

TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 INTRODUCTION	1.0-1
1.0.1 Once Through System	1.0-1
1.0.2 Recirculating System	1.0-1
1.0.3 Types of Cooling Systems	1.0-2
1.0.4 Mechanical Draft Towers	1.0-2
1.0.5 Atmospheric Towers	1.0-3
1.0.6 Natural Draft Towers	1.0-3
1.0.7 Spray Pond	1.0-4
1.0.8 Cooling Pond	1.0-4
2.0 COOLING TOWER PROBLEMS	2.0-1
2.0.1 Water Contaminants	2.0-1
2.0.2 Scale	2.0-1
2.0.3 Tower & Cooling Circuit Corrosion	2.0-2
2.0.4 Microbiological Growths	2.0-4
2.0.5 Location	2.0-4
2.0.6 Ice Formation	2.0-5
2.0.7 Fire Hazard	2.0-5
2.0.8 Cleaning	2.0-5
3.0 MATERIAL BALANCE	3.0-1
3.0.1 Evaporation Losses	3.0-1
3.0.2 Windage Losses	3.0-1
3.0.3 Cycles of Concentration	3.0-1
4.0 CHEMICAL TREATMENT	4.0-1
4.0.1 Water Analysis	4.0-1
4.0.2 Saturation & Stability Index	4.0-4
4.0.3 H ₂ SO ₄ Dosage	4.0-5
5.0 DESIGN CRITERIA	5.0-1
5.0.1 General Considerations for Sizing	5.0-1
5.0.2 Water Circulating Flowrate	5.0-8
5.0.3 Approach to Air Wet Bulb	5.0-8
5.0.4 Cooling Range	5.0-9

5.1	Process Specification	5.0-9
5.2	Auxiliary Equipment	5.0-11
5.2.1	Circulating Pump	5.0-11
5.2.2	Sulfuric Acid Injection	5.0-13
5.2.3	Chlorinator	5.0-15
5.2.4	Corrosion Inhibitor	5.0-15
5.2.5	Instrument and Flowsheets	5.0-17
5.3	Salt Water Cooling Tower	5.0-19
6.0	COOLING TOWER REQUISITION	6.0-1
6.0.1	Intent	6.0-1
6.0.2	Work by Others	6.0-1
6.0.3	Quality of Materials	6.0-2
6.0.4	Performance Tests	6.0-2
6.0.5	Requirements - Size, Capacity and Operation	6.0-2
6.0.6	Cooling Tower Details - Materials and Design	6.0-3

FIGURES

1	Various Types of Cooling Towers	1.0-5
2	Blowdown & Makeup	3.0-4
3	Operating & Saturation Curves	5.0-5
4	Cooling Tower Sizing	5.0-6
5	Tower Area & HP Correlation	5.0-7
6	Typical Performance Curves	5.0-12
7	Chart-Minimum Submergence vs. Velocity	5.0-14
8	Anti-vortex Baffle	5.0-14
9	Pump Arrangement	5.0-16
10	Typical Flowsheet	5.0-18

TABLES

1	Chemical Treating Agents	2.0-6
2	CaCO ₃ Saturation Index (Langelier)	4.0-6

1.0 INTRODUCTION

Cooling water is used for cooling process streams in exchangers and cooler boxes; condensing vapors in condensers, cooling the bearings, pedestals, packings, mechanical seals and lube oil of pumps, compressors and turbines; etc.

The cooling water systems are divided into two main types: once through and recirculating.

1.0.1 Once Through System

In the once through system, cooling water from well, river or sea makes one pass through the heat-exchange equipment and then is discharged to river or sea.

1.0.2 Recirculating System

Recirculating system can be closed-type or open type.

In the closed-type, water is circulated in a sealed circuit which includes an air cooler or water cooler to cool the circulating water. The use of a closed system is usually limited to cases where the nature of the products to be cooled (for example, high viscosity, high pour point materials) imposes a limitation to the film temperature in the coolers and therefore cooling water must be kept above a certain temperature. If this temperature is high, the closed system must be filled with treated water or condensate to prevent solid precipitation. If minimum temperature is required for cooling water open-type is generally preferred to closed-type system. Design of closed loop cooling water system is discussed in Support Facilities Design Manual Section 1.4.

Open-type recirculating system is the most frequently used for cooling water in industrial plants; the water is cooled by evaporation, exposing its surface to air, and then returned to the users.

Salt and solids concentration in the water is increased by evaporation and, therefore, a chemical treatment of water and blowdown, or purge, is required to prevent solid build-up and precipitation.

1.0.3 Types of Evaporative Water Cooling Systems are:

Towers - Mechanical-draught towers

 Atmospheric towers

 Natural draught towers

1.0.4 Mechanical Draught Towers

These towers are such that the air flow is obtained by one or more fans. There are two types of mechanical draught towers: forced draught and induced draught.

In the forced draught type, the fans are mounted at the base of the towers and the air is forced in at the bottom and discharged through the top. Due to the low exit velocity of air, this type of tower presents the disadvantage of an excessive recirculation of humid exhaust air back into the fan intakes so reducing tower performance (the air recirculating for forced-draught installation may run 3 to 10% of total inlet air, while for induced draught it is about 1 to 8% of all depending upon wind conditions). However, the location of the fans outside the tower is more convenient for accessibility during inspection and maintenance in addition to the fact that fans and drivers are not subject to the corrosive conditions of the humidity at top of tower.

The induced draught tower, in which the fans are mounted on top of the tower, is the most common used type and it is divided into counterflow and crossflow arrangement depending on the relative direction of air and water flows. The counterflow arrangement offers a better thermodynamic efficiency since the coldest water is contacted with the entering air, and usually a smaller plot area is required. However, for very low approaches between cold water temperature and air wet bulb temperature, the crossflow arrangement may be more economical since in this case a higher air flow is required and for high air flow cross sectional area, the cross flow tower is cheaper than the counterflow tower. A further advantage of cross flow towers is that recirculation of air has a limited effect, whereas in counterflow the loss due to recirculation can be of considerable magnitude. In fact, recirculating air in the cross flow enters the tower through the upper louvers where water is still warm with a slight reduction in the mean temperature difference; in the counterflow, recirculating air, entering through the bottom, increases the wet bulb temperature of entering air with strong effect on tower performance.

Cross flow type is by far the most popular.

Mechanical Draught Tower is the predominant type in the process industry because it is available in any size, from small package unit to large industrial installations (100,000 GPM); investment cost is moderate, they can be designed to fit any condition and they achieve the lowest cold water temperature.

1.0.5 Atmospheric Towers

In these towers the water is distributed over a structure and the cooling action is obtained by natural wind movement. This type is used primarily for small air conditioning loads and other non-critical services because of low investment, operating and maintenance cost. Approach to wet bulb temperature is rather high and dependent on wind velocity.

1.0.6 Natural Draught Towers

Natural draught, hyperbolic concrete towers find application when very large water quantities are required; in fact, they have been mainly used by the electric power generating industry. Air flow through the tower is due to the chimney effect created by the difference in density between the external cold air and the internal warm and humid air.

The advantages of a hyperbolic tower over a mechanical draft tower are the following:

For high capacity installation less area is required by hyperbolic tower,

Elimination of problems of fogging and recirculation of air (due to the elevated air discharge),

Reduction of windage losses,

As a consequence of the last two considerations, a hyperbolic tower can be located adjacent to plants or buildings where cold water is used, or if more than one hyperbolic tower is required, they can be placed on centers one and one-half times their base diameter. As a result there is a considerable saving in cost of piping for water distribution,

Operating and maintenance cost are minimum,

Service life of concrete hyperbolic towers can be expected to span many years. There are installations that after 49 years do not show any deterioration.

Investment cost required by hyperbolic towers is higher than for mechanical draught towers.

Typical sketches of various types of cooling towers are shown in Figure 1.

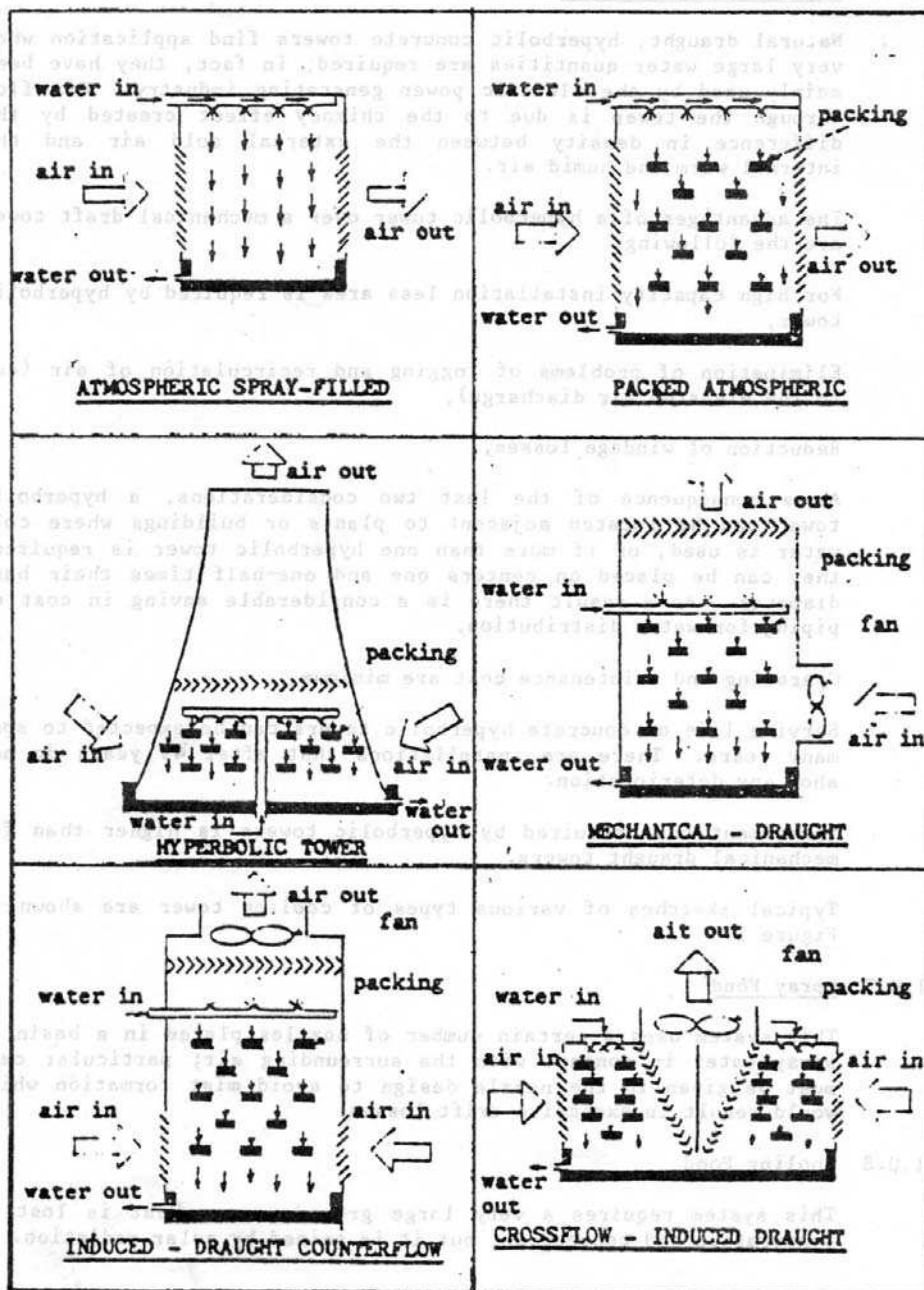
1.0.7 Spray Pond

This system uses a certain number of nozzles placed in a basin to spray water in contact with the surrounding air; particular care must be given in the nozzle design to avoid mist formation which would result in excessive drift losses.

1.0.8 Cooling Pond

This system requires a very large ground area. Heat is lost by evaporation and convection, but it is gained by solar radiation.

FIGURE 1
VARIOUS TYPES OF COOLING TOWERS



2.0 COOLING TOWER PROBLEMS

2.0.1 Water Contaminants

1. Dissolved Gases: Most common are O_2 , H_2S and NH_3 ; they are cause of metal corrosion.
2. Hardness: It is due to Ca and Mg salts. When hard water is heated, Ca and Mg carbonates deposit as hard scale.
3. Iron: Iron can be naturally present in the water or as a result of corrosion of the system. In presence of O_2 and high pH, insoluble $Fe(OH)_3$ is formed causing deposits.
4. Silica: Silica reacts with Ca and Mg resulting in deposits of Ca and Mg silicates.
5. Oil: It is most undesirable contaminant; in fact it interferes with corrosion inhibitors causing corrosion, restricts heat transfer and acts as a nutrient for biological contaminants.
6. Suspended matter: Clay, silt, sand, dirt, algae, etc.
7. Microbiological contaminants: Cooling tower is an excellent environment for micro-organism which can be either airborne or introduced with raw make-up water. Micro-organism cause sludge deposits on heat exchangers, decrease heat transfer efficiency in both tower and exchangers, and indirectly increase corrosion because they interfere with corrosion inhibitors. Further, wood used in cooling tower is subject to bacterial attack.

2.0.2 Scale

Scaling tendency of cooling water can be controlled by blowdown, by addition of chemicals such as H_2SO_4 , to keep in solution scale forming salts and by addition of antifoulant polymers to prevent agglomeration of individual particles on the metal surface. Antifoulants can have one of the three following actions:

- Flocculation: individual particles are agglomerated into light flocs remaining suspended in water.
- Dispersion: individual particles are kept apart by dispersant due to electrostatic charges.
- Chelation: certain organic compounds form with Ca, Mg, Fe, Al, Mg ions, soluble complexes preventing precipitation.

Corrosion occurs in the cooling tower as well as the cooling circuit.

2.0.3 Tower & Cooling Circuit Corrosion

Corrosion in the tower: Corrosion in the tower is due mainly to the particular conditions existing therein (air, humidity and temperature) and also to the chemical treatment of the water. All construction materials exposed to these conditions must be carefully selected. Hardware and piping for distribution headers have been successfully made with hot-dipped galvanized steel, cadmium coated steel, stainless steel and silicon bronze.

In induced-draught installations, cast aluminum is a suitable material for the fan blades, while ductile cast iron can be used for the fan hub providing fan blades are insulated from the iron hub to avoid galvanic corrosion.

Reinforced concrete is a very important material for cooling towers, where it is used for water basin, structure, water distribution system, fan stack, etc. Degradation of this material is expected by calcium sulfate deposition, however, special concrete formulation and good control of pH of the circulating water can solve this problem.

Cement asbestos boards are successfully used for drift eliminators, air inlet louvers, sheathing and even as fill.

Plastic materials have become very common in cooling towers for fill, louvers, sheathing and drift eliminators; these materials are mainly glass-reinforced polyester, polypropylene, polyethylene and rigid PVC. Some of these, however, can be sensitive to solvents or oils which can contaminate the water in case of large leakage from the coolers of the system. Wood has been and still is a basic material for cooling tower. However, special types of wood are required like California redwood, Douglas fir, western red cedar, and southern yellow pine.

Wood is subject to degradation by action of certain fungi destroying cellulose fibers; after attack the remaining wood is lignin (cellulose has been destroyed), which has no mechanical strength. The wood acquires a brown color. Chlorine, added to water for biological control, reacts with lignin to form water soluble compounds; with lignin binder removed, cellulose fibers are exposed and washed away; in this case the wood acquires a white, fibrous appearance. To prevent delignification, chlorine concentration should always be kept below 1 ppm.

To prevent this degradation, the wood must be subjected to a pressure preservative treatment with creosote, or pentachlorophenol, or erdalith (33% wt. copper sulfate, 56% wt. potassium dichromate and 11% wt. arsenic pentoxid).

A mechanical attack by crystal formations of the salts contained in the water and absorbed by wood can cause its destruction.

Corrosion of the cooling circuit is basically a metal attack of piping and exchangers in the water; electrochemical reactions are involved and metals dissolve at anodes.

Corrosion can be arrested by the use of the various inhibitors listed below:

1. Chromate ion: ferrous ions produced by corrosion are oxidized to ferric oxide by reduction of chromate with formation of a protective film of ferric and chromic oxide. This is probably the most effective inhibitor, however, its use is often restricted because of toxicity of chromates. (See note at Table 1).

The best result is obtained when metal is initially exposed to a high chromate level; later chromate concentration can be reduced to a lower level sufficient to keep the protective film intact.

2. Phosphates: (Sodium hexametaphosphate, sodium tripolyphosphate, polyphosphate, etc.). They are corrosion as well as scale inhibitors. Phosphate form a thin protective film on metal; high temperature and low pH reduce protection.
3. Zinc ion: is a weak corrosion inhibitor, but used in combination with other inhibitors magnifies their action.
4. Sodium silicate: forms a gelatinous protective film over first layer of corrosion product on metal surface.
5. Nitrite: is a passivator of steel when pH is kept above 6.
6. Organic inhibitors: Barrier films are developed on the metal surface as a result of attraction on the metal surface of the metalophilic portion of the organic chain.
7. Borax: is incorporated in nitrite formulations to maintain water pH in the 8-10 range.

In general, it is better to use a combination of inhibitors to take advantage of synergism of combined actions. In many cases, absolute prediction of best treatment concentration can only be obtained by in situ study; preliminary estimates are generally conservative.

2.0.4 Microbiological Growths

Microbiological growths on heat exchangers retard cooling, cut plant efficiency and increase maintenance cost. Iron and sulfur reducing bacteria are often a direct cause of corrosion. Indirect cause of corrosion is due to microbiological interference with corrosion inhibitors. Chlorine, hypochlorite and chlorinated phenols (Tri, tetra and pentachlorophenols) are the most commonly used chemicals to prevent attack from bacteria and algae.

Chlorine in water should not exceed 1 ppm to avoid wood delignification. Excessive chlorine can lead to equipment corrosion.

Other treating agents are: Organotin, organosulfur, quaternary ammonia compounds, complex amines and organo-thiocyanates; the last one is a very effective biocide for a broad range of microorganisms.

2.0.5 Location

Another factor which may create problems is the location of the cooling towers. The location of the cooling tower must be considered in respect to the prevailing wind direction and in respect to the plot plan of the plant.

Drift and fogging may be objectionable if tower is located upwind and too close to buildings, parking lots or streets; drift can cause icing problems on streets and short circuiting hazard if located adjacent to high voltage equipment.

Air recirculation or interference due to an adjacent cooling tower or other heat source, can be avoided or reduced by properly studying location of tower with respect to prevailing summer wind. Recirculation effects are generally reduced when wind direction is parallel to tower main dimensions, i.e., to tower air inlets. It is advisable to consult tower vendor on location of tower, especially when multiple towers are installed.

When sands or corrosive vapors can be entrained by wind into the cooling tower, location of tower upwind of sand or corrosive vapors source would solve the problem.

Tower location should also take into consideration sound level. Location of tower as far as possible from critical neighbors is usually the least expensive solution; in fact sound reduction accessories, as acoustical louver arrangement, are expensive. Placement of tower with the non-louvered side (quiet side) towards potential complaints is advisable.

2.0.6 Ice Formation

Ice formation is another factor that must be considered in the design of a cooling tower. To avoid ice formation in a cooling tower, different precautions can be taken; two speed motors for the fans, reversible fan pitch or injection of warm water in the colder section of the fill are the most common precautions to prevent ice formation.

2.0.7 Fire Hazard

Most of the materials used for cooling towers are combustibles, therefore, the fire hazard must be considered. If plastic materials or wood are used for sheathing, fire retardant types should be specified.

Standard 214 of NFPA (National Fire Protection Assn.) recommends that no combustible structure or equipment be placed within 100 ft. of a combustible cooling tower unless a sprinkler system is provided to protect the exposed surface.

2.0.8 Circuit Cleaning

All new cooling water circuits, lines and exchanger surfaces, must be cleaned before the start-up. In particular oil and grease deposits on metal surface, as well as rust, have a negative influence on heat exchange coefficients and must be removed from the circuit.

Specialized companies (such as Nalco, Milchem, etc.) will suggest the proper treatment for this purpose.

TABLE 1

CHEMICAL TREATING AGENTS FOR COOLING WATER TOWERS

Chemical and Common Name	Water Treatment Use	Quantity, ppm, in Circulating Water
Inorganic Chromate Salts	Corrosion Control	300~500 ppm of CrO_4
Inorganic & Organic Phosphates and Polyphosphates	Scale & Corrosion Control	2~10 ppm of PO_4
Chromate & Phosphate Combination Treatment	Corrosion Control	CrO_4 10~40 PO_4 20 + 50
Lignin & Tannin Organic	Scale & Corrosion	20~50 ppm
Silicates	Corrosion Control	5~20 ppm (SiO_2)
Organic Chromates	Corrosion Control	5~20 ppm
Chlorine & Chlorinated Phenols	Algae & Bacterial Slime	0.5~1 ppm
Quaternary Ammonium Copper Complexes	Algae & Bacterial Control	100 ppm intermittent
Sulfuric Acid	Solubility Control	As necessary to maintain same residual alkalinity

NOTE: The use of chromates for corrosion control must be analyzed rather carefully; in fact, the chromates are pollutant agents and their maximum content in the waste effluents is limited by law in various countries. In these cases, the blowdown from cooling tower can be treated by ion exchange (Nalco) for removal of chromates, which are recovered in a concentrated solution (2-5% CrO_4) when the ion exchange resin is regenerated. The recovered chromate solution can be reinjected in the cooling water system.

Another potential method of lessening pollution is to soften make-up water and thus reducing the blowdown volume.

3.0 MATERIAL BALANCE

As previously mentioned, the scaling tendency is controlled by drawing-off from the system a certain amount of circulating water as blowdown. Other losses from a cooling tower are due to evaporation and windage. These losses determine the fresh water make-up to the system.

3.0.1 Evaporation Losses

The evaporation of 1 lb. of water requires approximately 1,000 Btu; this heat will cool 100 lb. of water by 10°F. Therefore, the evaporation losses are approximately 1% of circulation water for each 10°F of cooling range.

3.0.2 Windage Losses

These losses vary with type of tower and local conditions. Reasonable values are:

Spray ponds	1-5% of circulation
Natural draught	0.3-1% of circulation
Mechanical draught	0.01-0.3% of circulation

Vendors have been recommending standard windage losses for new towers to be 0.05% for design purposes.

3.0.3 Cycles of Concentration

Cycles of concentration is the concentration of the dissolved salts in the circulating water divided by that of the make-up water. Usually the circulating water salt content is 3-7 times the make-up salt content.

The cycles of concentration is conveniently expressed as the ratio of the chlorides in circulating water to chlorides in make-up because chloride salts are soluble and remain in solution for the concentration increases involved in evaporative cooling water systems.

The basic items normally considered in the material balance of a cooling towers system are:

C = circulating water, USGPM

M = make-up as % of C

B = blowdown as % of C

E = evaporation losses as % of C = $0.1 \Delta T$

W = windage losses as % of C

X_c = ppm of any soluble salts in C (usually chlorides)

It must be noted that concentration of soluble salts in blowdown and windage losses equals that in circulating water.

X_m = ppm of any soluble salts in M

$$N = \frac{X_c}{X_m} = \text{number of concentration}$$

$$\text{Overall balance} \quad M = E + W + B \quad (\text{Eq. 1})$$

$$\text{Soluble salts balance} \quad MX_m = BX_c + WX_c \quad (\text{Eq. 2})$$

$$MX_m = X_c (B + W)$$

$$\frac{X_c}{X_m} = N = \frac{M}{B + W} \quad (\text{Eq. 3})$$

Substituting (3) in (1) we have:

$$M = E + \frac{M}{N}$$

$$M (N - 1) = NE \text{ but } E = 0.1 \Delta T$$

$$M = \frac{0.1 \Delta T N}{N - 1} \quad (\text{Eq. 4})$$

from equation (3)

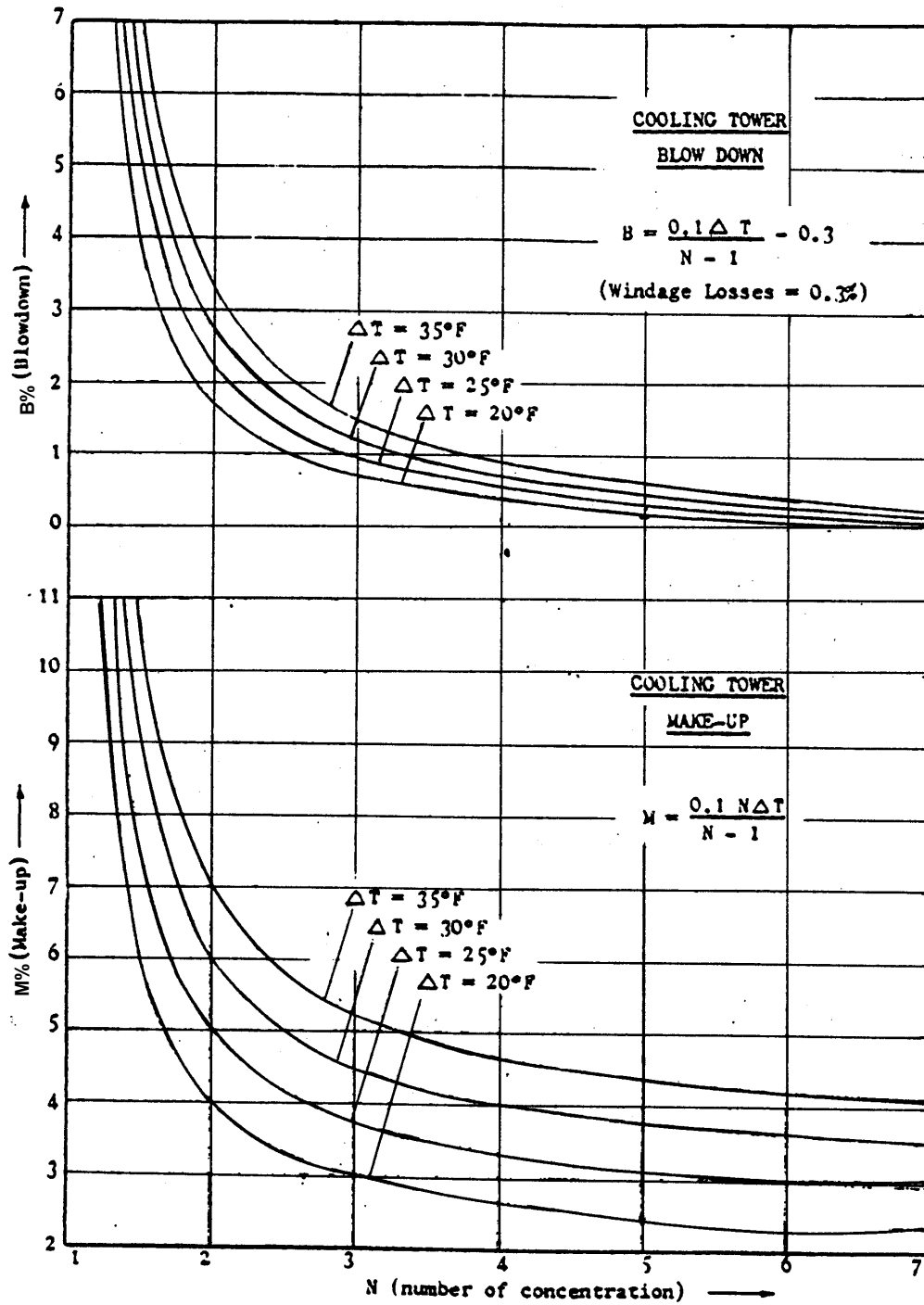
$$B + W = \frac{0.1 \Delta T}{N - 1}$$

and for $W = 0.3\%$

$$B = \frac{0.1 \Delta T}{N - 1} - 0.3 \quad (\text{Eq. 5})$$

Equations (4) and (5) are plotted on figure 2 and are the basic equations to calculate make-up and blowdown as function of number of concentration N; selection of proper value of N is underlined in the following paragraphs.

FIGURE 2



4.0 CHEMICAL TREATMENT

The compounds typically present in the fresh supply water are those of sodium, calcium, and magnesium in the form of chlorides, sulfates, silicates, carbonates, bicarbonates and hydrates. The water analysis is usually expressed in the following terms.

4.0.1 Water Analysis

Hardness is a measure of the calcium and magnesium compounds, reported as equivalent ppm of CaCO_3 even if these two actions are not present as carbonates only.

The hardness can be classified as:

Carbonate hardness, due to the presence of Ca and Mg carbonate and bicarbonate.

Non-carbonate hardness, due to the presence of other salts of Ca and Mg.

Total hardness, sum of carbonate and non-carbonate hardness.

Temporary hardness due to the presence of Ca and Mg bicarbonates. This hardness can be eliminated by boiling the water in order to transform bicarbonate into insoluble carbonate. Temporary hardness is slightly different from carbonate hardness because it does not take into account the presence of carbonate, which is slightly soluble.

Permanent hardness due to Ca and Mg residual in the water after boiling. This hardness is different from non-carbonate hardness because it measures also the carbonate remaining in the solution.

Units used to measure the hardness are:

French degrees = Grams of CaCO_3 per 100 liters water

German degrees = Grams of CaO per 100 liters water

English degrees = Grains of CaCO_3 per 1 Imp. gal. water

The relationship between the various evaluations are as follows:

1° French = 10 ppm of CaCO_3

1° German = 1.78 French = 17.8 ppm CaCO_3

1° English = 1.43 French = 14.3 ppm CaCO_3

It is also common practice to specify the calcium hardness (due only to calcium compounds) together with the total hardness (calcium and magnesium compounds).

With respect to total hardness, make-up water can be classified as follows:

<u>Type</u>	<u>Total hardness (ppm CaCO_3)</u>
Very soft	< 15
Soft	15 to 50
Medium hard	50 to 100
Hard	100 to 200
Very hard	> 200

Alkalinity is a measure of the concentration of all electrolytes which give basic reaction when hydrolyzed in water, i.e., salts of strong bases and weak acids, (hydrates, carbonates, bicarbonates, phosphates, silicates, borates, sulfites, etc.; chlorides and sulfates do not contribute to alkalinity).

The evaluation of alkalinity is made by titration and the results are reported in ppm of CaCO_3 as "P" alkalinity and "M" alkalinity.

"P" alkalinity is titrated to a phenolphthalein indicator end point or approximately an 8.3 pH; standard practice assumes that "P" alkalinity determines the alkalinity due to hydrates, half of carbonates and part of phosphates.

"M" alkalinity is titrated to a methyl orange indicator end point or approximately a 4.3 pH; it measures the total alkalinity including also that due to bicarbonates, silicates, etc., not measured by "P" alkalinity.

Sometimes the alkalinity is reported as cc of the acid (HCl or H_2SO_4) used for the titration of 100 cc of water. To convert to ppm of CaCO_3 , use the following relationship:

cc of 0.1N acid x 50 = ppm of CaCO_3

cc of 0.02N acid x 10 = ppm of CaCO_3

The number of cc of 0.1N acid used for titration of 100 cc of water are frequently called millivalents.

Other analyses for make-up water are:

pH

suspended solids, ppm

chlorides ppm Cl

sulfates ppm SO_4

silica ppm SiO_2

It is interesting to note that:

When the total alkalinity is less than the total hardness, then calcium and magnesium are present in compounds other than carbonates, bicarbonates and hydrates. In this case, the amount of hardness equivalent to total alkalinity is the carbonate hardness; the remainder is the non-carbonate hardness.

Thus, the non-carbonate hardness (total hardness minus total alkalinity) may be calcium and magnesium chlorides or sulfates or other non-alkaline compounds.

When the total alkalinity ("M" alkalinity) equals or exceeds the total hardness (calcium plus magnesium) then the hardness is due only to carbonates, bicarbonates and hydrates, i.e., water does not contain sulfates or chlorides of Ca and Mg.

4.0.2 Saturation and Stability Index

It is clear that when concentrated 3 to 7 times in a circulating water system, some of the salts can exceed their solubility limits, causing scale formation in pipes and coolers. The solubilities of the more common salts at approximately 120°F are as follows:

	Chloride ppm	Carbonate ppm	Sulfate ppm
Na	270,000	290,000	310,000
Mg	270,000	125	330,000
Ca	520,000	17	2,200

The purpose of the cooling water treatment is to avoid scale formation; this is achieved by injection of sulfuric acid to convert calcium and magnesium carbonates (carbonate hardness) into more soluble sulfates. The amount of acid used must be limited so as to maintain some residual alkalinity in the system. If the system pH is reduced too far below 7.0, it would result in accelerated corrosion within the system.

Scale formation and/or corrosion tendency is defined by the Saturation Index (Langelier Index) and Stability Index.

CaCO₃ Saturation Index (Langelier Index)

This index is given by the formula $\text{pH} - \text{pH}_s$

where pH = antilog of H^+ ion concentration

$$\text{pH}_s = (9.30 + A + B) - (C + D)$$

The values of A, B, C, D are obtained from Table 2 and are a function respectively of total solids, temperature, calcium hardness of water and alkalinity.

If index is 0, water is in chemical balance.

If index is positive, scale forming tendencies are indicated.

If index is negative, corrosive tendencies are indicated.

Stability Index

This index is given by the formula $2pH_s - pH$

If Stability index < 6.5 the water is scale forming

If Stability index 6.5 to 7.0 the water is in a good range

If Stability index > 7.0 the water is corrosive

The optimum value for Stability Index is 6.6.

These convenient indices, however, must serve strictly as guides rather than as absolute control methods, the reason being that uneven temperatures exist throughout a cooling system. Because of this, some exchangers will scale, some will be protected, while still others will corrode.

4.0.3 H₂SO₄ Dosage

Calculation of quantity of H₂SO₄ required to prevent scale formation, as explained in paragraph 4.2 is done as follows. Assume following make-up water analysis:

Total hardness	h ppm of CaCO ₃
Total alkalinity (M)	a ppm of CaCO ₃
Sulfates (of Na, Ca, Mg, etc.)	s ppm of SO ₄
Chlorides (of Na, Ca, Mg, etc.)	c ppm of Cl
Silica	e ppm of SiO ₂

Case 1 Total hardness exceeds total alkalinity (N is number of concentration).

(1) Sulfates in circulating water

Ns ppm SO₄

Ns $\frac{136}{96}$ ppm CaSO₄

TABLE 2

CaCO₃ SATURATION INDEX (LANGELIER INDEX) - TABLE 2

(Based on the Langelier Formula: Larzon--Buswell; Residue--Temperature Adjustments: Arranged by Nordell)

1. $pH_s = (9.30 + A + B) - (C + D)$
(NOTE: Values of A, B, C & D are obtained from tables A, B, C & D)

2. Saturation Index = $pH - pH_s$

If index is 0, water is in chemical balance.

If index is a plus quantity, scale forming tendencies are indicated.

If index is a minus quantity, corrosive tendencies are indicated.

Example: To find the saturation index at 124° F. of water which has the following characteristics: Total solids—400 ppm; calcium hardness as CaCO₃—240 ppm; alkalinity as CaCO₃—196 ppm; and pH of 7.2. Then:

Total solids 400 ppm = 0.16 (from table A)

Temperature 124° F. = 1.53 (from table B)

Calcium hardness

as CaCO₃ 240 ppm = 1.98 (from lower table C)

Alkalinity

as CaCO₃ 196 ppm = 2.29 (from upper table D)

Substituting: $pH_s = (9.30 + 0.16 + 1.53) - (1.98 + 2.29) = 6.72$ (or 6.7)

Saturation Index = $7.2 - 6.7 = +0.5$

A
Total Solids
in ppm

30	.07
75	.08
100	.10
150	.11
200	.13
300	.14
400	.16
600	.18
800	.19
1000	.20

B
Temperatures in degrees Fahrenheit

	UNITS				
	0	2	4	6	8
30		2.60	2.57	2.54	2.51
40	2.45	2.43	2.43	2.40	2.37
50	2.31	2.31	2.28	2.25	2.22
60	2.20	2.17	2.14	2.11	2.09
70	2.05	2.01	2.00	2.00	1.97
80	1.92	1.92	1.90	1.88	1.85
90	1.81	1.82	1.80	1.78	1.76
100	1.74	1.72	1.71	1.69	1.67
110	1.67	1.61	1.62	1.60	1.58
120	1.57	1.55	1.53	1.51	1.50
130	1.48	1.46	1.41	1.43	1.41
140	1.40	1.38	1.37	1.35	1.34
150	1.32	1.31	1.29	1.28	1.27
160	1.26	1.24	1.23	1.22	1.21
170	1.19	1.18	1.17	1.16	

C

Calcium hardness expressed as ppm CaCO₃
(For 1 to 200 ppm CaCO₃ use upper table)
(For 210 to 950 ppm CaCO₃ use lower table)

	UNITS									
	0	1	2	3	4	5	6	7	8	9
0										
10	0.50	0.64	0.65	0.72	0.75	0.78	0.81	0.83	0.86	0.88
20	0.50	0.92	0.91	0.96	0.98	1.00	1.02	1.03	1.05	1.06
30	1.00	1.05	1.11	1.14	1.15	1.16	1.17	1.18	1.19	
40	1.50	1.21	1.23	1.24	1.25	1.26	1.27	1.28	1.29	
50	1.50	1.31	1.32	1.33	1.34	1.35	1.36	1.37	1.37	
60	1.54	1.39	1.39	1.40	1.41	1.42	1.43	1.43	1.44	
70	1.45	1.45	1.45	1.47	1.47	1.48	1.48	1.49	1.49	
80	1.51	1.51	1.52	1.52	1.53	1.53	1.54	1.54	1.55	
90	1.56	1.56	1.57	1.57	1.58	1.58	1.59	1.59	1.60	
100	1.60	1.61	1.61	1.61	1.62	1.62	1.63	1.63	1.64	
110	1.64	1.65	1.65	1.65	1.66	1.66	1.67	1.67	1.67	
120	1.68	1.68	1.69	1.69	1.70	1.70	1.71	1.71	1.71	
130	1.72	1.72	1.72	1.73	1.73	1.73	1.74	1.74	1.74	
140	1.75	1.75	1.75	1.76	1.76	1.76	1.77	1.77	1.77	
150	1.78	1.78	1.78	1.79	1.79	1.79	1.80	1.80	1.80	
160	1.81	1.81	1.81	1.81	1.82	1.82	1.82	1.83	1.83	
170	1.83	1.84	1.84	1.84	1.84	1.85	1.85	1.85	1.85	
180	1.86	1.86	1.86	1.86	1.87	1.87	1.87	1.87	1.88	
190	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.90	1.90	
200	1.89	1.91	1.91	1.91	1.91	1.91	1.92	1.92	1.92	

D

Alkalinity expressed as ppm CaCO₃
(For 1 to 200 ppm CaCO₃ use upper table)
(For 210 to 990 ppm CaCO₃ use lower table)

	UNITS									
	0	1	2	3	4	5	6	7	8	9
0										
10	1.00	1.04	1.08	1.11	1.15	1.18	1.20	1.23	1.25	1.28
20	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.43	1.45	1.46
30	1.44	1.49	1.51	1.52	1.54	1.54	1.56	1.57	1.58	1.59
40	1.60	1.61	1.62	1.63	1.64	1.65	1.66	1.67	1.68	1.69
50	1.70	1.71	1.72	1.72	1.73	1.74	1.75	1.76	1.76	1.77
60	1.78	1.79	1.79	1.80	1.81	1.81	1.82	1.83	1.83	1.84
70	1.85	1.85	1.86	1.86	1.87	1.88	1.88	1.89	1.89	1.90
80	1.90	1.91	1.91	1.92	1.92	1.93	1.93	1.94	1.94	1.95
90	1.95	1.96	1.96	1.97	1.97	1.98	1.98	1.99	1.99	2.00
100	2.00	2.00	2.01	2.01	2.02	2.02	2.03	2.03	2.03	2.04
110	2.04	2.05	2.05	2.05	2.06	2.06	2.07	2.07	2.07	2.08
120	2.08	2.08	2.09	2.09	2.09	2.10	2.10	2.10	2.11	2.11
130	2.11	2.12	2.12	2.12	2.13	2.13	2.13	2.14	2.14	2.14
140	2.15	2.15	2.15	2.16	2.16	2.16	2.16	2.17	2.17	2.17
150	2.18	2.18	2.18	2.18	2.19	2.19	2.19	2.20	2.20	2.20
160	2.20	2.21	2.21	2.21	2.21	2.22	2.22	2.22	2.23	2.23
170	2.23	2.23	2.23	2.24	2.24	2.24	2.24	2.25	2.25	2.25
180	2.26	2.26	2.26	2.26	2.26	2.27	2.27	2.27	2.27	2.28
190	2.28	2.28	2.28	2.29	2.29	2.29	2.29	2.30	2.30	2.30
200	2.30	2.30	2.30	2.31	2.31	2.31	2.31	2.32	2.32	2.32

	TENS									
	0	10	20	30	40	50	60	70	80	90
200		1.92	1.91	1.92	1.93	2.00	2.01	2.03	2.05	2.05
300	2.05	2.09	2.11	2.12	2.13	2.15	2.16	2.17	2.18	2.19
400	2.20	2.21	2.25	2.21	2.25	2.26	2.27	2.27	2.28	2.29
500	2.30	2.31	2.32	2.33	2.34	2.35	2.36	2.37	2.37	2.37
600	2.36	2.39	2.39	2.40	2.41	2.42	2.43	2.43	2.43	2.44
700	2.44	2.45	2.46	2.47	2.47	2.48	2.48	2.49	2.49	2.50
800	2.51	2.51	2.52	2.52	2.53	2.53	2.54	2.54	2.54	2.55
900	2.56	2.56	2.57	2.57	2.58	2.58	2.59	2.59	2.59	2.60

	TENS									
	0	10	20	30	40	50	60	70	80	90
200		2.32	2.31	2.35	2.35	2.40	2.42	2.43	2.45	2.46
300	2.45	2.49	2.51	2.52	2.52	2.58	2.59	2.57	2.58	2.59
400	2.60	2.61	2.62	2.62	2.61	2.65	2.66	2.67	2.65	2.66
500	2.69	2.71	2.72	2.72	2.73	2.77	2.78	2.76	2.76	2.77
600	2.78	2.79	2.79	2.80	2.81	2.85	2.86	2.88	2.87	2.88
700	2.88	2.89	2.89	2.90	2.91	2.95	2.96	2.97	2.95	2.96
800	2.99	2.99	2.99	2.99	2.99	3.03	3.04	3.04	3.04	3.05
900	3.05	3.05	3.06	3.07	3.07	3.09	3.09	3.10	3.09	3.10

- (2) Additional sulfates formation permissible

$$2,200 - N_s \frac{136}{96} \quad \text{ppm CaSO}_4$$

$$2,200 \frac{96}{136} - N_s \quad \text{ppm SO}_4$$

Where: 136 is MW of CaSO₄

96 is MW of SO₄

2,200 ppm CaSO₄ solubility limit

- (3) Alkalinity in circulating water if not converted to sulfates

Na ppm CaCO₃

Assume that 10% of alkalinity is left unconverted to avoid corrosion; ppm of CaCO₃ to be converted to sulfate 0.9 Na.

- (4) Sulfates formed by conversion of CaCO₃

$$0.9 Na \frac{96}{100} \quad \text{ppm SO}_4$$

where 100 is MW of CaCO₃

This must not exceed the permissible sulfates formation as evaluated at step (2) above.

Case 2 Total alkalinity equal or exceeds total hardness.

Calculate permissible sulfates formation following steps (1) and (2) of Case 1.

- (3) Total hardness in circulating water

h N ppm CaCO₃

- (4) Sulfates that could be formed by converting the total hardness:

$$h N \frac{96}{100} \quad \text{ppm SO}_4$$

This must not exceed the permissible sulfate formation as evaluated in step (2) of Case 1.

In Case 2 since alkalinity exceeds total hardness even when total hardness is converted to sulfate, the alkalinity in excess of total hardness (a - h) insures a residual alkalinity of the water to avoid corrosion.

In both Cases, 1 and 2, the comparison done at point (4) allows the calculation of number of concentration N and, therefore, Blowdown, Make-up and quantity of H₂SO₄ to be injected.

It is interesting to compare, as shown in the following table, the analysis of the blowdown water (equal to that of the circulating water) with that of the make-up water.

		<u>Blowdown</u>		
		<u>Make-up Water</u>	<u>Case 1 h ≥ a</u>	<u>Case 2 h ≤ a</u>
Total hardness	ppm CaCO ₃	h	h N	h N
Total alkalinity	ppm CaCO ₃	a	0.1 a N	(a-h) N
Sulfates	ppm SO ₄	s	$s N + 0.9 a N \frac{96}{100}$	$s N + h N \frac{96}{100}$
Chlorides	ppm Cl	c	c N	c N
Silica	ppm SiO ₂	e	e N	e N

Example:

Using fresh water of the following composition:

		<u>ppm</u>
Ca hardness	as CaCO ₃	85
Mg hardness	as CaCO ₃	33
Total hardness	as CaCO ₃	118
Total alkalinity	as CaCO ₃	90
Sulfates	as SO ₄	20
Chlorides	as Cl	19
Silica	as SiO ₂	2

find number of conc., blowdown composition, make-up and sulfuric acid required for a cooling tower operating with $25^{\circ}\text{F}\Delta\text{T}$.

Total hardness > Total alkalinity

Assume 5 numbers of concentration

Sulfates in circulating water $5 \times 20 = 100 \text{ ppm SO}_4$

$$\text{or } 100 \times \frac{136}{96} = 142 \text{ ppm CaSO}_4$$

CaSO_4 solubility limit = 2,200 ppm CaSO_4

Additional sulfates formation permissible $2,200 - 142 = 2,058 \text{ ppm}$

$$\text{CaSO}_4 \text{ or } 2,058 \times \frac{96}{100} = 1,450 \text{ ppm as SO}_4$$

Alkalinity in circulation water if not converted into sulfates

$$5 \times 90 = 450 \text{ ppm CaCO}_3$$

Assume 10% of alkalinity left unconverted

$$= 450 \times 0.9 = 405 \text{ ppm CaCO}_3 \quad \text{CaSO}_4$$

$$\text{Sulfate formed } 405 \times \frac{96}{100} = 388 \text{ ppm as SO}_4$$

Draw-off Composition

					<u>ppm</u>
Hardness	as	CaCO_3	=	5×118	= 590
Alkalinity	as	CaCO_3	=	$0.1 \times 5 \times 90$	= 45
Sulfates	as	SO_4	=	$5 \times 20 + 388$	= 488
Chlorides	as	Cl	=	5×19	= 95
Silica	as	SiO_2	=	5×2	= 10

In this case a greater number of concentration would be possible because we have 488 ppm of SO_4 against 1,450 allowed. Assume in any case $N = 5$.

Sulfuric acid required

$$405 \times \frac{96}{98} = 397 \text{ ppm} = 0.0397 \text{ wt. } H_2SO_4 \text{ 100\% (on blowdown + windage)}$$

Make-up (0.3% windage losses) $M = (0.1 \times 5 \times 25) / (5-1) = 3.13\%$

Blowdown $B = (0.1 \times 25) / (5-1) - 0.3 = 0.325\%$

For a 100,000 GPM cooling water system, the sulfuric acid required

$$\frac{0.0397}{100} \times 100,000 \times 500 \frac{(0.325 + 0.3)}{100} = 124 \text{ lbs/hr (100\% } H_2SO_4)$$

5.0 DESIGN CRITERIA

5.0.1 General Consideration for Sizing

The water is cooled by evaporation of a small portion of water and by sensible heat due to the temperature difference between water and air. Approximately 80% of the heat is transferred by evaporation and the remaining 20% by temperature gradient. Therefore, the heat removal in a cooling tower depends on the temperature and moisture content of the air.

The air wet-bulb temperature is, theoretically, the minimum temperature to which the water can be cooled.

Practically the cold water temperature approaches the wet-bulb temperature of the air and the magnitude of this approach depends on the design of the cooling tower being a function of contact time between air and water, amount of fill surface, water distribution over the fill, amount and size of water droplets formed.

The cooling process involves both mass and heat transfer; the water surface existing on the tower packing is in contact with by an air film which is considered saturated at the water temperature.

The heat is transferred, by diffusion and convection, between this film and the main body of air, the driving force being the difference of enthalpy between the film and the surrounding air.

The number of transfer units, or tower characteristics, is based on overall heat and mass transfer.

$$\int_{t_2}^{t_1} \frac{dt}{h' - h} = KaV/L' \quad (\text{Eq. 6})$$

where:

h' = enthalpy of saturated air at water temperature (Btu/lb dry air)
(assumes air at air-water interface is saturated)

h = enthalpy of the main air stream (Btu/lb dry air)

a = contact area sq.ft./cu. ft. tower volume

K = mass transfer coefficient lb. (water)/hr. sq. ft. (transfer area)

V = active cooling volume cu.ft./sq.ft. ground plan area

L' = water rate lb./hr. sq.ft. tower cross section

t_1 = water inlet temperature

t_2 = water outlet temperature

Figure 3 shows the relations between the various variables involved in the cooling tower design:

Line A-B gives enthalpy h of air if saturated and at various temperatures included in the water cooling range; the points A & B are fixed by the outlet (t_2) and inlet (t_1) water temperature respectively.

Line C-D gives actual enthalpy h of air stream plotted versus water temperature and represents the air operating line and its slope as given by the ratio L'/G_a ; wet-bulb temperature at any point of C-D are found by projecting the point horizontally to the water operating line and then vertically to the abscissa of the diagram.

Line E-F gives actual enthalpy of air stream plotted versus actual air temperature; should line E-F cross line A-B there is a possibility of fog formation.

Lines B-C and A-D represent the initial and final driving forces respectively.

Area A-B-C-D is proportional to the reciprocal of the value of the integral: this value defines the characteristics of the tower and it is clear that the lower the area the higher is the value KaV/L' , i.e., high contact area (a) and high contact volume (V) therefore, high investment cost. The reduction of the investment cost and, therefore, the increase of area A-B-C-D can be achieved by increasing the approach or reducing the L/G ratio; the reduction of L/G ratio means high air mass velocity i.e. large power consumption for the fans.

Approach and cooling range are also indicated in the diagram. It is evident that the less the approach, the smaller is the area A-B-C-D and higher the investment cost.

Recent studies indicate that the performance of all commercially used cooling tower packings can be correlated as follows:

$$KaV/L' = 0.07 + A' N (L'/G_a)^{-n'} \quad (\text{Eq. 7})$$

where:

G_a = air mass velocity lb. (dry air) hr. sq. ft. (plan area)

A', n' = parameters depending on the type of packing

N = number of packing deck levels

N , in turn, fixes the total height of packing and, therefore, the time of contact between air and water. Packing height i.e., N , is selected as function of desired approach and a guide dictated by experience is:

Cooling Range, °F	Approach, °F	Packing Height, ft.
25 – 35	15 – 20	15 – 20
25 – 35	8 – 15	25 – 30
25 – 35	4 – 8	35 - 40

The simultaneous solution of equation (6), involving approach and cooling range and equation (7) involving type and number of packing decks gives the value of the ratio L'/G_a which satisfies the specified performance.

Cooling tower data have been plotted as KaV/L' versus L'/G_a for various air wet bulb temperatures and cooling ranges to avoid the need of using Equation 6. These graphs have been published by CTI (Cooling Tower Institute) and are similar to that shown in figure 4 for one particular value of wet bulb temperature and cooling range (Validity of these graphs is up to 3000 ft. elevation above sea level). The sizing of a cooling tower consists of plotting on figure 4 (selected for the wet bulb and the cooling range under consideration) equation 7; the intersection point of the graph representing equation 7 and the curve for the desire approach gives the value of L'/G_a which solves the problem.

The economics of mechanical draught cooling tower operation indicate that fan static pressure should not exceed 0.75 - 1.0 inches of water. This indicates that the height of packing should be kept minimum without dropping it to a low value where the performance becomes very poor.

It is possible to establish a correlation between ground area and height of packing. The economics suggests that the ground area should be so selected to have G_a of 2000 and 1400 lb/hr sq. ft. for packing height varying from 12 to 40 ft. respectively, being approximately a straight line function.

Therefore, once evaluating the value of L'/G_a from figure 4, G_a is selected in accordance to these economics above mentioned and the tower ground area is then evaluated from L' and the considered water flow.

It is interesting to note that in the counterflow tower the temperature conditions are constant across any horizontal section of tower while in the crossflow arrangement temperature conditions are different in both vertical and horizontal directions. This fact implicates a basic difference in the design of the crossflow towers since in this case the integral must also take into consideration the horizontal temperature variations.

In designing an induced draught counterflow type of cooling tower, it is suggested that reference be made to the following literature:

Ludwig, E. E.: Applied Process Design for Chemical & Petrochemical Plants

Gulf Publishing Co.

Vol. 22 pages 199-221

Approximate methods for the design of cooling towers (mechanical draft, atmospheric and natural draught) as well as cooling ponds are reported in:

Perry, J. E.: Chemical Engineers' Handbook

McGraw-Hill

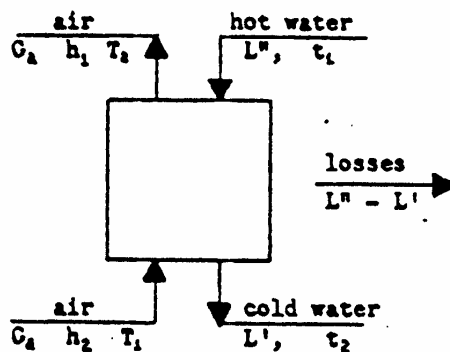
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Another approximate method for evaluating counterflow tower plan area and fan power absorption is indicated in figure 5.

The basic considerations to be made in the design of a cooling tower are essentially water circulation rate, wet bulb approach and cooling range.

FIGURE 3

FIG. 3
COOLING TOWER DESIGN :
OPERATING AND SATURATION CURVES



NOTE : for design purpose it
is assumed that $L'' = L'$

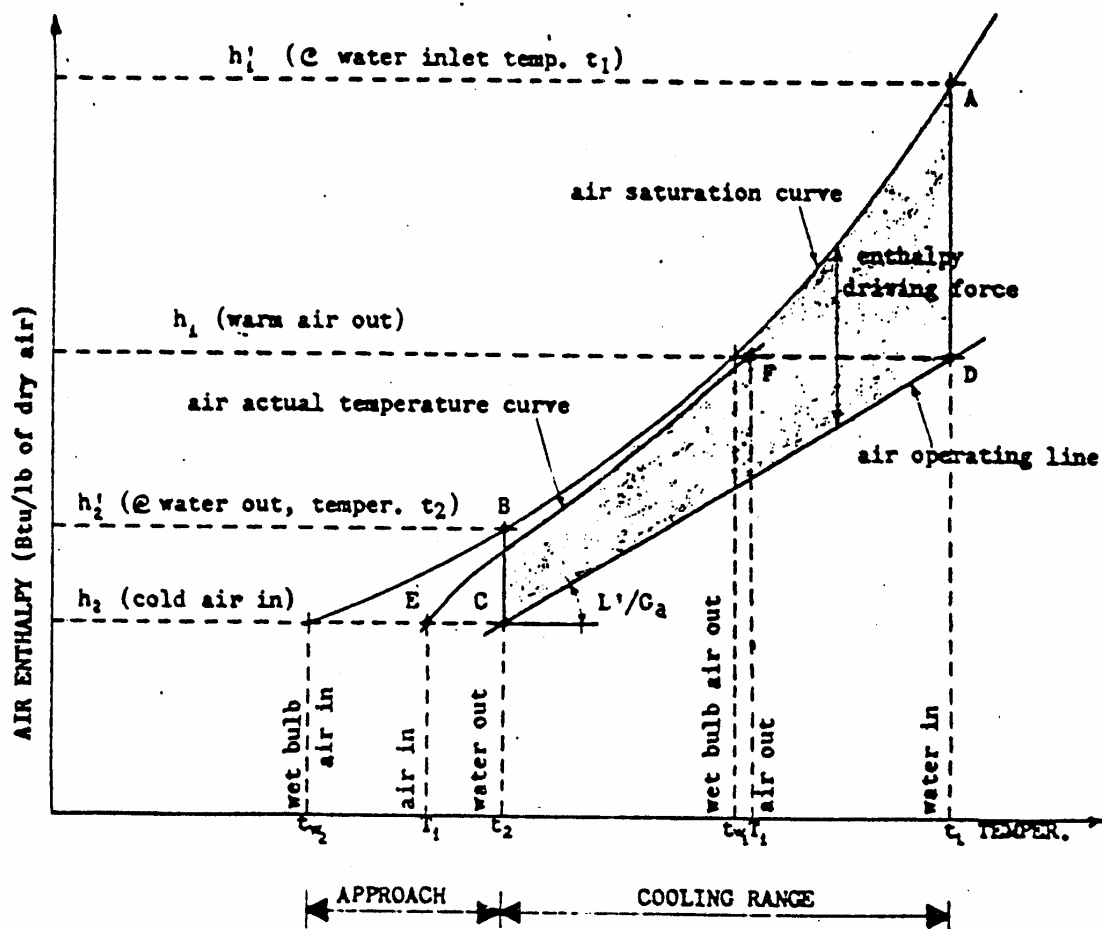


FIGURE 4 - COOLING TOWER SIZING

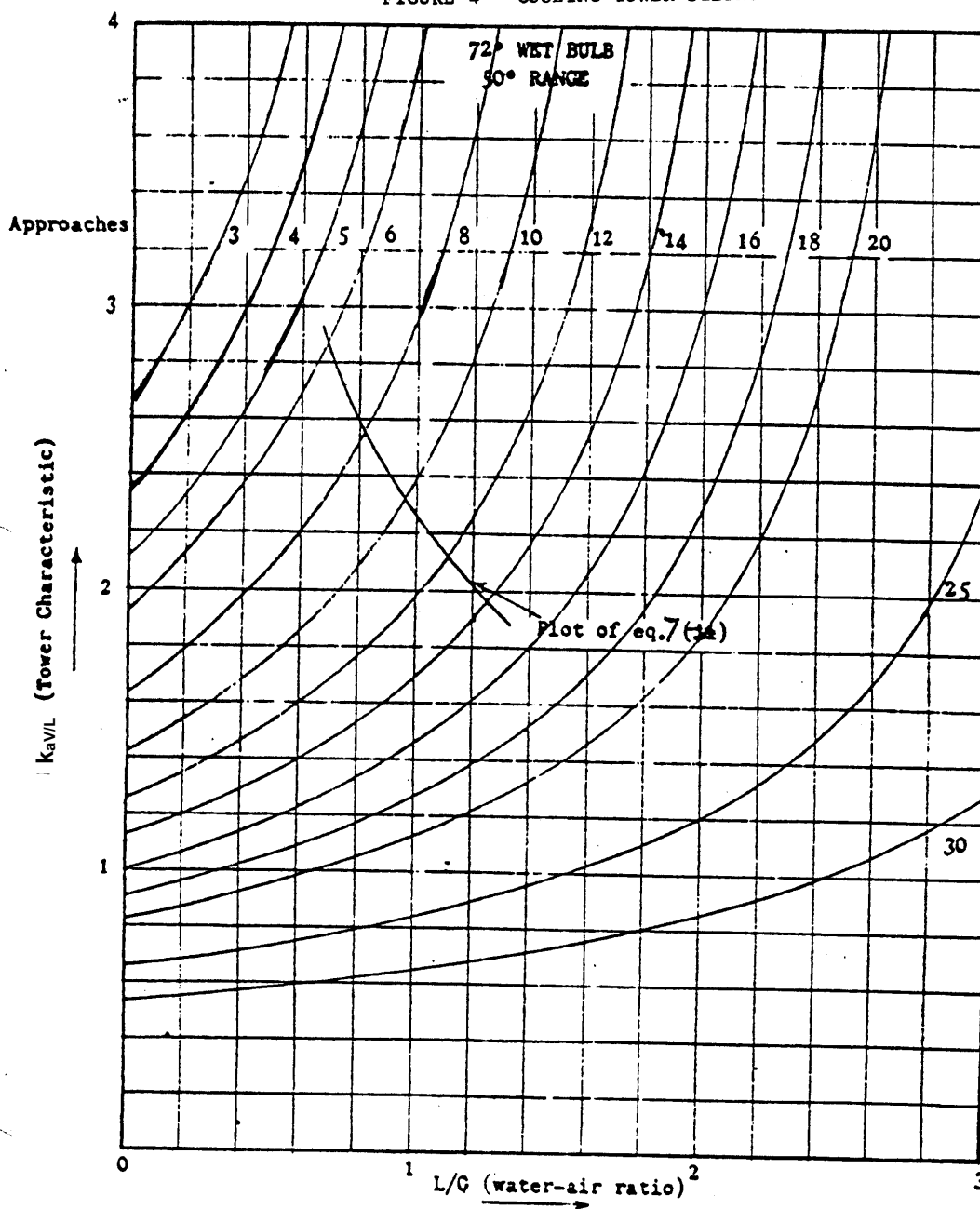
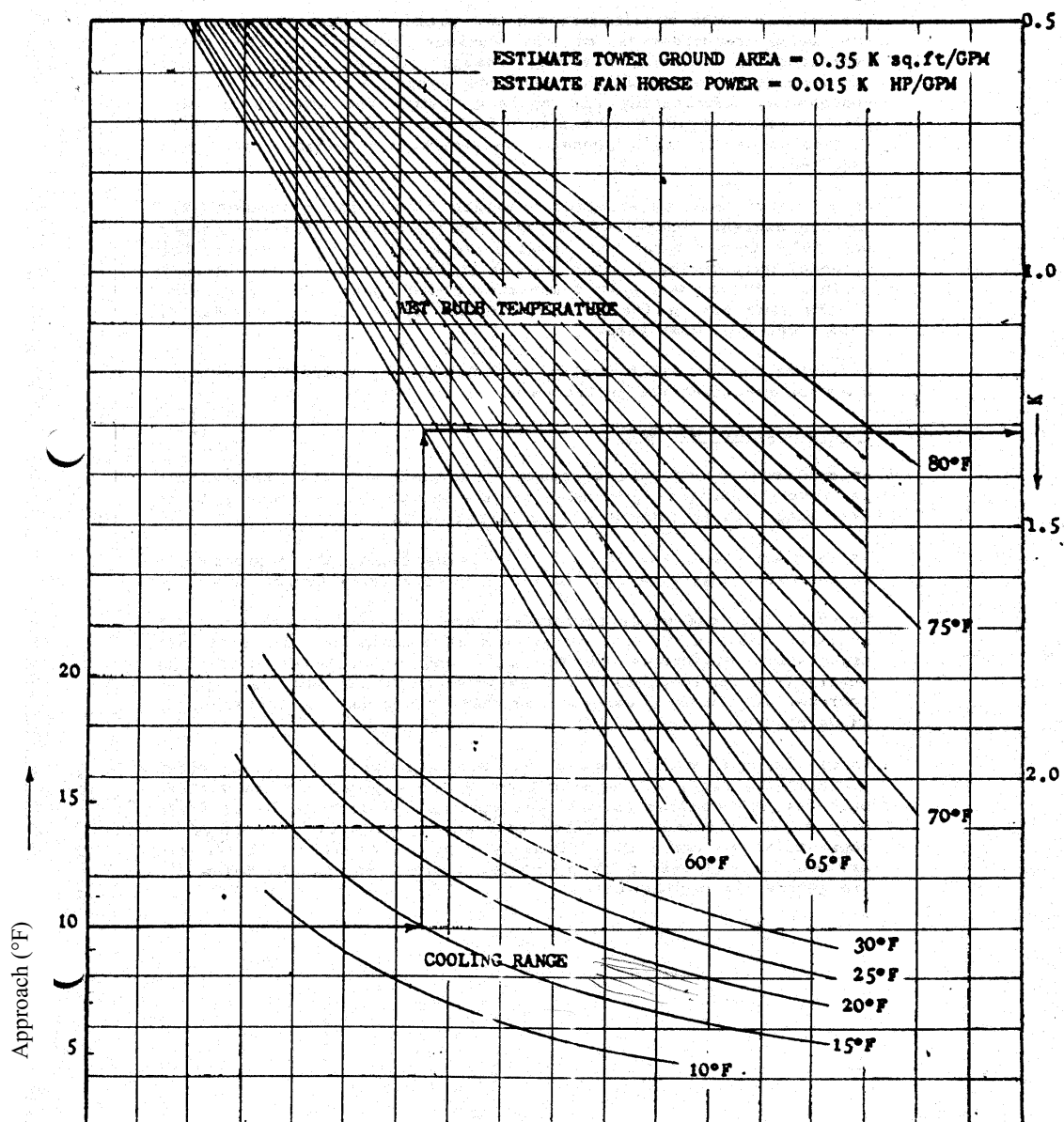


FIGURE 5 - COUNTER FLOW TOWER (INDUCED DRAUGHT)



5.0.2 Water Circulating Flowrate

The cooling water requirement for the process units is the sum of the water requirements of the various coolers in the plant corresponding to the maximum, design duties. Cooling water requirements for utility services such as steam turbine condensers, lubricating oil coolers, pumps and compressors are also based on design conditions. When the total water requirement is evaluated in this manner, no additional safety factor is required.

It is noted that an additional safety factor is introduced when setting ambient conditions for the cooling tower. The design air wet bulb temperature is normally selected as the temperature exceeded only during limited period of time (about 5% of 4 summer months). Actual wet bulb temperatures are lower than design 95% of the time during the 4 summer months resulting in potentially colder water at most times.

A further cushion is normally included by the tower manufacturer who must guarantee its performance.

5.0.3 Approach to Air Wet Bulb

As mentioned above, the approach to the air wet bulb temperature is a very important parameter in the design of a cooling tower affecting both investment and operating costs.

It is clear that, the air wet bulb being fixed, the approach can be increased only by accepting a higher cold water temperature.

However, the cold water temperature considerably affects the heat transfer surface of all water cooled exchangers; in fact the temperature difference on the cold end of a water cooler is generally much lower than the difference on the hot end, so an increase in the cold water temperature could cut drastically the LMTDs of the cooler.

There is not much freedom in the selection of cold water temperature, i.e., in the selection of the approach to the air wet bulb for the cooling tower. The optimum approach could be fixed only after detailed economical evaluation, which in most cases is impractical to carry out. Usually, approaches of 7 to 15°F are assumed for the design of a cooling tower. Approaches below 5°F are generally uneconomical.

5.0.4 Cooling Range

The cooling range is a direct function of the quantity of water circulated and the heat load; 120°F is usually considered a maximum value for the hot cooling tower water since excessive scaling would result at higher temperatures. Therefore, the cooling range is fixed by the selection of the cold water temperature and the imposition of 120°F as maximum hot water temperature.

5.1.0 Process Specification

The process specification shall include all necessary information for manufacturer to design the tower.

Type of Tower

Process Data

Circulating Water Flow USGPM

Water inlet temperature °F

Water outlet temperature °F

Air wet bulb temperature °F

Air minimum dry bulb temperature °F

Barometric Pressure mm Hg

Hot water pressure at ground level, psig

Drift losses, % of circulating flow

Electric power for fan driver, V/phase/cycles

Deicing facilities

Location of nearby heat source, ft.

Direction and intensity of prevailing wind

Orientation of longitudinal axis

Hold-up in cold water basin, minutes

Notes:

- (1) Type of tower, mechanical draught or natural draught must be specified.
- (2) Circulating water flow is evaluated by the sum of the design water requirement of the various users (for a consistent case of operation for blocked operation type plant) without safety factor as indicated under paragraph 5.0.2.
- (3) Barometric pressure or elevation above sea level must be indicated.
- (4) Drift losses should not exceed 0.05% (0.3% is a maximum for older towers).
- (5) Advise vendor if deicing facilities must be provided. Typical deicing facilities are: multispeed fan, reversible fan pitch, fan reversal, adjustable air inlet louvers, preheating air inlet by hot water bypass.
- (6) The volume in the cold water basin (including pump suction bay, if needed) shall allow for a minimum holdup of 10 minutes based on design circulating flow and normal operating water level. Typical water depths in the basin are 3 - 4 feet.
- (7) The cooling tower performance must be guaranteed as specified under process data. Since the performance test is run under conditions which will be different from those specified, the manufacturer must supply sets of performance curves, based on design fan horsepower, showing cold water temperature versus air wet bulb temperature for 90%, 100% and 110% of design water circulating flow and covering cooling ranges of 15°F, 20°F, 30°F and design range (an example of these curves is shown in figure 6).

The test Run of Cooling Tower must be performed in accordance with rules set by Cooling Tower Institute Acceptance Test Procedure ATP-105 attached at the end of this manual. Data collected during test must agree with manufacturer's performance curves.

Drift losses must also be guaranteed; to test drift losses a suggested method is to run the cooling tower system alone, with all exchangers off-stream. When system has reached equilibrium, no vaporization takes place and if blowdown is closed drift losses equals make-up rate.

5.2. Auxiliary Equipment

5.2.1 Circulating Pump

Design capacity of the pumps to be 110 - 115 % of normal capacity. The pumps must have suitable spare depending upon the number of pumps provided; for example two 100% capacity, or three 50% capacity pumps.

For large installation where more than two pumps normally running are required, one spare machine for every two pumps shall be considered.

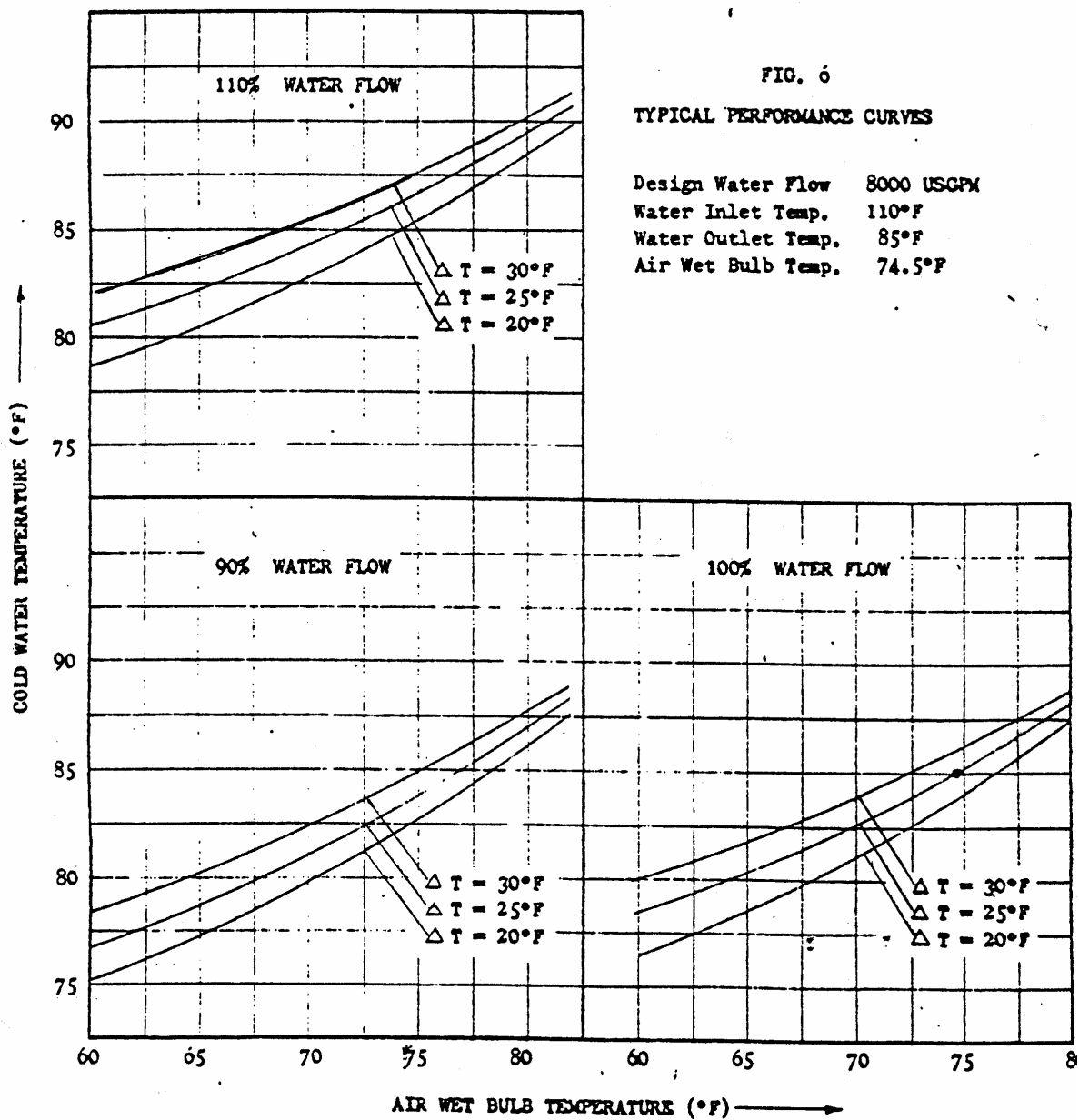
Pumps can be either horizontal or vertical and the selection of type depends on the water basin, which can be underground, or above ground. An economical evaluation should be made to ascertain which is the more convenient solution between above ground basin with horizontal pumps and underground basin with vertical pumps.

Pump installation is an important point to be considered rather carefully. The following criteria should be applied.

In case of vertical pumps, pump submergence should comply with vendor's specifications.

In case of horizontal pumps, designer should control these points:

1. It is strongly recommended that separate suction line be provided for each pump. In fact in a case of a common manifold, operation of one pump can interfere with operation of the other; however, if common manifold is used, it must be carefully designed with respect to velocity and geometrical arrangement.



2. Submergence of suction line water intake in the basin should be such to avoid vortex formation and consequently air entrainment. Suggested values are given in Figure 7. In some cases it may be impractical to respect velocity limitations given in Figure 7; in these cases higher suction velocity can be accepted by providing a vortex breaker as indicated in Figure 8.
3. Normal water level in the basin must be at 6" above the top of pump casing.
4. Water velocity in the pump suction line should not exceed 8.5 feet/sec. In the discharge line water velocity should not be greater than 12 feet/sec. to avoid excessive erosion of piping especially in case of sandy water.
5. Each pump must be isolated with suction and discharge valves. Suction valves can be substituted with less expensive sliding gates as shown in Figure 9.
6. It is advisable to provide in the basin a suction screen (say 3/8" openings) to stop leaves, pieces of wood and other foreign material (see Figure 9).

5.2.2 Sulfuric Acid Injection

For sulfuric acid addition a storage drum and a proportioning pump are normally provided. Alternatively, the acid may be added by gravity flow.

Storage drum for concentrated sulfuric acid of a capacity consistent with the capacity of the carriage used for the make-up (railroad tank or tank truck, etc.).

Carbon steel is a suitable material for concentrated sulfuric acid drum, providing that moisture does not enter the drum.

For safety reasons avoid a glass level gauge, instead install a floating type or a bubbler type level gauge.

FIGURE 7 - CHART OF RECOMMENDED MIN. SUBMERGENCE VS. VELOCITY

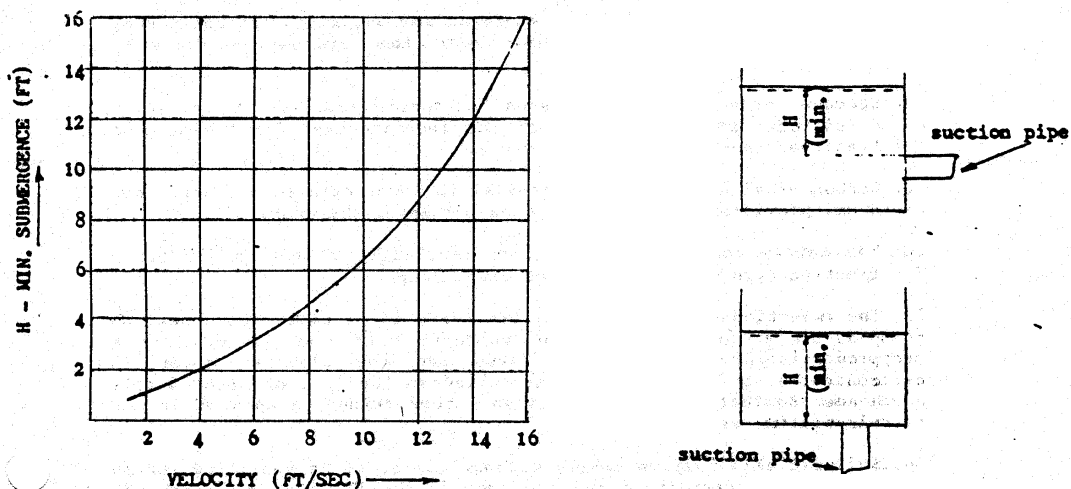
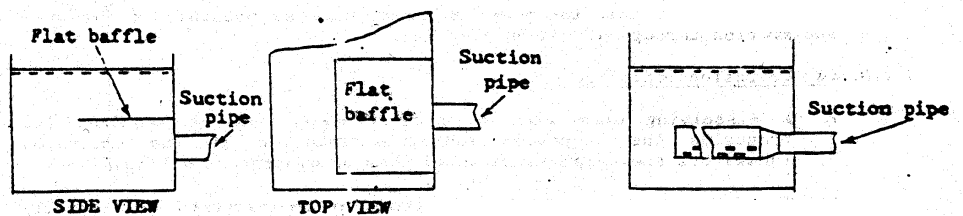


FIG. 8 : METHODS TO PREVENT VORTEX FORMATION



a) Flat baffle

b) Larger diameter section of pipe with slots cut into the lower third of the pipe wall

The injection point of the sulfuric acid is in to a trough near as possible to water inlet; the sulfuric acid pump is normally a proportioning pump, motor driven and the electric motor is controlled by a pH analyzer installed on the cooling water supply header so that the pump starts and stops depending upon pH in the circulating water.

Sulfuric acid pump, normally without spare, to be specified for 10 to 15 psi differential and the pump discharge line to be Sch. 80 PVC pipe. Pump capacity should be larger than stoichiometric requirements (usually twice).

5.2.3 Chlorinator

Chlorine or chlorinating agents are dissolved in water supplied by a line from the discharge of cooling water circulating pumps and are injected into the pump bay or as near as possible to the pump suction through a Sch. 80 PVC line.

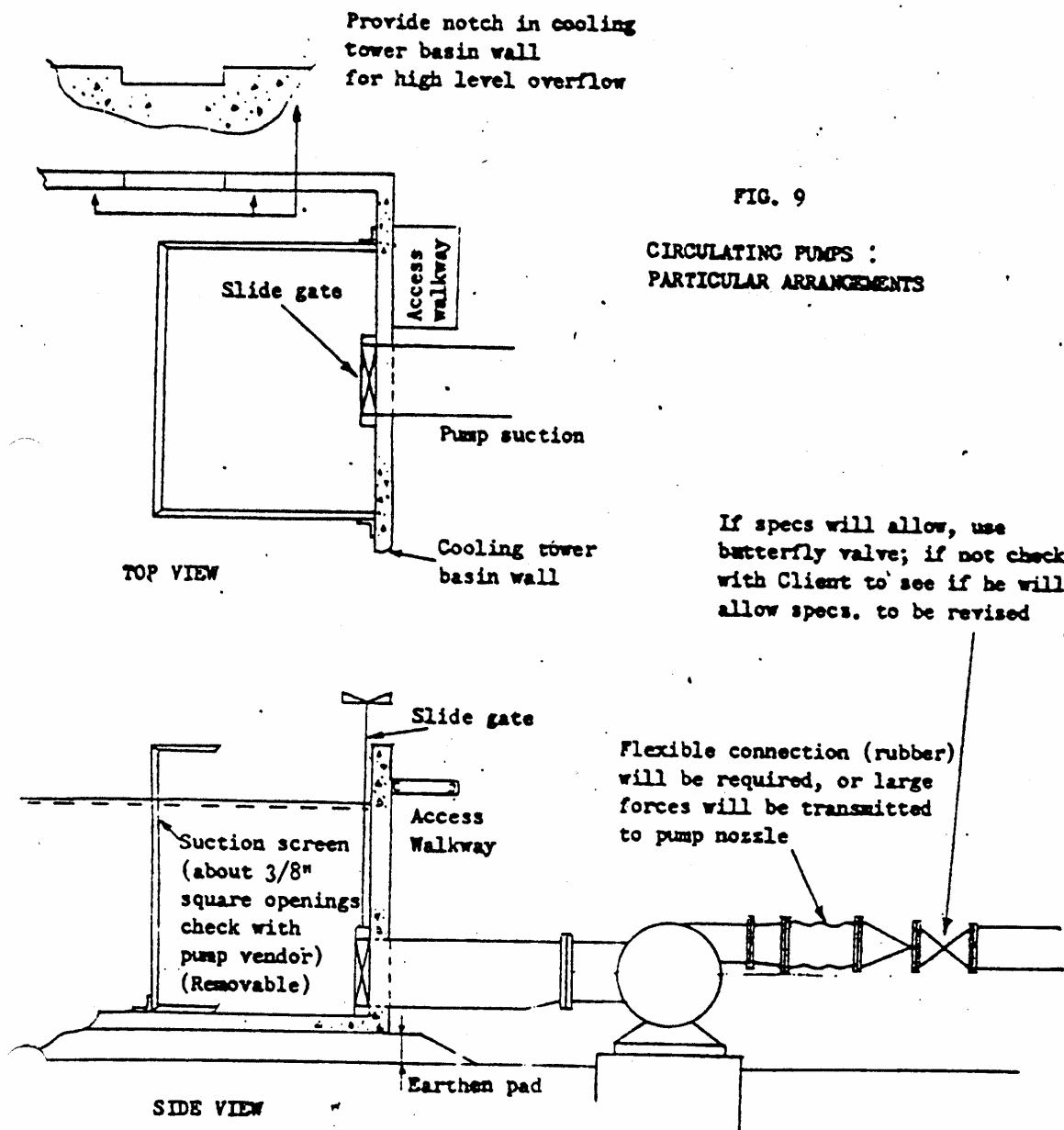
5.2.4 Corrosion Inhibitor

A dissolving drum with a portable mixer may be required for preparing the corrosion inhibitor solution if the corrosion inhibitors are supplied in solid form or concentrated liquid.

The concentration of the solution to be prepared is normally recommended by the inhibitor vendor (for example with Nalco 360, 5 to 10% solutions are used).

Corrosion inhibitor solution to be injected into the chemical trough by a proportioning pump (normally without spare). Alternatively corrosion inhibitors can be added manually in the water basin discontinuously. Another method is to provide a pot type feeder.

FIGURE 9



The injection point of the sulfuric acid is in to a trough near as possible to water inlet; the sulfuric acid pump is normally a proportioning pump, motor driven and the electric motor is controlled by a pH analyzer installed on the cooling water supply header so that the pump starts and stops depending upon pH in the circulating water.

5.2.5 Instrument and Flowsheets

The instruments usually provided for cooling towers and circulating pumps are:

LIC with low level alarm on cooling tower basin, actuating a valve on water make-up line. LIC control valve to open in case of air failure.

Unless specified by the client the level control should be set to allow approximately 2 hours make-up capacity between maximum and minimum operating levels of water in the basin.

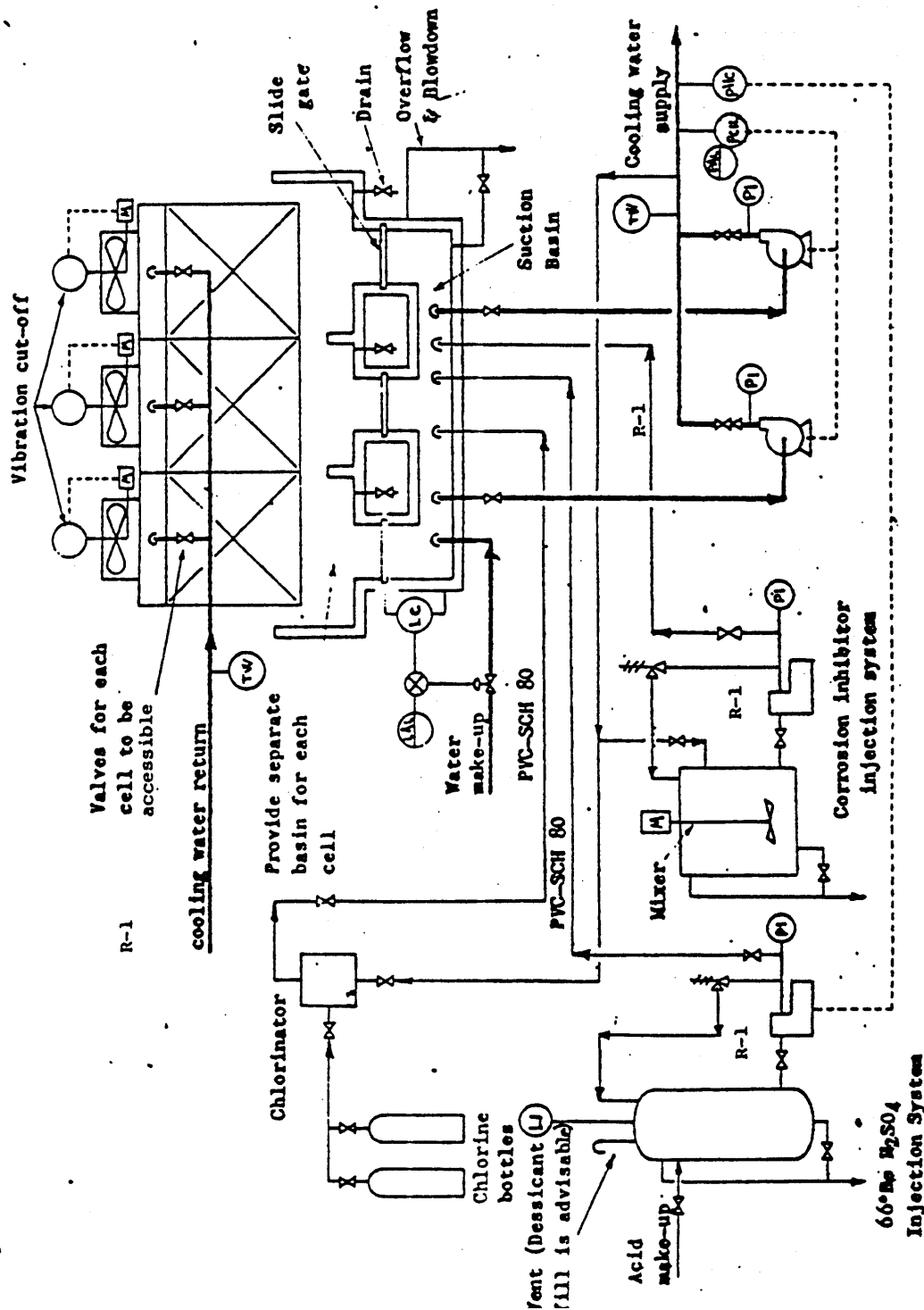
PIC with low pressure alarm on cooling water supply header with automatic cut-in devices to start the spare pump when supply pressure falls below a certain level. Time delay device to be added to automatic cut-in to avoid commissioning of spare pump in case of 8 hour time voltage dip. Electric motor of pump requires reacceleration.

pH analyzer with high and low pH alarms actuating the motor of sulfuric acid pumps.

Vibration cut-out switch with alarm to stop the electric motor of fans in case of high vibration. This switch must be provided with reset device to set its action at the desired level of vibration above normal. Vibration switch not to trip the motor at the start-up of fans. It must be noted that in case of failure of the fans with 10 minutes hold-up in the basin, it is possible to have cooling effect, by circulating water of approximately 30-40 minutes.

A typical flowsheet is shown in Figure 10.

FIG. 10 – COOLING TOWER TYPICAL FLOWSHEETS



5.3 Salt Water Cooling Tower

Thermal pollution of sea water in bay areas, caused by once-through salt water cooling system, has been receiving increasing attention. In areas where sweet water is not available for make-up, a circulating system operating on sea water can be used. A sea water cooling tower designed by Foster Wheeler and installed in 1957 at California Oil Company's Perth Amboy Refinery can be considered a pioneer application.

Analysis of sea water changes with location. Typical composition is:

Total solids	35000 ppm wt.
Na	10500 ppm wt.
K	380 ppm wt.
Ca	4000 ppm wt.
Mg	1300 ppm wt.
Cl	19000 ppm wt.
SO ₄	2700 ppm wt.
HCO ₃	1400 ppm wt.
Total Hardness	5000-7000 ppm of CaCO ₃
Temporary Hardness (1)	100-300 ppm of CaCO ₃
pH	8
Specific Gravity (20 ⁰ C)	1.025

Note (1): In sea water temporary hardness can be assumed to be equal to total alkalinity; in other words alkalinity is due practically to bicarbonates of Ca and Mg. Non-carbonate hardness = total hardness - temporary hardness is due to chlorides, sulphates, nitrates of Ca and Mg.

Prevention of scale buildup is controlled using the same technique used for sweet water. High initial concentrations of chlorides does not present problems due to the high solubility of these salts. High content of Ca and Mg instead requires the use of a fairly low number of concentration to avoid scale buildup. Sea water cooling towers are operated successfully up to 60000 ppm total dissolved solids. It has been proposed to raise this limit at far higher levels (160,000 ppm; $N = 4$) by adding meta-poly-phosphate additives, which keep scaling compounds in supersaturated condition. However, operation at these levels has not been demonstrated in industry and side effects (corrosion-fouling) are not known. To insure operability a maximum total dissolved solid of 60000 ppm is recommended.

The number of concentration for sea water cooling towers is 1.5 - 2.0

$$\frac{(60.000)}{35.000} = 1.7).$$

Make-Up rates of 6-8-10-12% and higher are not uncommon, depending on cooling range (see Figure 2).

Wet bulb temperature measured with pure water must be corrected for sea water (correction is generally $1 - 2^{\circ}\text{F}$; w.b. temperature with sea water being higher than w.b. temperature with pure water).

Design temperature approaches for sea water cooling towers are similar to the ones assumed for sweet water cooling towers; an approach of 10°F has been often assumed in the past for existing installations. Hot water temperature, returning to cooling tower, should not exceed 120°F to avoid excessive scaling.

Special consideration must be given to windage losses in case of salt water because of corrosion damage to surrounding facilities. To lower windage losses, a double drift eliminator is installed; there is a slight increase in pressure drop which causes a moderate increase in fan horsepower. Other precautions are the reduction of air velocity through the tower, and increase of stack height to obtain better dispersion (fan-stack of Rasiom cooling tower is 14 m. high). For sea water cooling tower Vendor should be requested to guarantee windage losses not to exceed 0.015 - 0.02% of circulation (0.015% was guaranteed for Rasiom cooling tower).

Selection of material is critical when sea water is processed. Impregnated redwood or cement can be used for the structure; impregnated wood or plastic material can be used for tower fill. Bolts, nuts and fastening should be high silicone bronze or 316 S.S.; fan blades and hub can be monel or fiber glass reinforced polyester or aluminum epoxy coated; water distribution system can be of carbon steel epoxy coated. Special consideration, if required, must be given to design of electrical system. Circulating pumps with 316 stainless steel impeller, Ni-resist casing, Teflon packing and monel shaft sleeve are acceptable. Drift eliminators and louvers can be cement asbestos.

Investment cost of a sea water cooling tower is higher than cost of a similar sweet water cooling tower; the difference is of the order of 25%.

Treating of circulating water is necessary to prevent fouling and scaling. Chlorine should be kept at 0.5 ppm with temporary shot injection up to 1.5 - 3 ppm to stop biological growth. It is advisable to obtain the advice of a consultant to stop algae and marine life reproduction.

Water velocity also effects biological growth; below 3 feet/sec. marine fouling becomes attached to practically any surface.

Sulfuric acid injection is required to prevent CaCO_3 scaling; pH is kept equal to 6.5 to 7.5. Saturation and stability index method (see section 4.0) can be applied to sea water systems.

All steel structures and equipment within 50 - 100 m. from cooling tower, should be adequately protected with coating.

6.0 COOLING TOWER REQUISITION

6.0.1 Intent

Design, supply all materials for delivery to site and supervise erection on prepared foundations, test and commissioning one mechanical induced draught cooling tower in accordance with the requirements of this requisition.

Manufacturer to supply also:

1. Tower outline dimensions including stairways, ladders, and location of water connections.
2. Water basin outline and loads on foundations and for all other concrete works.
3. Fill rack and drift eliminator details.
4. Tower sheathing arrangement.
5. Detailed instructions and drawings to permit field assembly by others.

6.0.2 Work by Others

The following shall be provided by others:

1. Construction of all concrete work.
2. Field assembly.
3. Tower circulating pumps and chemical treatment equipment.
4. All piping, valves and fittings to the cooling tower inlet connections.
5. All lighting.
6. All electric wiring and controls (or steam piping and controls).
7. Free use of station facilities such as power, water and sanitary facilities.

6.0.3 Quality of Materials

All materials shall be of first class quality and free from all defects, which would cause unworkmanlike appearance. All materials shall be suitable for the service under which they will operate.

6.0.4 Performance Tests

The cooling tower manufacturer shall conduct the acceptance performance test and shall supply the necessary instruments to conduct the test in accordance with the requirements of the CTI Test Procedure ATP-105, latest revision.

The manufacturer's proposal shall include performance curves of the tower, based on design fan horsepower, showing cold water temperature versus air wet bulb temperature for 90%, 100% and 110% of design water flow. The curves shall cover cooling ranges of 15°F, 20°F, 25°F, 30°F and design range.

6.0.5 Requirements - Size, Capacity and Operation

The cooling tower shall meet the following requirements:

A. Design Conditions

1. Water flow over cooling tower, USGPM
2. Inlet water temperature, °F
3. Outlet water temperature, °F
4. Wet bulb temperature, °F
5. Relative humidity, %
6. Altitude above sea-level, ft.
7. Pumping head limitations, ft.
8. Maximum drift losses

B. Physical Data

1. Maximum width, ft.
2. Maximum length, ft.

3. Maximum height, ft.
4. Location of nearby heat sources, ft.
5. Direction, and intensity of prevailing winds
6. Orientation of longitudinal axis of tower
7. Live wind load, lbs/sq. ft.
8. Earthquake load, g
9. Available power--volts/phase/cycles
Motors up to
Motors above
10. Preferred arrangement, (number of cells)

6.0.6 Cooling Tower Details - Materials and Design

A. Framework

The supporting structure will be an independent structure in reinforced concrete and so calculated as to be capable of carrying the static loads as well as the mechanical equipment. The construction will be properly reinforced and braced in order to transfer directly to the foundations all loads and trusses.

The anchor bolts will be included in the supply.

The structural frame of the tower shall be also be designed to withstand the wind pressure in any horizontal direction or earthquake loading as specified in Section II of the requisition.

B. Sheathing

The external wall shall be single wall construction (water tight design) using 3/8" flat or corrugated cement asbestos board according to CTI Standard 127 (Philip Carey Industrial AC Board, Johns-Manville Transite or equal) or glass reinforced polyester, fire-retardant opaque type.

Utility boards or similar grades of cement asbestos board are NOT acceptable. Vertical joints shall have an adequately sealed

overlap or be covered with a batten. Horizontal joints shall have an adequate overlap. Fasteners shall be of stainless steel to prevent staining. Nails shall not be used for attachments.

C. Filling

Individual fill assemblies shall be designed to be removable. Fill shall be properly supported and fastened to prevent warping or buckling under all expected operating or icing conditions.

Tower fill material to be impregnated fir, polypropylene or polyethylene and other approved plastic materials.

Manufacturer shall quote wood filling as an alternate to plastic filling.

Fill racks, used in the counter flow design shall be capable of supporting a man or 25 lb/sq. ft. live loading.

To prevent biological attack, one of the following preservatives may be selected to impregnate lumber for tower fill and other wood parts:

1. Erdalith Preservative shall be used to treat redwood lumber by the pressure treating process. The water-borne salts are, by weight, 33% copper sulfate, 56% potassium dichromate and 11% arsenic pentoxide. Lumber treatment shall be to an average retention at shipment of 0.75 pounds per cu. ft.
2. Creosote Preservative shall be used to treat redwood lumber by the pressure treating process. Lumber treatment shall be to an average retention at shipment of 10 pounds per cu. ft.

Treatment of the lumber by either of the above preservatives shall be in accordance with the American-Wood Preserver's Association Standards C1 and C2 for Pacific Coast Douglas Fir except that the lumber shall not be incised. The empty cell and full cell process shall be used for the Creosote and water-borne preservative treatments, respectively. Treatment shall be guaranteed to the extent that the average chemical retention will be as stated above.

D Distribution Systems

The distribution system shall be designed to permit flexible operation of the tower, and permit each cell to be taken out of service individually.

The nozzle shall be self draining, non-clogging type, non-ferrous material. All internal piping or header for multicells if employed shall be galvanized steel or cast iron.

Impregnated wood, glass reinforced polyester or precast concrete are acceptable materials for water basin.

E. Drift Eliminators

Eliminators shall be fabricated in easily removable panel sections and so designed to limit the drift loss to less than 0.05% of the water flow.

1. In the counter flow design, where eliminators are subject to live loads, the racks shall be capable of supporting the weight of a man or 25 lbs./sq. ft. The minimum thickness of wood slats shall be 1/2".
2. In the cross flow design, where eliminators are not subject to live loads, the minimum dimension of each board shall be 3/8".

F. Louvers

Air inlet louver boards shall be easily removable to permit access to the tower, and designed for an even air distribution into the tower. Minimum thickness of louvers boards shall be 1" nominal for wood and 3/8" nominal for corrugated asbestos cement.

Glass reinforced polyester louvers may be employed.

G. Partitions

Partition and air baffle walls shall be constructed of 1/2" net wood, or other approved material.

In multi-cell towers, the transverse internal partition walls shall extend the full height of the tower. The longitudinal partition wall in "back to back" cell arrangements shall extend from the fan deck to the elevation of the distribution system and in addition an air baffle shall be provided to at least the height of the air inlet louvers to prevent air from blowing through the louvered portion of the tower. The longitudinal partition wall in "inline" cell arrangement shall consist only of air baffle to the height of the air inlet.

H. Decks and Stacks

Fan and water distribution decks to be precast concrete designed for a live load of 60 lb. per sq. ft. plus any concentrated or distributed dead loads such as fans, motors and maintenance equipment.

Stacks shall extend to a height of at least 4 feet above the fan deck not only to provide protection for operating personnel but to properly direct the discharge air upward and away from the cooling tower.

I. Hardware

Bolts, nuts, washers and timber connectors shall be (galvanized steel) (yellow brass) (silicon bronze) (stainless steel). Anchor castings shall be cast iron unless non-ferrous fasteners are specified, then anchor castings shall be red brass. Nails shall be copper or bronze.

J. Mechanical Equipment

1. Fans shall be of a design that has operated satisfactory in cooling tower service for at least five years. The fans shall have a minimum of four (4) blades of aluminum alloy, stainless steel, monel or equal. Blades shall be adjustable for degree of pitch and shall be individually fastened to a hub of welded steel or cast iron (stainless steel optional at extra cost).
2. Gear Reducers shall be of the spiral bevel type or equal. The speed reducers shall be especially designed for cooling tower service and rated in accordance with the standard practices of the American Gear Manufacturers Association. A service factor of at least 2.0 shall be applied to the basic AGMA rating to correspond to continuous moderate shock operation. Gears must conform to cooling tower Institute Standard STD-III, latest revision.
3. Motors shall be squirrel cage induction type with (totally enclosed fan cooled) (encapsulated) (splash proof) enclosure and roller type bearings with NEMA Class A insulation.

Motors shall be (single speed) (two speed, one winding, variable torque) and power (voltage, phase and cycles available).
4. Turbines shall be suitable - guaranteed for continuous duty at the conditions of service specified by the purchaser. Turbines shall also be suitable and guaranteed for outdoor installation in cooling tower service. Materials of construction shall be manufacturer's standard for the service conditions specified. Turbines accessories shall include a mechanical flyweight constant speed governor, emergency overspeed governor operating separate trip valve, a hand speed changer, a corrosion resistant steam strainer, and a sentinel casing warning valve. All turbine pressure parts shall be hydrotested to 1-1/2 times the manufacturer's design pressure. Turbine rotor shall be statically and dynamically balanced.

5. Flexible Coupled Shaft shall be provided to connect each motor and speed reducer assembly. The coupling flanges shall be (zinc plated steel) (stainless steel) of the non-lubricated type with stainless steel flexing disc rings. The shaft shall be hollow tube (stainless steel) (zinc plated steel) of a sufficient size to adequately transmit the full rated motor horsepower. The shaft and coupling assembly shall be dynamically balanced.
6. Vibration Cut-Out Switches shall be supplied and installed outside the fan ring for wiring by the purchaser to the motor energizing circuit.
7. Mechanical Equipment Supports of galvanized structural steel shall be supplied to properly mount the fan, gear and motor assemblies. Each framework shall form an integral unit and be laterally supported by galvanized steel members bolted to the tower posts.

K. Access

A sufficient number of access doors, ladders and walkways shall be provided for safe and easy accessibility to internals and mechanical equipment of the tower for inspection and maintenance.

Access doors shall be tight, water resistant and easy to operate. Access ladders from the ground to be located in such a position to permit future cell addition.

GUARANTEE

Performance:

The cooling tower must be guaranteed to perform as specified herein when tested in accordance with the Cooling Tower Institute Acceptance Test procedure ATP-105, latest revision. Should the apparatus fail to meet the specified conditions after fair test run immediately following a thorough cleaning, and made in the presence of the manufacturer's representatives, the manufacturer must make such alterations, or furnish such additional equipment as may be necessary to meet these specifications free of cost to the user. The scope of services and equipment supplied as guarantee remedy are limited in kind to the services and equipment supplied under the contract.

The equipment shall be considered as accepted if tests shown that the guarantees have been fulfilled, or if no test is performed, within one (1) year after completion of erection.

Materials:

The manufacturer shall repair or replace without charge, any material which, within one (1) year from date of delivery, is proven defective in materials or workmanship, provided, however, that the purchaser shall have given the manufacturer written notice of such defect and that such defects are exclusive of corrosion, erosion and normal wear, and provided the equipment has been operated in accordance with generally approved practice.

DATE REQUIRED WITH BIDSA. Cooling Tower

1. Number of Cells
2. Cell dimensions, ft. – ins.
3. Tower length, ft. – ins.
4. Tower width, ft. – ins.
5. Tower height, ft. – ins.
6. Casing, material and dimensions
7. Structure, material and dimensions
8. Fill decks, material and dimensions
9. Partitions and baffles, materials and dimensions
10. Drift eliminators, material and dimensions
11. Fan stacks, material and dimensions
12. Fan deck, material and dimensions
13. Louvers, material and dimensions
14. Board feet or fill
15. Board feet total tower
16. Height of fan stacks, ft. – ins.
17. Post extension below curb, ft. – ins.
18. Total shipping weight, lbs.
19. Total operating weight, lbs.

B. Fans

1. Number of Units
2. Type and manufacturer
3. Diameter, ft. – ins.
4. Number of blades per fan
5. Blade Material
6. Hub Material
7. R. P. M.
8. Tip speed, F. P. M.
9. Mechanical efficiency, %
10. Static efficiency, %
11. Weight, lbs.

C. Motors

1. Number of Units
2. Size, H. P.
3. Type and manufacturer
4. Full load speed, R. P. M.
5. Frame Size
6. Full load current, amps.
7. Locked rotor current amps.
8. Weight, lbs.

D. Turbines

1. Number of Units
2. Size, H.P.
3. Type and manufacturer
4. Full load speed, R. P. M.
5. Steam rate # B.HP./Hr.
6. Maximum horsepower renozzled
7. Weight, lbs.

E. Gear Reducers

1. Number of Units
2. Type and manufacturer
3. Rating, H.P.A.
4. Shafts, material
5. Coupling Flanges, Material
6. Flexing Elements, Material

F. Drive Shafts and Couplings

1. Number of Units
2. Type and manufacturer
3. Rating, H.P.A.
4. Shafts, material
5. Coupling Flanges, Material
6. Flexing Elements, Material

G. Miscellaneous Equipment

1. Mechanical equipment supports, material
2. Vibration cut-out switches, included
3. Derrick for handling mechanical equipment, included

H. Distribution System

1. Number and size of inlet flanges
2. Height of water inlet above curb, ft. - ins.
3. Header material
4. Lateral material
5. Nozzle, or downspout material

I. Design Performance

1. Pumping head from top of basin curb, ft.
2. Spray loss, max. %
3. Evaporation loss, max. %
4. Fill wetted surface, sq. ft.
5. Total wetted surface, sq. ft.
6. Effective splash surface, sq. ft.
7. Effective cooling volume, cu. ft.
(from eliminators to water level)
8. Air volume per fan, CFM
9. Static pressure, inches of water
10. Output horsepower/motor/(turbine)
11. Tower loading, GPM/sq.ft.

J. Drawings and Performance Curve

1. Tower outline elevation
2. Foundation outline
3. Fill rack details
4. Drift eliminator details
5. Tower sheathing arrangement
6. A series of guaranteed performance curves within limits of CTI Test Procedure ATP-105, latest revision.

6. Test Procedure (CTI Bulletin ATP-105)

1. Scope and Purpose

1.1 Scope. This acceptance test procedure shall cover the determination of the water cooling capability of mechanical draft water-cooling towers.

1.2 Purpose. The purpose of this test procedure is to prescribe uniform methods and instrumentation for all conditions and measurements involved in determining tower cooling performance.

1.3 Flexibility. It is recognized that the data limitations specified throughout this test procedure represent ideal conditions which are frequently not available at the time the test is performed. In such cases actual conditions may be used providing written consent is obtained from the official representatives of the manufacturer, the purchaser and the CTI present at the time.

1.4 Other Uses. This test procedure may also be used for the certification of lines of towers in accordance with CTI Bulletin STD-201, in which case references to the "purchaser" are not applicable.

1.5 Impartial Testing Service. The CTI Observer referred to in this standard consists of a technically qualified representative of a nationally-known research institute and has no connection (other than a contractual agreement) with the Cooling Tower Institute nor with any of its members. It is thus a completely impartial party to the test.

2. Conditions of Test

2.1 Conduct of Test. Test shall be conducted by accredited representatives of the manufacturer and/or the purchaser, in the presence of an authorized CTI Observer. If the test has to do with a performance guarantee, it is desirable for representatives of both the manufacturer and the purchaser to be present at the time the test is performed. In such cases the manufacturer has the right to inspect the tower in advance and ready it for the test. Such representatives shall have the freedom to witness all phases of the test data collection. In no case shall any directly interested

party be barred from the test site. Test shall be conducted with CTI equipment or CTI-approved equal. Test shall be conducted within 12 months following structural completion of tower.

2.2 Condition of Equipment. At the time of test the equipment shall be in good operating condition with particular attention to the following:

- a) Water distribution system shall be clear and free of foreign materials which may clog or impede the normal water flow.
- b) Mechanical equipment shall be in good working order, with fans adjusted for proper rotation and specified horsepower loading.
- c) Drift eliminators shall be clear and free of algae and other deposits which may impede normal air flow.
- d) Filling shall be free of foreign materials such as oil, tar, scale or algae.
- e) Water level in cold water basin shall be at normal operating elevation and shall be maintained substantially constant during the test.

2.3 Operating Conditions. The test shall be conducted within the following limitations:

2.31 The wet bulb temperature shall be the inlet wet bulb temperature measured in accordance with Paragraph 3.3 of this test procedure.

2.32 The average wind velocity shall not exceed 10 miles per hour, with one-minute recordings not to exceed 15 miles per hour. The wind velocity shall be measured in accordance with Paragraph 3.4 of this test procedure.

2.33 The following variations from design conditions shall be permissible:

2.331 Wet bulb temperature not more than 3°F above or 7°F below design wet bulb temperature.

2.332 Heat load not more than 20 percent below or 20 percent above design. These are the governing limits for variations from design conditions. In the event one or more cells are shutdown, as provided in Paragraph 2.334 below, this limitation shall apply to those cells in operation.*

2.333 Range not more than 20 percent below or 20 percent above design.

2.334 Circulating water flow not more than 10 percent above or 10 percent below the design circulating water flow. In the case of a multi-cell tower it shall be permissible to shut down one or more cells if the foregoing total tower circulating water flow requirement cannot be met, providing the circulating water flow to each operating cell is within the above limits.

2.34 The water shall be distributed to all operating cells and/or parts of the tower as recommended by the manufacturer.

2.35 The circulating water shall contain not more than 5000 parts per million of total dissolved solids as determined by evaporation, and not more than 10 ppm of oil, tar or fatty substances, unless specifically agreed otherwise between purchaser and manufacturer.

2.4 Constancy of Test Conditions. During a test the variations of the set conditions on which the test is based shall be held within the following limits:

2.41 Circulating water flow shall not vary by more than 5 percent.

2.42 Heat load shall not vary by more than 5 percent.

2.43 Range shall not vary by more than 5 percent.

* For the purposes of this Acceptance Test Procedure, a "cell" is defined as the smallest subdivision of the tower, bounded by exterior walls and partition walls, which can function as one independent unit as air and water flow. Each cell may have one or more fans or stacks and one or more distribution systems.

2.44 Instantaneous readings of wet bulb temperatures may fluctuate, but the rate of change in the average wet bulb temperature shall not exceed 2°F per hour.

2.5 Duration of Test and Readings. After reaching steady-state conditions, the duration of the test shall be one hour. Readings shall be taken at regular intervals as follows, with ft, gpm, hp and mph reported to nearest integer, and temperatures reported in nearest 0.1°F;

Measurements	Number each hour	Unit
Wet bulb temperature	6*	°F
Cold water temperature	6	°F
Hot water temperature	6	°F
Circulating water flow	3**	gpm
Tower pumping head	3	ft
Fan driver power input	1	hp
Wind velocity	6*mpg	
Make-up temperature	2	°F
Make-up flow	2	gpm
Blow-down temperature	2	°F
Blow-down flow	2	gpm

* or recording

** single center point readings for comparison with full traverse readings before and after test (when measurement is made by pitot tube)

3. Instruments and Measurements

All instruments used shall be furnished by CTI or approved by CTI. All instruments shall be calibrated before test. All measurements shall be made in the manner provided in this Section 3.

3.1 Water Flow measurements

3.11 Water flow measurements may be made by any of the following means:

Pitot tube traverse
Orifice plate
Weir
Venturi meter
Volumetric or bulk

The procedure for using any of the above methods shall be as specified in the "Supplements on Instruments and Apparatus, Part 5, Chapter 4 (latest revision) or Power Test Code on Hydraulic Prime Movers(latest revision) as published by the ASME.

Any other CTI-approved methods of direct measurement may be used. The accuracy of any of the above methods shall be presumed to be within plus or minus 1.25 percent. The selection of method and location of measurement will be dependent upon the nature of the installation to be tested.

3.12 The following water quantities shall be measured:

- 1) Circulating water flow to the tower
- 2) Make-up water flow
- 3) Blow-down flow

3.13 If circulating water flow to the tower is measured by pitot traverse, two full readings should be made, one immediately preceding the test and one immediately following the test, in addition to the three center point readings taken during the test.

3.2 Water Temperature Measurements. Water temperature measurements shall be made by any of the methods prescribed in the "Supplements on Instruments and Apparatus" (latest revision) as published by the ASME, such as resistance thermometers or mercury-in-glass

thermometers. Instruments shall be designed to indicate or record in 0.2°F graduations. Temperature sensitive elements shall be carefully located where the water will be thoroughly mixed.

3.21 Hot circulating water temperature measurements shall be made in the tower riser or in a multi-cell tower, in the supply header just ahead of the first riser. Where various streams of different temperatures combine, complete mixing must be assured at the point of temperature measurement.

3.22 Cold circulating water temperature measurement should preferably be made at the circulating pump discharge, taking into account the temperature that is due to energy losses. Where circulating water is discharged from the tower basin through an open channel, the weighted average cold water temperature must be determined by a traverse of a selected section.

3.23 Make-up water temperature measurement shall be made at the point make-up water enters the system.

3.24 Blow-down temperature measurement shall be made at the point blow-down leaves the system.

3.3 Inlet Wet Bulb Temperature Measurement

3.31 The inlet wet bulb temperature shall be measured with mechanically aspirated psychrometers. The instruments shall be designed to indicate or record in graduations not exceeding 0.25°F. Temperature sensitive elements shall be so shielded as to "see" only surfaces which are substantially at the dry bulb temperature and to eliminate exposure to direct rays of the sun or other extraneous sources of radiant heat. The air velocity across the temperature sensitive elements shall be constant between 950 and 1050 fpm. The wicks shall be clean and shall be continuously supplied with distilled water at

approximately the wet bulb temperature to be measured.

3.32 For measurement of inlet wet bulb temperature, the psychrometers shall be located approximately 5 feet above basin curb elevation, within 4 feet of air intakes and at 3 equally spaced stations along each air intake side of the tower.

3.33 The average of 3 successive readings taken at 10-second intervals at each station shall be considered the wet bulb temperature at that time at that instrument station. The station averages shall be averaged to obtain the effective wet bulb temperature for that run. The arithmetic average of 6 such runs over the one-hour period of the test shall be considered the inlet wet bulb temperature and shall be used for the evaluation of results.

3.4 Wind Velocity. Wind velocity measurement shall be made with an anemometer of the rotation setup type. Measurement shall be made in an open and unobstructed location in the vicinity of and to windward of the tower at a point 5 feet above the basin curb elevation.

3.5 Tower Pumping Head. Tower pumping head shall be the sum of the total pressure above atmosphere (expressed in feet of water) at the centerline of the tower inlet and the vertical distance (measured in feet) of the center of the inlet above the basin curb.

3.6 Fan Driver Power. Power shall be determined as power input to the motor or driver. In the case of electrical motors, power input shall be determined by measurement of the voltage, current and power factor, or by direct measurement of the kilowatt input. Where guarantee is tied to driver output, efficiencies as given by the manufacturer of the driver may be used.

3.7 Water Analysis. A sample of the circulating water shall be taken during the test. If there is any question concerning the condition of the circulating water, the sample shall be analyzed by a recognized testing laboratory to determine conformance with paragraph 2.35 of this test procedure.

4. Report of Results

4.1 The report of the results of the test should, in addition to the data required by this test procedure, include a description of the cooling tower with its principal dimensions and orientations, and a sketch of the installation showing the location of points where water flow, temperature, and other required measurements were taken. Notation should be made of any buildings, obstructions or other equipment immediately in the vicinity of the tower tested. Notation should also be made of other equipment or facilities discharging heat or vapor in the immediate vicinity.

4.2 The test observations shall be entered on CTI form ATP-106 (or equal), prepared in triplicate, which shall constitute original log sheets to be authenticated by the signatures of the respective representatives of the purchaser and the manufacturer, and the designated CTI Observer. Upon completion of the test one copy becomes the property of the purchaser, one copy becomes the property of the manufacturer and the original sheet becomes the property of the Cooling Tower Institute independent testing service. (see 1.5).

4.3 A single summary sheet listing all important data and tower performance shall be prepared by the CTI Observer and mailed to the purchaser and the manufacturer within ten days following the test.

4.4 Information on any test will be available only to the purchaser, the manufacturer and the CTI Observer (an independent testing laboratory or research institute). Such information will not be available to CTI members.