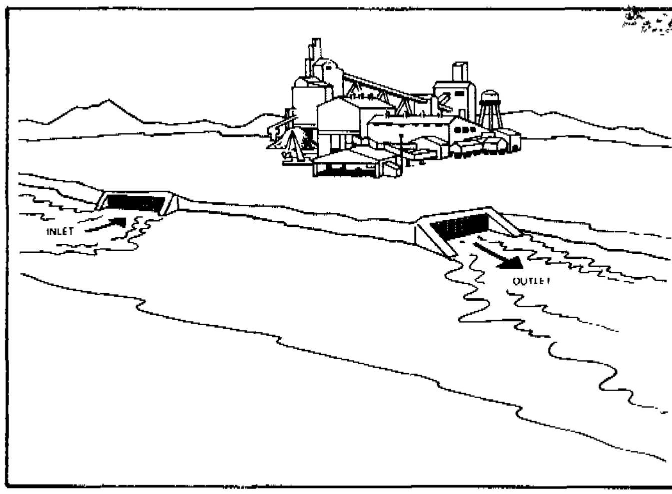
Once-Through Systems

Industry uses large amounts of water to remove heat from process streams. Initially plants were built near rivers so large volumes of water could be taken from the river, circulated through the process systems to remove the heat from the plant and then discharged to the river at a point further downstream. These types of systems are called **once-through cooling systems.** The river water passes through the units only once and is discharged to the river, expelling the heat taken from the process systems.

These types of systems are still extensively used in the power generation industry. However, due to environmental regulations and the desire to control thermal pollution, these types of systems are not as widely used as in the past.



Once-through cooling system.

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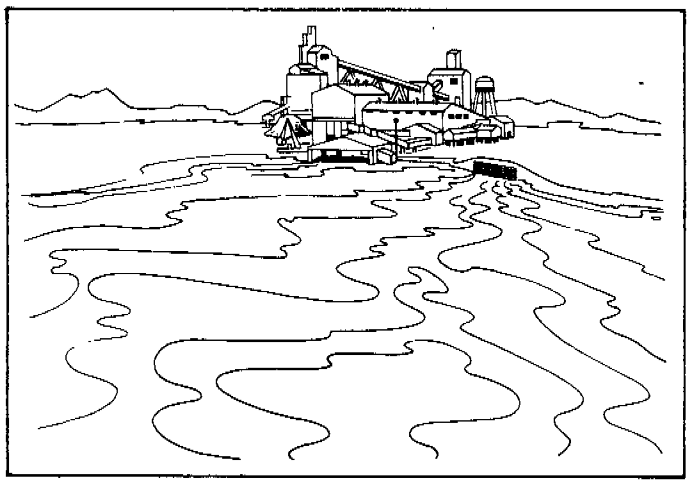
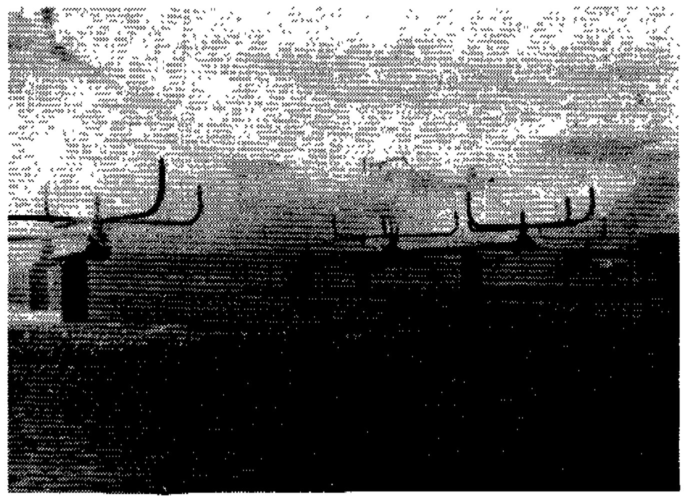
When flowing water from sources such as streams and rivers is not readily available, cold water can be taken from ponds or lakes, circulated through the process systems and returned to a pond or lake as hot discharge. Convection and conduction disperse the heat throughout the body of water and evaporation at the surface cools the water.

To provide sufficient conduction, convection and evaporation to cool the water, the volume of water within the pond or lake must be quite large, compared to the volume of water used in the process.

In order to provide more efficient cooling, air must be intimately mixed with water so that evaporation can take place to cool the water.



Pond Systems.



Spray ponds increase the evaporation rate and reduce the volume of water needed for the cooling process.

The introduction of sprays within the pond increases the surface area of the water exposed to air by breaking the water into small droplets. This increases the evaporation rate and boosts the amount of cooling and therefore substantially reduces the required volume of water compared to a pond without sprays. **Spray ponds** depend on air passing over the pond to bring dry air in contact with the water droplets. Water carried away by the air called **DRIFT** can become a significant problem. To control drift a fence can be put up around the spray pond. This is effective, but often reduces the efficiency of the spray pond by trapping humid air over the pond surface and lessening the driving force of evaporation.

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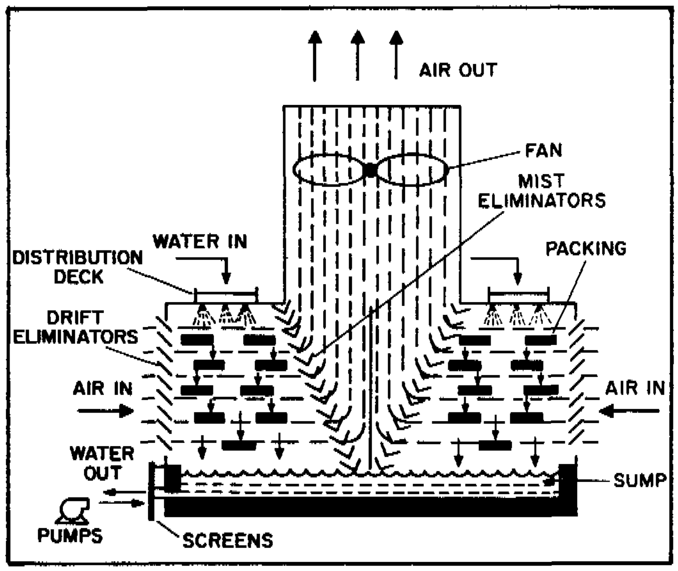
Cooling systems are designed primarily for one function, that is, to remove heat from the process systems.

Heat removal can be accomplished in a number of ways. Once-through water systems have been used for many years where sufficient water supply is available. Spray ponds or lakes can provide cooling for processes, but require substantial surface area for convection and surface evaporation to remove enough heat. **Cooling towers** on the other hand require substantially less space and have higher efficiency.

Cooling towers such as atmospheric towers, induced draft towers, forced-draft towers, natural-draft towers all have a number of parts in common. Refer to the figure as a guide as we review the following:



Parts of a typical cooling tower.

Sump: The cooling tower sump is the collection basin from where water is drawn and circulated to the system.

Screens: Cooling tower screens are designed to prevent large debris from going through the pump suction and circulating through the system and potentially reducing heat exchange.

Pumps: The circulating water pumps move the water through the system, where heat is removed from the process, and return the water to the tower.

Tower Distribution System: Tower distribution is accomplished through nozzles, sprays or a distribution deck.

Tower Fill: Tower fill is made up of splash bars which break up the water particles within the tower so intimate air and water contact is accomplished.

Mist Eliminators: Mist eliminators are used to reduce the amount of water lost due to entrainment in the humid hot air leaving the tower.

Drift Eliminators: Drift eliminators control the water droplets from blowing out of the tower due to air movement within the tower.

Details of tower operation and design will be covered in the continuing sections.

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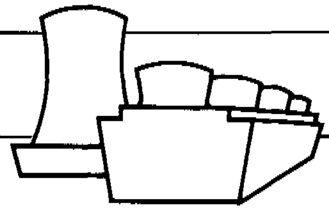
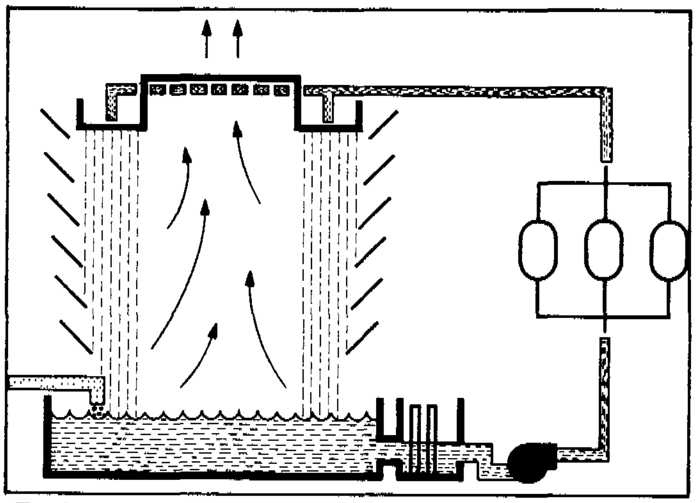


To optimize cooling efficiency, water must be broken into the smallest size possible in order to increase the surface area exposed to air. Cooling towers, by their design, break water droplets into small particles multiplying the amount of water surface in contact with the air. This increases evaporation and improves the cooling process.



Typical atmospheric towers are affected by wind and humidity.

In the **atmospheric tower,** water is sprayed through nozzles at the top of the tower. The water cascades down through a series of splash bars, called **fill,** which break up the water into small droplets. Air passing through the tower contacts the water droplet, resulting in evaporation and the cooling process. Louvers along the sides of the tower allow air to pass into the system, but limit the unwanted carry-off of water droplets called **drift.**

As water evaporates, a hot air draft rises out of the tower. This hot air draft can carry water droplets out of the top of the tower, creating additional water loss. Mist eliminators are added at the top of the tower to catch entrained water and drop the water particles back into the system.

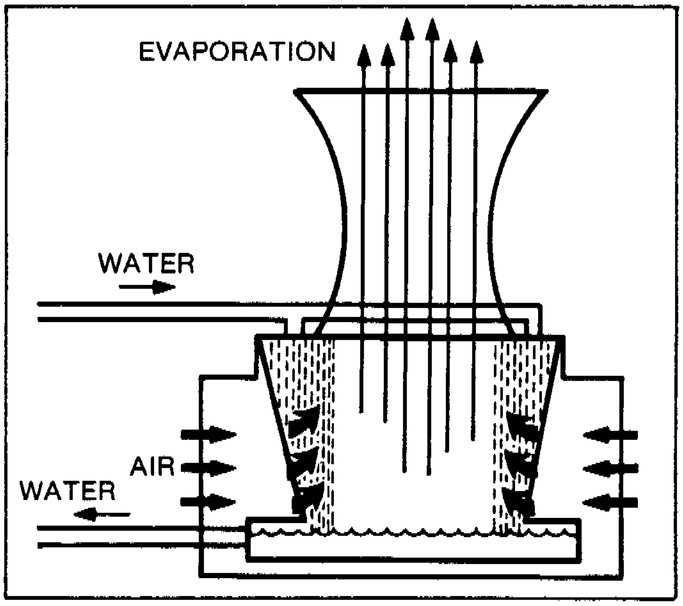
In every cooling tower system there will be some drift and water losses. These kinds of losses add to total tower blowdown and affect the number of cycles. We will cover blowdown and cycles in more detail later in the program.

As you can easily see, towers of this kind depend on two atmospheric conditions, wind and humidity. This is why they are termed atmospheric towers.

In the **natural draft tower,** water heats the air inside and causes it to rise in the tower. As the warm, less dense air rises, it reduces the pressure at the bottom of the tower, drawing cool drier air through the air inlets at the base of the tower. This air is then warmed and rises, as in a chimney, drawing the air through the water and enhancing evaporation.

In a natural draft tower, as in most tower designs, water is sprayed across the area of the tower. The height of the tower reduces the potential for water loss due to entrainment and allows the counterflow of air through the water to effectively remove heat as the water falls to the basin.

Natural draft tower efficiency depends on the temperature difference between the hot humid air within the tower and the cool drier air outside the tower. The smaller this difference, the less the driving force and the less the efficiency of the operation within the tower. So, humidity and temperature play a major factor in the performance of a natural draft tower.

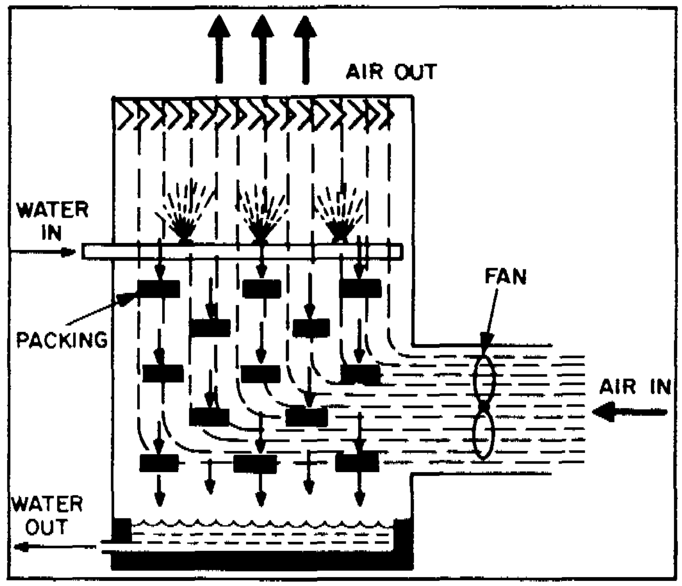


Natural draft towers.

Cooling towers which use fans are called **mechanical draft towers.** As can be seen in the drawing, air is forced through the side of the tower counterflow to the water, intimately mixing the water and the air, thereby causing evaporation. This type of tower is called a **forced draft tower.** Air is forced through the tower by the fans.

Forced draft towers have a water distribution system, fill, and mist eliminators as have been described in tower design.

To maintain the counterflow of air in a forced draft tower, the sides are enclosed. The fans are equipped with variable speed drives and blades are pitched to control the volume of air which passes through the tower.



Forced draft towers are mechanical draft systems which use fans to force air in the side of the tower and out the top.

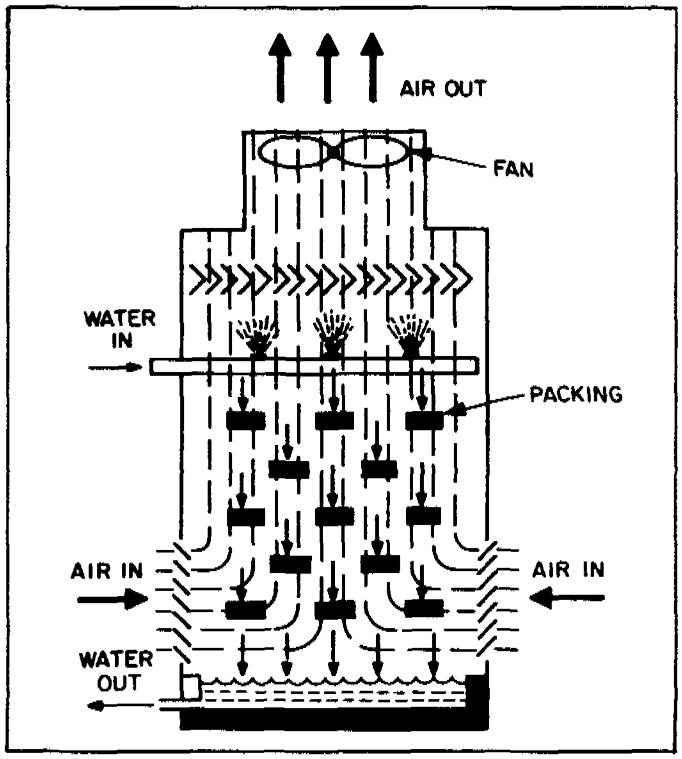
COOLING WATER SYSTEMS

Induced Draft Tower

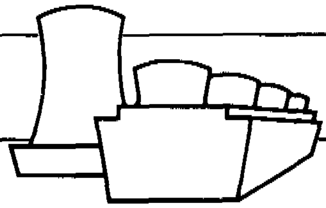
In *mechanical draft towers air is forced to mix* with the water flowing through the cooling tower by fans. In the **induced draft cooling tower** air is drawn up the tower with a fan located at the top, pulling the moist warm air out of the tower. This reduces the pressure in the tower and draws cool dry air through the sides of the tower producing a crossflow of air through the water allowing for evaporation.

Cooling within induced draft towers can be controlled by fan speed and/or blade pitch.

Some induced draft towers are designed for counterflow operation. These draw air in at the bottom and, as can be seen in the drawing, are constructed to provide for air flow counter-current to the water dropping to the basin.



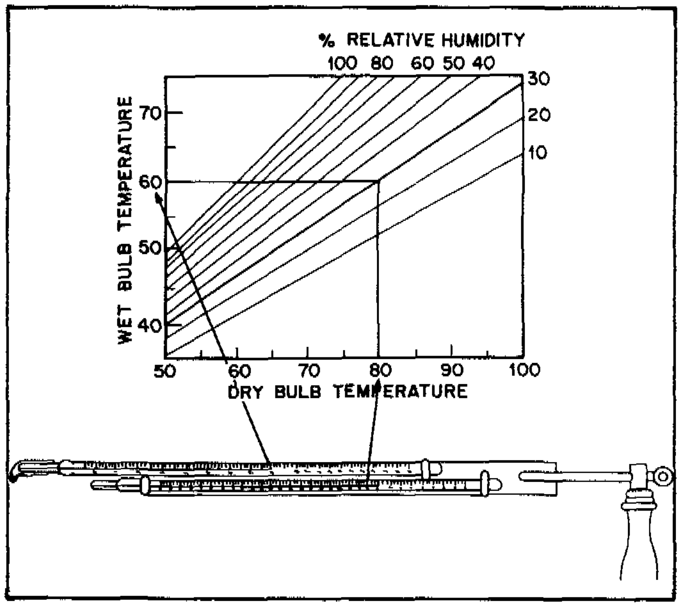
Induced draft towers use fans at the top of the tower to pull moist, warm air out.



Cooling tower efficiency depends largely on the relative humidity within the area of the cooling tower. As has been discussed, evaporation plays a major role in the cooling efficiency of the cooling tower system. If the relative humidity is high, the evaporation rate is reduced because the driving force for evaporation is not as great as if drier air were available to absorb more moisture from the system.

The measure of this driving force is called the **tower approach.** With the use of a sling psychrometer, the wet bulb temperature can be determined. This difference between the dry bulb and wet bulb temperature can be used to determine the relative humidity and in turn a representation of the driving force for evaporation.

The cooling tower, with water being intimately mixed with air causing evaporation, is similar to the wet bulb situation in the psychrometer. The closer the tower water basin temperature approaches the wet bulb temperature, the more efficient the tower. The difference of the two is called the tower approach.



The tower approach can be determined using a sling psychrometer, which shows the difference between the dry bulb and wet bulb temperatures.

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Evaporation, Cycles And Blowdown

Evaporation, as it takes place in the cooling tower system, is the prime source of heat removal. But, as evaporation takes place, solids remain in the bulk water system while pure water is carried off with the heat escaping to the atmosphere. As solids concentrate in the system and water is removed, additional water must be added to the system through **makeup.** Makeup brings additional solids to the system, continuing the cycle and increasing the total dissolved solids in the bulk water system. Each time we increase the total amount of solids equal to the amount of solids in the makeup water we indicate this as a **cycle of concentration** within the tower.

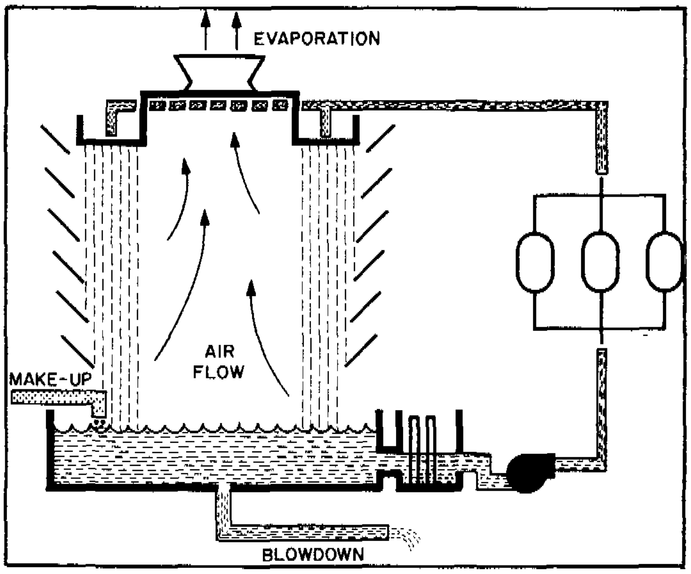
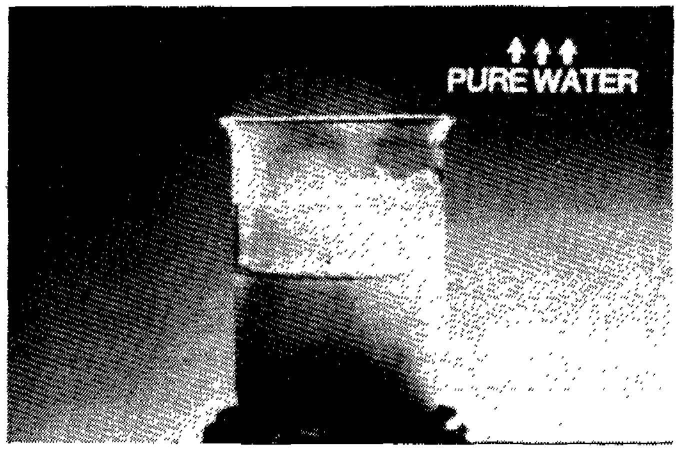


Diagram of basic cooling tower system.

For example, if the makeup water has a hardness of 100 ppm and the cooling tower bulk water has a hardness of 200 ppm, we say that the tower has cycled twice. If in this same water, the tower water has a hardness of 400 ppm, we say the tower has cycled four times. You can see that if allowed to continue, the tower would cycle until the water could no longer handle the dissolved solids and materials would drop out, usually in the hot exchange systems, reducing heat transfer and creating problems in the operation of the plant.

To control the concentrations of total dissolved solids in the bulk water system, we must remove some of the water containing the high concentration of solids. This constitutes system blowdown. **Blowdown** is the removal of any water from the system whether it be intentional through the use of opening a valve or unintentional as through the loss of water in pump glands or drift. Any loss of water reduces the total dissolved solids and consequently reduces the number of cycles the tower is experiencing. Blowdown is monitored and controlled based on the number of cycles desired in the cooling tower system.



This beaker demonstrates the effect of evaporation on solids concentration.

To review, evaporation is the removal of heat through the changing of water from liquid to vapor. Cycling is the number of times we concentrate the bulk water in the cooling water systems compared to the makeup water. Blowdown controls the number of cycles (the concentration of the dissolved solids) in the cooling tower system.

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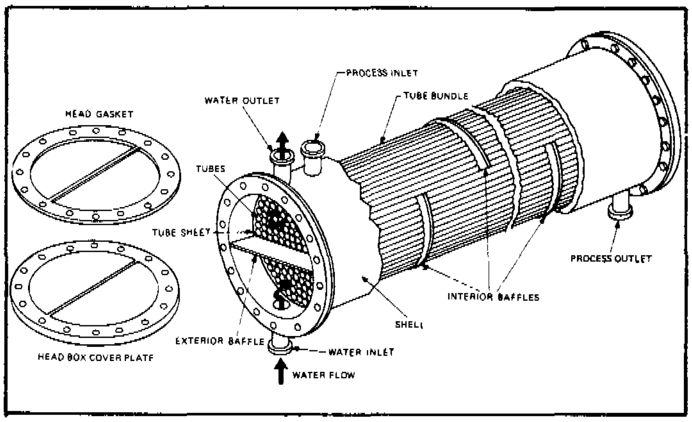
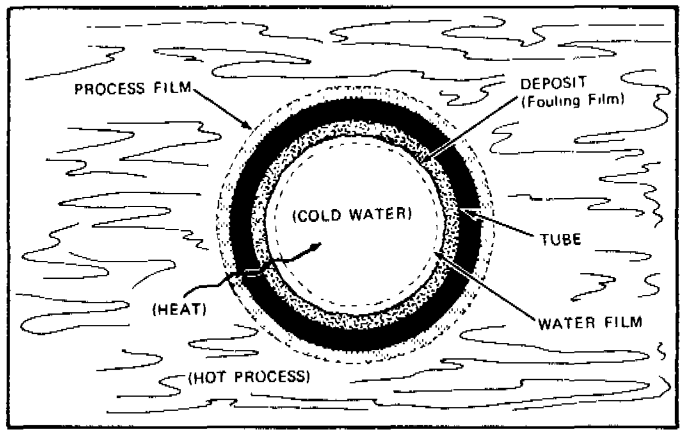
Heat exchangers in the cooling water system come in a variety of sizes and shapes. The workhorse of industry is the **shell and tube heat exchanger.** The most common design is the **two-pass exchanger** with water on the tube-side and the hot process stream on the



Typical two-pass heat exchanger with water on tube-side.

shell-side. As can be seen in the drawing, water flows in the inlet at the bottom of the exchanger to an area called the channel head. Water is distributed evenly to all the tubes, flowing the length of the exchanger into another head generally called the floating head; the water is then allowed to return through the remaining tubes back to the channel head and out the top of the exchanger. Consequently, the water makes two passes through the bundle, drawing heat from the process side, thus giving the exchanger its name—a two-pass exchanger.

In some applications water is circulated to the shell-side of the exchanger and process flows through the tubes. In these types of exchangers, water flow rates



The total resistance to heat flow is the sum of several individual resistances.

through the exchangers become extremely important since low flow areas on the shell side can cause deposition of suspended solids and contribute to the three basic enemies: corrosion, scale, and fouling.

Heat transfer takes place because of the difference in temperatures between the process and the cooling water. Heat is passed from the process fluid through the metal walls of the tubes and to the water being circulated through the system. The heat is then rejected in the cooling tower through evaporation. It should be noted that the coolest water generally is designed to see the hottest process stream in the exchanger.

Operational problems experienced in the exchangers are often a result of drastic changes in water or process fluid flow rates through the exchanger and deviations from design load. If these parameters change substantially, exchanger efficiency can be greatly reduced.

COOLING WATER SYSTEMS

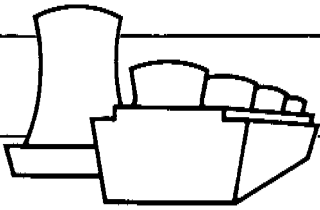
Tower Operation

In cooling tower operations, most cooling water problems are caused by neglect after startup. Poor or diminished tower performance can reduce cooling efficiency in the heat exchangers, resulting in needless expense. A preventive maintenance schedule should be outlined and implemented for key tower components. Such schedules are usually provided by tower manufacturers and include weekly, monthly and seasonal checklists. Screens, pumps, decks, and sump all require inspection and maintenance throughout the year.

The four major factors which influence the efficiency of the cooling tower are:
1) water flow rate,
2) air flow rate,
3) air-to-water distribution ratio, and
4) heat load.

Any water flow rate changes have a direct, but inverse, effect on air flow rates. Increasing the water flow rate over the tower will decrease the air flow, resulting in increased sump temperature. If air-to-water distribution is changed substantially, tower efficiency will also change.

A preventive maintenance program will help cooling systems operate efficiently.



COOLING WATER SYSTEMS

Review Questions

1. Water taken from a source, passed through heat exchange equipment and returned to the source or to discharge is generally referred to as a ________ ________ system.

2. Cooling towers are designed to accomplish one primary function. This function is the removal of heat from the process system. The cooling tower sump is the collection basin from where water is drawn and circulated to the cooling tower system.

3. The tower fill breaks up the water particles in the tower so water and air contact can be accomplished.

4. In atmospheric towers water is distributed and falls through the fill. temp and humidity are the atmospheric conditions which greatly affect this kind of tower's efficiency.

5. Natural draft towers employ the ________ effect to create a reduced pressure at the bottom of the tower to draw cool air in.

6. Forced draft towers ________ air through the tower where induced draft towers ________ air through the tower.

7. To determine the tower approach, subtract the wet bulb temperature from the cooling tower sump temperature.

8. If the ambient air temperature is 80°F and the wet bulb temperature is 60°F, the relative humidity is 20%.

9. Evaporation is the primary means of heat removal from the cooling tower system to the atmosphere.

10. To reduce the total dissolved solids created in the bulk water system due to evaporation, blowdown is required.

11. In a shell-side exchanger, velocity becomes critically important to control deposition due to suspended solids.

12. Four major factors which influence the approach and the efficiency of a cooling tower operation are:

(1) Water flow rate.

(2) Air flow rate.

(3) Air to water distribution ratio, and

(4) heat load.

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Cooling Water Impurities

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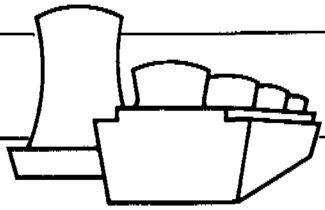

COOLING WATER IMPURITIES

Introduction

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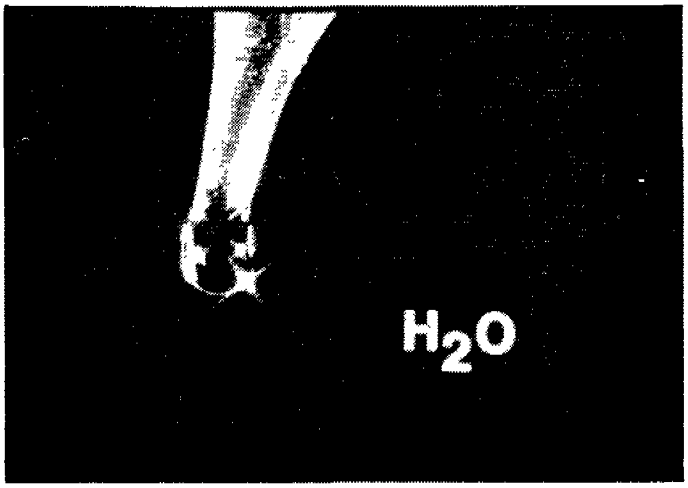
Pure water is colorless, tasteless and odorless. Its chemical formula is H_2O, which shows it is made up of two parts hydrogen and one part oxygen. In industrial cooling water, we rarely find absolutely pure water because one of the unique properties of water is its ability to dissolve, to some degree, almost anything with which it comes in contact on the earth's surface. Because of this unique property, it is often called the universal solvent.

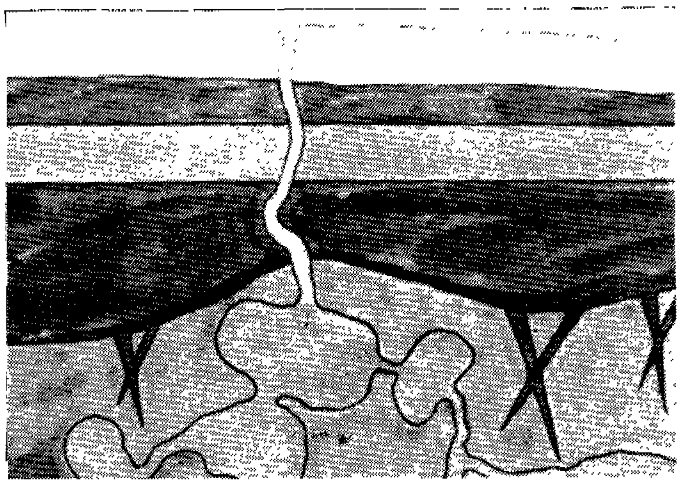
Sea water, which covers two-thirds of the world's surface is high in salt content and is certainly not pure. In reality, neither is the water we drink. The closest thing to pure water in nature is rain water, but even rain water as it falls through the atmosphere picks up small quantities of minerals, gases, and suspended solids from the air.



Chemically pure water: two parts hydrogen, one part oxygen.

Two typical kinds of water used for plant cooling tower makeup are **surface water** (lakes and rivers) and **ground water** (wells). These waters can be extremely different in their characteristic makeup. Surface water is usually high in suspended solids and relatively low in alkalinity. Ground water, conversely, usually is low in suspended solids and high in alkalinity.

But when either water source is used as makeup the dissolved solids and alkalinity in the tower become concentrated because of the evaporation.



Ground water is usually low in suspended solids, high in alkalinity.

In the following pages we will review in more detail the impurities, the water characteristics, and the problems that are potentially created because of the evaporation, circulation, and interaction of the impurities within the cooling water system.

Hardness, pH and conductivity are some of the parameters used to control cooling water operations. Understanding the interrelationships of blowdown, evaporation, and the effect that impurities have on the cooling water system is important to the overall operation and efficiency of the units and the cooling tower.

ANALYSIS: WELL WATER VS. SURFACE WATER

	Well	Surface
pH	8.0	7.2
Sp. Cond.	457	314
"M" Alk.	203	91
Sulfate	38	57
Chloride	5	26
Total Hardness	243	159
Calcium	159	80
Magnesium	84	79
SiO_2	13	9
Phosphate	<0.2	<0.2
Iron	0.17	0.10
Manganese	0.37	<0.10
Turbidity (JTU)	<1.0	50
CO_2	4	11
O_2	50	4.7

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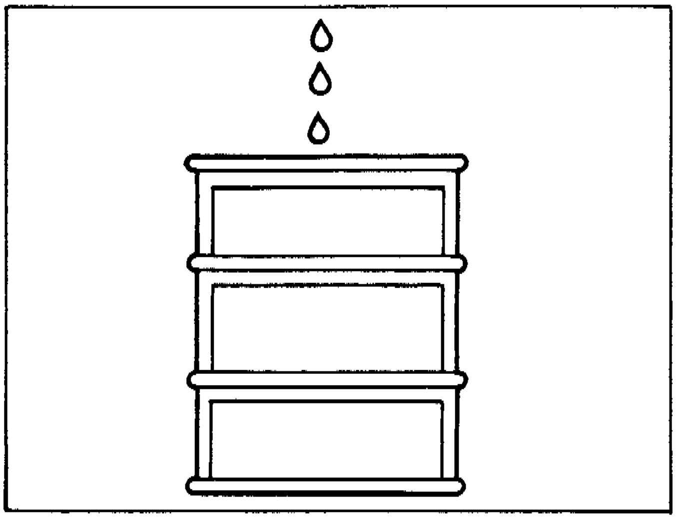
PPM

PPM means parts per million and is the unit we use to express impurities in water. To understand ppm's, it is the same as putting 1¼ oz. of liquid in a 6000 gallon tank truck or about 11 drops in a 55 gallon drum. In other words . . . a very small quantity.

But in cooling water, even these small concentrations of impurities within the water can create massive problems in cooling tower systems.

When we talk of ppm, often we talk of *milligrams per liter* as an interchangeable relationship.

Depending on the types of dissolved solids and their ppm concentrations, they can combine in very low concentrations to form scale and cause corrosion and fouling.



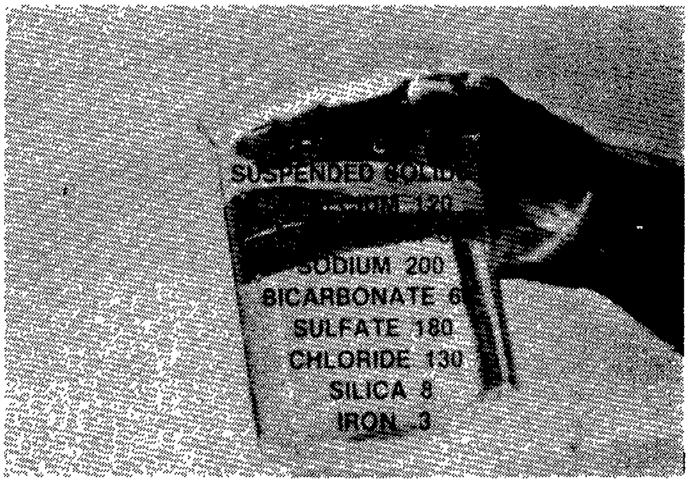
ppm—Parts per million or milligrams per liter. It's like placing a few drops in a 55-gallon drum.

Common Cooling Water Impurities

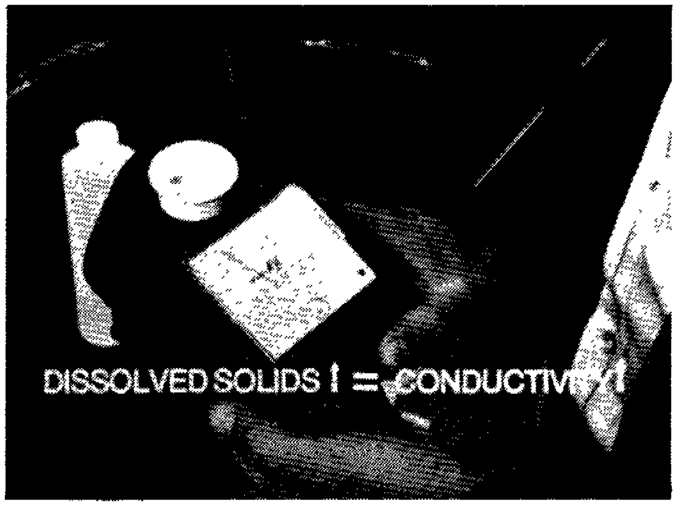
Let's review the typical kinds of impurities found in a common plant water supply.

oxygen	— 10 ppm	bicarbonate	— 50 ppm
suspended solids	— 20 ppm	sulfate	—180 ppm
calcium	—120 ppm	chloride	—130 ppm
magnesium	— 50 ppm	silica	— 8 ppm
sodium	—200 ppm	iron	— 0.3 ppm

All of these materials exist in the water as dissolved solids in the form of **ions.** These ions can combine to form compounds within the system that in turn cause scale, corrosion and fouling.



Impurities in common plant water.



As the amount of dissolved solids increases, the conductivity increases as well.

Calcium and magnesium are the cation salts representing hardness. Anions such as sulfate, silica and carbonate can combine with these cations to form potential problems.

All the ions which make up the dissolved solids in the water are electrically charged and consequently conductive. Conductivity is directly related to the amount of total dissolved solids within the water solution.

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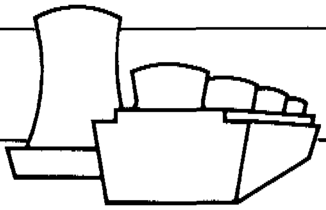


The **pH** of the water system plays an important role in the control of corrosion, scale or fouling.

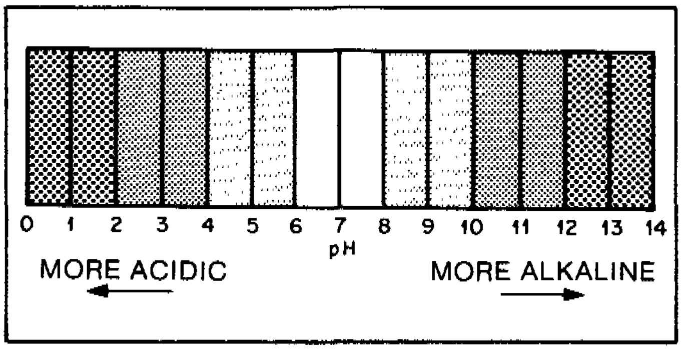
pH is the measure of relative acidity within the system with 7 being considered neutral in the pH scale. If acid is added to the system, the alkalinity is reduced and the pH is lowered toward 1. If hydroxide or additional alkalinity is added to the system, the pH is increased toward 14. It is important to realize that pH is a *logarithmic scale* as can be seen in the table below. At a pH of 4, the hydrogen ion concentration is .1 ppm: at a pH of 3 the hydrogen concentration is 1 ppm.

pH	**vs.**	**[H^+] Concentration (ppm)**
3		1.0
4		0.1
5		0.01
6		0.001
7		0.0001
8		0.00001
9		0.000001
10		0.0000001
11		0.00000001

$$pH = -Log\ [H^+]$$

At a pH of 4.2, we have reached what is called *"free mineral acidity"* where iron (the iron in cooling system equipment) potentially becomes soluble and can be dissolved by the cooling water over a period of time.

As pH increases into the alkaline range, depending upon the cation makeup and concentration, the potential for scale and fouling increases.



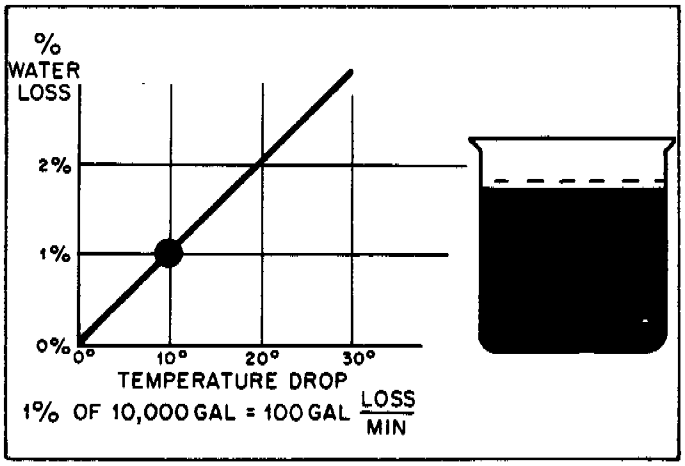
The pH scale measures the acidity of a system.

For each unit of pH change, the hydrogen ion concentration changes by a power of 10.

pH excursions, both high and low, can be devastating to a water treatment program. Increased corrosion, increased scale, and increased fouling can be anticipated if the pH is not maintained within the recommended range.

Cycling and Blowdown

Evaporation in the cooling tower system requires that additional makeup water be added to control the sump level. As water is added and pure water is evaporated, solids remain in the system, making *blowdown* necessary to control the total dissolved solids in the water. As can be seen in the table, for each 10°F drop between the return water from the process and the sump water temperature, approximately 1% of the circulating water is evaporated and removed from the system. This volume of water must then be replenished in addition to any water losses.



For every 10°F of water temperature drop, there is one percent loss of the circulating water.

Total blowdown can be calculated based on the amount of evaporation in the system divided by the number of cycles in the tower minus 1.

$$\textbf{Blowdown} = \frac{\textbf{Evaporation}}{\textbf{Cycles - 1}}$$

Control of evaporation, blowdown and cycling is essential for proper water treatment.

Cycles must be controlled to maintain the total dissolved solids in the system.

Cycles in the cooling tower system can be determined by picking a non-precipitating ion such as chloride and measuring this ion concentration in the makeup and in the tower basin. By dividing ion concentration in the tower by the ion concentration in the makeup, you determine the number of times that ion has concentrated or cycled in the tower.

$$\textbf{Cycles} = \frac{\textbf{Chloride in Tower}}{\textbf{Chloride in Makeup}}$$

Evaporation, blowdown, cycling and total dissolved solids are all interdependent as can be seen by the calculations. By watching these variables closely, control of the impurities which potentially create the problems of corrosion, fouling and scale is greatly improved.

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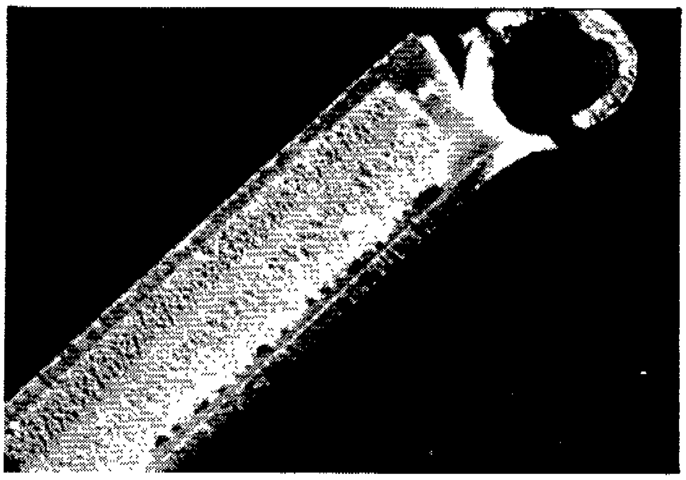
In the cooling tower system, heat from the process is removed by water passing through the heat exchanger. The heated water then returns to the cooling tower where the heat is rejected to the atmosphere through evaporation.

Impurities in the water can combine to form compounds which insulate the heat exchangers and



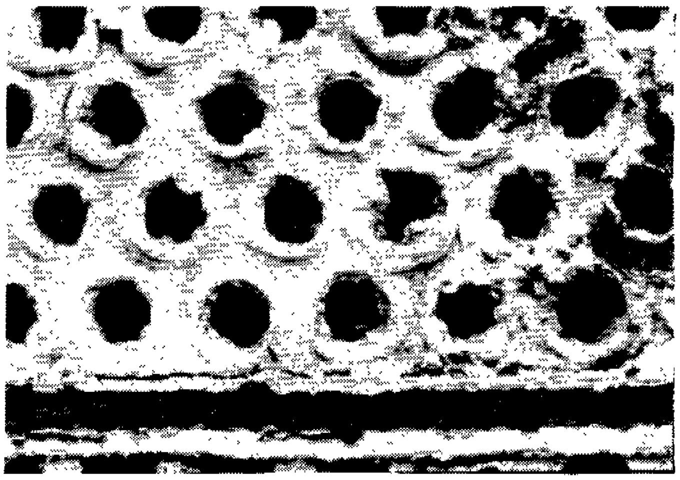
Calcium carbonate scale can reduce heat-transfer efficiency.

can impede heat transfer efficiency. Calcium can combine with carbonate or sulfate to produce a uniformly distributed scale across surfaces, reducing heat transfer efficiency.

Iron entering the system in makeup water can contribute additional problems to heat transfer. Trapped iron in the system can deposit out on high heat transfer areas, creating a fouling problem. This fouling can lead to underdeposit corrosion as well.

As corrosion takes place, metal surfaces become distorted and rough, like the edge of a file. As silt and debris pass through the cooling water system, suspended solids are trapped, increasing the fouling on heat transfer surfaces and reducing exchanger efficiency.

As you can see, corrosion, fouling and scale are all interdependent. One can easily lead to potential



Fouled heat exchanger.

problems with the other two, so care must be taken to protect the entire system against each of the problem trio.

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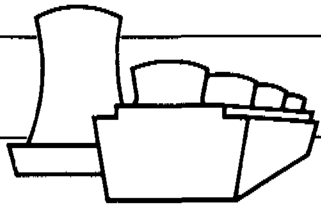

COOLING WATER IMPURITIES

Review Questions

1. In the chemical formula for water, H_2O, water is made up of two parts of hydrogen and one part of oxygen.

2. Typical cooling water makeup is supplied in general by two souces of water. These sources are ground water and surface water.

3. When we describe ppm's, we often talk in terms of ______ per liter.

4. When impurities dissolve in water they form charged particles which are referred to as cations and ______. ______ and ______ are the cation salts representing hardness.

5. Conductivity is the electrical measurement of dissolved solids in water.

6. If a water has a pH of 5 it is said to be ______.

7. If the pH changes from 5.0 to 6.0, the hydrogen ion concentration has changed by ______ times.

8. Given 10 ppm of chloride in the makeup water and 40 ppm of chloride in the tower, the number of cycles are ______

9. Given a temperature drop of 20°F in the cooling tower, ______% of the circulating water in the cooling system will be evaporated per minute.

10. Temperature ______ is the driving force for heat to travel from the process to the water through the heat exchanger.

11. Our problem trio, scaling, corrosion and fouling, are all interdependent and can ultimately affect the efficiency of heat exchange systems.

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