Content

Section *page*

Version 1

1. Cooling tower operation

1.0 Why cooling towers?

Cooling towers are, amongst others, used for an efficient cooling of cooling water in the process and food industry and for the cooling of water cooled cooling machines in for example air conditioning installations. Since the use of surface and spring water is less and less desirable, the practice of water cooling by cooling towers is increased. Before, water often was cooled with the help of cooling and spraying ponds. Later, these were substituted by the well-known natural draught cooling towers for large water debits. The principle of operation of these cooling towers is based on evaporation of a small amount of the circulating cooling water. Therefore, these towers are also called ‘evaporative cooling towers’. Because of the availability of electricity and the desire to build in a more compact way, the forced draught cooling towers became increasingly popular. This type of cooling tower is provided with one or more fans.

1.1 Wet bulb temperature

The wet bulb temperature is an essential notion for the selection of an evaporative cooling tower. This air temperature can easily be measured with the help of a psychrometer. Usually, this is a glass thermometer filled with mercury and it is put in a cotton cover. This cover is soaked in distilled water and when unsaturated air passes, water from the cover evaporates (figure 1). For this evaporation (latent) heat is extracted from the cover, causing it to cool down. Now the temperature of the cotton cover is lower than that of the passing air. Subsequently, (sensible) heat flows from the air to the cover. Influenced by the passing air, the cover gradually takes a temperature such that the heat flow of the air to the cover is exactly the same as the heat that is required for the evaporation of the water from the wet cover. This balanced temperature of the air is called the wet bulb temperature (Tnb).

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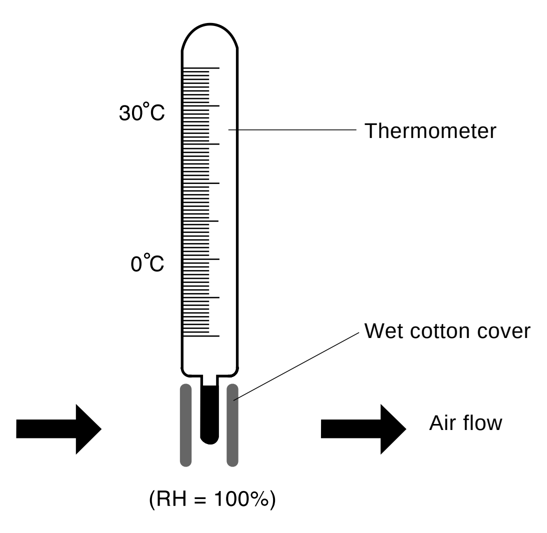


figure 1. Psychrometer principle

Put differently, for the wet bulb temperature of the wet cover the passing unsaturated air emits just enough sensible heat to support the latent heat flow (evaporation) of the water. The wet bulb temperature is also called the adiabatic saturation temperature.

1.2 Principle of operation

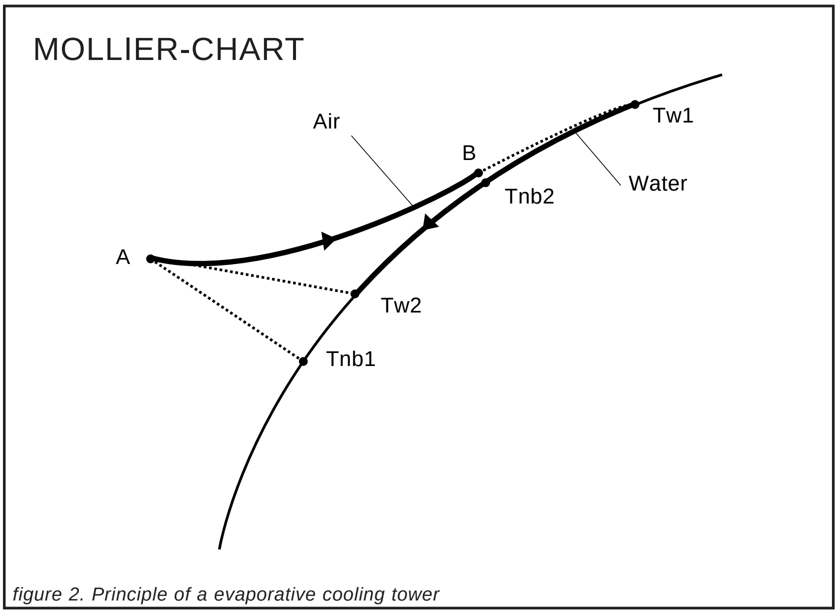


figure 2. Principle of a evaporative cooling tower

In an evaporative cooling tower circulating cooling water that is brought in direct contact with the drawn-in surrounding air is cooled. A process’ warm cooling water is spread out thinly over a contact body, which preferably has a large exchange surface. The air is led equally over this film of water.

The cooling water is cooled by evaporation of a small amount (1-2%) of the circulating water. Per kg evaporated cooling water 2491 kJ is extracted from the circulating cooling water. The unsaturated air flow absorbs the evaporated water and the heat belonging to it. The air stream is further heated in the contact body (cooling fill) until a heat-exchange balance between the air flow and the circulating cooling water is reached.
The decrease of the temperature of the cooling water and the increase of the air’s heat content in the cooling tower is a gradual process.
The operation of an (evaporative) cooling tower is based on the principle of combined heat and mass transfer. This is a transfer of sensible (dry) heat between circulating cooling water and passing air by convection and the transfer of latent (wet) heat by evaporation of the cooling water. This combined heat and mass transfer in a counter flow cooling tower is clarified in the Mollier diagram for wet air (figure 2):
Air with condition A and a matching wet bulb temperature Tnb1 passes a wet surface with the temperature Tw2. The condition of the saturated air in the border between air and water (just above the wet surface) equals the point Tw2, lying on the saturation line in the Mollier diagram.
When air and water pass one another in counter flow, the colder air comes into contact with the warm cooling water and the air absorbs more heat.
For this reason the condition of the air moves to the right and follows the curve A-B. In the point B, with a matching wet bulb temperature Tnb2, is a curve directed to the point Tw1. The air flow absorbs more and more water and will eventually be saturated. The force behind the total enthalpy increase of the air is the enthalpy difference between the air in the border layer air-water and the passing air.

In short, in the cooling tower the cooling water is cooled from temperature Tw1 to Tw2. The drawn-in air with condition Tnb1 is heated and humidified to a condition Tnb2, where the air is almost saturated.
A rule of thumb is that the wet bulb temperature of the air leaving the cooling tower almost equals the average of the cooling water’s in and outlet temperatures. This depends on the cooling tower’s efficiency.

2. Cooling tower types

2.0 Natural draught cooling tower

From early days on the natural draught cooling tower is the most well-known of cooling towers. The main characteristic of this type of cooling tower is its parabolic shape. Usually produced in a body of reinforced concrete, there are pieces with a diameter of no fewer than 40 meters and a building height of 100 meters. The most common application is for cooling of very large water debits (figure 3). Because the warm cooling water is equally distributed, a natural draught of the air flow in counter flow with the water occurs in the body. This effect is also called the 'chimney effect' because of the fact that hot air rises. Because of this air flow evaporation and cooling of the circulating cooling water occurs.

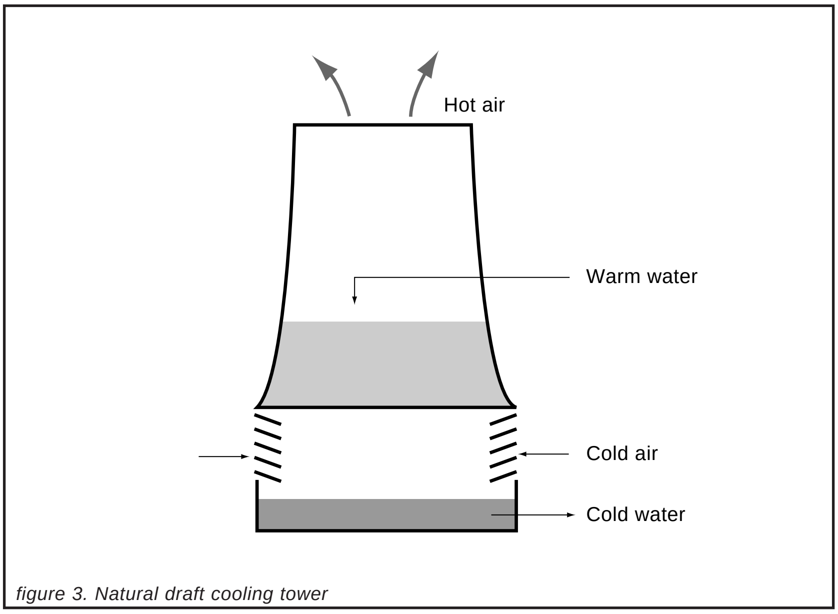


figure 3. Natural draft cooling tower

2.1 Forced draught cooling tower

The characteristic of forced draught cooling towers is that one or more fans cause an air flow in the cooling tower. This causes a significantly higher air speed in the cooling tower and a better cooling than in the natural draft cooling tower per m2 surface. The disadvantage of the required energy for the fan is outbalanced by the advantage of building for lower costs because the manner of building is more compact.

The most well known examples of this category of cooling towers are the counter flow and the cross flow cooling towers. In a counter flow cooling tower the water falls down in a vertical manner and the air rises in opposite direction. In a cross flow cooling tower the water falls in a vertical manner, crossed by the air flow in horizontal direction.

3. Cooling tower notions

When selecting a cooling tower, the cooling water temperatures as well as the wet bulb temperatures are important data.
The cooling water inlet temperature (Tw1) is the temperature of the circulating cooling water debit (Qw) that is led into the cooling tower. The cooling water outlet temperature (Tw2) is the temperature of the cooling water leaving the cooling tower.
The difference between the in and outlet temperatures of the cooling water is also called ‘range’ (Tw1-Tw2).
The difference between the outlet temperature of the cooling water and the wet bulb temperature is also called ‘approach’ (Tw2-Tnb).

The cooling capacity (KC) of a cooling tower is calculated as follows:

KC = (Tw1 - Tw2) * 4,187 * 1000 * Qw
(kW) (°C) (kJ / kg) (kg / m^3) (m^3 / s)

- specific heat of water = 4,187 kJ / kg
- specific mass of water = 1000 kg / m^3

The cooling capacity of a cooling tower is always equal to the cooling load. This is the energy that is added to the circulating cooling water during the cooling process.
The efficiency (η) of a cooling tower in a formula is:

$$\eta = \frac{Tw1 - Tw2}{Tw1 - Tnb}$$

The theoretically lowest possible cooling water outlet temperature (Tw2) in an evaporative cooling tower is equal to the wet bulb temperature (Tnb). In that case the efficiency of the cooling tower is 100%. For this to be realised the cooling tower should be infinitively large. For this reason we can say that the water outlet temperature can never be lower than the wet bulb temperature of the drawn-in air in the cooling tower.

Another frequently used notion in the cooling tower technique is the water load (R), also called “Q over A ratio”. This is the amount of circulating cooling water per square meter wet cooling tower surface (m^3 / m^2 / h).

4. Heat exchange

4.1 Cooling fills

The most important part of the heat and mass exchange between water and air takes place in the cooling fill of the cooling tower. As a contact body the cooling fill exists in many constructions. We have waved synthetic foils (film fills), which exist of manageable blocks and the well-known wooden splash bars. When the water is slightly polluted, nowadays synthetic splash fills are used as well.

In order to achieve a maximum heat exchange in the cooling fill, the following points must be considered:

- The cooling water should cover a maximally large surface with respect to the air stream. Therefore, a thin water film and a large exchange surface (m^2 surface per m^3 contents) of the cooling fill are of great importance.
- The speed of the heat exchange is enlarged by a more turbulent air stream (among others a high air speed).
- The rougher the surface of the cooling fill, the more turbulent is the air / water stream.
- A longer stay or contact period of the cooling water in the cooling fill enhances the heat exchange between water and air. Usually, the stay is stretched by enlarging the depth / height of the cooling fill (in the direction of the air).
- A good water distribution above the cooling fill due to a correctly designed water distribution system in the cooling tower.
- An equal distribution of air speed in the cooling fill due to an aerodynamic cooling tower.

Film fill

In the modern synthetic film fill (figure 4b) the water is distributed over a large surface in a thin, levelled film of water. For this type of cooling fill it is necessary to have a good water distribution system. Film fills are available for counter flow as well as for cross flow cooling towers.
Due to the crossed channel structure of the film cooling fill, which usually has a mesh width of 12 to 19 mm. and a building height of 600 to 1500 mm., the air stream is very

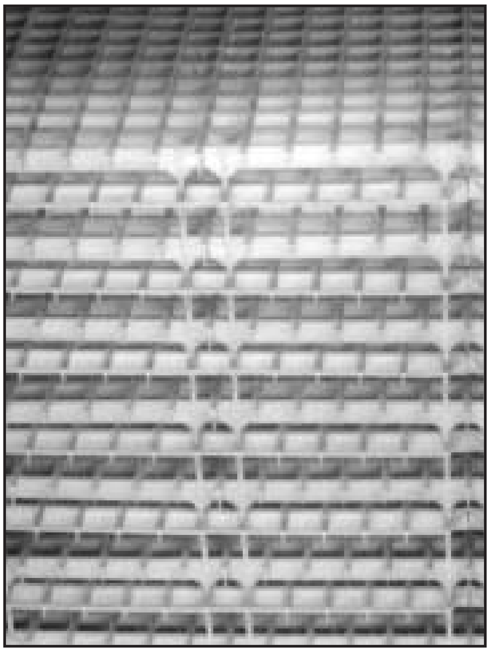


figure 4a. Grid fill

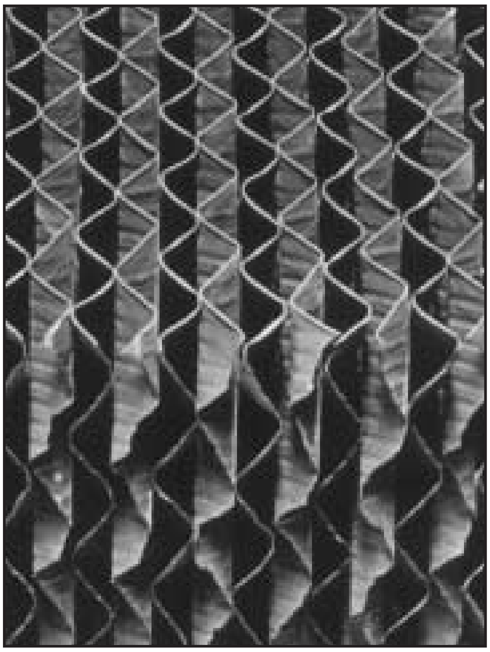


figure 4b. Film fill

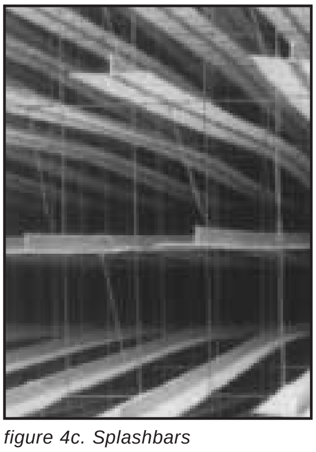


figure 4c. Splashbars

turbulent. Therefore, the film fill is a very efficient cooling fill and it is used frequently. The term ‘efficient’ can be explained in the following way:
A large exchange surface (ca. 250 m^2/m^3) in a compact block shape with a relatively low airside resistance. In other words: a lot of cooling capacities per m3 cooling fill against low energy costs (of the fan).

Bar fill

The dated use of wooden bars in a cooling tower is based on the principle of splashing (figure 5). The bars are mounted in alternating manner having vertical and horizontal distances of e.g. 150 mm. between them. Cooling fill heights up to 8 m. and depths up to 3 m. are no exceptions. The cooling water disperses on every bar so that small water drops emerge. The result of this is a more effective heat exchange surface. The splash effect also lengthens the stay of the cooling water. In general we can say that these splash bars are a moderately efficient cooling fill (a small exchange surface m^2/m^3).
Synthetic splash bars (figure 4c) are a good alternative for the wooden bars in older cooling towers. Using these, the cooling capacity and the efficiency of the cooling tower is usually enlarged. Splash bars are used more frequently in cross flow cooling towers than in counter flow cooling towers or than in a combination of these.

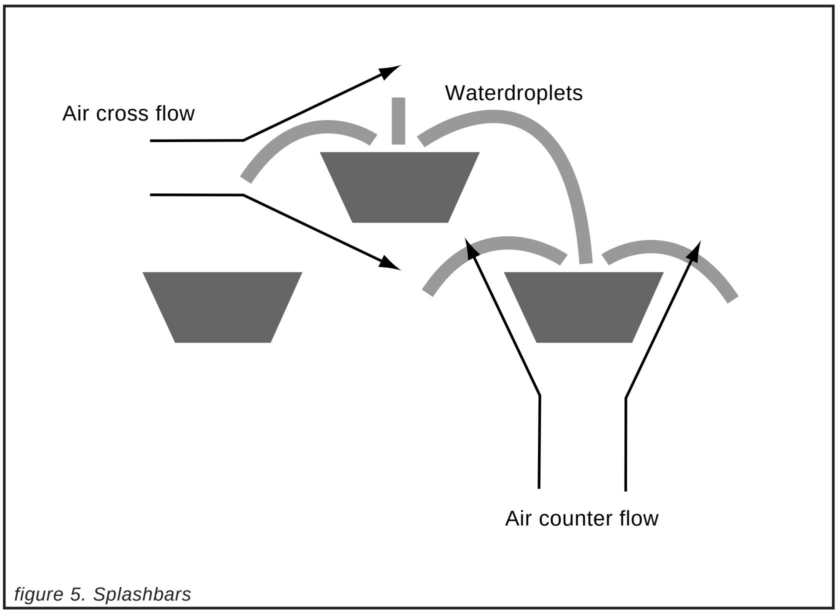


figure 5. Splashbars

Splash fill

The splash fill (figure 4a) is a good alternative of the film fill mentioned above. The mesh width is for example 40 mm. with a vertical splash distance of about 40 mm. The use of the splash fill is based on a combination of the splash effect of the splash bars and a thin water film around the splash surface. The exchange surface is ca. 150 m^2/m^3. Because of the good redistribution of the cooling water of this cooling fill, there is less demand on the water distribution system in the cooling tower. The splash fill is also used for extra redistribution of the water and as a mechanical protective layer on the film fills with a high nozzle pressure. In counter flow cooling towers the overall heights vary from 900 to 1500 mm.
These splash fills are not very frequently used in cross flow cooling towers with bigger cooling fill heights.
It should be clear that the splash fill is less efficient than the film fill, but more efficient than the splash bars. The most important advantage of the splash fill over the film fill is that it is less sensitive for pollution that is due to a lesser quality of the circulating cooling water in the cooling tower.

4.2 Counter flow vs. Cross flow

As already mentioned in section 2.1, counter flow and cross flow cooling towers belong to the category of forced draught cooling towers. The principle of both these forms of building is sketched in a combined drawing (figure 6). The counter flow cooling tower is usually produced with a water distribution system with preferably full- cone nozzles. With the cross flow cooling tower a so-called pressureless water distribution system is usually used, operating by the principles of gravitation. The dispersed water in the counter flow cooling tower necessitates the use of a drift eliminator. This is not always necessary for a cross flow cooling tower. For the air circulation both types of cooling towers use induced draught fans that are placed on top of the cooling tower.

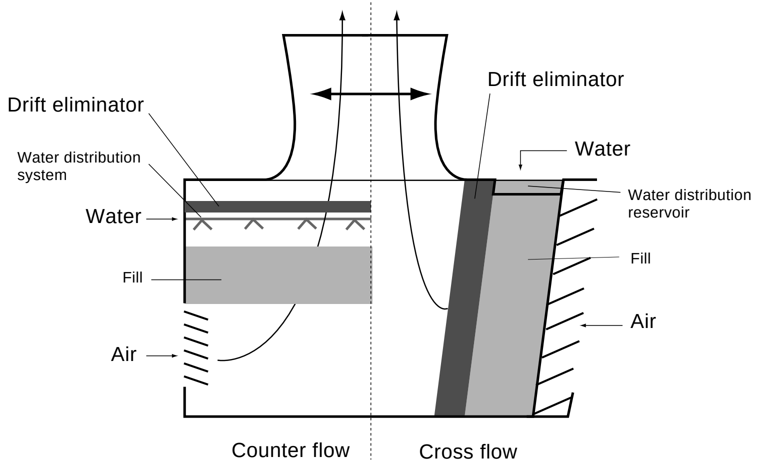


figure 6. Principle counter/cross flow

Counter flow

The heat exchange in a counter flow cooling tower is schematically depicted in figure 7. The cooling fill is divided in 5 imaginary layers:

- Air-sided: In the bottom cooling fill layer the inlet wet bulb temperature Tnb1 increases when ascending. The outlet Tnb of the first layer is the inlet Tnb of the second cooling fill layer etc., until the final Tnb2 is reached.
- Water-sided: In the fifth cooling fill layer the inlet water temperature Tw1 decreases when descending. The outlet wet Tw of the fifth layer is the inlet Tw of the fourth § cooling fill layer etc., until the final Tw2 is reached.

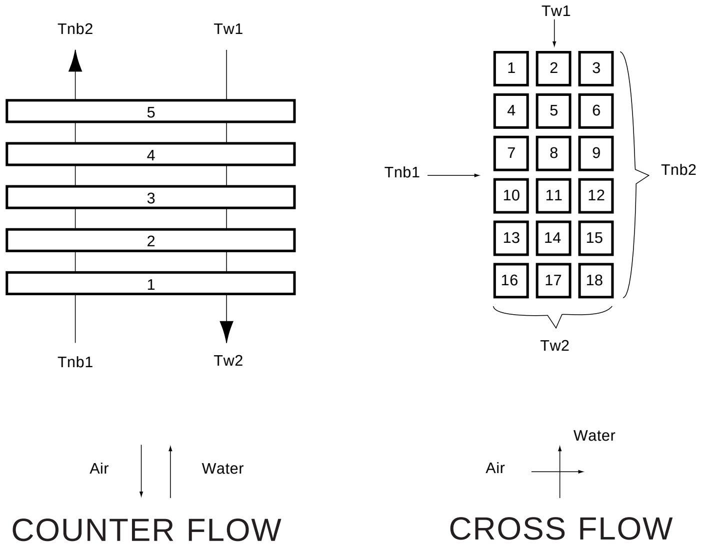


figure 7. Heat transfer principle

Cross flow

For a cross flow cooling tower (figure 7) the heat exchange can be depicted in a similar way. Here we divide the cooling fill in 18 imaginary blocks:

- Air-sided: In the blocks 1-3 the inlet wet bulb temperature Tnb 1 increases. This is also true for the blocks 4-6, 7-9 etc. The final Tnb per horizontal layer (3 blocks) differs. The values of the outlet Tnb of the blocks 3-18 is averaged to Tnb2, the outlet wet bulb temperature of the entire cooling fill.
- Water-sided: When the cooling water with an inlet water temperature Tw1 passed the blocks 1-16, 2-17 and 3-18 in vertical direction, an average can be taken of the water outlet temperature of the blocks 16, 17 and 18, the water outlet temperature Tw2 of the entire cooling fill.

Amplification

- It may be clear that the air- and water-sided heat balance should be in equilibrium in every cooling fill layer or block. So the increase in enthalpy of the air must be equal to the decrease of the heat content of the cooling water. With the help of modern calculation techniques the physical evaporation process in a counter flow or cross flow cooling tower is thus calculated.
- With the principle of the cross flow we may notice that the first block cools the water the most effective, because in here the warmest water comes into contact with the coldest air. Reasoning this way we can say that the water flowing from block 16 is colder than the water flowing from block 17 and 18 respectively. This could be a reason to moisten the cross flow fill asymmetrically on top (more cooling water on the air inlet side of the cooling fill). The blocks 3-18 do not cool the water to the same degree as the blocks 1-16 and 2-17 (in vertical direction). This tells us that it is not always useful to select a deeper cooling fill (air sided). Sometimes, an enlargement of for example 50% of the depth of the cooling fill only raises the cooling capacity with 15%. In vertical direction, on the other hand, it is more useful to choose a higher cooling fill, on the condition that this is not a problem for the whole construction or the internal water economy.

- As a rule the counter flow cooling fill is always more effective than the cross flow cooling fill, because in counter flow less m^3 cooling fill is required (for example 30%) than in cross flow, assuming that the design data and cooling fill characteristics as type and mesh width are the same. Depending on the approach the turning point of the choice between counter flow and cross flow is more closely, as we will explain in a later article. We then will compare the advantages and disadvantages of these two cooling tower types in more depth.

So far, we gave a first theoretical onset in explaining the functioning of the (evaporative) cooling tower. In this chapter, the cooling fill is given extra attention, because this actually is the ‘heart’ of the cooling tower. In the following chapters we will explain the functioning of several other cooling tower components in more detail. In the following article we will try to clarify several misunderstandings concerning the operation and business operation.

5. Dynamic cooling tower functioning

Normally, a cooling tower is selected on one design condition. With this, actually one operation point of the cooling tower is determined, usually the most important one, with a corresponding wet bulb temperature. In order to give an impression of the cooling tower performance beyond this operation point, we need a performance curve (figure 8). Such a curve gives a good indication of the cooling tower functioning in different climatologically circumstances, with fluctuating cooling water temperatures and with a possible variation in cooling water flow. The air flow throughout the cooling tower is assumed to be the same.
Such performance curve immediately shows that the cooling tower is flexibly working equipment. Guided by several questions, we will explain this dynamic operation:

1. Which factor determines the range (delta T) (= the cooling range Tw1-Tw2) of the circulating cooling water in the cooling tower?
In a cooling tower this delta T is always determined by the cooling process. The cooling tower is adjusted to this. In other words, the cooling tower does not determine the size of delta T, but takes this from the cooling process. The cooling tower follows the cooling process and not the other way around. This was a misunderstanding that occurs quite regularly in practice.

2. What is the influence of the approach (Tw2-Tnb) on the size of the required cooling surface?
By the term cooling surface we usually understand the horizontal, wetted surface of the cooling tower. As already mentioned in the first article (chapter 3), it is increasingly difficult for a cooling tower to cool the water with a smaller approach. The smaller the difference between the cooling water outlet temperature and the wet bulb temperature, the bigger the dimensions of the cooling tower should be (see figure 9). For this the water load ($m^3/m^2/h$), the cooling range, the air speed and the wet bulb temperature are assumed to be constant. Obviously, this is also the case with an unvarying choice of the cooling tower and the cooling fill.

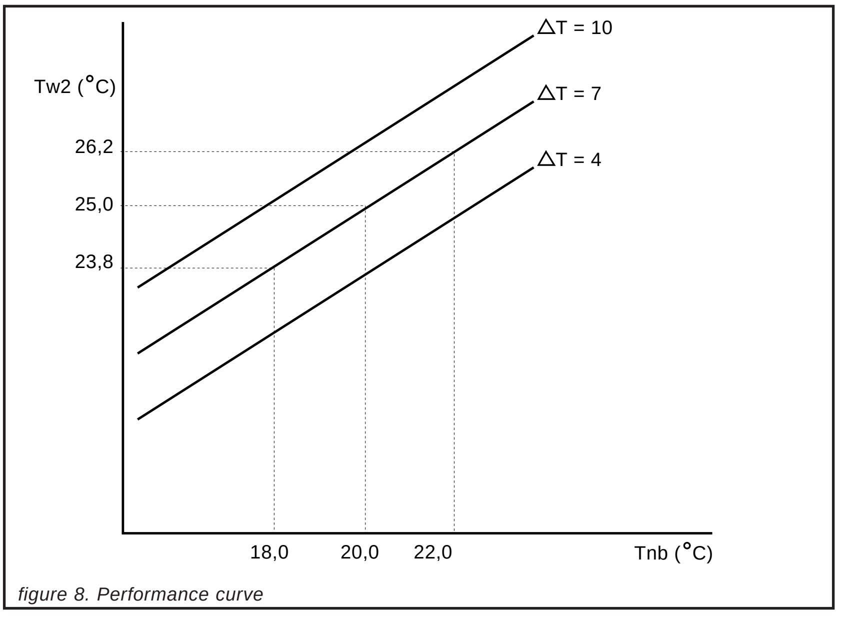


figure 8. Performance curve

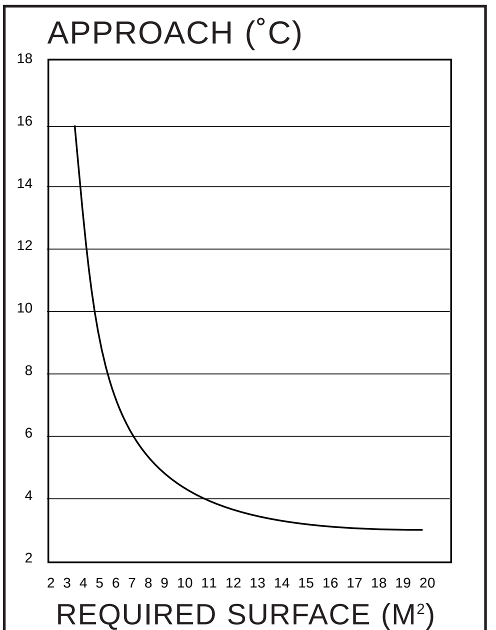


figure 9. Example required wet surface

Example:

approach	[°C]:	8	4
	[%]:	(100)	(50)
cooling tower	[m^2]:	5	10
surface	[%]:	(100)	(200)

From the above example we can conclude that when the approach is divided into two, the required cooling tower surface must be twice as big. This shows us that every increase or decrease in degrees Celsius of the approach is of direct influence on the required cooling tower surface. One needs to be aware of this when selecting a cooling tower. When a higher selection water outlet temperature of the cooling tower is not acceptable, maybe a slight decrease of the wet bulb temperature in the selection is (see question 6). An economical guide value with the selection of a cooling tower is an approach of 4 to 5 °C. With this, we yet again point to the fact that an approach increase of 4 °C with 1 °C to 5 °C results in a decrease of the cooling tower surface of 20%.

3. What happens to the approach (Tw2-Tnb) when the wet bulb temperature changes? The cooling range (delta T) is taken as a constant value. When the wet bulb temperature increases, the cooling water temperature and the outlet temperature will increase as well. The entire cooling range Tw1-Tw2 then changes to a higher temperature. A decrease of the wet bulb temperature, on the other hand, results in a decrease of the entire cooling range. Herewith it is incorrect to suppose that when the wet bulb temperature increases with 1 °C, the cooling range also increases with 1 °C. As a rule of thumb we can assume that when the wet bulb temperature increases with 1 °C the cooling range does so with 0,6 °C. The cooling water outlet temperature then is 0,6 °C higher and the approach is 0,4 °C lower.

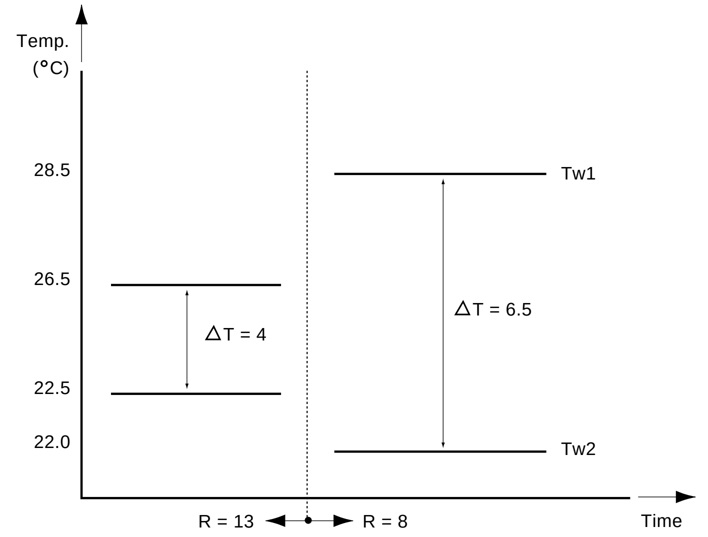


figure 10. Variable waterflow

Example:

Tw1	[°C]:	30,8	32,0	33,2
Cooling range	[°C]:	7,0	7,0	7,0
Tw2	[°C]:	23,8	25,0	26,2
Approach	[°C]:	5,8	5,0	4,2
Tnb	[°C]:	18,0	20,0	22,0
efficiency	[-]:	0,55	0,58	0,63

In spring, autumn and winter the outside temperature, and therefore the wet bulb temperature, usually is lower than in summer. This means that the cooling tower can reach the required outlet temperature most of the year, because then the approach is bigger. Put differently, the cooling tower's dimensions are actually too large for the most of the year, unless the user wants to reach a colder water temperature than the temperature for which the tower is selected.

In the above example it is apparent that the cooling tower works less efficient with a lower wet bulb temperature and somewhat more efficient with a higher wet bulb temperature. With this we assume standard water/air debit proportions in the cooling tower.

4. *What is the influence of a variation in the cooling water debit (with equal cooling load) on the cooling water temperatures?*

As a starting point we take the example given in figure 10. In the starting situation a constant water load (R) of 13 m^3 / m^2 / hr on the cooling tower, a constant wet bulb temperature and a water inlet temperature of 22,5 °C with a corresponding cooling load value of (13*4=) 52 are assumed. When the water load in the cooling tower is suddenly decreased to 8 m^3 / m^2 / hr, the delta T will increase from 4 to 6,5 °C. The cooling load remains constant with a value of (8* 6,5=) 52. It should be noted that the water outlet temperature Tw2 is decreased with 0,5 °C. In this example it is thus possible to obtain somewhat colder water from the cooling tower by lessening the water debit over the cooling tower. It must be remarked that the corresponding increase of the water inlet temperature in the cooling process can be unacceptable. Furthermore, the water distribution system is in many cases not designed for great variation in the cooling water flow.

5. *Is a cooling tower able to cool a larger cooling load than it was originally designed for?*

The answer to this question is yes. This is illustrated by figure 8. In our example a constant wet bulb temperature of 20 °C is chosen. With a delta T of 7 °C, the water outlet temperature Tw2 of the cooling tower is 25,0 °C. When the cooling load of the cooling process increases to a delta T of 10 °C, the water outlet temperature of the cooling tower increases to about 26,7 °C. An increase of the cooling load of 43% results in an increase of the Tw2 of the cooling tower of 1,7 °C. In this example the approach increases from 5 °C with 1,7 °C to 6,7 °C; this is an increase of 34%.

In practice we sometimes hear a remark of the kind: ‘the cooling tower only cools for half its capacity’. The cooling tower then is designed for a capacity of 300 kW, but cools 150 kW. It will now be clear that this is not the responsibility of the cooling tower. It is possible for the cooling tower to cool 300 kW as long as this is indicated by the cooling process or the factory’s adjustment. The only correct way of measuring the functioning of the cooling tower is by means of the cold water temperature (Tw2), or the range (Tw2-Tnb), as already explained in question 2.

6. *What is the preferable wet bulb temperature for the selection of a cooling tower?*

As already mentioned the choice of the wet bulb temperature (Tnb) is important for determining the size of the of the cooling tower surface. For the choice of the cooling tower we start from a selection Tnb that is adjusted to the climatological circumstances of the environment in which the cooling tower is placed. With this we also take the possible recirculation of blown out air of the cooling tower into consideration, because this can increase the Tnb with the air inlet of the cooling tower. For a correct choice of the Tnb it is also important to consider the number of working hours and the part of day in which the cooling tower is used. During winter, the Tnb is as good as similar to the dry bulb temperature (Tdb), but during summer a large difference between these two may exist. With higher surrounding temperatures the relative humidity of air is often lower. For example, an air condition of Tdb = 27 °C with a corresponding R.V. = 60% accords to Tnb = 21 °C.

The graph that is depicted in figure 11 shows the upper and lower limits of the wet bulb temperature in the Netherlands, measured in De Bilt, in the period 1961- 1980 on the basis of 24 hours a day. With the help of this graph we can trace approximately how many hours per year the cooling tower will not reach the desired (selected) cooling water temperature. From this it is clear that an average Tnb of 21 °C is only exceeded in 0,18% of the time looking at one year on a yearly basis. In the table below we give a short survey of the most common Tnb with the corresponding upper limits.

For cooling towers that are situated on the coast of the Netherlands, a wet bulb temperature of 19 °C can be taken. This has to do with the slightly lower outside temperature on the coast. For climate installations in the inland of the Netherlands a Tnb of 20-21 °C is usually taken.

Tnb °C	***Exceeding in the Netherlands %***	***Exceeding in the Netherlands hours/year***
>22	0,08	3
>21	0,18	11
>20	0,47	25
>19	1,00	47
>18	1,96	84

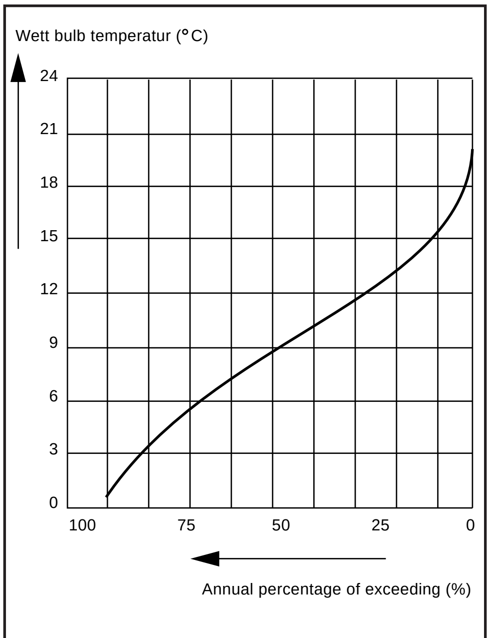


figure 11. Wetbulb versus percentage of exceeding

6. Water consumption

The water consumption of an evaporative cooling tower exists of three components, i.e. evaporative losses, splash and drain water losses.

6.1 Evaporative losses

The operation principle of an evaporative cooling tower is based on the evaporation of a small part of the circulating cooling water. The latent heat exchange between air and water in an evaporative cooing tower is assumed to be 95% maximum. The sensible heat exchange is at least 5 %. The heat content of 1 kg water is 2491 kJ, so per kg. evaporated cooling water 2491 kJ energy is extracted from the circulating cooling water. The evaporated water with corresponding heat is absorbed in the air stream through the cooling tower. With the help of the data given above, it can be deduced that for every kW energy that is discharged an evaporative cooling tower evaporates a max. off 1,37 Kg cooling water per hour (3600/2491) * 0.95= 1.37.

6.2 Splash water losses

The splash water losses of an ‘open’ counter flow evaporative cooling tower are usually divided into splash water losses of drift eliminators (water that is carried by the air stream) and losses through air inlets of the cooling tower.
As a rule of thumb we can state that the water loss of the drift eliminators is about 0,025% of the circulating cooling water debit. The splash water losses through the air inlets can be set from 0 up to 0,8% of the cooling water debit. This mostly depends on the air speeds of the cooling tower’s location and the quality of the air inlet bars. Polacel sets the average splash water losses on 0,04%.

6.3 Drain water losses

Since a cooling tower only evaporates water, the concentration of present salts will increase if no fresh water is added. The amount of water will decrease, causing undesirable chalk sediments.
The amount of drain water is determined with the help of the so called thickening factor. This is the quantity of the salt concentrations in the circulating cooling water in relation to the freshly added water.
A minimal thickening factor of 2 (i=2) is an acceptable starting point when the water quality is good. A thickening factor of 2 tells us that the water quantity that is to be sluiced is equal to the quantity of evaporated water.

6.4 Example of calculation

As an example we use a counter flow evaporative cooling tower with:

- Circulating cooling water debit: 240 [m^3/h]
- Tw1 – Tw2 (Range) : 10 [°C]
- Cooling capacity : 2791 [kW]

What amount of water needs to be supplied? In this example the required amount of supplied water is 2,8 kg/ h per kW cooling capacity.

As a percentage of the circulating cooling water debit this is:

- Evaporative losses	1,593 %
- Splash water losses	0,065 %
- Drain water losses	1,593 %

- Supplied water	3,251 %

As a rough indication we use figure 12. In this figure we can see the average required amount of supplied water as a percentage of the circulating water debit for several delta T's.

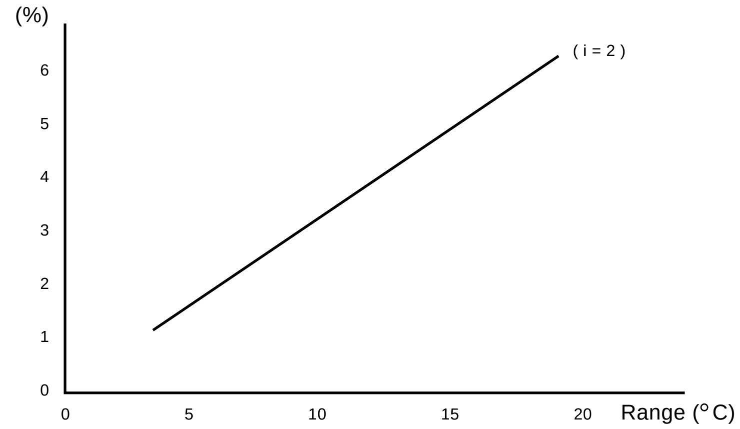


figure 12. Average required suppletion in function of the circulating water

7. Cooling tower regulation

7.1 Why regulating?

Since the capacity of the cooling tower increases when the wet bulb temperature decreases, a regulation is desirable if we want to preserve a fixed cold water temperature.

The cooling capacity of the cooling tower is preferably regulated by the amount of air that flows through the cooling tower and that is generated by a fan. The two speed regulation is a practical and economically attractive solution. By this we understand that the electric motor that activates the cooling tower fan is selected in a two speed model with a fixed revolution speed ratio of 1:2/ 3 or 1:1/ 2. An adjustable two stage thermostat regulates the fan because the thermostat changes on a fixed water outlet temperature of the cooling tower. A good alternative for the two speed electric motor is the more expensive frequency regulated electric motor.

7.2 Regulation of cells

When a cooling tower exists of several separated cells, and each cell has its own fan, it seems to be useful -keeping the issue of energy saving in mind- to switch off one or more fans. The starting point for this is a steady cooling load on the cooling tower.

Example

As an example we take a cooling tower that exists of three separate cells, which have a cooling water debit of 33 m3/ h each. The three cooling tower cells are placed above a shared cold water basin (see figure 13). The total (steady) cooling load on the three cell cooling tower is 3* 384 = 1152 kW and the desirable cold water temperature is 25 °C.

For several indicated wet bulb temperatures the cooling tower is able to cool the cooling water from 35 °C to a Tw2 that is indicated in table 1.

The first of the three cooling cells can be switched off when the other two can give a cooling capacity of 1152/ 2 = 576 kW each. This is the case with a wet bulb temperature of about 10 °C and lower.

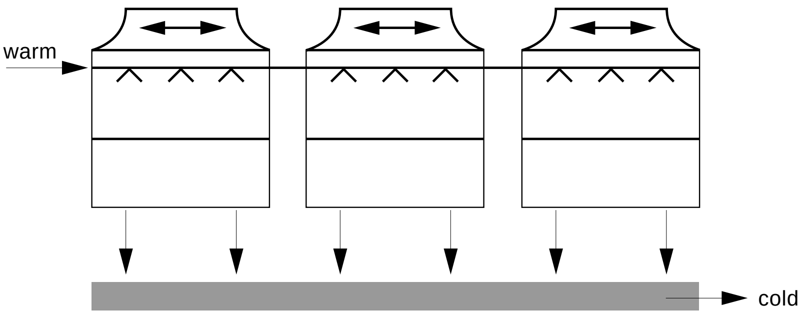


figure 13. Basic arrangement three cooling towers

In the next section it will become clear that it is not very useful to choose a multiple cell cooling tower with a one speed fan / motor for the sake of energy saving. For this, a two speed regulation is definitely preferred.

Then, the energy use will be indicated, using the (limited) example below. The amount of mentioned Tnb hours is chosen on a yearly basis (24 hours a day) (see table 2).

If the used capacity of the three fans on high speed is set on15 kW in total, the energy consumption will be: 1.591* 15 = 23.865 kWh.

7.3 Two speed regulation

For a two speed regulation we assume that the cooling tower exists of three air- sided cells.

Every cooling tower cell has a fan that is directly driven by a two speed electric motor that circles in low revolution speed on 2/ 3 of high revolution speed (think for example about a 1500/ 1000 min-1 electric motor).

This cooling tower is in 2/ 3 revolution speed able to cool the cooling water from 35 °C to a Tw2 indicated in the table for the indicated several wet bulb temperatures. The three cell cooling tower is, with the 2/ 3 revolution speed, able to give a desired cold water temperature of 25 °C with a wet bulb temperature that is lower or equal to 16 °C. For this temperature we could simultaneously switch the three fans back to a lower revolution speed.

The theoretical energy consumption of a 2/ 3 revolution electric motor can be calculated with the help of the capacity formula:
P = (n1/ n2)3; this gives P = (2/ 3)3 = 8/ 27 = 30%

Energy consumption (high revolution speed) = 53* 15 = 795 kWh
Energy consumption (low revolution speed) = 1896* 0,30* 15 = 8.532 kWh
Total 9.327 kWh

The energy saving of the two speed regulation in relation to the on/ off regulation is in this (limited) example:
(23.865 – 9.327 =) 14.538 kWh, this is 61%.

Tw1	35	35	35	35	(°C)
Tw2	25	22	19,5	17	(°C)
Tnb	20	15	10	5	(°C)
Capacity	384	499	595	691	(kW)

Tabel 1.

Tnb °C	***Tnb hours***	***High speed %***	***High speed hours***	***High speed cells***	***Switched off %***	***Switched off hours***	***Switched off cells***
20	25	100	25	3	0	0	0
18	85	88	75	3	12	10	0
16	232	80	186	3	20	46	0
14	415	74	307	3	26	108	0
12	533	69	368	3	31	165	0
10	509	64	326	2	36	183	1
8	499	61	304	2	39	195	1
total	2.298					707	
	(100%)					(31%)	

Tabel 2.

Tw1	35	35	35	35	35	35	(°C)
Tw2	26,6	26,1	25,7	25,3	24,8	24,4	(°C)
Tnb	20	19	18	17	16	15	(°C)

Tabel 3.

Tnb	***Tnb***	***High speed***			***Low speed***			***Switched off***		
°C	hours	%	hours	cells	%	hours	cells	%	hours	cells
20	25	100	25	3	0	0	0	0	0	0
18	85	33	28	1	67	57	2	0	0	0
16	232	0	0	0	98	227	3	2	5	0
14	415	0	0	0	91	378	3	9	37	0
12	533	0	0	0	85	453	3	15	80	0
10	509	0	0	0	80	407	3	20	102	0
8	499	0	0	0	75	374	3	25	125	0
total	2.298		53			1.896			349	
	(100%)		(2%)			(83%)			(15%)	

Tabel 4.

8. Measuring the cooling tower capacity

8.1 Introduction

In order to determine the cooling tower's functioning, we can carry out a 'cooling tower capacity measurement'. For such measurement all the entities that are relevant to the functioning of the cooling tower are being measured.
We carry out these capacity measurements to check whether the supplied cooling tower meets its design capacity. This check is usually carried out with new, bigger cooling towers, for which the manufacturer and the customer decided that the guaranteed values are checked by means of a measurement. Another common reason to carry out a capacity measurement is a stock-taking of the cooling tower's condition. In this case we usually deal with existing (older) cooling towers that are being used for a longer period of time. The user may have changed the process in due course. Possibly, the number of users has changed as well. Also, the functioning of the cooling tower itself may have deteriorated. We then determine the condition of the cooling tower. In order to do so, we consider a correct air movement, a good water distribution, fill pollution etcetera. Often, the user is also discontented with the cold water supply. By means of a capacity measurement we are not only able to pin down the real functioning but also to base conclusions or possible amendments on these.

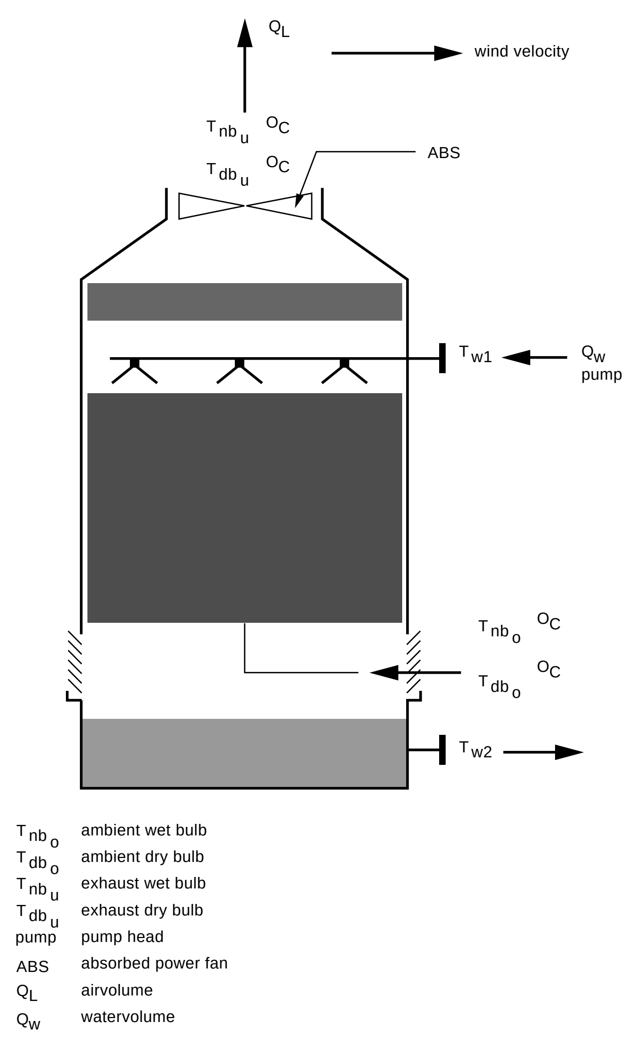


figure 14. Measurement units of a mechanical draft cooling tower

8.2 Measurable entities

In order to determine the cooling tower capacity we measure several entities. These entities together reflect the cooling tower functioning. The following entities are important for the measuring of the cooling tower capacity (see figure 14).

Temperatures

- The water inlet temperature (Tw1) of the water supply that needs to be cooled. This temperature is measured in the supply pipe to the cooling tower or in the water distribution system.

- The water outlet temperature (Tw2) of the cooled water from the cooling tower that goes to the cooling process. This temperature is preferably measured in the drain of the cooling tower because in there the water temperature is average. The influence of the supplied water needs to be fixed because sometimes the water supply cannot be switched off during measuring.

- The wet bulb temperature of the surrounding air of the cooling tower. This temperature is measured before the air inlets of the cooling towers with the help of an Assman psychrometer.

These temperature measurements are preferably registered by a computer so that possible fluctuations in the system can be tracked down.
For this, PT100-recorders are often used because of their stable functioning.

Water flow

In order to fix the water flow (Qw) several methods can be used. Preferable methods are standard measurements such as orifice plate covering (which usually is not very suitable for cooling towers) or measurement by Pitot's tube. The measuring points, then, need to be included in the design of the installation. Points to consider are a straight length of pipes before and after the measuring point and the location of the measuring points.
The advantage of the measurement by Pitot's tube is that the user of the cooling tower can assemble two simple ball- or push cranes per pipe (a free culvert is required), in which the Pitot's tube can be shoved (see figure 15).
Other possible water flow measurements are electro-magnetic or inductive flow methods or turbine meters, which obviously need to be fixed as well.

Boosting of the cooling tower

The water distribution system of the cooling tower requires a certain pump boosting. This boosting is defined as the sum of the pressure of the water distribution and the difference in height between the water inlet connection and the bottom of the air inlet.
In some types of cooling towers the water distribution is without pressure because of the use of the drains and the required pump boosting is the difference in height.

Used capacity of the fan

One of the criteria of the cooling tower functioning is the used electric capacity of the fan (obviously exclusively for a forced draught cooling tower). For this the electric used capacity of the driving motors is measured.
If we want to know the used shaft capacity of the fan, we will have to include the efficiency of the drive in the calculation.

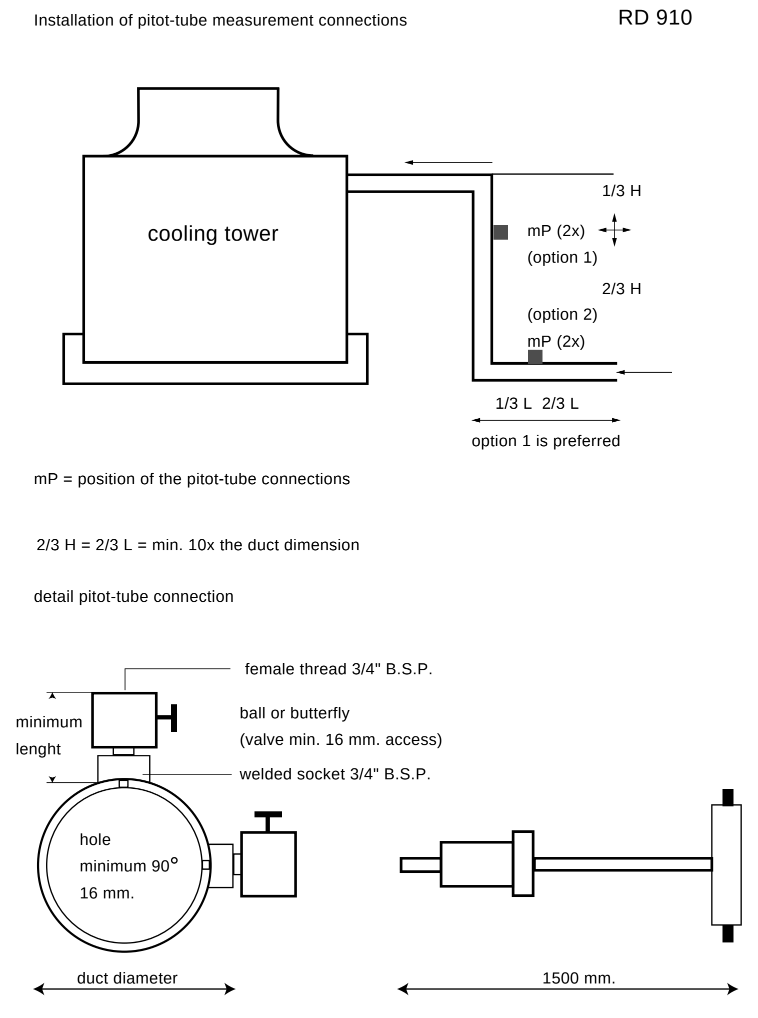


figure 15. Pitot-tube arrangement

Air debit and static boosting

For the inspection of the cooling tower capacity the air flow is in fact of secondary importance, because the user is only interested in the water-side temperatures, capacity and the used electric capacity.

In order to get a good view of the functioning of the cooling tower and the working of the fan, the air flow measurement usually gives a lot of additional information.

The air debit is preferably fastened by a traverse Pitot's tube measurement in the fan cone under the fan. In order to do so, four diagonally placed holes should be drilled in the planes, over which the measurement can be carried out. The term 'traverse' is used for a measurement in which the surface that has to be measured is divided into a number of equal surfaces. For each surface the speed of air in the centre of gravity of this surface is measured.

The result of these measurements can be averaged quite easily. When a Pitot's tube measurement is not possible due to the cooling tower construction, we can also measure the air debit with a so-called winged rado meter. For this we need to measure over this surface over several points.

In addition, the pressure drop over the cooling tower is a useful notion when one wants to check whether the cooling tower is polluted. With this we can also compare the functioning of the fan with the fan curve.

Temperature and humidity of the outlet air

The condition of the air on the outlet of the cooling tower can be recorded with the help of an Assman psychrometer.

These data are especially important for formulating a heat balance. This heath balance is the comparison between the capacity (kW) that is released by the water and the capacity (kW) that is absorbed by the air. These capacities should be equal to one another. For the air sided heath absorption the enthalpy content of the air can be determined from the conditions of the air. However, it is quite hard to measure this, because in the outlet there are drops that disturb the measurement. The heat balance is used as a coarse indication to check whether the measurement is reliable. Deviations up to 20% can be prevented because the air sided capacity is hard to be determined more accurately.

Air speed

The speeds of air near the cooling tower that occur during the measurement need to be measured as well. The speed of air is checked because an air speed that is too high influences the air flow throughout the cooling tower.

8.3 Conditions for a good measurement

Obviously a cooling tower capacity measurement needs to be carried out under certain circumstances. Otherwise the deviating circumstances will influence the accuracy and the reliability of the measurement too much. In order to carry out a capacity measurement of the cooling tower, the following conditions must be met:

- The wet bulb temperature of the surrounding air should not diverge too much from the design. It should preferably lie between +3K and -7K with respect to the design wet bulb.
- The speed of air should not be too high because this influences the air flow throughout the cooling tower. Air speeds higher than 3 m/ sec continuously and sudden gusts of wind higher than 5 m/ sec are considered to be unallowable.
- The water debit over the cooling tower needs to be close to the design. The water distribution is influenced negatively by large deviations of the water flow. Examples of this are bad functioning of the sprinklers, insufficient moistening when the water flow is too low, excessive water on the sides or flooding of the drains when the water flow is too high. During the measurement, the water flow should preferably lie within 10% of the design value. Furthermore, during the measurement the water flow should be as constant as possible. The air flow should not be changed during the measurement by switching the fans. These should be set on

'high' throughout the measurement.

- Further deviating conditions concerning the functioning of the cooling tower should be discussed with the user and before the measurement agreements should be made.
- Obviously, the cooling tower should be checked for its mechanical functioning. This includes the functioning of the nozzles, pollution or damage to the fill and the condition of the fan and the drive.

8.4 Norms for the performance of the cooling tower capacity

Already several norms are drawn up for the execution of the so-called performance of newly realised cooling towers. These norms consider the prerequisites under which the measurement can be carried out, the measuring equipment that should be used and the working proceedings and evaluation techniques of the results.
Some well-known norms are:

- DIN 1947 'Thermal performance acceptance testing of water cooling towers'. This norm is characterised by a very detailed description of prerequisites, working-method and measuring equipment. The measurement is complicated and time-consuming. Measurements by this norm are thus extremely expensive.
- CTI code ATC-105 'Acceptance test code for water cooling towers'. This norm is frequently applied in the USA and is characterised especially by the evaluation of measuring results with the KAV/L-formula.
- VDMA 24419 'Wärmetechnische Abnahmemessungen an zwangsbelufteten standarisierten Nasskühltürmen'.
  This norm is characterised by a simpler approach and method so that it is applicable in practice. A characteristic of this method is the calculation back to Tw2.

Other norms are for example the British Standard (BS 4485-1, 4485-2, 4485-3), the French norms according to AF-NOR (X10-251X10-252X10-253) and the American norms according to ANSI/ ASME (PTC23-1986).

At the moment the European cooling tower manufacturers, in co-operation within Eurovent, are drawing up a completely renewed measuring protocol that can be realised in practice without difficulty.

8.5 Evaluation of the functioning of the cooling tower in relation to the design

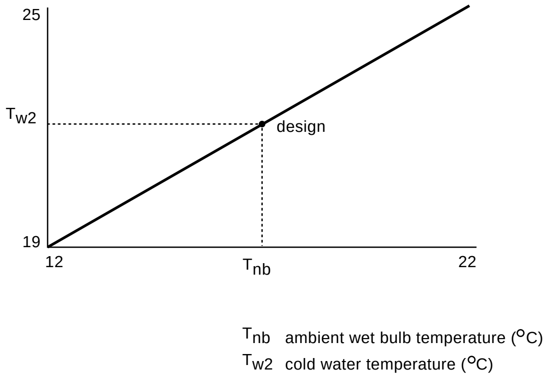
In order to be able to evaluate the measuring results in connection with the design data, the measured values need to be compared to the cooling tower's design data. There are several methods that can be used to evaluate the measurement. Nowadays, the following evaluations are commonly used:
Firstly, the comparison between the measured KAV/L (this is the cooling tower's code) and the design KAV/L. This method, however, is not a practical evaluation for the user's conceptualisation of the cooling tower.
Another frequently used evaluation is the comparison between the design water outlet temperature and the water outlet temperature that is calculated from the measuring data and that the cooling tower reaches in practice. In fact, this method reflects a practical deviation of the present functioning of the cooling tower with respect to the design.

Obviously, calculations by computer enable fast calculation of the measuring values of the design and can easily reflect deviations in the water outlet. However, curves that show the influence of an entity that is to be measured with respect to the Tw2 are still being used. Examples are the two curves displayed in figure 16. By means of these curves one is able, with the help of certain calculation basics, to identify the present water outlet temperature (Tw2-ist). The design data reveal what the water outlet temperature (Tw2-soll) should be. We can also determine a total inaccuracy of the measuring tolerances of the measuring instruments and the uncertainties of fluctuations in the system (*Tw inaccuracy).

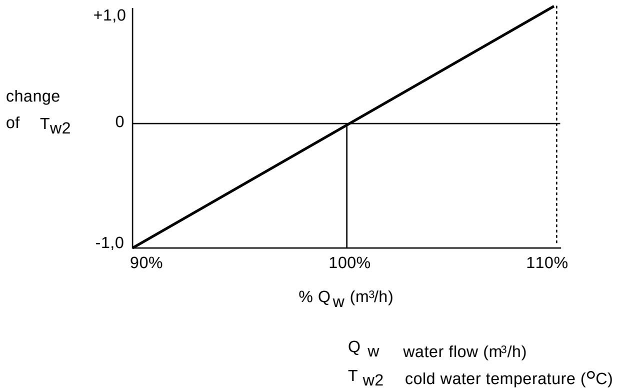
The formula then is:

Tw2-‘soll’ + *Tw inaccuracy ≥ Tw2-‘ist’

In other words, the measured and ‘recalculated’ water outlet temperature should be lower than the design water outlet temperature heightened with the total measuring inaccuracy.
When this condition is met, we could say that at the moment of measuring the cooling tower complies with its design, within the active measuring tolerances.



Correction curve influence T_{nb}



Correction curve influence water flow

figure 16. Examples of correction curves for Tw2

9. Cooling tower components

9.1 Introduction

A cooling tower exists of a number of functioning components that can be found in every cooling tower in a certain form. As an example we consider a mechanical draught counter flow cooling tower. The main components of this cooling tower are:

1. The casing of the cooling tower. The casing is built from e.g. wood, steel or synthetic fabric. The casing may be self-carrying or it may be mounted on a metal frame.

2. The air inlet bars. These should take care that the minimal amount of water spurts through the air inlets and that the air is led into the cooling tower in an optimal way; i.e. the air should not choose the shortest way to the fan. Therefore, the bars are usually directed downwards, so that the air is led further into the cooling tower and streams into the cooling fill more gradually. These bars can be made of synthetic material, steel or wood.

3. The cooling fill. The different types of cooling fills and their functioning are already discussed extensively in part 2 of these series and therefore will not be further discussed here.

4. The water distribution system will be discussed in more detail in this part.

5. The drift eliminator will be discussed in this part.

6. The fan section. For an induced draft cooling tower (see figure 18) this consists of an induced draft fan, driven by an electromotor. For bigger cooling towers the revolution speed of the electro motor needs to be reduced by means of a reduction component. This because of the maximum tip speeds that, for e.g. synthetic fans lie between 50 and 70 m / s., depending on the construction and the choice of materials. This reduction component can exist of a geared motor that drives the fan directly or of a right angle gearbox with an intermediate shaft and a foot mounted motor, where this electromotor usually is outside of the fan stack (see figure 18).

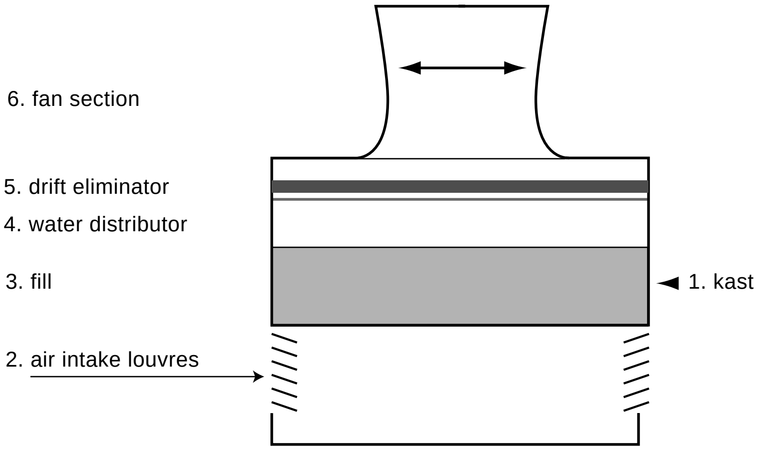


figure 17. Functional cooling tower parts

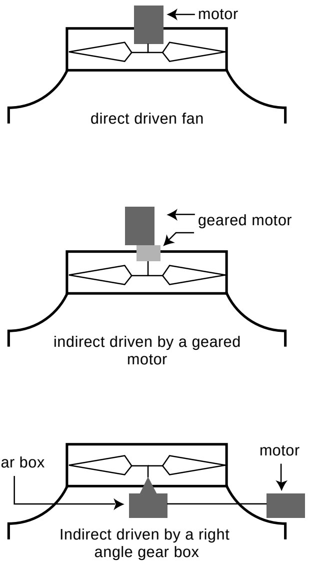


figure 18. Impeller arrangement induced draft

Obviously, a good technical adjustment of these components and the optimal functioning of the cooling tower deserve extra attention.
The following points are taken into consideration:

- The relative proportion of the fan's diameter compared to the drift eliminator's surface and the cooling fill's surface. We choose a large enough fan, so that no extreme air speeds occur in the fan cone while there is a correct air speed in the cooling fill and the drift eliminator (the air speeds in the fan cone vary from 1-15 m / sec).
- The distance between the fan and the drift eliminator should be large enough to prevent local differences in air speed in the drift eliminator.
- The inlet shape of the fan cone and the fan's tip space in the cone are important to the ultimate fan profits and therefore for the energy consumption of the cooling tower as well.
- The nozzles should be distributed in such way that the water streams through the cooling fill instead of along the sides of the casing, for water streaming along the sides will not be in sufficient contact with the drawn-in air. This portion of water will then reduce the cooling capacity.

9.2 The drift eliminator section

Principle of operation

The functioning of a drift eliminator is based on the inertia of a drop of water. Every drift eliminator incorporates a specially constructed curve or turning brim that causes the air to change direction. Because of this change of direction, the drop flies out of the curve and is caught in the drift eliminator's profile. From this principle follows that for the drift eliminators there is a minimal speed for which the drops still fly out of the curve. Also, a drift eliminator is best in catching the drops when the speed is high (the flow-in speeds for a drift eliminator lie between 2 to 4 m/ sec). Below the minimal speed the smaller drops can 'whirl' through the drift eliminator.
Of course there also is a maximum speed for the drift eliminator; this has to do with turbulence and too much resistance.

Drift eliminators for cooling towers are usually produced in synthetic materials like PVC and PP. The reason for this is that these materials are more aerodynamic in design than e.g. wood. For special uses in the process industry, where high temperatures can be reached, they can also be manufactured in stainless steel.
When placing the drift eliminators we make sure that the adjacent eliminators are fitted close together because if slits occur, drops could fall through them.

Horizontal drift eliminator

This type of drift eliminator is used in counter flow cooling towers (see figure 17). The air speed in this drift eliminator is about 2-4 m/ sec. In these drift eliminators the smaller 'whirling' drops are assembled into bigger drops which then fall back into the cooling tower (see figure 19).

Vertical drift eliminator

In this type of drift eliminator the drops are collected in special drains through which they are drained away in downward direction. When constructing this type of drift eliminator we take care that the water can be carried back from the bottom of the drift eliminator to the basin. The air speed of this type of drift eliminator may be between 2 and 8 m/ sec, dependent on the design and construction.

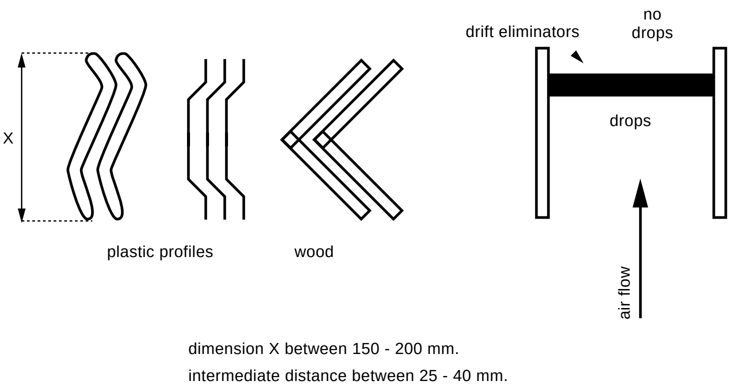


figure 19. Basic principle horizontal drift eliminators

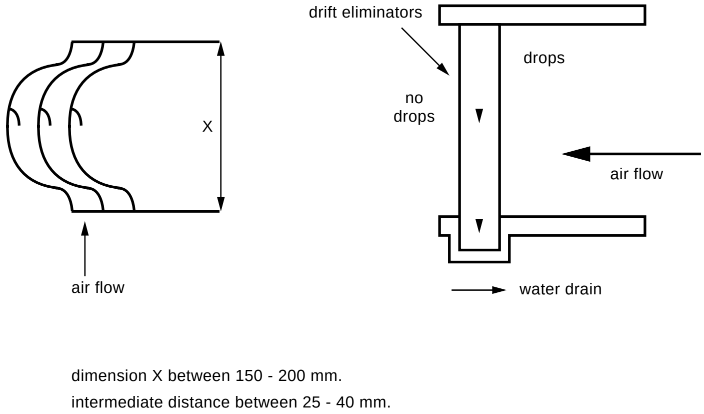


figure 20. Basic principle vertical drift eliminators

9.3 The water distribution system

For the distribution of water in a cooling tower several systems can be used.
A condition for a well-functioning water distribution system is that the water is equally distributed over the cooling fill in order to obtain optimal contact between water and air.

Cross and counter flow cooling towers

In counter flow cooling towers (see figure 18) water distribution systems that disperse the water in a fine drizzle over the fill are always used. Two systems are recognised:

Regular low pressure nozzles

These nozzles are usually carried out according to the full cone principle, in order that the entire surface beneath the nozzle can be wetted. The boosting usually lies between 20 and 50 kPa. The water is distributed by means of a so-called whirl-plate that causes a good spraying result. When the pressure over the nozzle drops too low, the spraying result decreases and the spraying angle will become smaller than that it was designed for. When the pressure over the nozzle is too high, the shape of the full cone nozzle changes to a hollow cone nozzle because the water is hurled out more. The spraying angle usually is 120°; therefore the building height of the part of the nozzles can remain low.

Splash nozzles without pressure

These nozzles operate by the principle of gravity, which causes the water to stream through open drains or half-filled pipes to the spraying points.
The drawback of open drains is that there is the chance of heavy algae growth, which can cause blockages. Through an outlet pipe the water falls on a specially constructed disc, where it diffuses into a hollow spraying result. The advantage of this nozzle is that pressure is not required. The disadvantage is that these nozzles do not form a full cone because of the disc construction. For this reason the fill right beneath the nozzle does not get wet. In order to wet every fill, the nozzles must overlap one another. In general, the water distribution with splash nozzles is not as good as with low pressure nozzles. However, for the bigger cooling towers with somewhat coarser fill types the splash nozzles suffice.

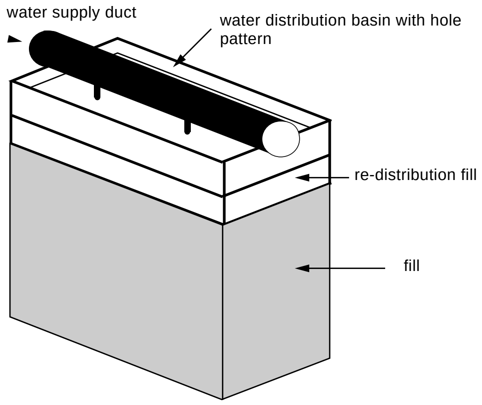


figure 21. Water distribution cross flow cooling towers

9.4 Water distribution system for cross flow cooling towers

In cross flow cooling towers a water distribution system without pressure is most commonly used. In this system the water is distributed over the fill by a distribution basin with a special perforated pattern (see figure 21). These perforations are usually carried out in the form of so-called tops, which are tubes with a fixed outer diameter and varying inner diameters. This enables us to adjust the diameters of the hole in the basin to a design for a different water debit. The large number of tops per m3 already deals with the water distribution quite well. By using a redistribution fill between the water distribution system and the cooling fill an optimal water distribution is realised.

10. Sound of the cooling tower

A cooling tower is always directly connected to the open air because the tower cools using surrounding air. Obviously, completely built-in constructions can be thought of that make use of ‘sucking’ and ‘draining channels’. This, however, is not a normal situation. Moreover, the cooling towers are usually located on a high level on the roofs of buildings or on wasted places on the terrain that may be close to a border.
The modern forced draught cooling tower is provided with a fan with drive, which is a potential sound source. Another source of sound may be the water falling in the cooling tower’s basin. This sound may be annoying because of its high pitch.
In the present nuisance acts and environmental laws increasingly higher demands are set up for cooling towers. In this chapter we will elaborate on the sound-production of cooling towers. We only consider elementary knowledge of a sound-source with a continuum devoid of peeks.

What is sound?

Sound is a vibration of air that is caused by movement of an object. This movement causes differences in pressure that move through the air in the form of vibrations. Human beings sense these vibrations by means of sound.

Humans can sense sound pressures that range from 20μPa (audibility threshold) to 200 Pa (pain threshold). The force of the sound pressure is defined in decibels in the following manner:

$$Lp = 20*\log \frac{P}{P_\circ} \qquad \text{(dB)}$$

P = occurring sound pressure
P_o = sound pressure of the audibility threshold (20uPa)

The value of the sound pressure always needs to be given together with the distance to the source. In our formula the sound pressure of the audibility threshold will be 0 dB and of the pain threshold this will be 140 dB.

Besides the strength (the loudness that can be heard), sound can also be heard in different pitches. These pitches occur because of the speed of changes in pressure; this is called frequency. For very rapid changes, a high frequency, we hear high pitches. For slow changes we hear low pitches; the bas tones. In general, the human ear can hear sound frequencies of 16-20.000 Hz.

A third well-known entity is the sound capacity. This sound capacity is defined analogous to the sound pressure. The difference is that for the sound capacity the starting point is not a pressure, but a capacity (Watt) that is brought into the air.

$$Lw = 10*\log \frac{W}{W_\circ} \qquad \text{(dB)}$$

Lw = Current sound capacity
w0 = Reference sound capacity (10-12 Watt)

This value is independent of the distance and cannot be measured directly with the measuring equipment. The sound capacity is frequently used to characterise the force of a specific sound source.
We can calculate the sound capacity and the sound pressure (on a specific distance) with the help of for example the formula mentioned below. This formula only accounts for a point source in an acoustically free field without influence from the soil or reflections:

$L_w = L_p + 10\log(4*\pi*R^2)$
R = distance to the source, the radius (m).

To work with these entities

In practice, the entities mentioned above are put to use in different ways. In fact, we can determine the sound pressure for all frequencies with a spectrum-analyser. However, this is so extensive that in practice –for the sake of simplicity as well as for

comparison- a number of middle frequencies are used, for which the total spectrum is divided into ranges that are shown in the table below.
Additionally, in order to reflect the sound with a simple number, a filter spectrum that is in accordance with the human audibility can be used. For this spectrum, it is researched which pitches are the most annoying for human beings. The commonly used dB(A) filter is also shown in the table below:

Medium frequency	Band limits	dB(A) filter
63	45 - 90	-26
125	90 - 180	-16
250	180 - 355	-9
500	355 - 710	-3
1000	710 - 1400	0
2000	1400 - 2800	1
4000	2800 - 5600	1
8000	5600 - 11200	-1

From the A-spectrum can be concluded that high pitches especially are experienced as annoying.
In order to determine the value from the dB(A) spectrum, the middle frequency values are added logarithmically according to the formula below:

In practice, the sound meter is provided with a dB(A) filter, so that the dB(A) sound pressure level can be read directly.

$$\begin{aligned} dB(A) = 10\log[10^{\frac{(\text{value - correction value})}{10}} &+ \\ +10^{\frac{(\text{value - correction value})}{10}} &+ \\ +10^{\frac{(\text{value - correction value})}{10}} &+ \\ +........................) \end{aligned}$$

Rules of thumb for calculations with sound

For calculations with sound there are a number of rules of thumb that can be applied quite easily. For several sources counts that the sound pressures of the sources in a measuring point can be added logarithmically using the following formula:

$$L_{ptotal} = 10\log[10^{\frac{(Lp_{source\ 1})}{10}} + 10^{\frac{(Lp_{source\ 2})}{10}} + 10^{\frac{(Lp_{source\ 3})}{10}}...]$$

For several equal sources for the sound pressure increase in the example counts the following:

-For 2 equal sources = 10 log(2) = +3 dB
-For 3 equal sources = 10 log(3) = +5 dB
-For 4 equal sources = 10 log(4) = +6 dB

When the distance from measuring point to source changes, counts theoretically, preserving air- and ground dampening, a resonance of other influences:

$$L_{Pnew} = L_{Pold} - 20\log\left(\frac{\text{distance new}}{\text{distance old}}\right)$$

For rotating machines it counts that when the revolutions are changed, it can be stated (theoretically) that LPnew can become LPold following the following formula:

$$L_{Pnew} = L_{Pold} - 50\log\left(\frac{\text{original speed}}{\text{new speed}}\right)$$

An example for electrically driven machines is:

- 2/3 rotations = +50log(0.67)= -9 dB
- 1/2 rotations = +50log(0.5) = -15 dB

We must note here that for fans more influences are of importance, which we will examine in due course of this booklet.

The sound of the fan and the drive

The fan is a possible sound source. This source is examined thoroughly, in the course of which it is tried to grasp the sound production in an empirical formula:

$$L_{WA} = L_{WAS} + 10\log W + 10\log\frac{U^3}{D}$$

L_{wa} = the sound capacity of the fan dB(A)
L_{was} = the specific sound capacity of the used fan dB(A)
W = the fan capacity kW
U = rotation speed $\frac{m}{sec}$
D = the fan diameter m

From the above we can conclude, concerning an optimal fan-sound, the following:

- The rotation speed of the fan is the most influential factor. This rotation speed is equal to the rotation. A fan having the same amount of air and boosting with a lower rotation speed will therefore produce less sound.
- The diameter also influences the sound production of the fan. A fan with a large diameter with the same design conditions will bring about less sound.
- The used capacity of the fan is also an influence on the sound. Because the capacity is the same as the (air debit) boosting divided by the profit, starting from a given required debit and boosting, only the profit is relevant. Therefore, a fan with a higher profit will produce less sound.

When the above technical design aspects are thoroughly examined but too much sound is produced anyway, we can check the outlet dampers on the cooling tower (see figure 21). The disadvantage of an outlet damper is that it causes additional air- sided resistance, which increases the fan capacity. The production of the sound source (the fan) then increases according to the formula above. It may now be clear that from a technical and economical viewpoint maximising the fan drive by a relatively more expensive fan and one that is as large as possible (with a maximised blade shape and more profit for lower rotation speeds) is preferred.
Good reduced-sound fans are available these days, so that now the drive of the fan plays a part. For a cooling tower drive we pay attention to the electro-motor for electric sound and cooling fan sound. When, on top of that, a rotation-reduction by a gearbox or by a reductor is being used, we also pay attention to sound of the gear wheel. When this happens, a quickly rotating intermediate stage can cause problems. When the sound of the drive is significantly less than the fan sound in practice, a minimal difference of 10 dB is stated and the drive will, as a rule, not cause problems.
It is advisable to compare this for the entire spectrum, so that possible peak sounds in specific frequencies are not annoying.

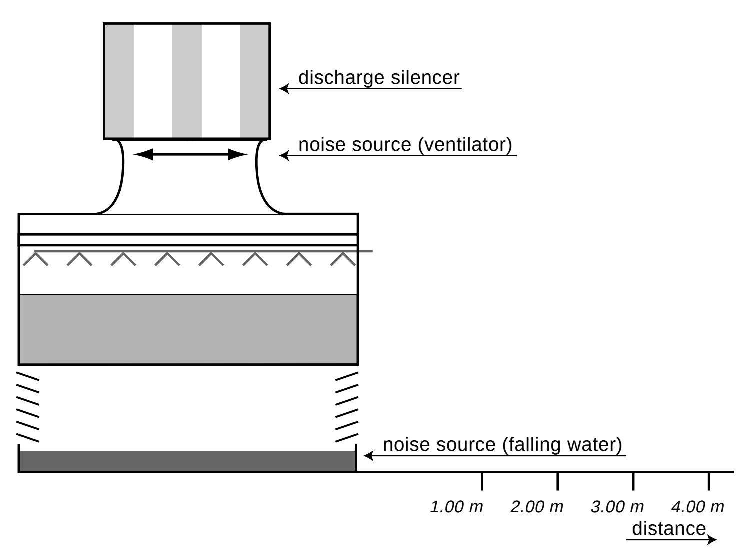


figure 21. Cooling tower with discharge silencer

The sound of falling water

A counter flow cooling tower produces not only fan sound but also splash sound of the water that falls from the cooling fill into the basin. A counter flow cooling tower is explicitly mentioned, because in a cross flow cooling tower the water streams directly from the fill into the basin, an activity which does not produce sound and is therefore one of the advantages of a cross flow cooling tower. For the modern smaller counter flow cooling tower with a film fill (e.g. the Polacel CMC and CMD type) it counts that in general the sound pressure measured in the air inlet bar is about 81-84 dB(A).
The sound production is, however, very much dependent of construction matters as:

- Falling height in the cooling tower;
- Water load over the cooling fill;
- Type of cooling fill and the size of the drops;
- Construction of the basin and the possible water level.

Every manufacturer of cooling towers will give a personally measured sound level that is determined by means of equal cooling tower types. As an example of a sound pressure level that can happen in practice, the following sound pressures are given for a CMC-type cooling tower of about 2.5 *2.5 meter:

Medium frequency	Air intake	Sound pressure level at 10 m.
63	72	50
125	72	50
250	70	48
500	75	53
1000	78	56
2000	77	55
4000	78	56
8000	76	54
dB(A)	83	61

In order to reduce the sound of the falling water, we can place side-wing dampers around the cooling tower or we can place a sound wall at some distance of the cooling tower (see figure 22).
It is also possible to make sound facilities in the basin yourself. Slanting fences or especially constructed, floating mats that catch the drops and break them, causing less splash sound, could be placed in the basin. These dampers can reduce the sound about 10 to 11 dB(A).

Example of a sound-situation

As an example we choose a standard cooling tower of 2.5 * 2.5, with a height of 3.5 meters and with a standard fan. This fan should move 19 m3 / sec air with a boosting of 140 Pa. The used capacity of the fan is then 4.8 kW with a rotation of 720 rpm.

For this fan counts on 10 meters a sound pressure release of:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	61	63	64	62	59	54	48	42	64

If we want to replace this type of fan by a reduced-sound type that can do with less revolutions, we can realise less sound release. For a used capacity of 4.9 Kw and a revolution of 501 rpm this fan suffices. For this fan counts a sound pressure release on 10 meters of:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	53	56	58	56	53	49	42	35	58

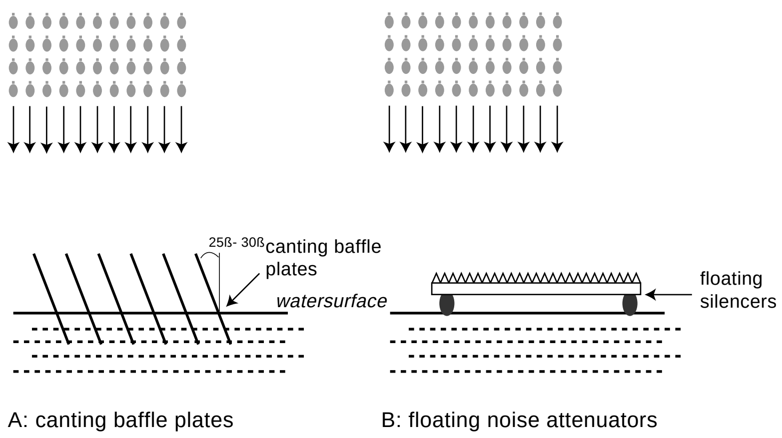


figure 22. Attenuation of the noise by the falling water

For the falling water of this cooling tower counts, as already mentioned in the former section, a sound pressure release on 10 meters of:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	50	50	48	53	56	55	56	54	62

When we consider the total sound pressure level of this cooling tower we will find as a sum of the water sound and the fan sound for the standard situation on 10 meters a sound pressure release of:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	61	63	64	62	61	57	56	54	66

In the situation with a reduced-sound fan counts on 10 meters a sound pressure release of:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	55	57	58	58	58	56	56	54	63,5

Considering the above, we see that especially in the reduced-sound situation the water sound plays a great part. In this situation we could with the help of for example floating dampers (sound attenuators) reduce the sound of falling water to a sound release from 10 meters of:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	50	50	48	48	44	45	45	39	52

For the total sound of the combination reduced-sound fan with dampened water sound, counts on 10 meters:

Hz	63	125	250	500	1000	2000	4000	8000	dB(A)
dB	55	57	58	57	53	50	47	40	59

Conclusion

We find that by the use of a sound-reduced fan and by dampening of the splash water sound a sound reduction from 66 dB(A) to 59 dB(A) of the standard fan and the sound of the water is possible at a distance of 10 meters. Obviously, this situation is just an example. Every situation should be considered separately.