppb
DO_2	4.4 –7.0 mg/l

For the seawater composition shown in Table 3, the water treatment requirements was sought from a reputable water treatment company. They recommended chemical additives to control alkalinity, scaling, corrosion, and bio-fouling, as well as set limits on the suspended solids and minimum flow velocity.

Most significant, was a limit on the Concentration Cycle of 1.4 (maximum TDS of 60,000 ppm), which sets the quantity of makeup flow required, and a maximum Water Temperature of 49 ^oC, which limits the Range. The following shows how the concentration cycle is related to the makeup flow.

The Recirculating system is operated to maintain two mass balances; 1) Water Balance, and 2) Salts Balance. For water balance we have:

$$Q_{MU} = Q_{BD} + Q_E + Q_D \qquad (1)$$

Where Q_{MU}, Q_{BD}, Q_E, and Q_D are the Makeup, Blowdown, Evaporation, and Drift flow rates respectively. For salts balance we have:

$$C_{MU}\, Q_{MU} = C_{CW}\, (Q_{BD} + Q_D) \qquad (2)$$

Where C_{MU} and C_{CW} are salts concentration in the Makeup and Cooling Water (water being recirculated) respectively. Concentration Cycle, R_C, is the ratio of C_{CW} to C_{MU} and is given by rearranging Eq. 2:

$$R_C = Q_{MU} / (Q_{BD} + Q_D) \qquad (3)$$

Substituting for Q_{MU} from (1) into (3) and rearranging gives:

$$Q_{BD} = (Q_E / (R_C - 1)) - Q_D \qquad (4)$$

Equation 4 is used to determine the Blowdown for a given Concentration Cycle, Evaporation and Drift. Blowdown is then used in Eq. 3 to determine the Makeup. At the limit of $R_C = 1$ in Eq. 4, $Q_{BD} = Q_{MU}$, and the system is Once-through.

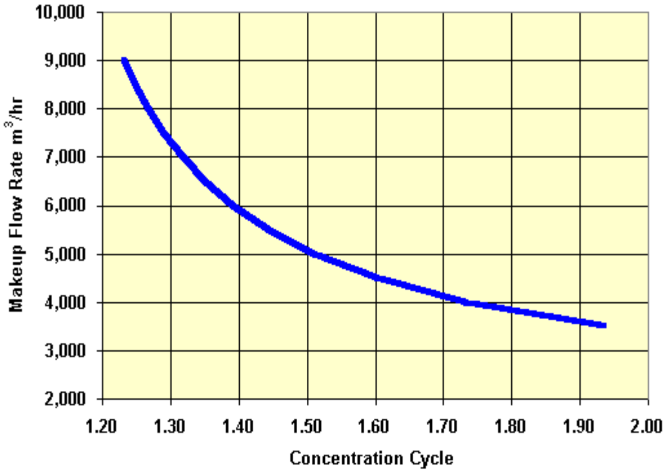
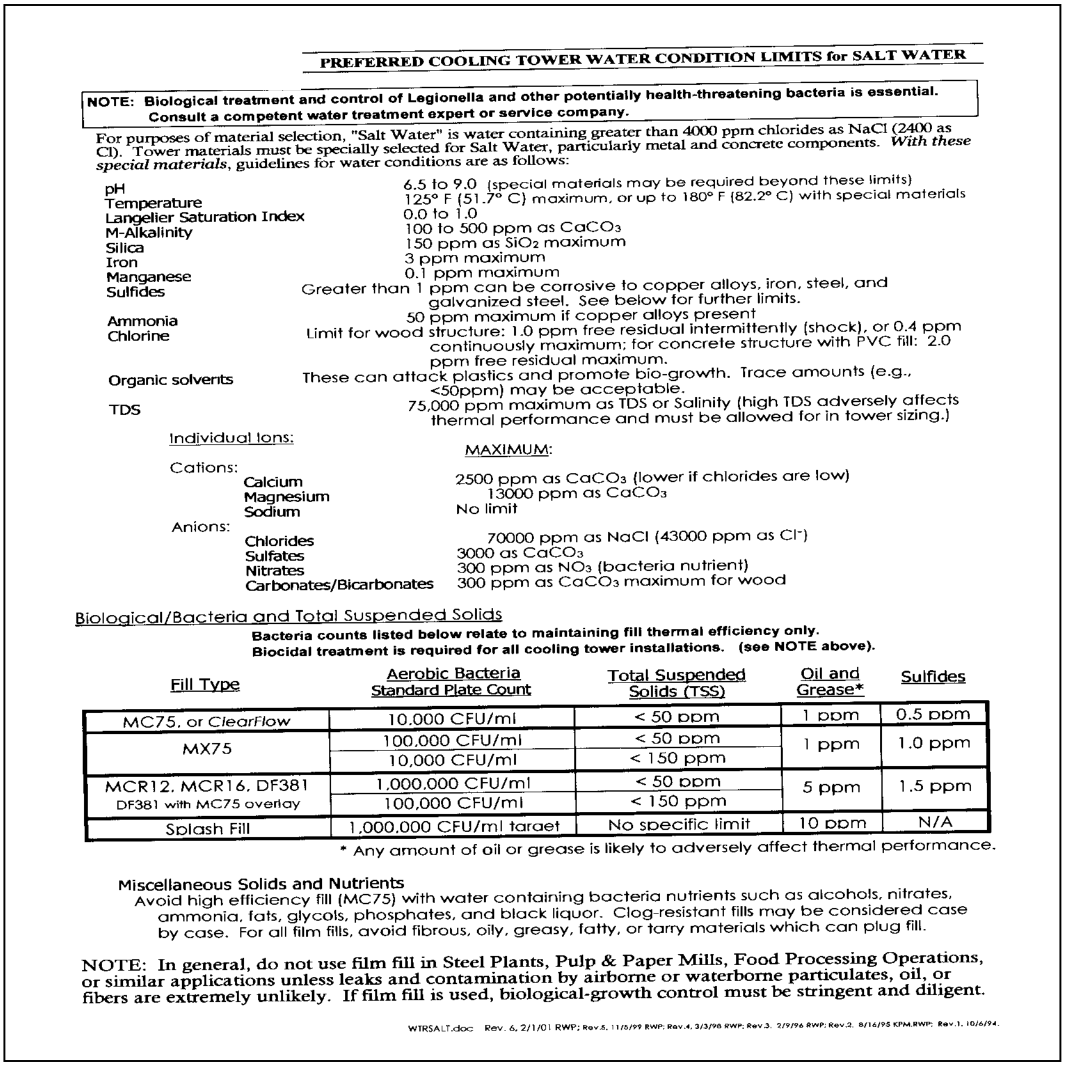


Figure 4: Variation of Makeup Flow with Concentration Cycle

Using the above procedure, makeup flow for concentration cycles ranging from 1.2 to 2.0 were calculated for an example case of 100,000 m^3/hr cooling flow. The results are plotted in Figure 4. A maximum concentration cycle of 1.4 means that at a minimum, 5900 m^3/hr of Makeup, which is 5.9 % of the cooling flow, is required. The corresponding Blowdown, as calculated from Eq. 4 is 4200 m^3/hr.

In addition to scaling considerations, salts concentration must be limited to manage corrosion per materials specifications in the cooling system. Another important consideration is concerning health issues. Table 4 shows a manufacturer's guidelines on salt concentration limits based on materials specifications. Also provided are limitations imposed by health considerations.

Table 4: Salt concentration limits in cooling water because of materials specifications and health considerations (4)



PREFERRED COOLING TOWER WATER CONDITION LIMITS for SALT WATER

NOTE: Biological treatment and control of Legionella and other potentially health-threatening bacteria is essential. Consult a competent water treatment expert or service company.

For purposes of material selection, "Salt Water" is water containing greater than 4000 ppm chlorides as NaCl (2400 as Cl). Tower materials must be specially selected for Salt Water, particularly metal and concrete components. ***With these special materials***, guidelines for water conditions are as follows:

pH	6.5 to 9.0 (special materials may be required beyond these limits)
Temperature	125° F (51.7° C) maximum, or up to 180° F (82.2° C) with special materials
Langelier Saturation Index	0.0 to 1.0
M-Alkalinity	100 to 500 ppm as $CaCO_3$
Silica	150 ppm as SiO_2 maximum
Iron	3 ppm maximum
Manganese	0.1 ppm maximum
Sulfides	Greater than 1 ppm can be corrosive to copper alloys, iron, steel, and galvanized steel. See below for further limits.
Ammonia	50 ppm maximum if copper alloys present
Chlorine	Limit for wood structure: 1.0 ppm free residual intermittently (shock), or 0.4 ppm continuously maximum; for concrete structure with PVC fill: 2.0 ppm free residual maximum.
Organic solvents	These can attack plastics and promote bio-growth. Trace amounts (e.g., <50ppm) may be acceptable.
TDS	75,000 ppm maximum as TDS or Salinity (high TDS adversely affects thermal performance and must be allowed for in tower sizing.)

Individual Ions:		MAXIMUM:
Cations:	Calcium	2500 ppm as $CaCO_3$ (lower if chlorides are low)
	Magnesium	13000 ppm as $CaCO_3$
	Sodium	No limit
Anions:	Chlorides	70000 ppm as NaCl (43000 ppm as Cl^-)
	Sulfates	3000 as $CaCO_3$
	Nitrates	300 ppm as NO_3 (bacteria nutrient)
	Carbonates/Bicarbonates	300 ppm as $CaCO_3$ maximum for wood

Biological/Bacteria and Total Suspended Solids

Bacteria counts listed below relate to maintaining fill thermal efficiency only.
Biocidal treatment is required for all cooling tower installations. (see NOTE above).

Fill Type	Aerobic Bacteria Standard Plate Count	Total Suspended Solids (TSS)	Oil and Grease*	Sulfides
MC75, or *ClearFlow*	10,000 CFU/ml	< 50 ppm	1 ppm	0.5 ppm
MX75	100,000 CFU/ml	< 50 ppm	1 ppm	1.0 ppm
	10,000 CFU/ml	< 150 ppm		
MCR12, MCR16, DF381	1,000,000 CFU/ml	< 50 ppm	5 ppm	1.5 ppm
DF381 with MC75 overlay	100,000 CFU/ml	< 150 ppm		
Splash Fill	1,000,000 CFU/ml target	No specific limit	10 ppm	N/A

* Any amount of oil or grease is likely to adversely affect thermal performance.

Miscellaneous Solids and Nutrients

Avoid high efficiency fill (MC75) with water containing bacteria nutrients such as alcohols, nitrates, ammonia, fats, glycols, phosphates, and black liquor. Clog-resistant fills may be considered case by case. For all film fills, avoid fibrous, oily, greasy, fatty, or tarry materials which can plug fill.

NOTE: In general, do not use film fill in Steel Plants, Pulp & Paper Mills, Food Processing Operations, or similar applications unless leaks and contamination by airborne or waterborne particulates, oil, or fibers are extremely unlikely. If film fill is used, biological-growth control must be stringent and diligent.

WTRSALT.doc Rev. 6, 2/1/01 RWP; Rev.5, 11/5/99 RWP; Rev.4, 3/3/98 RWP; Rev.3, 2/9/96 RWP; Rev.2, 8/16/95 KPM,RWP; Rev.1, 10/6/94.

The points noted in this section highlight the importance of the composition of the salts in the water so as to ensure the correct limit on salts concentrations based on the different governing considerations.

Salts Emission (Drift)

A significant reservation with using seawater cooling towers was salts emission brought about by the Drift, and its impact upon the environment. In fact, this has historically been the single reason for rejecting this technology.

Recent advances in "Drift Eliminators" developed for seawater cooling towers have significantly minimized this problem. Major manufacturers are now able to guarantee a maximum drift of 0.0005% of total cooling flow for salt water applications (4, 10). This drift rate is in fact the smallest amount that can be physically measured per existing test equipment (4).

Verification of the drift rate can be required by the client as a part of the acceptance testing. The Cooling Technology Institute (CTI) test codes ATC-140 "Drift Testing of Wet, Wet/Dry, Closed Circuit Cooling Towers" is specifically designed for this purpose and is performed by licensed agencies (4).

The 0.0005% drift converts into a small concentration of salt particles in the cooling tower plume. For a typical cooling tower cell with 5000 m^3/hr having a fan diameter of 8.5 m and an air flow of about 800 m^3/s (air flow velocity of about 13.9 m/s), a drift of 0.0005% means a saltwater discharge of 25 liter per hour into the atmosphere. If this saltwater has a concentration of 60,000 ppm (mg/l), it means a salts discharge of 417 milligrams per second with the plume. This salt is mixed in with the fan air flow of 800 m^3 per second exhausted from the tower. Therefore, the concentration of salts in the plume is 0.52 micro grams per liter of air. Such a concentration is several times lower than the concentration of salts in the sea-air, which originate from the seawater spray and aerosol.

An import aspect is the size of the water droplets in drift. Larger droplets result in larger salt particulates when dry, and are more likely to fall out. Table 6 shows the predicted mass distribution of drift particle size from modern drift eliminators (4).

Table 5: Distribution of drift particle size from modern drift eliminators (4)

Mass (%)	Droplet Size (Microns)
1.0	above 275
4.0	230 - 275
5.0	170 - 230
10.0	115 - 170
20.0	65 - 115
20.0	35 - 65
20.0	15 - 35
20.0	Below 15

A droplet size of about 150 microns is a reasonable cut off size for salts fallout (4). Table 5 shows that more than 90% of the droplets are smaller than 150 microns i.e. less than 10% of the drift could result in fallout. US EPA permits the use of the entire cooling tower drift as "PM-10 Particulate Mass Emissions" i.e. particles that are or dry to less than 10 microns, and may therefore be treated as particulates (which remain suspended in the air).

Therefore salts deposition, near and/or down-wind of cooling towers, should not be significant. There is comprehensive practical experience to support this. For this study, three major cooling tower manufacturer's provided clients lists of seawater cooling tower users. Those contacted did not report any particular problems associated with the drift. In fact, the drift phenomenon was unknown to some operators. At least two long-time operating saltwater cooling tower installations were visited. These did not exhibit any visible signs of salts fallout.

Perhaps the most convincing evidence on drift is the comprehensive studies of Chalk Point Cooling Tower Project funded by the Maryland Department of Natural resources in the USA, from 1972 to 1980 (Refs. 5 through to 9). The studies concentrated on the drift from a 60,000 m^3/hr (260,000 gpm) cooling tower system, circulating water at 14,000 ppm having a drift rate of 0.002% (i.e. 4 times more than latest technology cooling towers @ 0.0005%). The studies found no measurable increase in soil salts concentration in the tobacco fields near the facility.

Based on the above, it was concluded that drift as it impacts salt concentration in the air, and salts fallout from cooling towers should not pose a serious problem. The additional salts introduced are not expected to have a significant impact on the extreme corrosive environment of the Gulf region. Therefore, no additional corrosion protection measures for nearby facilities would be required, and the specifications and measures already in use would be sufficient.

Siting Issues

Siting is the location and orientation of the towers within the site and with respect to other cooling towers. Given the minimized impact of drift, siting issues with seawater cooling towers should really be no different from those with freshwater towers. However, some additional precautionary considerations would be prudent.

The primary concern with siting is thermal performance as affected by "Recirculation" (entry of tower's own plume into tower its intake), and "Interference" (entry of the plume from one tower into another). Recirculation is minimized by the correct orientation of towers with respect to the predominant wind direction (broad side parallel to wind direction), and Interference is addressed by the correct arrangement of the towers to observe a certain minimum distance between towers depending on the windrose (3).

Siting requirements favor locating the cooling towers on individual industry sites. This precludes a central cooling tower arrangement for the industrial complex, which would physically concentrate the towers. A de-centralized tower arrangement is also favored by considerations of cooling water distribution. A central cooling tower arrangement would distribute the entire cooling water flow as opposed to the Makeup flow (which is about 5%). Another advantage is the ability to cater to individual industry needs.

Although drift is minimized, prudence still calls for special care with the siting of seawater cooling towers. There is a potential for impact on the down-wind facilities, and a compounded effect on Interference and Recirculation (due to salts in the plume). As a precautionary measure sensitive facilities, such as electrical switch-gear should not be located downwind of cooling towers in general, and seawater cooling towers in particular..

Therefore, cooling towers should be sited at each industry with broad end parallel to the predominant wind direction, as far apart from one another as possible, and away from sensitive equipment (as a precaution). Any additional siting considerations for seawater cooling towers as compared with freshwater towers are of precautionary nature only.

Operation and Maintenance

The operation and maintenance concerns with seawater cooling towers were rooted in doubting the suitability of cooling towers as a whole (sea or freshwater) for petrochemical application. The concerns were compounded by the perceived potential complications with the use of seawater in the towers.

The main areas of concern were; performance during extreme wet bulb conditions (as it impacts the cold and hot water temperatures), performance compared with the exiting once-through system, and operation and maintenance issues (down times, redundancy requirements, clogging, chemical additives, impact of blowdown discharge, etc.).

Performance During Extreme Wet Bulb Conditions

Engineered solutions are seldom designed for the worst possible natural event. So, there are times when and event exceeds the design conditions. For petrochemical applications, a stringent 1% wet bulb exceedence level was considered appropriate. The concern was cooling tower performance during exceedence times, particularly the cold and hot water temperature, and the risk of plant shutdown.

To answer the above, a generic case of 70,000 m^3/hr cooling tower system with a duty of 32 ^oC Design (entering) Wet Bulb, 35 ^oC Cold Water, and 45 ^oC Hot Water temperatures, was simulated (10) for a short-spell hike in the actual wet bulb temperature to 34.5 ^oC. The results predicted an increase in the cold and hot water temperatures to 37.1 and 47.1 ^oC respectively, for uninterrupted industry operation. So, if an increase of 2.1 ^oC in both the cold and hot water temperature is acceptable, there would be no impact on the industry during such an event.

If not, one option is to increase the cooling circulation rate in order to reduce Range. Cooling towers can accommodate up to 20% increase in flow rate above design (10). For such a case, thermal modeling showed that a cold and hot water temperatures of 37.7 °C, and 46.1 °C (8.4 °C Range) respectively. Industries sensitive to the higher hot water temperature that must maintain 100% load during such conditions could use this option.

If the increase in the hot water temperature is still unacceptable (because of a particular temperature sensitive process), then the industry must either reduce production or design for the 34.5 °C wet bulb temperature. In the case of the latter, a 91,000 m^3/hr cooling tower system with a duty of 34.5 °C WBT, 37.3 °C CWT, and 45 °C HWT (2.8 °C Approach and 7.7 °C Range) would be specified. This would cost more. The same option can be used for even higher design wet bulb temperatures (if necessary).

Assuming that the prediction models are reasonably accurate, cooling towers would perform adequately during extreme conditions with a number of options possible. No plant shut down is necessary. Extreme wet bulb condition usually occur during a certain period in the year (the month of August). Industry should schedule their annual plant maintenance during this period to reduce the occurrences of operating above design conditions.

Performance compared with once-through system

The industrial complex of this study has been operating a central once-through system for about 20 years. To be accepted, the proposed seawater cooling towers were expected to perform as good as or better than the existing system. The notion was that once-through systems are not exposed to environmental extremes, whereas cooling towers are at the mercy of ambient conditions.

Investigation of the existing once-through system showed that industries do have to adjust their operation to cope with the seasonal variation of Gulf water temperature. They adjust the Range and water use accordingly to limit the hot water temperature while maintaining the same heat load. This is demonstrated in Figure 5.

The cooling water supply temperature increases to a high of about 35 °C in the Summer and Low of about 15 °C in the winter. To limit the return water temperature, the collective complex response is to reduce the range to about 7 °C in the Summer and 9.5 °C in the winter. Consequently, the water use increase to a high of about 15.5 M m^3/day in the summer and 10.5 M m^3/day in the winter.

The cooling tower system is also faced with seasonal ambient variations. It has to cope with the variations in the wet bulb temperature, which directly affect the cold water temperature. The temperature of the cold water emerging from the tower can only is about 3.0 °C higher than the wet bulb temperature.

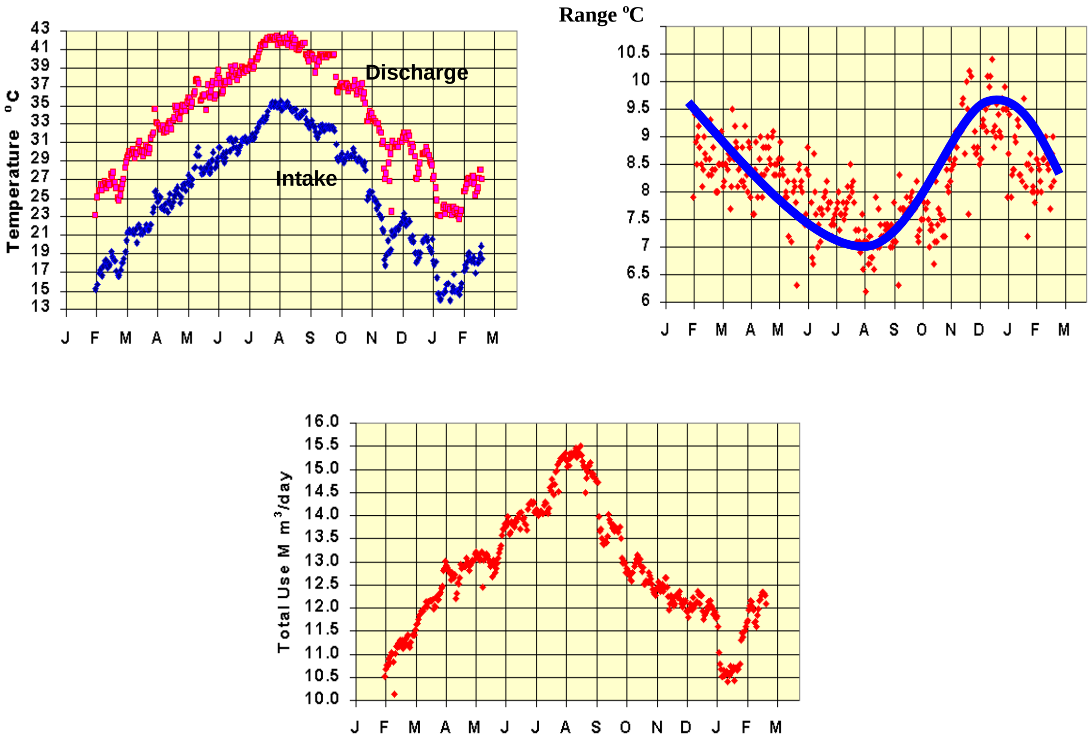


Figure 5: The existing once-through system temperatures and water use – Y2001

Figure 8 shows the hourly ambient wet bulb temperature data for year 1999 (one of the hot years on record), for the site of this study. The general trend is similar to that of the seawater temperature shown in Figure 5. The highest recorded single hour ambient wet bulb temperature value is about 34.0 °C. The corresponding entering wet bulb temperature could be a couple of degrees higher due to the salt effect, recirculation, and interference described earlier.

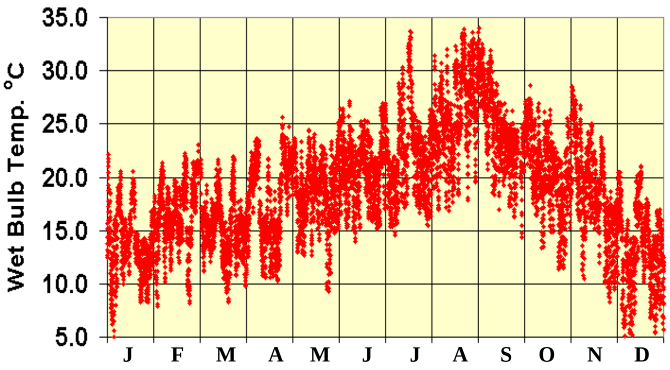


Figure 8: Hourly ambient wet bulb temperatures –Y1999

The consequence is that for short spells during the month of August the cooling tower could be faced with an entering wet bulb temperature of about 36.0 ^{o}C, and that the coldest water temperature emerging from the tower could be as high as 39 ^{o}C. This is higher than the cold water temperature of the once-through system.

Given that the limit of hot water temperature is 49 ^{o}C (see Table 4), a cold water temperature of 39 ^{o}C still leaves 10 ^{o}C Range for the industry to utilize. Individual industries could opt to achieve a lower hot water temperature (reduced Range) if necessary using options discussed in the previous section. No shut down, or even reduced production is required.

It follows that, both the cooling tower and the once-through systems are fundamentally similar. Both are faced with seasonal variations in temperature that directly impact the cold water temperature. For either system, such variations can either be designed for initially, or coped with operationally without any significant consequences.

Operation and Maintenance Issues

Operation and maintenance concerns were with regards to down times, redundancy requirements, clogging, chemical additives, bio-fouling, and the environmental impact of blowdown discharge.

These issues were primarily investigated by contacting long-time seawater cooling towers users. In addition, cooling tower suppliers and water treatment companies were consulted. Tables 6 and 7 are lists of seawater and brackish-water cooling tower installations, provided by two major tower manufacturers. Additional information on operating seawater cooling tower installations may be obtained from each manufacturer. A recent large-scale seawater cooling tower installation is the Cantarell Nitrogen Complex in Mexico's Campeche state, which processes a seawater cooling flow of 80,000 m^3/hr (18).

Regarding downtimes, the message from existing seawater cooling tower installations was that no extensive maintenance is required. No special measures other than an annual walkthrough inspection in each cell, is generally required.

On redundancy, there is no strict requirement to have any standby cells, as no significant downtime is expected. However, having one or two additional tower cells (out of a total of 15 to 20 cells), would be a reasonable investment to ensure higher reliability, as well as to provide for increased cooling flow capability.

Clogging problems appear to have mostly been resolved by the tower manufacturers through the special attention to the design of the distribution nozzles, and the development of "clogging – free" or "splash-type" fill material. Acid treatment, as specified by the water treatment company, is used to reduce the risk of scale formation in the piping. Operation experience shows that these measures are apparently working.

The chemical additives used are primarily acid treatment to reduce scaling, and chlorination to control bio-fouling. The acid treatment dosage may be higher than once-through systems because of the higher salinity, while chlorination dosage is similar. The quantity and the cost of such treatment are reportedly not exorbitant.

The blowdown from cooling tower is more concentrated in salts than the original seawater (by the concentration cycle). It also has acid and chlorine residuals. These must conform to environmental discharge regulations. Operation experience shows that this can be done. The blowdown discharge from a seawater cooling tower is similar in composition to the return flow from a desalination plant, only a lot less in quantity. The Gulf region accommodates large desalination plants that have been discharging their return flow into the gulf for considerable time.

Therefore, based on the operation experience gained from existing towers, it appears that the O&M problems associated with seawater cooling towers are for the most part manageable.

Attachment 2

Table 6: List of Saltwater/Brackish Water Cooling Towers (4)

Location	Owner/Project	Design Conditions Flow@HWT/CWT/WBT [1)]	Year
Oklahoma, USA	Oklahoma G& El. Co.	13,680 m^3/hr@40/30/23.9ºC	1953
Kansas, USA	American Salt Co.	1,140 m^3/hr@32/27.2/24ºC	1964
New Jersey, USA	Exxon Chemical Co.	5,016 m^3/hr@44.4/27.8/23.9ºC	1968
Stenungsund, Sweden	ESSO Chemical AB	23,040 m^3/hr@41.1/19/15ºC	1969
Judibana Falcon, Venezuela	Lagoven Amuay	7,752 m^3/hr@48.9/33.9/29.4ºC	1970
Okinawa, Japan	Exxon Petroleum Co.	3,329 m^3/hr@48.9/31/27.8ºC	1971
Florida, USA	Gulf Power Co.	37,620 m^3/hr@49.8/32.8/28.2ºC	1971
Texas, USA	Dow Chemical Co.	13,680 m^3/hr@42.8/30.5/26.7ºC	1973
Maryland, USA	Potomac El. P. Co. Plant 3	59,280 m^3/hr@48.9/32.2/25.6ºC	1974
Virginia, USA	Virginia Electric Co.	75,240 m^3/hr@45/31.7/25.6ºC	1975
North Carolina, USA	Pfizer Co.	12,442 m^3/hr@37.8/30.6/26.7ºC	1975
California, USA	Dow Chemical Co.	2,736 m^3/hr@40.6/25.6/21.1ºC	1976
Washington, USA	Italco Aluminum Co.	9,348 m^3/hr@36.7/29.4/22.8ºC	1976
California, USA	Pacific Gas & Electric Co.	84,816 m^3/hr@37.8/27.8/21.1ºC	1976
Texas, USA	Houston Light & Power Co.	54,720 m^3/hr@43.3/34.7/27.8ºC	1977
Mississippi, USA	Mississippi Power Co.	39,444 m^3/hr@48.9/32.2/26.7ºC	1980
Maryland, USA	Potomac El. Pwr. Co. Plant 4	59,280 m^3/hr@48.9/32.2/25.6ºC	1981
Arizona, USA	Palo Verde I Plant	133,836 m^3/hr@48.2/30.7/25ºC	1985
Arizona, USA	Palo Verde II Plant	133,836 m^3/hr@48.2/30.7/25ºC	1986
Florida, USA	Stanton En. #1 Station	45,600 m^3/hr@45.4/32.8/25.6ºC	1986

Table 6: List of Saltwater/Brackish Water Cooling Towers (4) –Continued

Location	Owner/Project	Design Conditions Flow@HWT/CWT/WBT [1)]	Year
Arizona, USA	Palo Verde III Plant	133,836 m^3/hr@48.2/30.7/25ºC	1987
Texas, USA	Houston L. & Power Co.	54,948 m^3/hr@43.3/34.7/27.8ºC	1987
Delaware, USA	Delmarva Power & Light	46,170 m^3/hr@47.1/32.2/26.1ºC	1989
California, USA	Delano Biomass En. Co.	4,423 m^3/hr@36.7/28.3/22.7ºC	1991
Florida, USA	Stanton En. #2 Station	45,600 m^3/hr@45.4/32.8/25.6ºC	1995

1) Hot Water/Cold Water /Wet Bulb Temperatures

Attachment 2

Table 7: Installation List of Seawater Cooling Towers (10)

Year	Client	Project	Country	Flow (m^3/hr)
1973	I. S. A. B.	SIRACUSA	IT	16,000
1973	ATLANTIC CITY ELECTRIC CO (NJ)	BEESLEY'S POINT	US	14,423
1976	PUBLIC SERV. ELEC. & GAS CO	HOPE CREEK	US	250,760
1978	E. B. E. S. - DOEL NUCLEAR PP	DOEL	BE	183,240
1979	JEDDAH INT. AIRPORT	JEDDAH	SA	35,400
1981	JACKSONVILLE ELEC. AUTH.	JACKSONVILLE (FL)	US	112,520
1984	GUJARAT ELECTRICITY BOARD	PANANDRA KUTCH - GUJARAT	IN	33,100
1985	SIAPE	SFAX	TN	8,000
1990	FLORIDA POWER CORP.	ST PETERSBURG	US	156,000
1990	C. E. G. B.	KILLINGHOLME	GB	46,872
1991	BASF	ANVERS	BE	14,500
1992	ATLANTIC CITY ELECTRIC CO	B. L. ENGLAND, N. J.	US	16,280
1993	POWERGEN	CONNAH'S QUAY	GB	85,392
1993	E. G. A. T.	BANG PAKONG	TH	71,100
1995	E.G.A.T.	SOUTH BANGKOK	TH	33,500
1996	AMATA EGCO B	BANG PAKONG	TH	12,168
1996	MEDWAY POWER Ltd	MEDWAY	GB	35,380
1997	GEM METHANOL TRINIDAD	TRINIDAD		12,513
1997	ECOELECTRICA, LP	PENUELAS		2,184
1997	ECOELECTRICA, LP	PENUELAS		35,408
1998	EGAT	KRABI	TH	48,100
1999	KALTIM PARNA INDUSTRY	BONTANG	ID	17,000
1999	ESSO SINGAPORE PVT LTD	SINGAPORE	SG	4,088
1999	FLORIDA POWER COPR CRYSTAL RIVER PLANT	CRYSTAL RIVER FLORIDA	US	67,229
2000	ESSO SINGAPORE PTE LTD	SINGAPORE	SG	14,082
2000	ENDESA	SAN ROQUE	ES	16,142
2000	ST JOHNS RIVER POWER PARK	JACKSONVILLE FL.	US	56,258
2001	GB3	LUMUT	MY	34,050
2001	ENDESA	TARRAGONA	ES	28,272
2001	PETROBRAS	TERMORIO	BR	55,000
2002	JUBAIL UNITED PETROCHEMICAL	JUBAIL	SA	66,605

Costs

The true cost of a cooling system to the industry is determined by accounting for both the initial and the running costs over the economic life of the system (life-cycle cost). The initial costs are comprised of equipment purchase, transport, customs clearance, taxes, land acquisition, power acquisition, civil, mechanical, electrical, piping works, and testing and commissioning. The operation and maintenance costs include makeup & blowdown charges, electricity, water treatment, O&M crew, parts, and materials.

For this study, a typical 70,000 m^3/hr system with a duty of 45 ^{o}C HWT, 35^{o}C CWT, and 32 ^{o}C WBT was selected for life-cycle cost analysis. Such a tower would require a total fan power of 2.9 MW and total pump power of 4.1 MW (tower pumping only, excludes pumping through system piping and heat exchangers). Table 8 shows the estimated installed cost of such a system in Saudi Arabia.

Table 8: The installed cost of a 70,000 m^3/hr seawater cooling tower in Saudi Arabia

Equipment Procurement	$ 5,170,000
Concrete Structure	$ 2,250,000
External Piping & Pumps	$ 380,000
Electrical Hookups	$ 800,000
Equipment Installation	$ 520,000
Total Installed Cost	**$ 9,120,000**

The cost of land for the 1.0 ha required, was negligible. At 8% discount rate and 15 years, the total installed cost in Table 8 is equivalent to $1,065,485 per year.

Table 9 shows the basis for the annual operation and maintenance costs. Based on the figures shown in Tables 8 and 9, as well as data obtained from water treatment companies and tower manufacturers (for water treatment and routine O&M costs respectively), the estimated Total Annual Costs were as shown in Table 10.

Table 9: Basis for estimating annual O&M costs

Cost of Electricity	$ 0.032 per kW-hr,
Charge for Makeup	$ 13.3 per 1000 m^3 of seawater *
Charge for Blowdown	$ 0 (included in the charge for makeup)*
Makeup	30.7 Mm^3/yr (at 5%, 3500 m^3/hr)
Pump operation time	8,760 hrs/yr,
Fan operation time	7,500 hrs/yr

* Same as seawater charge for existing once-through system

Table 10: Total Annual Cost of a 70,000 m^3/hr seawater cooling tower in Saudi Arabia

Capital Investment	$ 1,065, 485		28.3%
Electricity (Fan + Pumps)	$ 1,837,705		48.9
Makeup & Blowdown	$ 408,800		10.9
Water Treatment	$ 300,000		8.0
Routine O&M	$ 150,000		4.0
Total Annual Costs	**$ 3,761,990**	**per year**	**100 %**

Table 10 shows that the electricity costs constitute almost half of the annual cost of the seawater cooling tower, with the capital investment comprising about one third.

Larger towers require less power for operation, so there may be some potential for optimization by increasing the tower size (capital investment) and thereby reducing the power required (electricity cost), so as to minimize the overall cost.

Makeup and Blowdown are payments for the seawater makeup-supply/blowdown-return (“Makeup”) service, to the provider, and rank third at 10.9%. However, this may vary depending on the rates charged for this service. Water treatment and O&M costs rank 4th and 5th respectively, and are relatively low.

At 70,000 m^3/hr flow and 8,760 hours of pump operation, the system delivers a total of 613.2 M m^3 per year cooling seawater to the industry. Therefore the unit cost of seawater for the industry is $6.14 per 1000 m^3. This is less than half charge for the seawater-supply/hotwater-return service industries currently pay for once-through cooling. So, seawater cooling towers would cost the industry about 50% less than the existing once-through system. This was a significant finding of this study.

A sensitivity analysis showed that the unit cost of $6.14 per 1000 m^3 is quite robust. For example, increasing the equipment procurement cost by 50% (from $ 5,170,000 to $7,755,000) would increase the unit cost by about 8% (from $6.14 to $6.63). Similarly, increasing the water treatment cost by 100% (from $300,000 to $600,000) would increase the unit cost by about the same (from $6.14 to $6.62).

A controversial issue was the charge for “Makeup”. It was argued that setting this to equal the once-through charge for seawater-supply/hotwater-return, is not correct and that a charge of $133.9 per 1000 m^3, which would fully recover the cost of the “Makeup” infrastructure for the new industrial park should be used in the analysis.

With the above rate, the annual cost of Makeup jumps to $4,104,352, and the total annual cost becomes $7,757,542. “Makeup” cost is now the biggest cost at 52%, with electricity at 23.2% and capital cost at 13.7% ranking second and third respectively. The unit cost of seawater increases to $12.65 per 1000 m^3, which is still less than the existing charge of $13.3 per 1000 m^3 with the once-through system. This was an important find, which provided the necessary reassurance to proceed with this technology for the development of the new industrial park.

Summary and Conclusions

This study investigated the feasibility of seawater cooling towers for a major petrochemical complex development in the Gulf region.

Salts in cooling water affect the thermal performance, are emitted in the drift, cause scaling and bio-fouling, and raise environmental and O&M concerns. The net impact on thermal performance, is to reduce the Approach by a up to about 1.1 ^oC. This would require up to 20% larger tower.

Drift is minimized by “drift eliminators”, which are claimed to reduce the drift rate down to 0.0005%. This converts into a small concentration of salts in the plume.

Tests to verify this at commissioning are available through CTI. Data on drift droplet size shows the most droplets to be too small to fall out. Evidence from operating towers suggests insignificant salts fallout.

Scaling is controlled by limiting concentration cycle and acid treatment, based on the water chemistry. Bio-fouling is controlled by chlorination in the similar dosage as for once-through systems.

This study did not directly investigate environmental impacts. However, if drift rate is indeed as low as claimed, then environmental impacts from towers emission should be minimal. No significant impacts from blowdown return is expected.

Numerical simulation of Tower thermal performance during extreme wet bulb conditions of 35 ^oC showed that the usual not-to-exceed hot water temperature of 45 ^oC can be maintained. For the site of this study, a design entering WBT of 32 ^oC is satisfactory, and a maximum hot water temperature of 49 ^oC may be tolerated.

Existing seawater users were contacted on O&M issues. No major O&M problems that could be considered difficult, expensive, or objectionable were reported.

Life-cycle cost analysis showed that the unit cost of water from cooling towers is about 50% cheaper than the existing once-through system.

Based on the findings of this study, it may be concluded that:

1- Using seawater in cooling towers is technically and economically feasible.
2- Seawater cooling towers can satisfy the cooling needs of petrochemical industries. WBT variations are handled by design or operation.
3- No significant O&M complications with seawater cooling towers is reported.
4- Seawater cooling tower economics are favorable as compared with the once-through system.
5- Petrochemical development schemes or individual plants planning expansions would be wise to consider seawater cooling towers as an alternative.

Based on the above conclusions plans are under way to double the size of what is already the largest petrochemical industrial complex in the region.

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Attachment 3

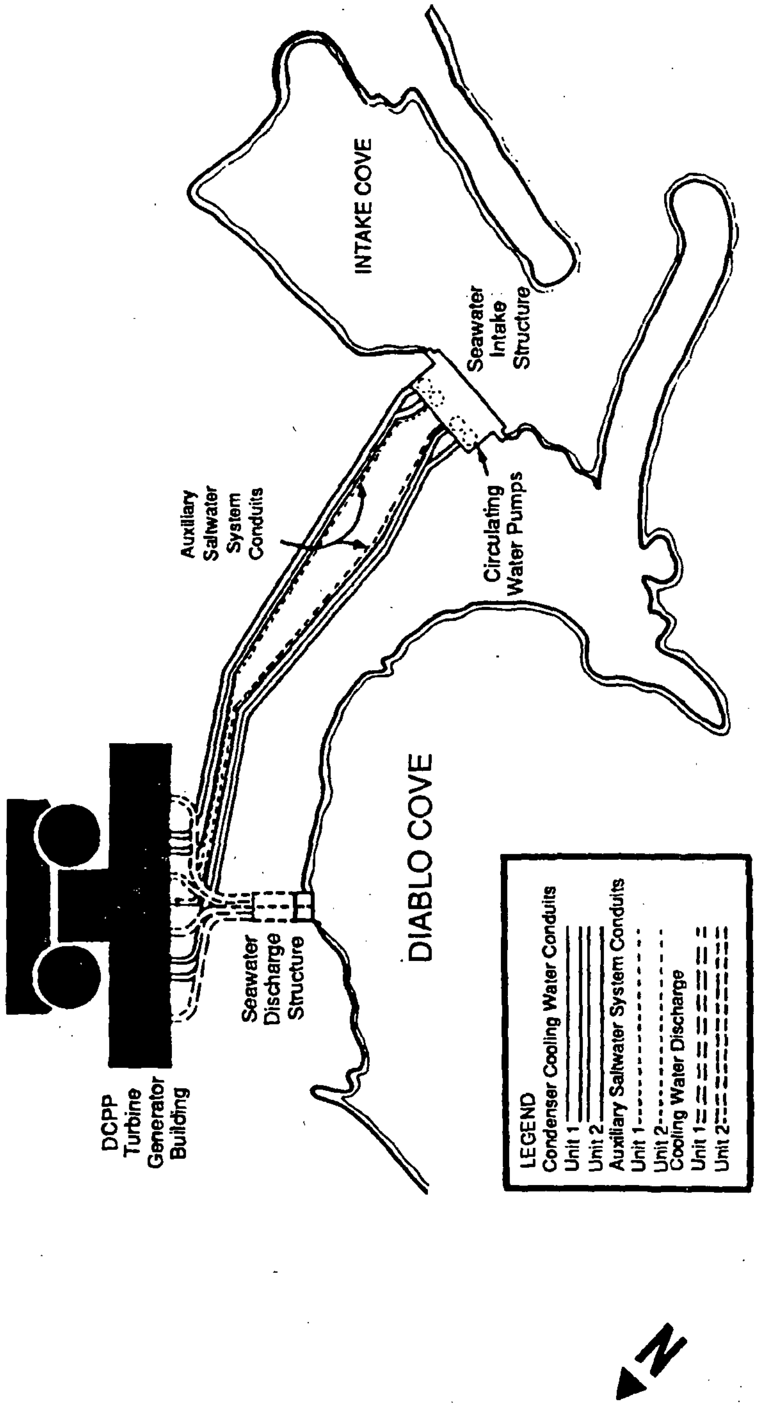

Figure 2-2

General Configuration of the Diablo Canyon Power Plant Cooling Water System

source: PG&E Letter DCL-1 0-124, Information to Support NRC Review of DCPP License Renewal Application (LRA) Environmental Report - Operating License Renewal Stage, October 27, 2010, Figure 2-2, p. 2-4.