Chapter 5

Cooling Water Systems

5.1 Introduction

Heat is a by-product of human activity. Comfort cooling, machines and industrial processes all generate a large amount of heat. This heat must be dissipated continually – and flowing water is a good medium to remove heat – which is dissipated through evaporation.

Industries such as steel, aluminium, chemical and oil refining involve a number of heat-intensive processes. To control these processes and protect process-equipment from overheating, cooling water is used to transfer waste-heat from the process. Cooling water use – and associated evaporative losses – constitutes the highest consumptive use of water in most of these industries.

Water more than any other medium is used for cooling because it is

- readily available
- cheap
- has an ability to absorb large amounts of heat per square area (relative to air-cooled systems)
- can be discharged to the public utility sewers, creek or sea.

Therein lies the popularity of water in cooling systems.

Table 5.1 shows the percentage of overall water used in cooling systems in different industries. Power plants – by far – are the largest users of cooling water, as they require large amounts of cooling water to condense steam. For example, a 1000 megawatt (MW) power plant requires about 1500 m^3/minute (400 000 US gal./minute) cooling water. This chapter is, however, devoted to industrial and commercial cooling towers – which are by far – the most numerous.

There are a number of water sources that can be used as cooling water such as potable water, river water, ground water, sea water and recycled water (tertiary treated sewage effluent) and other process streams. Salt water is abundantly available at coastal locations. The use of ground water for cooling purposes is now under increasing scrutiny.

Table 5.1 Percentage of water used in cooling systems

Industry	Water used in cooling systems as percentage of total
Office building	30%
Food manufacturing – refrigeration	10–30%
Cool rooms	80%
Oil refineries and chemical plants	60–85%
Steel mills	87%
Power plants	90–95%

5.2 Types of Cooling Systems

There are three types of cooling water systems. These are

1. once through
2. closed circuit
3. open recirculating.

Once-through systems – They require large amounts of water – since the water only circulates once within the system. Once-through cooling systems are commonly found in thermal power plants (and other industrial plants) located in coastal areas which have access to sea water for cooling. These cooling systems due to their potential for environmental damage from thermal shocks and pollution are under increasing regulatory scrutiny and are being phased out in some countries.

Closed circuit systems – In closed circuit cooling systems the cooling water is completely confined within the systems pipes and heat exchangers. Reliable temperature control for industrial processes – such as the cooling of gas engines and compressors – is often achieved by closed recirculating cooling. Other applications for closed cooling systems are in chilled water and refrigeration systems. In such systems, water circulates in a closed cycle and is subjected to alternate cooling and heating – without air contact. Heat absorbed by the water is normally transferred by a water-to-water exchanger to the recirculating water of an open recirculating (or a once-through) cooling system. Closed-loop systems are not designed to lose water except for leaks.

Open recirculating systems – Open recirculating cooling water systems are the focus of this chapter as they have the greatest potential to save water.

The attributes, advantages and disadvantages of each system are shown in Table 5.2.

Table 5.2 **A comparison of three cooling systems**

System	Advantages	Disadvantages	Capacity of industrial process
Once through direct	• Low capital cost • Low operating cost • Low temperature sink	• Obtaining water intake and discharge permits may be difficult • Imparts thermal shock • Biological fouling from intake water • Pollution of waterways • Expensive heat exchange metallurgy costs for sea water or brackish water	<0.01– >2000 MW (0.034–6823 MMBtu/h*)
Open recirculating	• Low make-up water rate • Low discharge water rate • Good chemical control	• High capital cost • Power for fans and pumps • High chemical treatment costs • Risk of Legionella	<0.01– >2000 MW (0.03–6823 MMBtu/h)
Closed recirculating	• Minimum make-up water rate • High quality make-up • No biological fouling • No risk of *Legionella* • Minimal chemical requirements • Carbon steel acceptable for most components	• Expense of secondary cooling system • Metallurgy of water – water heat exchanger set by final heat sink • Heat load limitations, including temperature approach to final heat sink • Additional pumps and piping required	0.2–10 MW (0.7–34 MMBtu/h)

* MMBtu/h-million Btu/h

5.2.1 Open Recirculating Cooling Water Systems

Cooling towers, due to their apparent simplicity, are often taken for granted and in commercial buildings they are often located on top of the building – rendering them even less visible. So the old adage out of sight – out of mind often applies to cooling towers.

Table 5.1 shows that cooling water systems can use a large percentage of the total water intake and therefore need to be considered in any water conservation programme.

The primary purpose of cooling water systems is to cool process fluids so the plant can operate at maximum efficiency. Lack of attention to cooling systems can result in

- plant shut-downs due to scaling and the corrosion of critical heat exchangers
- increased risk of Legionellosis
- large quantities of water wastage
- increased water costs, wastewater costs and chemical treatment costs.

The Melbourne Aquarium case study serves as a grim reminder of the risks posed by cooling towers.

Fouling and poor maintenance of cooling tower fill can lead to a deterioration in thermal performance of the cooling tower and consequently an increase in cold water temperatures – leading to scaling potential of heat exchangers.

Case Study: Melbourne Aquarium, Australia [1]

The Melbourne Aquarium was opened in early 2000 and became a very popular tourist destination.

In April 2000, Legionnaire's disease was identified. It killed three people and seven were hospitalised in a critical condition. Ninety-three (93) people contracted the disease. The source of the pathogen were the cooling towers. Despite replacement of the cooling towers with air cooled chillers, attendance dropped by almost 50%. The court awarded the victims A$450 000 to be shared amongst them. Future litigation by the affected parties is a possibility.

5.2.1.1 Recirculating Cooling Water Systems – Operational Principles

The principle of a recirculating cooling tower, whether it is in a power plant or in an air-conditioning system is the same.

Figure 5.1 shows the basic equipment in a typical recirculating cooling system.

Cold cooling water at temperature T_{cw} is recirculated by the recirculating water pump. The water picks up heat from the heat exchangers (condensers). The hot water at temperature T_{hw} enters the cooling tower at the top. The water is sprayed through nozzles to the plastic or timber splash fill to disperse

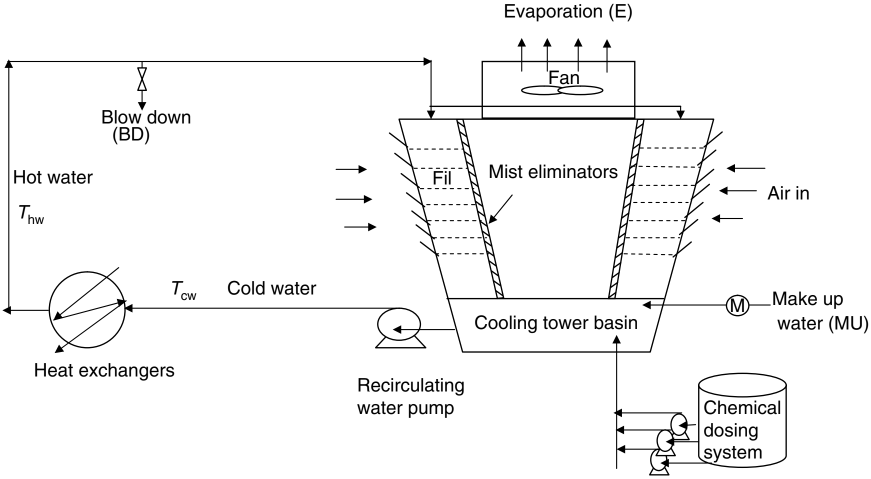

Figure 5.1 A schematic of a typical recirculating cooling system induced draught cross-flow cooling tower

the water into small droplets. The droplets exchange the heat with the incoming air flow that is sucked into the cooling tower by the induced draft fan.

The basis of cooling tower operation is sensible heat transfer and evaporative cooling. Sensible heat transfer takes place between the air stream and the hot water droplets. It accounts for only 25% of cooling. The bulk of the cooling (75%) takes place due to evaporation of water droplets when it comes into contact with an air stream. Water has a very high latent heat of evaporation (equal to 2431 kJ/kg or 1000 Btu/lb) compared to sensible heat transfer (4182 J/kg at 50° C) which is 582 times more. So, for every kg or pound of water that is evaporated, it removes 2431 kJ/kg (1000 Btu/lb) of heat from the rest of the water body. This results in cooling the rest of the water body. The evaporated water vapour leaves the cooling tower as hot moist vapour. Under normal operating conditions this approximates to 1.2% for each 5.5° C (10° F) temperature rise ($T_{hw} - T_{cw}$).

Thus, cooling water requirements are dictated by the amount of heat that needs to be removed from the hot cooling water.

Since only pure water and volatile impurities evaporate, all the non-volatile impurities (such as dissolved solids including calcium and magnesium hardness, chlorides, iron and suspended solids) concentrate in the cooling water. A constant bleed (BD) is maintained by regulating the blowdown valve to maintain a desired dissolved solids level, to minimise the impact of these impurities on the cooling water system. A freshwater makeup line maintains the water level in the cooling tower.

A small amount of water also is lost as fine droplets (entrained) in the air stream. This is called "windage" or commonly known as "drift" (DR). Drift is defined as the water lost from the tower as liquid droplets entrained in the exhaust air. It is independent of water lost by evaporation. Unlike evaporation, drift contains dissolved solids that are in the cooling water. Drift eliminators reduce drift loss by removing entrained water from the discharge air by causing sudden changes in direction of air flow. The resulting centrifugal force separates the drops of water from the air, depositing them on the eliminator surface from which they flow back into the tower. Drift is expressed as a percentage of the recirculation rate and typically ranges between 0.1 and 0.002% of the recirculation rate. The rate of drift loss depends on the age and design of the tower.

Splashing from the cooling tower is another source of water loss. This is generally due to poor maintenance of fill, or strong wind blowing through the tower.

Make-up water (MU) is added to replenish the water lost from evaporation, blowdown, drift, splash and other areas.

5.2.1.2 Recirculating Cooling Water Systems – Basic Concepts

In cooling tower design the variables of importance are

- The heat load imposed on the tower (Q)
- Cooling water flowrate (RR)
- Cooling range ($T_{\mathrm{hw}} - T_{\mathrm{cw}}$)
- Ambient wet bulb temperature (T_{wb})
- The approach temperature defined as the difference between the cold water temperature and the wet bulb temperature of air ($T_{\mathrm{cw}} - T_{\mathrm{wb}}$)
- Evaporation rate (ER)
- Make-up water (MU) flow rate
- Concentration ratio (CR)
- Blowdown (BD).

These concepts are explained below.

Calculating the heat load Q. Cooling water requirements are dictated by the heat transfer load. The heat transfer load is the sum of all heat loads from all exchangers and can be calculated from Equation (5.1):

$$Q = \sum UA(\mathrm{delta}\ T_{\mathrm{m}}) \tag{5.1}$$

where

Q – Heat transfer, kW (Btu/h)
U – Heat transfer coefficient, W/(m^2)(°C) or [Btu/(h)(ft^2)(°F)]
A – Heat transfer surface area, m^2(ft^2)
Delta T_{m} – Mean temperature difference between fluids, °C (°F).

Cooling water requirement. Once the heat transfer requirements for each heat exchanger has been calculated, the volume of cooling water needed to remove the heat is determined using Equation (5.2 or 5.3):

$$\mathrm{CW} = Q/[4.2(T_{\mathrm{hw}} - T_{\mathrm{cw}})] \qquad \mathrm{L/s} \tag{5.2}$$

For US units,

$$\mathrm{CW} = Q/500(T_{\mathrm{hw}} - T_{\mathrm{cw}}) \qquad \text{US gal./min} \tag{5.3}$$

[The unit conversion factor of 500 is derived from 8.33 lbs/gal. × 60 min/h × 1 Btu/(lb)(°F)].

The overall cooling water requirement is the sum of CW plus any other equipment that uses cooling water.

Cooling range ($T_{\mathrm{hw}} - T_{\mathrm{cw}}$). The cooling range ($T_{\mathrm{hw}} - T_{\mathrm{cw}}$) is independent of ambient temperatures and is only a function of heat load. For air-conditioning systems with electric compressors this is generally around 5.5° C (10° F). In manufacturing plant cooling systems this typically can be in the range of 5° C–30° C (9° F–54° F).

Ambient Wet Bulb Temperature T_{wb}. The ambient wet bulb temperature is the temperature achieved when a thermometer covered with a moist porous material is placed in an unsaturated flowing stream of moist humid air. The evaporation from the porous material causes a heat loss from the bulb, which causes a drop in the bulb temperature and hence in the thermometer reading.

The value that is equalled to, or exceeded by, 5% of the time – during the four hottest months – is generally the ambient wet bulb temperature chosen for cooling tower design.

Approach temperature ($T_{\mathrm{cw}} - T_{\mathrm{wb}}$). The difference between the ambient wet bulb temperature T_{wb} and the cold water temperature T_{cw} has a pronounced effect on the cooling tower size and cost. It is impossible for a cooling tower to cool water below the wet bulb temperature T_{wb}. Therefore designers try to minimise the difference.

However, there is a trade-off between performance and capital cost. For an example, by reducing the approach temperature from 8.3° C to 4.4° C the tower requirements increases by 50% and the fan operating cost by 65%. Thus various approach temperatures need to be evaluated to determine the minimum cost to the total system, including the heat exchanger surface areas, piping network, pumps and cooling tower costs.

Typical approach temperatures range from 2.8° C to 11° C (5° F– 20° F). Once the approach temperature has been selected it is important to operate as close as possible to this to minimise operating expenditure on energy.

In air-conditioning systems an increase of T_{cw} by 1° C increases the energy required by 3.5% to 4%. This is because as the cold water temperature increases, less heat is removed from the refrigerant gas and more energy is therefore required to compress the gas.

The relationship between approach temperature and cooling range is shown in Figure 5.2 below.

Evaporation rate. Once the cooling water circulation rate and the cooling range is known it allows one to calculate the expected evaporation rate (ER) from the cooling tower as given in Equations (5.4 and 5.5):

$$\begin{aligned} \mathrm{ER} &= \frac{\text{Thermal load}}{\text{Latent heat of evaporation}} \\ &= 0.8 \times \mathrm{RR} \times (T_{hw} - T_{cw})^{\circ}\mathrm{C} \times 4.2/2431\ \mathrm{kg/s} \end{aligned} \tag{5.4}$$

where

RR – pump recirculation rate L/s
0.8 – evaporation factor (typically ranges from 0.75–0.85).
4.2 – specific heat of water (kJ/kg °C)
2431 – latent heat of evaporation of water, kJ/(kg)(°C).

In US units,

$$\mathrm{ER} = 0.8 \times \mathrm{RR} \times (T_{hw} - T_{cw})/1000 \qquad \text{US gal./min} \tag{5.5}$$

where

RR is in US gal./min
1000 is the latent heat of evaporation of water, Btu/(lb)(°F).

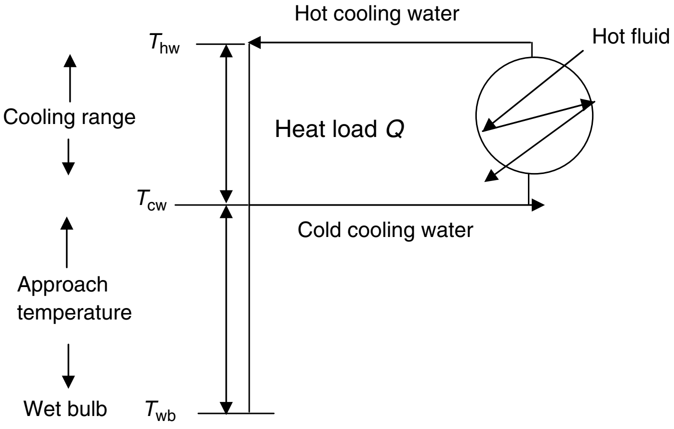

Figure 5.2 Schematic of thermal variables in a cooling tower

Make-up water required. Make-up water (MU) is added to replace evaporation (ER), blowdown (BD) and drift loss (DR) and system losses (L) as given in Equation (5.6).

By material balance,

$$\mathrm{MU} = \mathrm{ER} + \mathrm{BD} + \mathrm{DR} + \mathrm{L} \tag{5.6}$$

Studies conducted by Sydney Water [2] on cooling towers in commercial buildings showed that on average 88% of the water is evaporated, bleed accounted for 5%, and drift and splash accounted for 7% of the make-up water.

The MU is normally measured using flowmeters. In the absence of a flowmeter, MU can be estimated using Equation (5.7).

$$\mathrm{MU} = \mathrm{ER} \times (\mathrm{CR}/\mathrm{CR} - 1) \tag{5.7}$$

where CR is the cycles of concentration.

Cycles of concentration. Cycles of concentration (CR) measure the number of times the water circulates within the cooling system before lost to blowdown. It is the ratio of an ion in the cooling water (C_{cw})/ to that of the make-up water (C_{mu}).

$$\mathrm{CR} = C_{\mathrm{cw}}/C_{\mathrm{mu}} \tag{5.8}$$

Typically the ions considered are magnesium or silica. For convenience, total dissolved solids (TDS), conductivity or chlorides (when the chlorides contribution from chlorination is insignificant) are also used.

The objective is to maximise CR so that water loss through blowdown is minimised. The maximum CR that can be maintained in a cooling water system is subject to the salinity of make-up water quality and other considerations such as system metallurgy.

Example

Calculate the cycles of concentration if the cooling water chloride concentration is 150 mg/L and make-up water chloride is 30 mg/L using Equation (5.8)

$$\mathrm{CR} = C_{\mathrm{cw}}/C_{\mathrm{mu}} = 150/30 = 5 \text{ cycles.}$$

Blowdown. Voluntary blowdown (BD) is the water that is purposely removed from the system to maintain concentration of solids within a desirable range. It can be measured using flowmeters or (where impractical) can be determined as follows:

By mass balance, the input solids = output solids.

$$\mathrm{MU} \times C_{\mathrm{mu}} = \mathrm{BD} \times C_{\mathrm{cw}} \qquad \mathrm{BD} = \mathrm{MU} \times C_{\mathrm{mu}}/C_{\mathrm{cw}}$$

Therefore substituting Equation (5.8)

$$\mathrm{BD} = \mathrm{MU}/\mathrm{CR} \tag{5.9}$$

$$\mathrm{CR} = \mathrm{MU}/\mathrm{BD} = C_{\mathrm{cw}}/C_{\mathrm{mu}} \tag{5.10}$$

The objective when operating cooling water systems is to maximise CR, to reduce water and chemical use and minimise BD.

System losses. Water in cooling systems is lost through pumps, gland seals, washing of floor areas and splash from cooling towers. If there is a mismatch between the cycles of concentration calculated as MU/BD and when calculated as $C_{\mathrm{cw}}/C_{\mathrm{mu}}$, then it is a clear indication that leaks are occurring. The calculation concentration (or CR) as makeup divided by BD could be artificially high in systems that are leaking. Therefore, a better way to calculate the CR is using dissolved solids $C_{\mathrm{cw}}/C_{\mathrm{mu}}$.

From the overall water balance we get,

$$\mathrm{BD} = \mathrm{MU}/\mathrm{CR} = \mathrm{ER}/(\mathrm{CR} - 1) - \mathrm{DR} - \mathrm{L} \tag{5.11}$$

5.3 Types of Cooling Towers

Cooling towers are classified as natural draught and mechanical draught. Natural draught cooling towers found in electric power plants are hyperbolic with water flows as much 136 000 m^3/hr (600 000 US gpm). These are not the focus in this chapter.

Mechanical draught cooling towers are most commonly found in buildings and process industries. Fans are used to provide air flow of a known volume through the tower therefore improving thermal performance and stability. Cooling towers are commonly characterised by the location of the fan in the tower and by the direction of airflow. There are four different types of towers. These can be classified by location of fans and air-flow movement.

By location of fans:

- Induced draught
  - the fans are located at the top of the tower
  - the fans suck the air.
- Forced draught
  - the fans blow air
  - the fans are located at the inlet side of the tower.

By movement of airflow:

- Cross-flow towers
  - the air is admitted from the sides of the tower.

- Counter-flow towers
  - the air is admitted at the bottom of the tower and travels vertically upwards through the fill against the direction of the water flow.

Cooling towers are a combination of location of the fan and air flow. Thus they can be either induced draft counter-cross-flow or forced draft counter-cross-flow.

The selection of the most appropriate cooling tower is a function of

- required capacity
- cleanliness of the water
- location of the tower
- space availability
- operating efficiencies
- capital costs of the different types of towers.

In explaining the basics of cooling towers, only induced draft towers are considered in detail.

5.3.1 Induced Draught Cross-flow Cooling Towers

In cross-flow towers, the air enters the tower through the louvers that extend from the basin curb to the distribution deck on the sides of the tower – and travels horizontally – through the tower fill and drift eliminators. It then flows vertically upwards through the fan stack. The water flows from the open distribution system near the top of the tower – on the sides vertically down through the fill – and into the basin. Figure 5.1 is a schematic of an induced draught cross-flow cooling tower. Induced draught cross-flow towers are still preferred in applications where the circulating water can become contaminated with debris, for example in steel mill applications.

5.3.2 Induced Draught Counter-flow Cooling Towers

Counter-flow towers owe their popularity to the highly efficient film fill. Film fill is manufactured from formed sheet polyvinylchloride into a "honey comb" appearance with a large wetted surface area and with a number of various sized openings available. As a rule of thumb, 1 m of film type fill can be equivalent to 10 m of the traditional splash type fill, thus increasing the air/water contact area. This makes the counter-flow towers space efficient. Thermal efficiency is also greater because the counter-flow tower's average driving force for heat and mass transfer is greater than cross-flow since the coldest water contacts the coldest air and the warmest water contacts the warmest air [3].

Counter-flow cooling tower fill is less exposed to sunlight therefore reducing algae growth. However, this feature also makes them harder to service

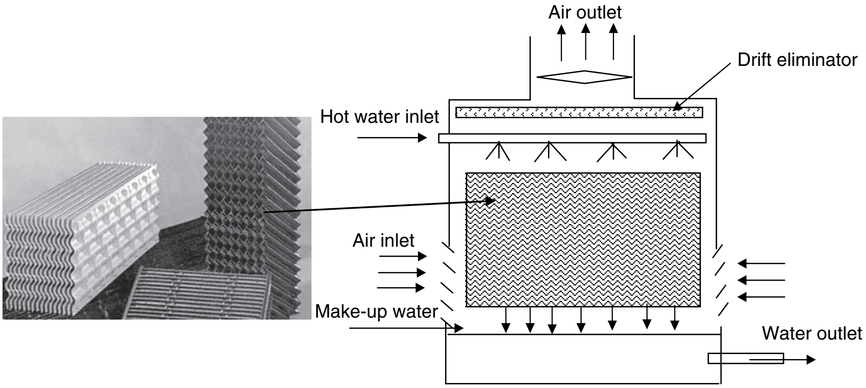

Figure 5.3 Schematic of induced draught counter-flow cooling tower with photo of fill

Photograph courtesy of Baltimore Aircoil.

and more prone to a deposit build up. Figure 5.3 shows induced draught cooling tower with a photo of cooling tower fill.

5.3.3 Forced Draught Wet Cooling Towers

The difference these ones have is that the cooling tower fans are located at the base of the cooling tower thus forcing the air through the tower. Thus they are easy to maintain. Normally these are of counter-flow design.

5.3.4 Evaporative Condensers

These are normally found in the refrigeration industry, where the refrigerant is cooled directly by the water circulating in the tower (known as the evaporative condenser). These are also known as mechanical draught wet closed cooling systems. They are characterised by having a very shallow basin and a small cooling water circuit. The hot refrigerant gas (normally ammonia in food processing plants) is cooled directly by the condenser water.

5.4 Water Conservation Opportunities

How can water conservation opportunities be maximised in cooling towers?

The key areas to maximise opportunities are by

- reducing involuntary water loss
- reducing voluntary water loss
- improving operating practices

- substituting alternative water sources to potable water
- converting to alternative cooling systems (Chapter 6).

These methods are described below.

5.4.1 Reducing Involuntary Water Loss

Involuntary water loss can be minimised by

- minimising overflow of water from cooling tower basins
- adjusting incorrectly set piping configuration
- arresting leaks in tower basin joints, pump seals
- reducing filter backwash water flow rates
- reducing excessive drift
- reducing water splash.

It is worth spending some time on each of these areas.

5.4.1.1 Minimising Overflow of Water from Cooling Tower Basins

Incorrectly set or defective ball float valves are frequently the cause of cooling tower basin overflows. As Figure 5.4 shows, when the float valve is set too high, the water overflows through the overflow pipe. They require periodic inspections.

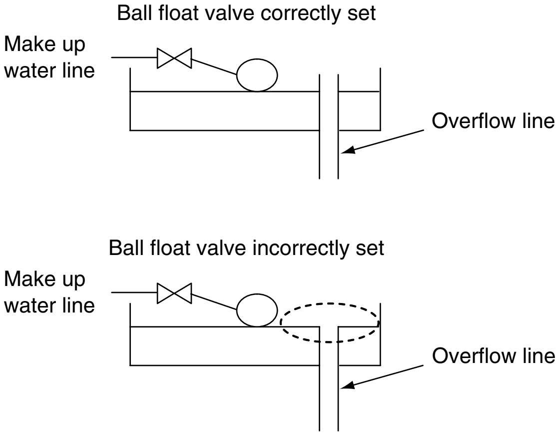

Figure 5.4 Incorrectly set ball float valves

Adapted from Sydney Water, *Best Practice Guidelines for Commercial Cooling Towers*, 2004.

5.4.1.2 Incorrect Piping Configuration

Incorrect piping configuration is quite common in air-conditioning systems. If the condenser water pipes run above the height of the tower spray heads, when the pump shuts down, water could flood back into the tower.

5.4.1.3 Leakage from Pipes, Joints and Pump Glands

With the passage of time, tower basin joints and other joints frequently leak. Leaks can be minimised through a well-managed maintenance programme. Pump gland leaks can be addressed in a timely manner by repacking them.

5.4.1.4 Drift Loss

All cooling towers lose water due to drift. Excessive drift results in water and chemical losses making it harder to control voluntary blowdown. It is also a nuisance when excessive drift leads to spotting of cars, buildings and windows. If the cooling tower drift eliminators have not been inspected recently, organise for a specialist to assess the performance.

5.4.1.5 Splash

Constant wetness around the cooling tower is an indication of splash. This may be due to high winds or a design flaw. Install anti-splash louvers to minimise splash.

5.4.2 Reducing Voluntary Water Loss

As mentioned earlier, a portion of the water is required to be blown down to minimise excessive concentrations of impurities in the water depositing on hot heat transfer surfaces, reducing thermal performance of the heat exchanger, causing corrosion or leading to fouling of tower internals.

The amount to be blown down is dictated by the quality of the make-up water. More often than not operators tend to blowdown excessively. As Figure 5.5 demonstrates, sometimes there is very little blowdown due to blocked blowdown valves.

The reasons for excessive blowdown are

- incorrect setting of conductivity controllers
- the water-treatment supplier not managing the cooling water-treatment programme (in the interests of the customer)
- poor operation and maintenance practices.

There are a number of ways of reducing voluntary water loss and these are described below:

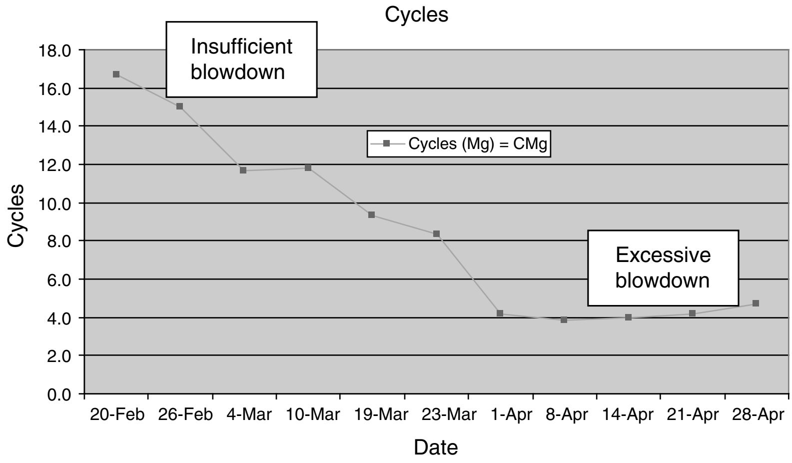

Figure 5.5 Cooling tower cycles in a shopping mall

5.4.2.1 Increasing Cycles of Concentration

Significant water savings can be achieved if the cycles are less than 5 in typical cooling water applications. The percentage of cooling water consumption that can be conserved by increasing the cycles of concentration is given in Equation (5.12).

$$\text{Per cent conserved} = \text{CR}_n - \text{CR}_i/\text{CR}_i(\text{CR}_n - 1) \times 100\% \qquad (5.12)$$

where

CR_i Cycles of concentration before increasing cycles
CR_n Cycles of concentration after increasing cycles.

Using Table 5.3 the percentage of make-up water saved can easily be calculated.

For example, by using Table 5.3 the percent make-up water that can be saved by increasing cycles from 3 to 10 is equal to 26% for any make-up water volume.

If we assume the following costs, then

Cost of water	\$1.20/m^3
Cost of sewer usage charge	\$1.20/m^3
Cost of chemical treatment, electricity	\$6.0/m^3
Total cost of cooling water	\$8.40/m^3
Initial make-up water flow rate	20 m^3/d
System operates for	300 days/yr 24 hrs/day

Table 5.3 Percent of make-up water saved

Initial concentration (CR_i)	New Concentration (CR_n) 2	2.5	3	3.5	4	5	6	7	8	9	10
1.5	33%	44%	50%	53%	56%	58%	60%	61%	62%	62.5%	63%
2	–	17%	25%	30%	33%	38%	40%	42%	43%	43.8%	44%
2.5	–	–	10%	16%	20%	25%	28%	30%	31%	32.5%	33%
3	–	–	–	7%	11%	17%	20%	22%	24%	25%	26%
3.5	–	–	–	–	5%	11%	14%	17%	18%	20%	21%
4	–	–	–	–	–	6%	10%	13%	14%	16%	17%
5	–	–	–	–	–	–	4%	7%	9%	10%	11%
6	–	–	–	–	–	–	–	3%	5%	6%	7%
7	–	–	–	–	–	–	–	–	2%	4%	5%

Adapted from North Carolina Department of Environment and Natural Resources. *Water Efficiency Manual*. August 1998.

Annual water savings

Water savings increasing from 3 to 10 cycles	$5.2\,\mathrm{m}^3/\mathrm{d}$
Annual water savings	$300 \times = 1560\,\mathrm{m}^3$
Annual Cost savings	$\$8.40 \times 1560 = \$13\,104$

Annual water and chemical treatment charges at 3 cycles equals $\$50\,400$.

The result is a slashing of the water and chemical treatment bill by 26% with no extra capital or operating expenditure.

5.4.2.2 Install Flowmeters on Make-up and Blowdown Lines and Conductivity Meters in Blowdown Lines

This will allow the operator to closely monitor the volume of water being used and verify that the system is operating at optimum cycles of concentration. Ideally all three signals need to be fed to a central data monitoring point so that the operators can remotely check the performance of the system.

5.4.2.3 Operate Blowdown in Continuous Mode

Cooling towers that have automatic conductivity controls are typically bled when the conductivity reaches a specified conductivity value releasing a large quantity of water. Blowdown control by this method leads to large fluctuations in the conductivity, which wastes water. A better method is to operate on a continuous bleed mode by keeping the conductivity close to the upper control limit. Statistical process-control software (supplied by reputed water treatment vendors) allows this to be achieved with greater accuracy. The upper and lower control limits are divided into one, two and

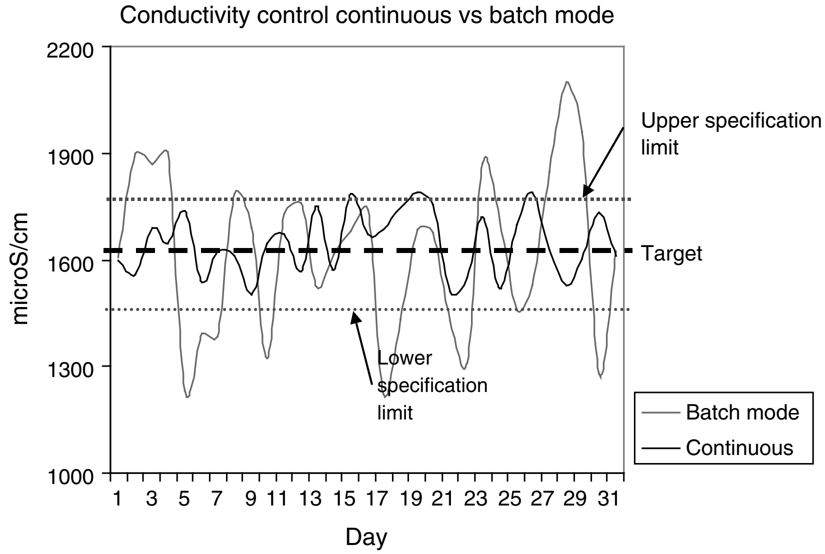

Figure 5.6 Continuous conductivity control vs batch mode

three standard deviations. The objective is to control within one standard deviation.

Figure 5.6 shows the difference between these two modes of control.

5.4.2.4 Install Sidestream Filtration

Cooling towers are good scrubbers of air-borne particulate matter, especially in dusty environments such as in steel mills. Suspended solids contribute to fouling of cooling system, plugging of cooling tower nozzles resulting in irregular distribution of cooling water in cooling towers, and in the tower sump, suspended solids accumulate and if not cleaned regularly create an environment for corrosive anaerobic bacteria to thrive.

In the cooling system, suspended solids contribute to clogged spray nozzles, erosion of piping, pumps and heat exchangers resulting in unscheduled plant shut downs.

The usual response from plant operators is to increase blowdown rates or to add chemical dispersants. Both these methods do not address the root cause. Blowdown wastes water and chemicals. The use of additional chemicals adds to chemical-treatment costs.

A smarter solution is to continuously remove a percentage of the solids loading using a sidestream filter.

Granular media filtration, bag and cartridge filters, hydrocyclones and self-cleaning screen filters are used for sidestream filtration. Typically, 1–20% of the recirculation flow is passed through a sidestream filter.

Modern automatic self-cleaning filters such as screen filters (as shown in Figure 5.7) can reduce the particle size down to 10 μm (if the particles are

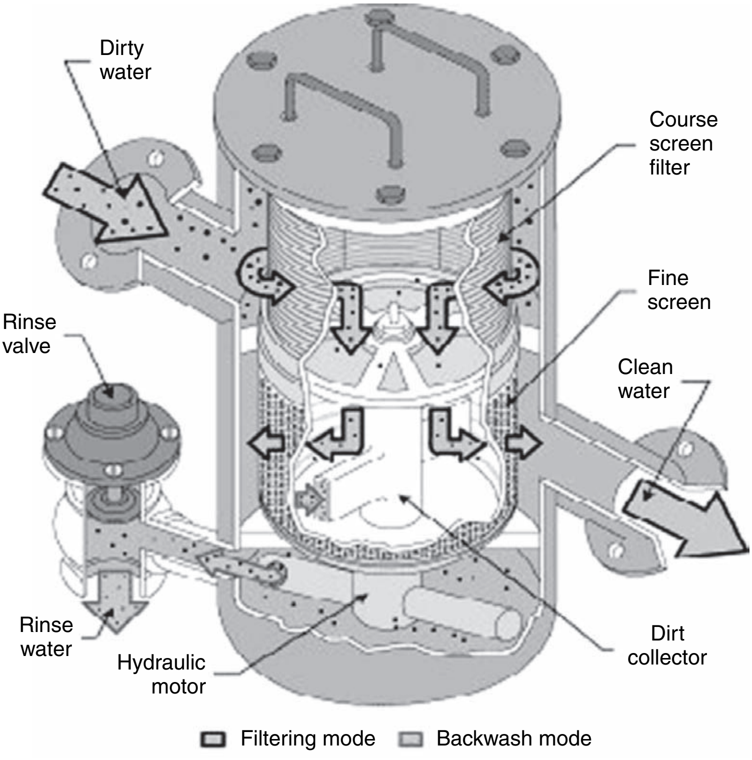

Figure 5.7 Schematic of a self-cleaning automatic filter

Courtesy of Automatic Filters Inc.

less than 25 μm it is considered an excellent outcome). In screen filters, the cooling water passes through a wedge-wire, woven-wire or perforated cylindrical elements with solid particles retained on the screen surface. They remove both organic and inorganic particles. The filters work on the principle of differential pressure. When the pressure differential which is normally 7–14 kPa (1–2 psi) is exceeded, the filter initiates the automatic cleaning cycle for about 40 seconds. The total volume of water used can be as low as 1% or less, which is significantly less than granular media filters use for backwash. Figure 5.8 shows how one of the ways an automatic self-cleaning screen filters is installed.

5.4.3 Improving Operating Practices

5.4.3.1 Shut Off the Unit When not in Operation

When the building is unoccupied or when the plant is not operating shut down the cooling water system.

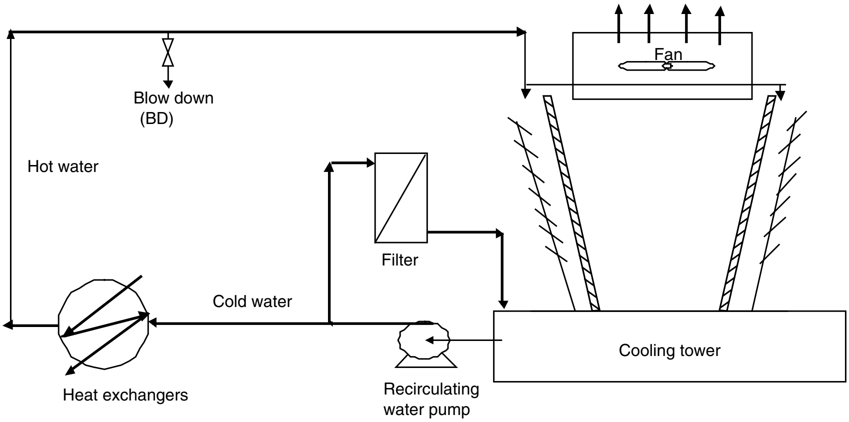

Figure 5.8 Schematic of a simple side-stream filtration system

5.4.3.2 Minimise Process Leaks to the Cooling System
Minimise process leaks to the cooling water system, such as glycol from the closed-loop system or hydrocarbons. Hydrocarbons increase microbial growth in the cooling water.

5.5 Alternative Water Sources

As shown in Table 5.4, there are a range of alternative water sources that can replace potable water. Cooling towers do not require water with the highest purity and therefore the alternative sources are generally cheaper than potable water. However this needs to be balanced again several criteria such as

- Health and safety requirements
- Impact on the cooling system performance
- Impact on heat exchanger metallurgy – corrosion
- Potential for fouling of heat exchangers
- Ease of control – cooling water chemistry
- Increased pumping requirements
- Security of supply – potential for supply disruption
- Increased chemical treatment costs.

5.5.1 Maximum Allowable Concentrations

The maximum allowable concentrations arising from the use of alternative water sources in a cooling tower are dictated by their potential to cause scaling, corrosion and fouling in cooling water systems. For each system

Table 5.4 **Comparison of alternative water sources**

Source	Positives	Negatives
River water	A secure source of supply	High in suspended solids, turbidity and organics. May also contain NH_3 and aerobic and anaerobic microbiological organisms resulting in reduced heat transfer and increased corrosion.
Ground Water	A secure source of supply	May contain high levels of hardness, TDS, Fe and Mn, Silica and alkalinity. Refer to Chapter 2 for more details.
Reverse osmosis reject water (brine) and demineraliser regeneration water	Good-quality water if the TDS is not too high	Can increase cooling water TDS levels as well increase the scaling and corrosion potential of water
Boiler blowdown	Boiler water frequently has a lower conductivity than city water	Hot. Contains polymers and phosphates that may interfere with cooling water chemistry. Increase phosphate loadings and is a nutrient for micro-organisms.
Steam condensate	Similar to boiler blowdown	Hot. Can contain ammonia and amines leading to increased microbial growth and corrosion of copper metallurgy.
Air-conditioning condensate (from air handling units)	A source of cool water	Variable source of supply. Condensate may only be available during the summer months.
Recycled sewage effluent from secondary and tertiary treatment plants.	PO_4 can reduce chemical treatment costs	Micro-organisms, NH_3, PO_4, biochemical oxygen demand (BOD), TDS, PO_4 and Cl. Refer to Chapter 2. PO_4 will contribute to Ca phosphate scale. If high levels of suspended solids are present these can settle out in low flow areas of the cooling system. Chemical treatment costs will be higher than that for potable water.
Rain and storm water	Suitable for buildings with large roof areas	Storm water may contain oil and other organics. Variable supply source.
Sea Water	Suitable for new plants	Cycles will have to be controlled to 1.5–2 cycles. Requires special towers and titanium or other exotic metallurgy.

Table 5.5 Typical concentrations in cooling systems

Contaminant	Source	Typical cooling system level mg/L	Potential problem
Aluminium	River water	0	Fouling
Amine	Steam Condensate	0	Microbiological growth and fouling. Corrosion of copper alloys
Ammonia	Steam condensate, recycled sewage effluent	0	Microbiological growth and fouling Corrosion of copper alloys
BOD	Various	Not usually measured	Microbiological growth and fouling
Ca as $CaCO_3$	Various	100–1000	Scaling
Chlorides	Sea water	<1500	Corrosion
Hydrocarbons	Oily water. Storm water	0	Fouling, microbiological growth
Iron	Ground water	0–3	Fouling
Manganese	Ground water	0	Fouling and corrosion
Phosphate	Treated sewage effluent, boiler blowdown	0–25	Calcium PO_4 scale
Suspended solids	Various	20–150	Fouling
TDS	All sources	<2000	Corrosion, scaling

these need to be individually evaluated. Using generic guidelines without consideration of other system conditions may expose the system to risk of system failure. Therefore no maximum values are given. Table 5.5 shows typical concentrations.

Case study: Petrochemical Plant, China

A petrochemical plant in China using 50–70% of river water as make-up consistently had high levels of nitrifying bacteria, iron-oxidising bacteria, *E. Coli*, Sulphate-reducing bacteria, fungi and algae in addition to high levels of organics, suspended solids, Ammonia. The river water composition was as follows:

pH	N/A	7.5
Ca as $CaCO_3$	mg/L	93
M – Alkalinity as $CaCO_3$	mg/L	160
Conductivity	µmhos/cm	880
Ammonia as NH_3	mg/L	32
Organics as TOC	mg/L	30
Chlorides as Cl	mg/L	170
Copper	mg/L	0.05
Iron as Fe	mg/L	2.0
Free chlorine	mg/L	0.2

Case Study: Duke University installs water reuse system [4]

Duke University, Orange County, USA has a chemistry building with an area of 12 913 m^2 (139 000 ft^2). The facilities maintenance staff installed systems to collect and pump condensed water from the building cooling systems to existing cooling towers. The investment was only two sump pumps and piping. Condensate water replaced evaporated water in the cooling tower system that was previously made up with potable water. As a result, Duke University saved in excess of 7570 m^3 (2 million US gal.) in the first year of operation.

5.6 Cooling Water Treatment for Recirculating Water Systems

The objectives of cooling water treatment are to maintain system performance and minimise occupational health and safety hazards.

The major areas of concern are

- scaling
- fouling
- corrosion
- microbial growth.

All of these phenomena are interrelated and affect system performance. Contributing factors such as process leaks, high temperature, suspended solids, low flow, ammonia and organics as shown in the Figure 5.9 will exacerbate one or several phenomena. Therefore all of these factors need to be considered in a comprehensive cooling water-treatment programme.

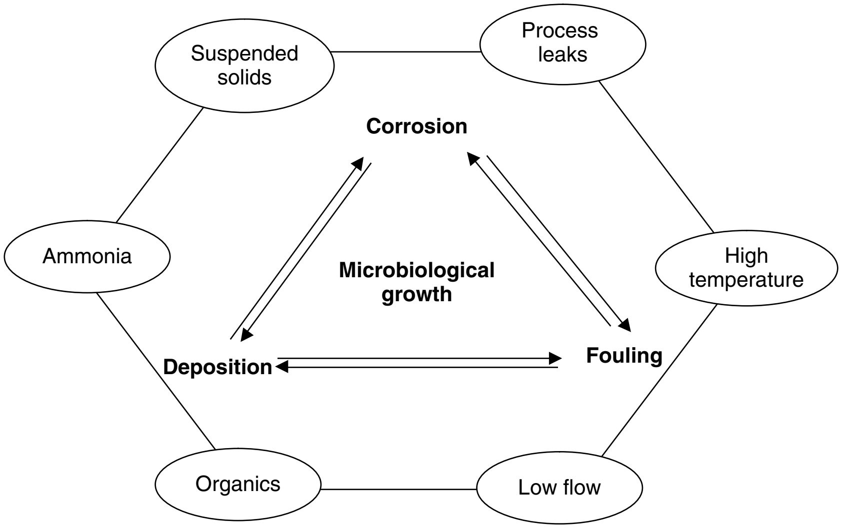

Figure 5.9 Critical factors affecting system performance

5.6.1 Scaling

The primary cause of scale deposition is due to supersaturation. The deposit forming salts exceed their solubility limits at a given temperature and deposition occurs. Common scale-forming salts are calcium carbonate (calcite), calcium phosphate, calcium sulphate and silicates. All of these exhibit inverse solubility with temperature. That is when the temperature increases the solubility decreases. Scaling reduces the performance of the heat exchanger; since the thermal conductivity of these scalants is significantly lower than that of steel. For example, the thermal conductivity of calcium carbonate is 25 times less than that of steel. Figure 5.10 shows the brick-like crystalline structure of calcium carbonate crystals and their large surface area allowing them to bind to each other.

As Figure 5.10 shows, scaling results in some of the heat exchangers becoming partially or totally blocked. As a result the heat transfer surface reduces resulting in the hot process stream (in the case of air-conditioning systems the refrigerant) leaving the exchanger hotter than specified. Moreover, scaling also results in the need to use extra pumps to pump water against the greater resistance of the blocked tubes.

The secondary causes of scale formation are

- Temperature
- Changes in water chemistry (Alkalinity, pH, ion concentrations)
- Pressure changes
- Flow rate changes
- Surface geometry.

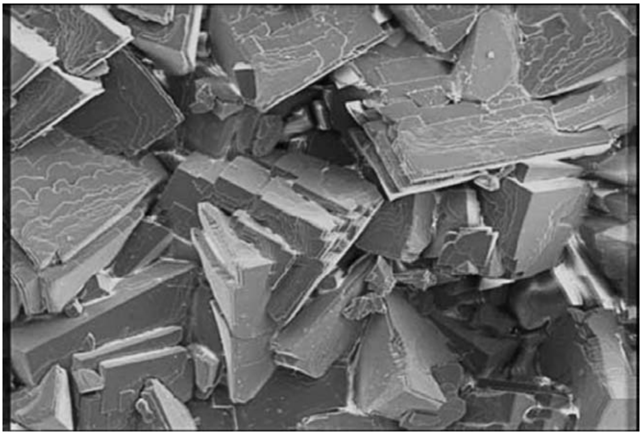

Figure 5.10 Calcium carbonate crystals

Courtesy of New Logic Research Inc.

When these conditions are met the solubility of the sparingly dissolved substances are exceeded. These concepts are discussed in Chapter 2.

Calcium carbonate is by far the most common scale found in cooling water systems. As reaction 5.13 shows, it is the result of the breakdown of calcium bicarbonate. Therefore the degree of scaling is dependent on the calcium hardness and bicarbonate alkalinity in the cooling water.

$$Ca(HCO_3)_2 \longrightarrow CaCO_3 + H_2O + CO_2 \qquad (5.13)$$

Figure 5.11 shows $CaCO_3$ scaling in an air-conditioning condenser.

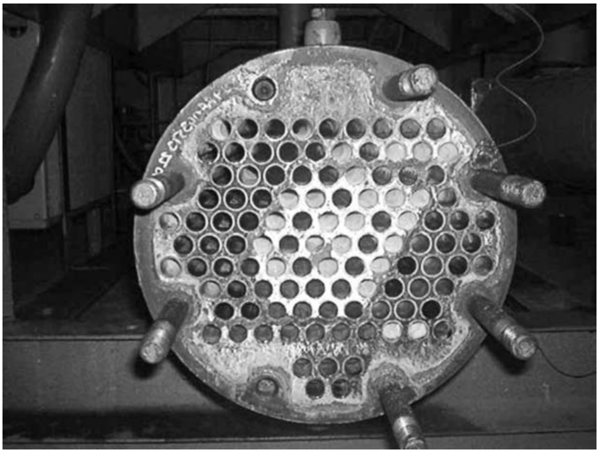

Figure 5.11 $CaCO_3$ scaling in condenser tubes

Courtesy of Absolute Water Treatment Pty Ltd.

5.6.1.1 Scaling Indices

There are a number of models to predict the scaling potential of $CaCO_3$ in water. They are

- Langelier Scaling Index (LSI)
- Ryznar Scaling Index (RSI)
- Practical Scaling Index (PSI).

The LSI is the oldest and is the most common. Dr John Ryznar and Paul Puckorius developed the RSI and PSI indices respectively and are variations of LSI.

The LSI is a model to predict the degree of saturation of water with respect to $CaCO_3$. The LSI approaches the concept of saturation using pH as the main variable. The LSI can be interpreted as the pH change required to bring water to equilibrium (LSI = 0).

The LSI is calculated using the following formula:

$$\mathrm{LSI} = \mathrm{pH} - \mathrm{pH_s} \tag{5.14}$$

$$\mathrm{pH_s} = \mathrm{pK_2} - \mathrm{pK_{spCaCO3}} + \mathrm{pCa} + \mathrm{pAlk} \tag{5.15}$$

where

pH_s – pH at which $CaCO_3$ is at saturation
pK_2 – second dissociation constant for carbonic acid (from HCO_3^- to CO_3^{2-})
$pK_{spCaCO3}$ – Solubility constant for $CaCO_3$
pCa – minus of the logarithm of the molal concentration of Ca^{2+} in moles per 1000 g of water.
pAlk – minus of the logarithm of the molal concentration of M Alkalinity in moles per 1000 g of water.
pH – Measured pH of the solution
M Alkalinity – Molal concentration of HCO_3^- to CO_3^{2-} and OH^-
Molal – gram moles of ion per 1000 g of water.

The rules for interpretation of LSI are given in Table 5.6.

For an example, water with an LSI of 2.5, LSI is 2.5 pH units above saturation. Reducing the pH by 2.5 units will bring the water into equilibrium.

Table 5.6 Rules for interpreting LSI

LSI	Saturation pH	Comments
+	pH of water > pH_s of $CaCO_3$	$CaCO_3$ precipitation likely. Scale can form.
−	pH of water < pH_s of $CaCO_3$	No potential for scaling. $CaCO_3$ will dissolve.
0	pH of water = pH_s of $CaCO_3$	Stable water. If the temperature of water or other factors change, scaling may occur.

As the pH is decreased the CO_3^{2-} component of alkalinity decreases reducing the driving force for $CaCO_3$.

LSI = 2.5
pH of cooling water = 9
Therefore pHs = 9.0 − 2.5 = 6.5
pH > pHs $CaCO_3$ scaling is likely.

Acid addition will depress the pH.

5.6.1.2 What the LSI is Not

The LSI does not predict the corrosivity of water. Corrosion may still occur due to dissolved oxygen and dissolved solids such as chlorides. It does not predict the scaling potential of other salts.

The indices provide only the thermodynamic *driving force* for scaling – not the quantity of $CaCO_3$ – that will actually precipitate. In the presence of crystal-modifying chemical inhibitors, these indices are not accurate [6].

5.6.1.3 Scale-control Methods

A number of methods exist to control scale formation. These are

- acid addition to reduce the pH
- increasing the solubility of scale-forming substances
- removing calcium hardness from the water
- precipitating the scale-forming substances.

(i) Acid addition

Sulphuric or hydrochloric acid addition was the traditional method to reduce scale control by depressing the pH as per Equation (5.16).

$$H_2SO_4 + Ca(HCO_3)_2 \longrightarrow CaSO_4 + 2CO_2 + 2H_2O \qquad (5.16)$$

Given that calcium sulphate ($CaSO_4$) is 50 times as soluble as $CaCO_3$, sulphuric acid addition is commonly used as an inexpensive method in power plants to control LSI. However, this introduces another potential scalant and a safety hazard.

(ii) Chemical inhibitors

In industrial cooling systems scale inhibitors such as crystal modifiers and dispersants are able to handle high hardness waters without the risks associated with acid handling [6–8]. These compounds include phosphonates and polymers such as polyacrylate or its co-polymers. Crystal modifiers act by distorting the $CaCO_3$ crystal structure – and dispersants act by reinforcing the negative charge present on the surface of colloidal matter – to prevent them binding together.

Calcium can be removed by lime soda softening, ion exchange or membrane filtration (nanofiltration or reverse osmosis).

5.6.2 Fouling

Fouling occurs due to suspended solids in the cooling water forming deposits on the system's surface.

Suspended solids can be

- air-borne substances from exhaust vents located nearby
- sand
- biofilms
- aluminium floc
- iron oxides and other corrosion products
- process leaks such as hydrocarbons.

Fouling prevents biocides and corrosion inhibitors to reach the microorganisms and the metal surface. Control of fouling is now more important than ever, given that cooling systems are operated for longer periods between cleanings.

Fouling-control strategies are

- sidestream filtration of cooling water
- increasing cooling water velocities
- addition of dispersant chemicals (1–10 mg/L as active ingredient) to reinforce the negative charge of suspended materials.
- injecting rubber balls to maintain clean heat exchanger tubes
- equipment redesign to remove low flow areas.

5.6.3 Corrosion

Corrosion can be defined as the destruction of a metal by chemical or electrochemical reaction with its environment resulting in the formation of metal compounds that decrease the structural strength of the metal. Therefore corrosion contributes to equipment failure, plant downtime and decreased heat transfer due to accumulation of corrosion products.

The most common types of corrosion in cooling systems are

- General corrosion
- Pitting corrosion
- Galvanic corrosion
- Stress corrosion cracking
- Dezincification.

General corrosion is a uniform attack over the entire metal surface. Corrosion products are voluminous and contribute to fouling and under deposit corrosion.

Pitting corrosion is far more serious than general corrosion since the attack occurs over a small localised area where overall metal loss is negligible and can lead to heat exchanger failure. Chlorides concentrate in the pit and produce an acidic environment with low oxygen concentration.

Galvanic attack occurs when two different metals are in contact with one another. Common examples are steel pipes screwed into a bronze valve. The steel pipe is the anode and the bronze valve is the cathode. The anode corrodes faster than the bronze valve.

Stress corrosion cracking in cooling systems is due to chlorides and is most prevalent in austenitic stainless steels (304 and 316). **Dezincification** is where the zinc is preferentially removed from a copper alloy leaving the metal brittle.

Figure 5.12 shows a series of carbon steel corrosion coupons with varying corrosion rates.

The principal factors governing corrosion are shown in Table 5.7.

Corrosion control in cooling water systems is achieved by

- selecting non-corrosive metals
- application of protective coatings
- application of sacrificial anodes
- adjust pH
- dosing of corrosion inhibitors such as anodic, cathodic and filmforming corrosion inhibitors. Examples are ortho-phosphate (anodic), zinc (cathodic) and tolyltriazole (film forming).

Table 5.8 gives guidelines for assessing corrosion rates.

Figure 5.12 Corrosion coupons illustrating the types of corrosion

Courtesy of Absolute Water Treatment Pty Ltd.

Table 5.7 Principal factors contributing to corrosion

Factor	Comments
pH	Acidic and slightly alkaline water dissolves metal and the protective oxide film on metal surfaces. Alkaline water favours the formation of the protective oxide layer.
Dissolved oxygen	Oxygen is essential for the cathodic reaction to take place.
Temperature	Below 71° C (160° F) for every 13–27° C (25– 50° F) increase in temperature causes the corrosion rate to double.
Dissolved salts	Cl and SO_4 increases the conductivity of water and increases corrosion rates. A measure of corrosion potential is the Larson – Skold indicator.
Velocity	High-velocity water increases corrosion by transporting oxygen to the metal surface and by carrying away corrosion products at a faster rate. It also causes erosion of metal surfaces. Specified water velocity for carbon steel is 1.0–1.8 m/s and for 90/10 copper nickel 1.0–2.5 m/s.
Microbial growth	Microbial growth promotes microbiologically influenced corrosion (MIC) due to the formation of corrosion cells. By-products of anaerobic bacteria forms acids.
Process leaks	Process leaks can lead to increased sulphate-reducing bacterial growth which causes corrosion.

Table 5.8 Guidelines for assessing corrosion

Metal	Corrosion Rate		Comment
	µm/y	mpy*	
Carbon steel	0–50	0–2	Excellent corrosion rate
	50–75	2–3	Generally acceptable for all systems
	75–125	3–5	Moderate corrosion ()
	>125	>5	Unacceptable. Iron fouling is likely
Copper alloys	0–5	0–0.2	Acceptable corrosion rates
	5–12.5	0.2–0.5	Corrosion rates too high. Can cause copper plating of mild steel exchangers.
	>12.5	0.5	Unacceptable
Stainless steel	0–25	0–1	Acceptable
	>25	1	Unacceptable corrosion rates

mpy* –mils per year (one thousandth of an in.)

5.6.4 Biofouling and Microbial Growth

Cooling towers and evaporative condensers are highly effective scrubbers. Temperature and pH are ideal for the growth of micro-organisms in the presence of plenty of nutrients. Contributing to this favourable environment is sunlight and oxygen. In once-through sea water or brackish water systems biofouling is due to macrofoulants such as zebra mussels or Asiatic clams or similar species. Macrofoulants are not considered in this section.

Biofilms due to micro-organisms are undesirable because they plug nozzles, decrease flow rates, hinder heat transfer and contribute to under deposit corrosion. A 1 μm (0.00004 in.) thickness biofilm on a stainless steel tube is equivalent to a 25 μm increase in tube thickness [11]. The thermal conductivity of biofilm is approximately 0.65 W/m-K. In contrast, metals have conductivities between 16 and 384 W/m-K. Therefore they are 25–600 times more resistant to heat transfer than metals. In a power plant this difference translates to thousands of dollars lost per hour.

There are three types of micro-organisms of interest:

1. Algae – found in distribution decks of cooling towers
2. Fungi – contributes to wood decay
3. Bacteria – causes fouling, Legionnaires' disease and corrosion.

5.6.4.1 Microbiological Control

To combat microfouling biocides are added to the cooling water. Biocides act to decrease the rate of microbiological activity by killing the organisms through variety of ways. Biocides addition need to form part of a holistic microbiological control strategy.

Legionella control is one such example. Many organisations and regulatory bodies have developed guidelines [13–17]. Specific action on *Legionella* control could be to develop a risk management plan in line with the requirements of your local regulatory body for the control of *Legionella*. The Victorian Department of Human Services, Australia [13] and Standards Australia [14] have developed such risk management plans.

The following are the three types of disinfection methods:

- Oxidising biocides such as chlorine, sodium hypochlorite, bromine, ozone, organic halogen donors, chlorine dioxide, peroxides and monochloroamine. They are non-specific and have broad-spectrum biocidal activity. The active ingredient in halogen chemistry is hypochlorous (HOCl) or hypobromous (HOBr) acids. HOBr is more effective at pH above 8. They dissipate in the cooling tower and for this reason they are added continuously or slug dosed daily. Halogen-based products have a residual effect and are added to maintain a free chlorine residual of 0.5–1.0 mg/L. Halogens form trihalomethanes (THM), a controlled substance, and for this reason halogenation is under scrutiny.
- Ultraviolet disinfection at a wavelength of 253.7 nm at a minimum dosage of 30 000–40 000 $\mu W - s/cm^2$ is also effective [15]. However, it also suffers from not having a residual effect.
- Non-oxidising biocides (made from complex organic molecules) are much more specific to one or more organisms, slow to react and some compounds degrade to benign substances. They need to be dosed

in large concentrations, are persistent and relatively expensive. The most common are isothiazolones, 2,2-dibromo-3-nitrilopropionamide (DBNPA), glutaraldehyde and quaternary ammonium compounds. The last compound also has surfactant properties and is therefore effective against sessile bacteria.

Typical non-oxidising biocide dosages are

Isothiazolinone (1.5%)	75 mg/L
Glutaraldehyde (45%)	100 mg/L
DBNPA (20%)	40 mg/L.

When dosing biocides, it is important to consider the holding time index (HTI) of the biocide in the cooling water. The HTI is the amount of time that it takes a biocide to halve its concentration. High bleed rates will make the biocide ineffective once it decreases below its effective dosage. The following calculation best illustrates this point.

Holding Time Index is given as HTI = 0.693 × volume/blowdown rate

Lets assume that the biocide was dosed at 100 mg/L and is expected that the biocide addition is done once a week. The minimum concentration required is 75 mg/L. The volume of the cooling system is 1000 m^3. Blowdown rate at 2 cycles of concentration is 50 m^3/hr and at 4 cycles of concentration is 17 m^3/hr. The effective HTI values for these two scenarios are

HTI at 2 cycles of concentration = 14 hrs
HTI at 4 cycles of concentration = 42 hrs.

Thus at high blowdown rates (2 cycles of concentration) there is wastage of biocides since it has been depleted in less than a day to below its effective dosage.

Other possible actions to control microbiological organisms are

- eliminate plumbing ‘dead-ends’ or modify closed loops
- select the biocides based on system half-life and water chemistry (isothiazolones, glutaraldehydes are effective for *Legionella* control)
- use a mixture of oxidising and non-oxidising biocides
- prevent build up of solids in the cooling tower sump
- shield wetted areas from sunlight if practical.

Guidelines for microbial monitoring are given in Table 5.9. *Legionella* testing needs to be carried out by specialised laboratories. Total plate counts need to be based on agar petri dish method rather than dip slides which are unreliable.

Table 5.9 Guidelines for microbial control

Total plate count cfu/ml	*Legionella* count CFU/mL	Comments
0–10,000	<10	Effective microbial control
10,000–10^5	10–100	General microbial control is satisfactory but *Legionella* control is unsatisfactory. Increased monitoring required. Increase biocide dosage if required.
>10^5	100–1000	Potentially hazardous situation. Re-evaluate microbial control programme.
>10^5	>1000	Serious situation. Shutdown immediately and decontaminate.

Cfu/mL = colony-forming units per millilitre.

5.7 Role of Water Treatment Contractors in Water Conservation

Most cooling water-treatment programmes are outsourced to water treatment companies. Therefore gaining their commitment is critical to the success of the water conservation programme. A knowledgeable cooling water specialist can be of immense assistance to making the water conservation programme a success. Therefore, contracts for cooling water treatment contracts should never be awarded on the *lowest price* as the sole criterion.

Below are some suggestions to get the best from your cooling water contract and vendor.

- The cooling towers need to be operated at the highest practical cycles of concentration. For this to happen, the contract needs to stipulate the desired number of cycles. Use this as a key performance indicator (KPI).
- Cooling water contracts need to stipulate a 'management fee' and a 'performance fee'. The management fee is to meet the basic contractual terms such as on-time delivery, dosing pumps maintained and reporting of trends. The performance fee is to ensure that the KPIs for water consumption, system chemistry, corrosion, microbial levels are met or exceeded. The minimum analytical requirements need to be stipulated in the contract.
- The make-up water flow and blowdown water flow and conductivity should be monitored, logged and charted. The cycles of concentration should be logged and charted and reasons given for any variations.
- Acceptable corrosion rates should be included in the contract. Corrosion monitoring should be reported at 30-, 60- and 90-day intervals. The corrosion coupon rack should be sited at the outlet of the hottest heat exchanger, if accessible. Otherwise the results may not be

representative. It is a good idea to stipulate the corrosion inhibitors for the metallurgy present in the system.

- Some vendors – when asked to raise cycles – bring in the spectre of *Legionella*. Increasing cycles of concentration has nothing to do with *Legionella* control. Be wary of such vendors. It is more a case that their water-treatment chemicals are incapable of handling stressed conditions.
- During site visits to the facility, the vendor should examine the water systems for indications of leakage, overflows and other types of water loss (or other deleterious conditions) and report them promptly for corrective action. Any overflows in the cooling tower, problems or leaks need to be promptly reported to the customer.
- The chemical treatment programme must specify the ingredients not the trade names (most are meaningless), dosage and active % used for corrosion, scaling and microbial treatment, so that chemical treatment programmes can be compared against each other or should be based on $ to treat 1 m^3 of blowdown water.
- Regular quarterly reviews with plant manager are needed to be held to assess performance. Statistical control packages are available these days to chart all the variables and this will show the percentage of time that the key variables were within the specified limits. They tell a better story.
- Use of alternative water sources should be assessed by the supplier. The performance fee needs to be tied to this. Computer programs such as Water Cycle™ are available for this purpose.
- Provide instructions and 'hands on' training to plant and building engineers as required so that water-treatment programme instructions, tasks and remedial actions for out-of-control situations are understood.

5.8 Conclusion

We have examined the types of cooling towers, the water conservation opportunities both voluntary and non-voluntary, alternative water sources, factors to consider in water treatment of cooling water systems and finally the role water-treatment specialists in managing water use in cooling water systems.

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