

Reducing water use in cooling towers and evaporative condensers



Many industrial processes generate large amounts of heat, known as thermal loads. These need to be dissipated to avoid a build-up of heat. Evaporative cooling is a common and efficient way of reducing thermal loads and is based on the principle that, when water is evaporated, energy is absorbed from the surrounding environment, thus reducing its temperature. The energy required to change water from one state to another - about 2,430 KJ (around 0.675 kWh) is used to evaporate 1 litre of liquid water to vapour at 30°C.

Cooling towers use this principle. They cool water to a temperature lower than the ambient air dry-bulb temperature with very little energy input compared with refrigerated systems. Because of this, they are often used to dissipate large thermal loads in industry and to cool large refrigeration or air-conditioning systems (e.g. to cool a large enclosed building or a building housing electronic equipment that produces heat as it operates).

Evaporative condensers, such as those used in a refrigeration unit, use the same evaporative cooling effect of water to directly cool the coils in the unit. This makes the system compact and more energy efficient.

However, cooling towers and evaporative condensers require significant quantities of 'make-up' water to compensate for losses associated with evaporation, drift (or mist) and blowdown (or purge). Water may also be used in ancillary feedwater treatment processes, such as softening.

HIDDEN COSTS

Reducing water consumption in cooling towers and evaporative condensers can save more than the value of the water alone. Understanding the true cost of water is important. Make-up water is often pre-treated before use (e.g. softened) and, in line with Health and Safety Commission (HSC) Approved Code of Practice and Guidance (L8), will have conditioning chemicals added to it to control legionella. Each of these water-treatment steps adds significantly to the overall cost of the water.

Typical costs for make-up water are:

UK mains supply ¹	£0.59 - £1.75/m ³
Softened water	£1.00 - £2.16/m ³
Reverse osmosis (RO) treatment ²	£1.51 - £3.83/m ³
Demineralised/deionised water	£2.53 - £3.70/m ³

¹ UK mains supply based on standard 2010/11 tariffs

² Note this does not include capital costs (including membrane replacement, etc) which can be significant for RO plant

Remember that additional costs will also be incurred for disposal of any water to sewer (e.g. reject water, blowdown or purge), typically between £0.54 and £2.67/m³.

Action

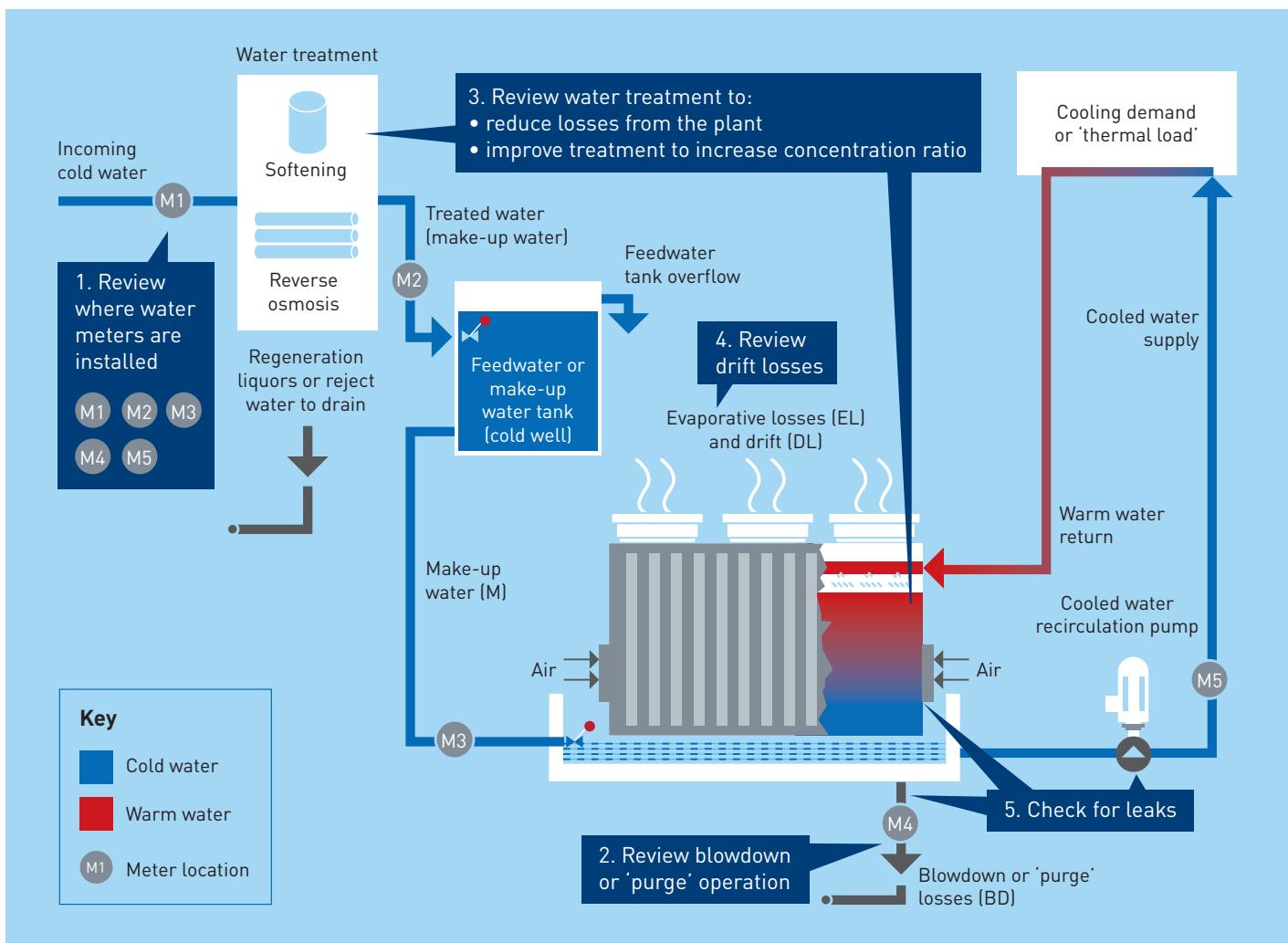
1. If not already known, determine the value of water used in your cooling towers and evaporative condensers.

Understanding where water is used

Many businesses do not know how much water is being used by their cooling towers and evaporative condensers (through evaporation, blowdown or any other loss, such as drift). There may also be water losses at the water treatment plant.

Monitoring the amount of water used in each step of the process enables the water efficiency of the cooling towers and evaporative condenser installations to be determined. It also allows malfunctions or reductions in efficiency to be identified, particularly if the water make-up consumption is plotted on a graph. Installing meters is an easy, effective and inexpensive way of measuring water use at each step in the process. A simple 30 mm water meter with a pulsed output costs around £75 - £95, excluding fitting. Figure 1 highlights some potential areas for investigation in a typical evaporative cooling tower. These would be similar for evaporative condensers.

Figure 1: Potential areas for water efficiency improvements in a typical evaporative cooling tower



In this example, installing meters in the suggested locations would allow the following to be calculated:

$$M_1 - M_2 = \text{water used (loss) at water treatment plant}$$

$$M_3 - M_4 = \text{evaporation and drift loss across the cooling tower}$$

With cooling towers, it is worth checking whether the water actually used is in 'balance' with what should be used. A water balance for a cooling tower can be summarised as:

$$\text{Make-up water (M)} = \text{Evaporation loss (EL)} + \text{Blowdown (BD)} + \text{Drift loss (DL)}$$

While BD can be measured easily, EL and DL are more difficult to measure, but they can be estimated. The theoretical water consumption of a cooling tower can be calculated using the following steps:

Figure 2: Complicated pipework around cooling towers and evaporative condenser plant illustrates the importance of labelling pipework



Step	Calculation	Symbol	Unit	Formula
1a	Thermal load	A	kW	$A = \text{Flow} \times 4.2 \text{ kJ/kg°C} \times (\text{Temp water}_{\text{in}} - \text{Temp water}_{\text{out}})$ Where 4.2 kJ/kg°C is the specific heat of water
1b	Cooling load due to airflow	B	kW	$B = \text{Airflow} \times 1 \text{ kJ/kg°C} \times [\text{Temp air} - (\text{Temp water}_{\text{in}} - 3)]$ where 1 kJ/kg°C is the specific heat of air Note: B could be negative
1c	Evaporative load	C	kW	$C = A + B$
1d	Evaporation loss	EL	kg/s	$EL = C/2,430 \text{ kJ/kg}$ where $2,430 \text{ kJ/kg}$ is the latent heat of evaporation of water at 30°C
2	Blowdown volume	BD	litres/s	$BD = \frac{EL}{N - 1}$ Where N = concentration ratio in the tower (typically 1.5 : 1 for very hard water, 2:1 for hard water, 3:1 for soft water and greater than 6:1 for deionised/reverse osmosis water)
3	Drift loss (estimate only)	DL	litres/s	$DL = \frac{0.005 \times \text{recirculation rate around tower (litres/s)}}{100}$ Note: 0.005% loss is for a good, modern, drift eliminator
4	Make-up volume	M	litres/s	$EL + BD + DL$

If the actual water consumption (indicated by your water meters) is significantly greater than the theoretical consumption, further investigations should be taken to find out why. Possible causes include greater thermal-load dissipation than used in the calculations, leakage from the system, the blowdown valve is stuck or the system is malfunctioning. There are often many pipes around cooling towers and evaporative condenser plants (see Figure 2). Unless they are easy to follow, it can be difficult to understand what flows where, making water management more difficult. Labelling pipework to indicate the contents and flow direction will make this much easier, and may be particularly useful in an emergency.

Actions

1. Review where water meters are installed around cooling towers and evaporative condenser installations. If necessary, install more meters to monitor water use effectively.
2. Check your actual water use against theoretical use and investigate discrepancies.
3. Label pipework to indicate the contents and flow direction.

Blowdown or purge

Optimising blowdown is often the greatest opportunity to reduce water consumption in cooling towers and evaporative condenser installations.

The concentration of total dissolved solids (TDS) will increase in the closed-loop system as the water evaporates. Bleeding off the system water by blowdown or purging is usually necessary to prevent scale building up in cooling towers and evaporative condensers, which can impair efficiency or structurally damage the unit.

Typically, TDS concentrations in the cooling water should be no more than 2,000 – 3,000 mg/litre, but this will depend on specific operating conditions.

Blowdown can be controlled manually, by timer or automatically. Automatic methods are usually based on conductivity measurement, which is proportional to TDS concentration. Using an automatically controlled system is preferable because TDS concentrations are monitored constantly, resulting in smaller volumes of water being blowdown more frequently to maintain the concentration within the desired range, minimising the total amount of water discharged.

The amount of blowdown water required can be estimated using the make-up water TDS concentration and desired maximum TDS concentration in the cooling water. For example, for water with an average TDS concentration of 400 mg/litre and a required maximum TDS in the cooling water of 2,000 mg/litre:

Blowdown required (%)

$$\begin{aligned}
 &= \frac{\text{TDS of feedwater (mg/litre)}}{\text{Maximum increase in concentration of TDS (mg/litre)}} \times 100 \\
 &= \frac{400}{2,000 - 400} \times 100 \\
 &= 25\% \text{ of make-up water flow}
 \end{aligned}$$

Blowdown is usually discharged to drain, but there is an increasing trend to re-use this water provided water quality allows.

Actions

1. Check if the blowdown water volumes are known. If not, try to measure or calculate them.
2. Determine if blowdown volumes can be reduced, possibly by improving treatment of the make-up water.
3. Investigate whether blowdown can be automated.
4. Investigate the potential for blowdown water to be re-used.

Treatment of make-up water

Blowdown can be minimised if the concentration ratio (CR) or cycle of concentration (COC) is high.

$$\text{CR (or COC)} = \frac{\text{TDS concentration in cooling water}}{\text{TDS concentration in make-up water}}$$

Concentration ratios of around 3:1 – 5:1 are typical for many cooling tower and evaporative condenser installations, but these will depend on feedwater quality and optimal TDS or specific ion (e.g. chloride) levels.

To prevent scaling and minimise blowdown, most make-up water will have some form of pre-treatment, which include:

- softening (changing the chemical composition of some of the dissolved salts) to reduce scaling; and
- demineralisation or reverse osmosis to remove the majority of TDS.

The blowdown required may be significantly reduced by improving the treatment process for make-up water to reduce the TDS of the feedwater and increasing the CR/COC.

Typical savings in make-up water that can be achieved by improving water treatment to increase CR/COC are shown in Table 1.

Table 1: Volume of make-up water (%) saved by increasing the concentration ratio

Initial concentration ratio	New concentration ratio										
	2	2.5	3	3.5	4	5	6	7	8	9	10
1.5	33%	44%	50%	53%	56%	58%	60%	61%	62%	63%	64%
2		17%	25%	30%	33%	38%	40%	42%	43%	44%	45%
2.5			10%	16%	20%	25%	28%	30%	31%	33%	34%
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%

Source: North Carolina Department of Environment and Natural Resources, Division of Pollution Prevention and Environmental Assistance

Therefore, improving water treatment to reduce TDS can significantly improve the water efficiency of cooling tower and evaporative condenser installations.

Remember that the type of water-treatment process used may also offer an opportunity to improve water efficiency. If an ion exchange process is used, such as softening or demineralisation, the ion exchange beds will require periodic regeneration. These regeneration processes not only use water and chemical reagents, but also generate effluent, all of which incur costs.

Undertaking a daily regeneration process, or a similar time-dependent basis, irrespective of the amount of water that has been treated, can lead to more frequent regeneration than is necessary. Using automated systems based on volume of water treated or a measured value (e.g. conductivity breakthrough) can be much more efficient and minimise the number of regenerations required.

If reverse osmosis is used, a permeate stream and reject water (or concentrate) stream is produced. The permeate is essentially pure water and will be used to supply the make-up water. The reject water can typically account for 30% of the incoming flow and, even though this will have elevated salt concentrations, it is still likely to be suitable for recovery and re-use elsewhere on site.

Actions

1. Calculate the CR/COC and assess if any water-treatment improvements would increase the CR/COC and what make-up water savings could be achieved.
2. If softeners or demineralisation processes are used, check whether the frequency of the regeneration cycles can be reduced.
3. If reverse osmosis treatment is used, assess the potential to re-use the reject water elsewhere on site.

Drift

Water, in the form of small droplets, is often lost in the airflow leaving cooling towers and evaporative condenser installations, and is called drift, also known as mist (see Figure 3).

Drift eliminators are often fitted to prevent this loss, but it is usually still present to some degree. Depending on the design of the eliminator, water losses through drift can be 0.05% – 0.2% of water flow through cooling towers and evaporative condensers. Good tower and drift eliminator design may reduce this significantly. Losses on modern units are typically around 0.005% but can be as low as 0.001%.

Action

1. Inspect your tower for drift losses and, if necessary, install drift eliminators.

Figure 3: Evaporative losses from a cooling tower



Losses and leaks

Although cooling towers and evaporative condensers are relatively simple items of plant, they can be large and may have a significant pipework system.

The most common leaks are from the enclosure of the cooling tower or evaporative condenser itself, faulty pump glands, pipework flanges and joints, all of which should be repaired as soon as possible (see Figure 4). The waste through even a small leak can be high and costly as cooling towers and evaporative condensers are usually in constant operation.

Sticking or poorly sealing blowdown valves can result in a continuous flow of blowdown water. As well as using a lot of water, this will also lead to the excessive use of chemicals in the treatment regime for the cooling tower. Blowdown valves should be routinely checked and corrective action taken if any are found to be defective.

Figure 4: Leaking pipes can have significant cost implications if they are not repaired



Actions

1. Undertake routine surveys of cooling towers and evaporative condensers for leaks and losses, and take remedial action as soon as possible.
2. Repair or replace poorly operating blowdown valves promptly.
3. Check overflows (e.g. make-up water tank) and ensure they are not overflowing.