**Task 38**
**Solar Air-Conditioning and Refrigeration**

# Hygienic Aspect of Small Wet Cooling Towers

## A technical report of subtask C

**Date: 17.12.2009**

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**By Harald Moser[1] and Erich Podesser[2]**

**[1] Graz University of Technology**
**Institute of Thermal Engineering**
**Inffeldgasse 25 B**
**A-8010 Graz**

| | |
|---|---|
| **Phone** | **+43 (0)316 873 7304** |
| **Fax** | **+43 316 873 7305** |
| **e-mail** | **harald.moser@tugraz.at** |

**[2] on behalf of AEE - Institut für Nachhaltige Technologien**
**Feldgasse 19**
**A-8200 Gleisdorf**

| | |
|---|---|
| **Phone** | **+43 (0)316 672605** |
| **Fax** | **+43 (0)316 672605** |
| **e-mail** | **erich.podesser@utanet.at** |

# Contents

# 1 Introduction

This chapter shall give a very short description of thermally driven heat pumps especially with respect to the heat rejection sub-system and temperature level. Furthermore different technologies for rejecting the heat to the air are briefly discussed and compared to each other for different climatic conditions.

## 1.1 General

Heat rejection for thermally driven heat pumps is a crucial subsystem especially in solar assisted air conditioning, because:

- The necessary temperature level of the driving heat and the efficiency of the system depends on the temperature level of the heat rejection system significantly
- The amount of heat to be rejected is about twice to triple bigger than the cooling load
- The electrical energy consumption as well as the initial and operating costs of the heat rejection system are significantly high

In order to minimize the temperature level of the heat rejection wet cooling towers can be used. As these systems bring the air and cooling water into direct contact hygienic problems can occur. This leads to a high maintenance effort and operational costs and to legislative restrictions.

This report focuses on the heat rejection system for small thermally driven heat pumps. It describes in a comprehensive way the potential, operation and design criteria as well as hygienic aspects of wet cooling towers. Furthermore possible solutions to overcome the drawback of the poor hygienic conditions of wet cooling towers are discussed.

This report is structured in 6 chapters. Chapter 1 gives a very shot overview on available heat rejection technologies for thermally driven heat pumps. In Chapter 2 the special needs of small scale wet cooling towers are discussed and Chapter 3 describes a calculation procedure for a wet cooling tower which can be used for commissioning optimization purpose. Chapter 4 is focused on Legionella in small scale wet cooling towers and Chapter 5 describes measures to avoid uncontrolled Legionella multiplication especially using UV-light and silver-copper ionisation. Chapter 6 summarizes the report content and gives short conclusions.

## 1.2 Thermally Driven Heat Pumps

Neglecting the electrical (mechanical) energy input a thermally driven heat pump (THP) for cooling purpose is characterized only by heat flows at three temperature levels:

- at high temperature level the driving heat ($Q_{DRV}$) is taken up,
- at medium temperature level the waste heat ($Q_{HRJ}$) of the process is rejected, and
- at low temperature level the cooling load ($Q_{COL}$) is taken up.

Due to energy conservation the amount of heat which has to be rejected at medium temperature level has to be the driving heat plus the cooling load (compare Figure 1-1).

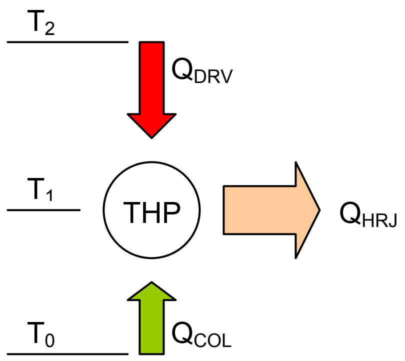



*Figure 1-1: Sketch of heat flows and temperature levels for a thermally driven heat pump*

The "Coefficient of Performance" for cooling ($COP_C$) is defined as shown in Eq. 1 (if the mechanical energy can be neglected). It can be easily shown, that the amount of heat which has to be rejected ($Q_{HRJ}$) per cooling capacity ($Q_{COL}$) is directly dependent on the $COP_C$ (compare Eq. 2)

$$COP_C = \frac{Q_{COL}}{Q_{DRV}} \qquad \textit{Eq. 1}$$

$$\frac{Q_{HRJ}}{Q_{COL}} = 1 + \frac{1}{COP_C} \qquad \textit{Eq. 2}$$

For different technologies (ad- or absorption), process configurations and working pairs (e.g. $H_2O$/LiBr or $NH_3$/$H_2O$) of thermally driven heat pumps the COP of a real application varies depending on the three temperature levels. Furthermore the temperature level of the driving heat has to be at a certain minimum level, depending on the temperature level of the cooling load and heat rejection.

However, in order to estimated the relevance of the temperature level of the heat rejection system a theoretical thermodynamic approach can be used. In terms of energy conversion a thermally driven heat pump combines two cycles, a power generation and a heat pump cycle. Using the Carnot efficiency of these cycles the theoretical possible efficiency of the thermally driven heat pump can be calculated using the three temperature levels mentioned above.

In Figure 1-2 the two Carnot cycles for a thermally driven heat pump are shown. The cycle on the left hand side generates the work to drive the heat pump cycle on the right hand side.

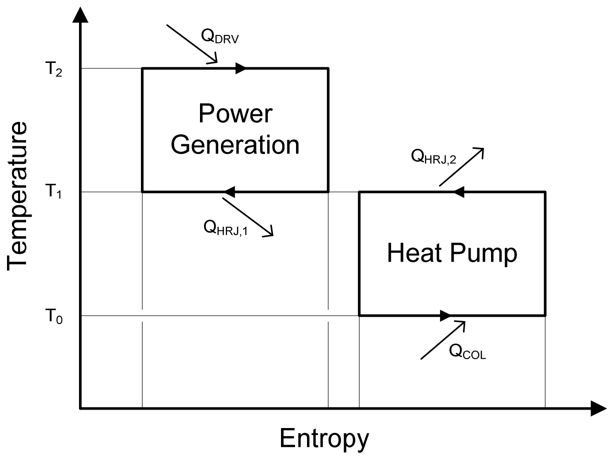



*Figure 1-2*: *Carnot cycles of a thermally driven heat pump*

Acc. to Eq. 3 the theoretical COP of the Carnot process for cooling of a thermally driven heat pump can be calculated.

$$COP_{th,C} = \eta_{PG} \cdot \varepsilon_{HP} = \frac{(T_2 - T_1)}{T_2} \cdot \frac{T_0}{(T_1 - T_0)} \qquad \textit{Eq. 3}$$

Evaluating Eq. 3 using different temperature levels for heat rejection and constant temperature levels of the driving heat $T_2$ = 80°C and of the cooling load $T_0$ = 5°C leads to a characteristic shown in Figure 1-3.

The Carnot-efficiency shows, what is thermodynamically possible. A real technical solution will be far below this value. Thus a further line has been drawn in Figure 1-3 which represents 40% of the Carnot efficiency ($COP_{th,C,40\%}$). The 40%-value has been chosen arbitrarily but the results represent approximately the performance of real NH3/H2O AHP-applications for a temperature level of the heat rejection of approx. 30°C. The $COP_{th}$ and $COP_{th,C,40\%}$ show a strong dependency on the temperature level of the heat rejection system, e.g. the $COP_{th,C,40\%}$ is above 0.6 for a heat rejection temperature of 30°C and decreases below 0.4 for 40°C.

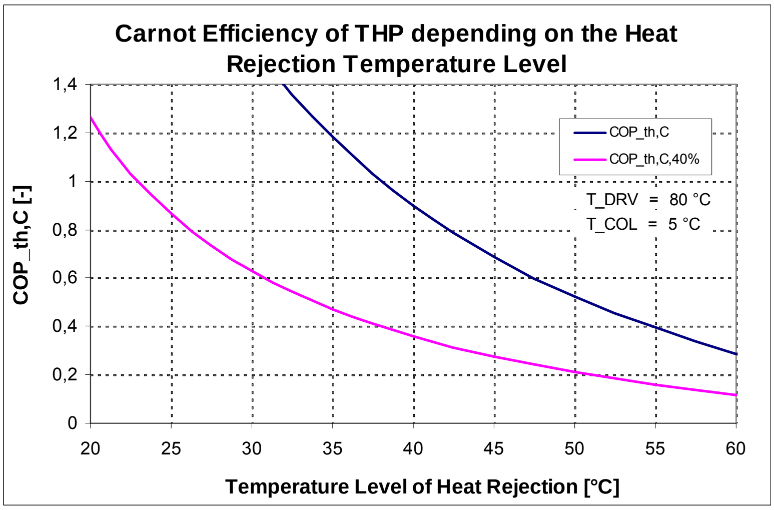



*Figure 1-3: Carnot efficiency for different temperature levels of the heat rejection system ($T_{DRV}$=80°C, $T_{COL}$=5°C)*

For the calculation of the Carnot-efficiency represented in Figure 1-3 the temperature level of the driving heat was constant. Operating a real thermally driven heat pump a minimum temperature level for the generator is required. E.g. in an Absorption Heat Pump (AHP) a certain temperature level is needed in order to be able to evaporate the rich solution in the generator. This temperature level is generally dependant on the medium and low temperature level.

In order to discuss this dependence thermodynamic calculation of a AHP with the working pair NH3/H2O has been set up. In Figure 1-4 left the result for the theoretical minimum temperature level in the generator, were the evaporation of the rich solution starts is shown. In order to be able to evaporate a certain portion of the rich solution the temperature level of the driving heat has to be higher than this theoretical minimum. In Figure 1-4 right typical temperature levels for NH3/H2O-AHP are shown.

The shown figures and values should not be treated as assured absolute values for real applications but as theoretical approach in order to show the general tendency of the heat rejection temperature level to the driving heat temperature level.

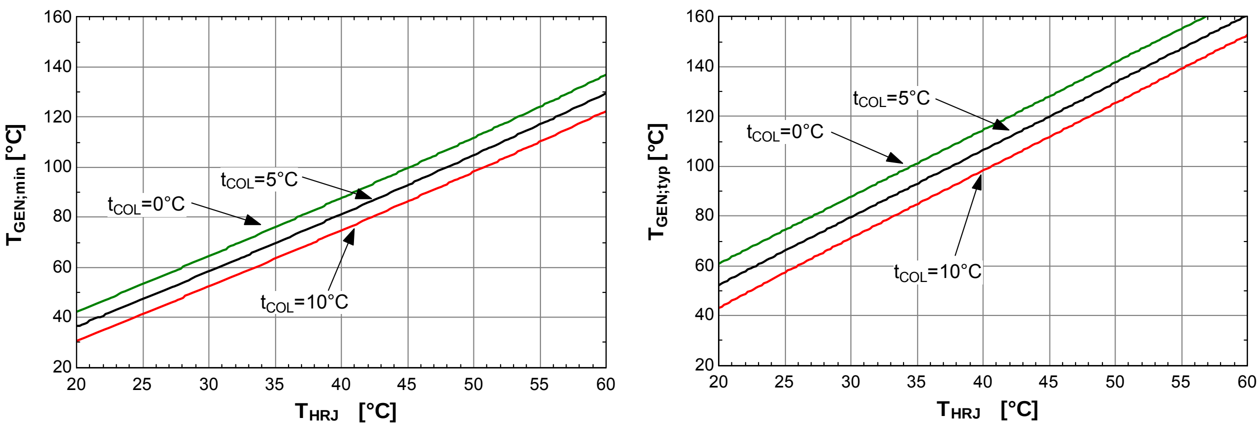



*Figure 1-4: Thermodynamic calculation of the minimum (left) and a typical (right) temperature level of driving heat depending on heat rejection temperature level.*

In conclusion it can be seen from Figure 1-4, that the temperature level of the driving heat has to be increased with increasing heat rejection temperature level significantly. For a low temperature heat source of 5°C and a heat rejection temperature of 30°C the minimum temperature level of the driving heat is at approx. 60°C. If the heat rejection temperature increases to 50°C the minimum driving temperature level has to be increased to approx. 105°C as well.

In Figure 1-5 the efficiency of different solar collectors at varying working temperature levels are shown (Heß, 2007). The efficiency of standard collectors decreases dramatically with increasing working temperature. This effect underlines the need of low heat rejection temperature levels to enable as low driving temperature levels as possible, standard flat-plate collectors and increase system efficiency.

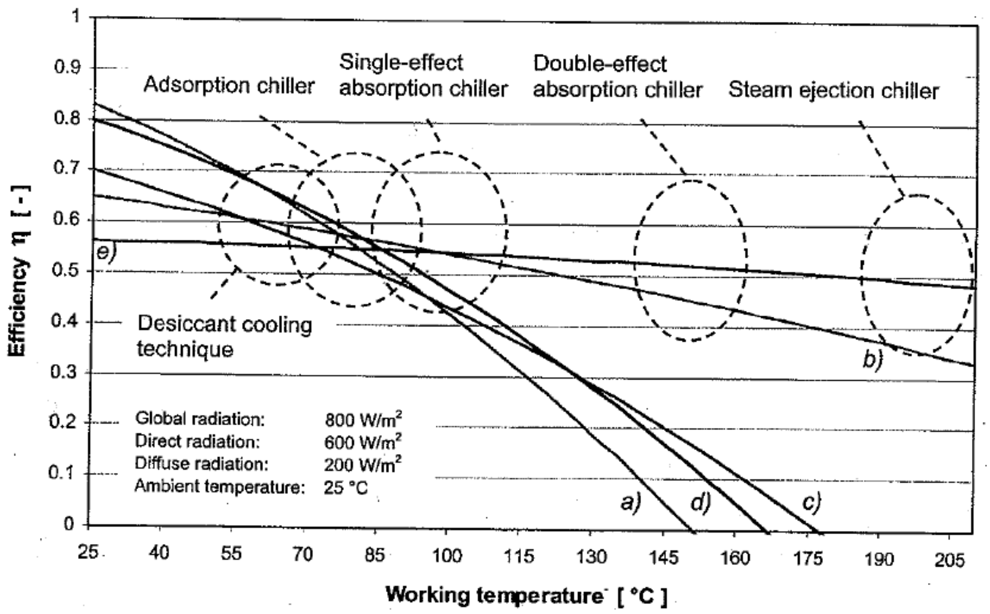



*Figure 3: Comparison of different collectors at 800 W/m². a) Single glazed flat-plate with AR, b) Evacuated tube collector of the Sydney type, c) CPC flat-plate with Teflon foil, d) Flat-plate with double AR-glazing and inert gas filling, e) Small parabolic trough (under development; only the fraction of direct radiation = 600 W/m² can be used). The values are for normal irradiance and refer to the aperture area.*

*Figure 1-5: Comparison of the efficiency of different solar collectors designs at varying working temperature levels. (Heß, 2007)*

Note: Dealing with solar cooling applications one important factor is the part load operation. In other words: what cooling capacity can be achieved at certain temperature levels of the heat sink and the heat sources. By the use of different assumptions (e.g. that the mass flow through the solutions pump is constant) a “characteristic equation” can be derived. This equation brings together in a linear correlation the cooling load ($Q_{COL}$) and a function of the temperature levels ($\Delta\Delta t$) in the four main components (Genarator, Absorber, Condenser and Evaporator) of an AHP. A detailed description of this correlation can be found in Ziegler (1997). Evaluating the temperature level of the heat rejection system it can be concluded, that if the heat rejection temperature increases the cooling capacity of an AHP will decrease significantly.

## 1.3 Comparison of Heat Rejection Technologies

As discussed the temperature level of the heat rejection system should be as low as possible in order to reduce the necessary temperature level of the driving heat and increase the system efficiency and capacity.

Generally different heat sinks are possible to reject the heat, e.g. air, ground or water. While the use of ground and water depends strongly on the local conditions air is available for almost all applications.

For rejection of heat to the ambient air in principle two types of systems are considered, open cooling towers (or wet cooling towers) and closed cooling towers or (dry coolers). As a combination of these adiabatic pre-cooling of the air in e dry cooler and hybrid cooling towers should be mentioned.

The main difference between these technologies is that in the dry cooler the cooling water rejects the heats to the air via a heat exchanger und in wet cooling towers the cooling water is sprayed into the air and a direct heat and mass transfer takes place. Thus in dry coolers only sensible heat and in wet cooling towers mainly latent heat is exchanged.

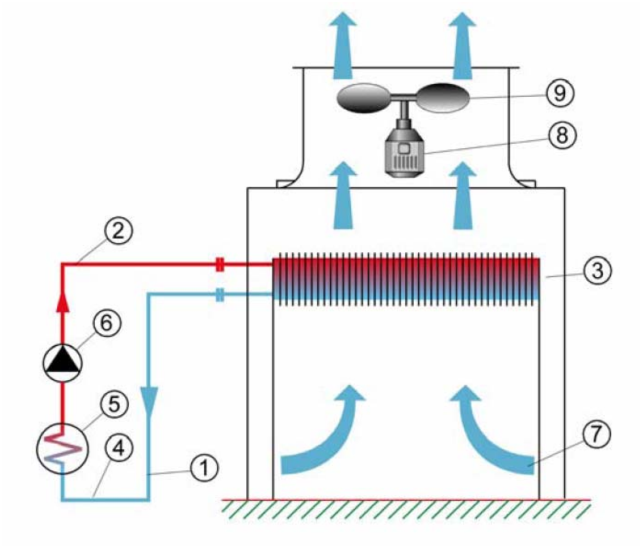
### 1.3.1 Dry Cooler

Dry coolers consist generally of finned heat exchangers (air to water), fans and a casing. The water circulates in a closed circuit and by passing ambient air over the finned surfaces the heat is rejected to the air (compare Figure 1-6).

With air-cooled heat exchangers, it is not possible to cool the medium below the ambient dry bulb temperature. In this case the approach temperature between the medium outlet temperature and the inlet temperature of the dry air depends mainly on the size and capacity of the dry cooler - typical values of the approach temperatures are 5 to 9 K (SWKI, 2003).

Dry coolers are often used for cooling refrigerants, oils or water/glycol mixtures. Compared to wet cooling towers they have lower operational and maintenance cost and because the cooling water comes not in direct contact to the air they have no hygienic problems or legionnaires risk. Further advantages are low noise, easy installation and a low profile.

The main disadvantages compared to wet cooling towers are higher re-cooling temperatures much higher investment costs, energy consumption and space requirement.




1. cooling circuit
2. inlet flow
3. cooling element (heat exchanger)
4. return flow
5. heat source
6. circulating pump
7. cooling air
8. fan drive
9. fan

*Figure 1-6: Sketch of a dry cooler (SWKI, 2003)*

Note: One alternative of dry-cooler is the adiabatic pre-cooling of the air upstream the heat exchanger in case of high ambient air temperatures. In that case water is sprayed into the air inlet stream and should evaporate before it arrives at the heat exchanger surface. Thus the air is cooled down near the wet bulb temperature and the dry-cooler can be operated at lower operating temperatures. The spraying should only take place at limited operating hours when it is needed due to the operating conditions, because the excessive use can lead to increased corrosion and the formation limestone at the heat exchanger.

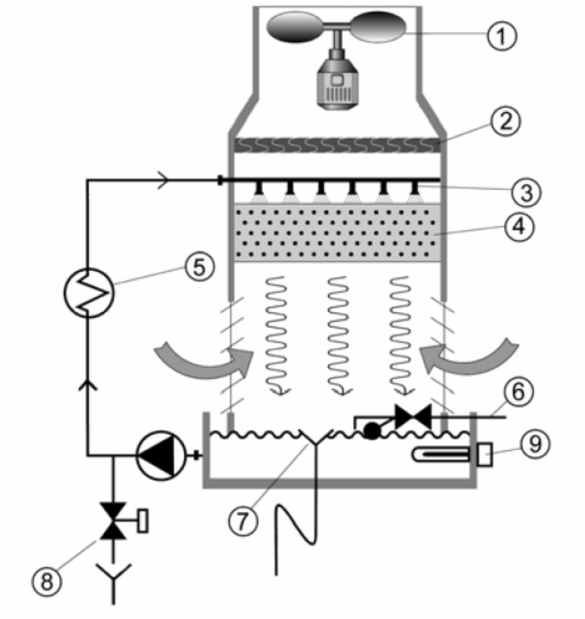
### 1.3.2 Wet Cooling Towers

Wet cooling towers (open loop evaporative cooling tower) consists of a shell containing packing/fill material with a large surface area. Nozzles arranged above the packing, spray and distribute the cooling water onto the packing. The water trickles through the packing into a basin from which it is pumped back to the condenser. The water is cooled by air, drawn or blown through the packing by means of a fan. The air flow, which is either in counter flow or cross flow to the water flow, causes some of the water to evaporate, thus latent heat, is exchanged from the water to the air.

The evaporated water is continuously replenished by make-up water. Due to the fact, that evaporation also increases the concentration of the dissolved solids in the cooling water, blow down of the cooling water is necessary.

In wet cooling towers the wet-bulb temperature determines the degree of cooling and thus cooling below the ambient dry bulb temperature is possible. The characteristic approach temperature, which is the difference between the water outlet temperature and the ambient wet-bulb temperature, of wet cooling towers lies between 4 to 8ºK (SWKI, 2003).

Compared to dry coolers wet cooling towers, are able to cool the cooling water to lower temperature level, requires less space and have much lower investment costs. The main disadvantages of wet cooling towers are hygienic problems, water consumption and high maintenance effort.




1. fan with drive
2. drift eliminator
3. spray nozzels
4. trickle packing
5. heat source
6. float valve and fresh water inlet
7. overflow
8. bleed off
9. frost protection heating

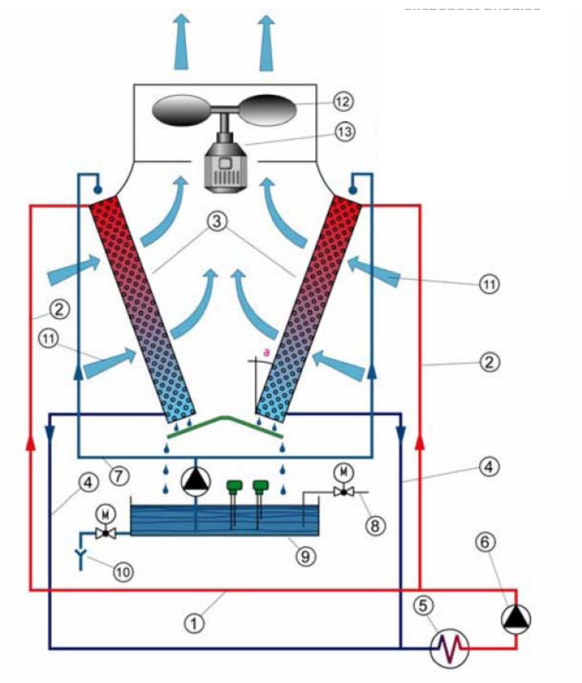
*Figure 1-7: Sketch of a wet cooling tower (Jaeggi, [http://www.guentner.ch/pdfs/Evaluation of Aircooled Cooling Systems.pdf](http://www.guentner.ch/pdfs/Evaluation of Aircooled Cooling Systems.pdf), 26.03.2009)*

### 1.3.3 Hybrid

Hybrid dry cooler combines the two methods of dry cooling and evaporative cooling. The cooling water is circulated by a pump in a closed primary cooling circuit from the heat source to cross current air to water heat exchanger.

In cool weather conditions this process cools down the cooling water sufficiently and the hybrid cooler operates like a dry cooler. At high air temperatures the hybrid cooler uses the principle of evaporative cooling in order to achieve lower cooling temperatures. Therefore a pump circulates water from a basin to the cooling element where the water flows back via the finned surface of the air to water heat exchanger. The air flowing past the heat exchanger causes the water to evaporate on the fin surface, and takes the heat from the fins.

Comparing a hybrid dry cooler to common dry cooler it has the advantage to use evaporative cooling at hot whether conditions and therefore cools down the cooling water below the dry bulb temperature, it has a higher capacity and lower energy consumption. On the other side the hybrid dry cooler has higher investment costs, maintenance effort and water consumption. Furthermore, hygienic measures have to be taken as for the wet cooling tower.



1. primary cooling circuit
2. inlet flow
3. finned tube heat exchanger
4. return flow
5. heat source
6. circulating pump
7. deluging water circuit
8. make up water inlet
9. water collector
10. bleed off
11. cooling air
12. fan
13. fan drive

*Figure 1-8: Sketch of a hybrid dry cooling system (Jaeggi, [http://www.guentner.ch/pdfs/Evaluation of Aircooled Cooling Systems.pdf](http://www.guentner.ch/pdfs/Evaluation of Aircooled Cooling Systems.pdf), 26.03.2009)*

## 1.4 Climatic Conditions

Wet cooling towers are able to cool down the cooling water near the wet bulb temperature and dry cooler refer to the dry air temperature. The difference between these temperatures depends on the geographic location of the plant or the climatic conditions respectively.

For comparison of the climatic conditions four different locations have been chosen:

- Frankfurt, Germany: represents a moderate, Central European climate.
- Stockholm, Sweden: represents a moderate, Northern European climate.
- Madird, Spain: represents a Mediterranean, continental climate with high temperatures during summer but moderate air humidity.
- Palermo, Italy: represents Mediterranean coastal climates with high humidity and temperature during summer

Using the commercial database Meteonorm® (Meteotest, 2003) it is possible to calculate on hourly bases climate date for one year for a certain site, e.g. for the dry and wet bulb temperature. This is shown in Figure 1-9 (left) for Frankfurt. By sorting these data according the dry bulb temperature the annual temperature distribution curves can be drawn as shown in Figure 1-9 (right). The dots represent the wet bulb temperatures dedicated to the dry bulb temperatures.

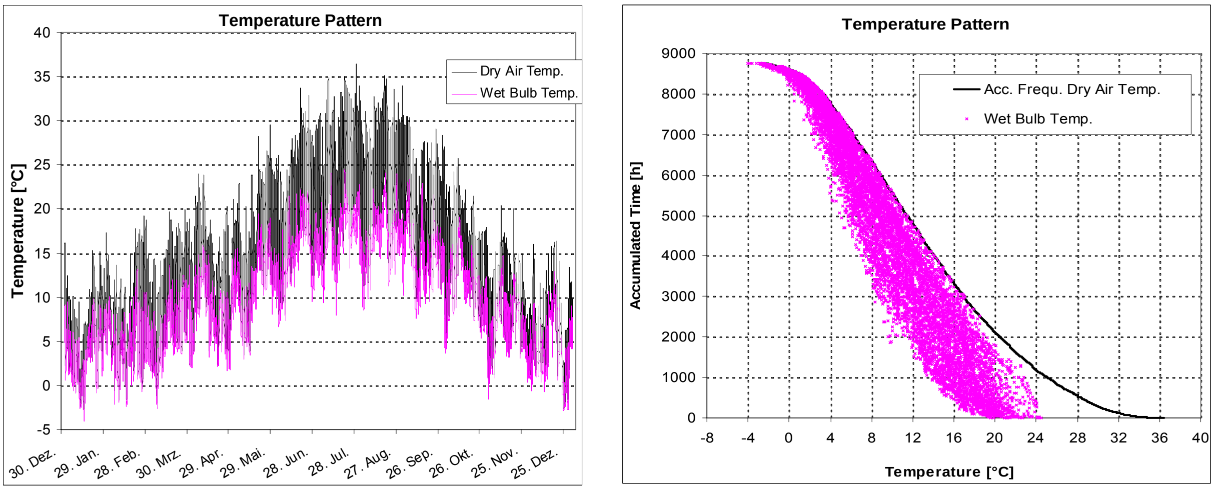



*Figure 1-9: Dry and wet bulb temperature on hourly basis for one year of Frankfurt (left) and annual temperature distribution curve for dry bulb temperature with dedicated wet bulb temperatures (right).*

In Figure 1-10 and Figure 1-11 the lower section of this diagram is shown for four different sites and a further line (blue) is drawn, which represents the annual temperature distribution curve of the wet bulb temperature. Comparing the temperature distribution of the dry air and wet bulb temperature for Frankfurt Figure 1-10, left) to each other it can be seen, that the dry air temperature is approx. 940 hours above 20°C and the wet bulb temperature only approx. 170 hours. The mean temperature difference between dry and wet bulb temperature is ca. 7.4 K when the cooler operates only at dry air temperature above 20°C.

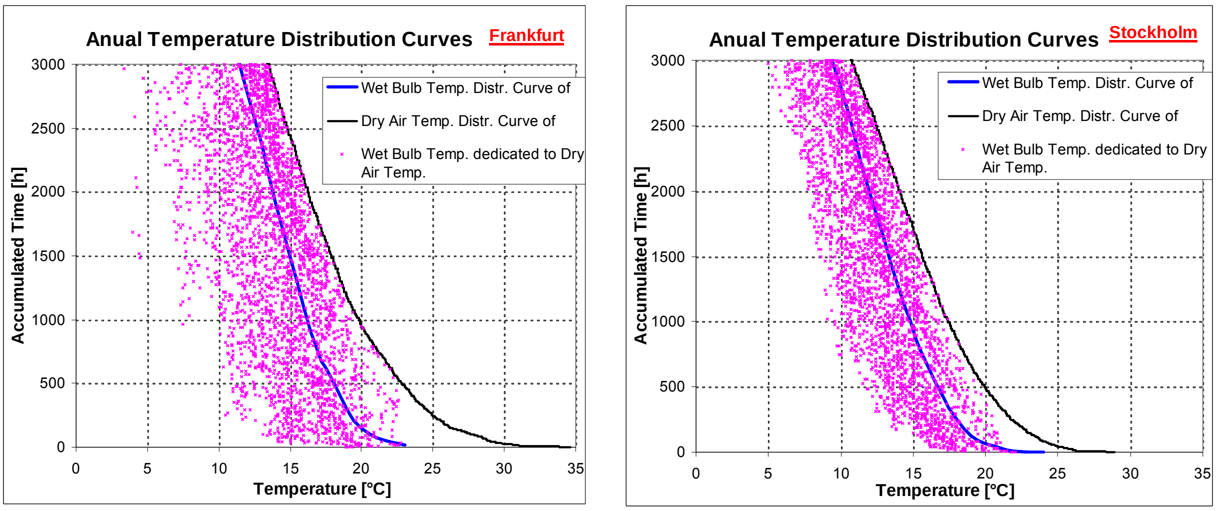
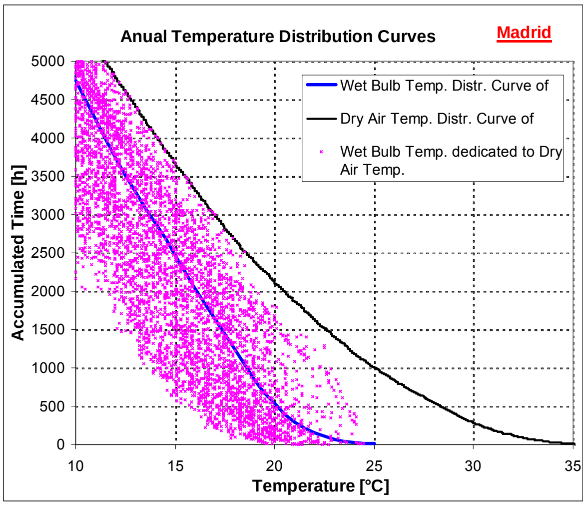



*Figure 1-10: Annual dry air temperature distribution curve with dedicated wet bulb temperatures and annual wet bulb temperature distribution curve for Frankfurt (left) and Stockholm (right)*



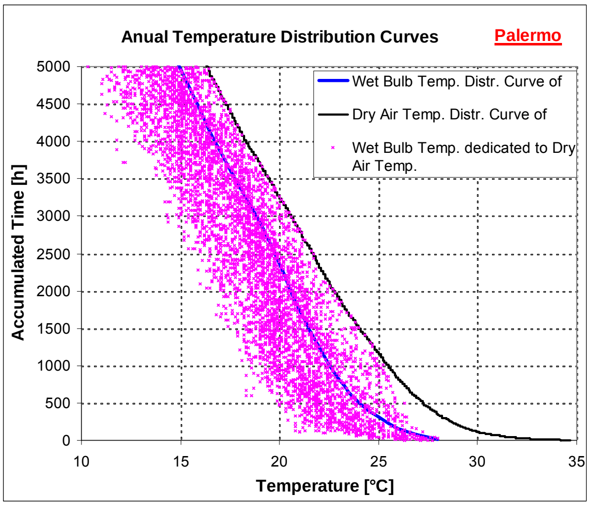




*Figure 1-11: Annual dry air temperature distribution curve with dedicated wet bulb temperatures and annual wet bulb temperature distribution curve for Madrid (left) and Palermo (right)*

Table 1-1 shows an overview of the operating hours and the maximum and mean temperature levels for different sites for dry cooler and wet cooling tower assuming that the cooler is in operation when the dry air temperature exceeds 20°C.

The locations with moderate climatic conditions Frankfurt and Stockholm show only few operating hours with a low mean wet bulb temperature of about 16.5°C. The mean temperature difference between dry cooler and wet cooling towers is 5.5 K for Stockholm and 7.4 K for Frankfurt. At maximum air temperature the temperature difference is at ca. 12 K in Frankfurt.

At Mediterranean climate conditions (e.g. Palermo or Madrid) the period of time with dry air temperatures of more than 20°C is far longer, e.g. 3237 h for Palermo. While the maximum dry air temperature in Madrid (36.4°C) is higher than in Palermo (34.7°C) the maximum wet bulb temperature is much lower (Madrid: 24.5°C and Palermo 28°C).

As expected, the wet cooling tower benefits most in dry hot climates but also in humid coastal climates the resulting cooling water temperatures are significantly lower, especially at very hot weather conditions.

When the maximum cooling load is required the dry cooler delivers cooling water with a temperature level of 42.4°C and the wet cooling tower of 30.5°C in Madrid which represents a difference of 11.9 K. In Palermo the dry cooler delivers a temperature of 40.7°C and the wet cooling tower of 34°C thus the temperature difference is still 6.7 K.

*Table 1-1: Overview heat rejection temperature levels for dry coolers and wet cooling towers at different locations.*

| | | Frankfurt | | Stockholm | | Palermo | | Madrid | |
|---|---|---|---|---|---|---|---|---|---|
| Operating hours for $T_{dry,air} > 20°C$ | [h] | 937 | | 482 | | 3237 | | 2102 | |
| | | max | mean | max | mean | max | mean | max | mean |
| Dry air temperature | [°C] | 34,6 | 23,7 | 28,9 | 22,3 | 34,7 | 24,2 | 36,4 | 25,4 |
| Wet bulb temperature | [°C] | 22,7 | 16,3 | 22,1 | 16,8 | 28 | 20,5 | 24,5 | 17,4 |
| Temperature difference dry - wet | [K] | 11,9 | 7,4 | 6,8 | 5,5 | 6,7 | 3,7 | 11,9 | 8 |
| Cooling water temperature- dry cooler ($\Delta T_{approach,dry} = 6$ K) | [°C] | 40,6 | 29,7 | 34,9 | 28,3 | 40,7 | 30,2 | 42,4 | 31,4 |
| Cooling water temperature for wet cooling tower ($\Delta T_{approach,wet} = 5$ K) | [°C] | 28,7 | 22,3 | 28,1 | 22,8 | 34 | 26,5 | 30,5 | 23,4 |
| **Temperature difference dry - wet** | **[K]** | **11,9** | **7,4** | **6,8** | **5,5** | **6,7** | **3,7** | **11,9** | **8** |

Wet cooling tower are able to cool down the cooling water to a significantly lower temperature than dry coolers. Furthermore the electricity demand and investment costs are much lower than for dry coolers. The main drawbacks of wet cooling towers are water consumption, hygienic problems and linked to that high maintenance costs.

# 2 Wet Cooling Tower - Operation

A short description of wet cooling towers is already given in section 1.3.2. Within this chapter the special needs of small scale wet cooling towers should be discussed.

In wet cooling towers an intensive heat and mass transfer takes place by direct contact of the cooling water and the air.

## 2.1 Nutrients and Biofilm

Because wet cooling towers bring large quantities of air in contact with the cooling water they are highly efficient air scrubber and organic material and other debris can be accumulated in the cooling water. This material may serve as nutrient source for micro-organism like Legionellae and may cause the formation of biofilm on any wetted surface in the cooling tower. Thus it is necessary to remove organic material from the cooling tower frequently during maintenance work.

## 2.2 Water Consumption

The water consumption in a wet cooling tower consists of three different losses, because of:

1. evaporation,
2. blow off or drift and
3. blow down

Cooling occurs in a cooling tower mainly by the mechanisms of evaporative cooling (latent heat) and minor by the exchange of sensible heat. Approx. 2-3% of the cooling water flow rate evaporates in the cooling tower and leaves its dissolved salts behind in the bulk of the water which has not been evaporated. Thus the salt concentration in the circulating cooling water is rising. To prevent the salt concentration of the water from becoming too high, a portion of the water is drawn off (blow down) for disposal. Furthermore a small portion of the cooling water is lost in form of mist carried out of the tower with the waste air. In order to limit these losses drift baffles or drift eliminators are installed in the cooling tower.

In small cooling towers the blow down mechanism is often controlled manually but a better approach is to use a conductivity controller to continuously bleed and refill water in the system. Continuous systems maintain water quality at a more consistent level without wide fluctuations in the dissolved salts. Thermal efficiency, proper operation, and life of the cooling tower are related directly to the quality of the recirculating water in the tower.

To compensate the losses fresh water (makeup water) has to be supplied to the tower basin. In praxis higher water consumption is often needed due to e.g. back flush of filters, cleaning operations and exchange of water due to contaminations of the cooling water.

Water supply to cooling towers is a limiting source to operation of cooling towers. To reduce fouling in cooling towers and the remaining cooling system make-up water needs to contain relative low concentrations of nutrients that may support growth of biofilm and *Legionella* (i.e. biofouling). Hence, when ground water or drinking water is scarce and expensive resource pre-treatment of make-up water from other sources, e.g. rivers and lakes, is required. Furthermore, the efficiency of chemicals for prevention of corrosion and biofouling is dependent on the water quality of the circulating cooling water.

## 2.3 Water Treatment

The makeup water is fresh water added to the cooling towers to replace evaporation, blow down, and drift losses. The amount and chemistry of makeup water added directly affects the quality of water in the systems.

The relationship between blow down water quality and make-up water quality can be expressed as a concentration ratio. This concentration ratio is typically between 2 and 5 (VDMA 24649), which means that the salt concentration in the circulating water is 2 to 5 times higher than in the makeup water. Limits for the concentration of different minerals are usually given in the operating manuals of the cooling tower manufacturer.

As the concentration of salts increase the water may not be able to hold the minerals in solution and they can precipitate out as mineral solids and cause fouling and heat exchange problems in the cooling tower.

Beyond the necessary limitation of the mineral content water treatment might be required to avoid scale, corrosion and growing micro organism.

## 2.4 Aerosols in the Waste Air

As discussed a small portion of the cooling water is lost in form of mist carried out of the tower with the waste air. In Order to limit these aerosols in the waste air drift eliminator are installed in the air outlet. The effectiveness of these drift eliminator varies in a far range between 0.0005 and 0.1% of the circulation cooling water flow rate is released to the waste air (Aquaprox, 2007). This means that the drift eliminator affects the aerosol discharge of the cooling tower and with that also the release of micro-organism very much.

However, it must be assumed that some droplets are within the critical size for human intake of 5 micrometer or smaller. Larger droplets leaving the cooling tower may be reduced to 5 micrometer or less by evaporation (ASHRAE Guideline 12-2000).

Even the best drift eliminators do not eliminate aerosols entirely. Thus it cannot be the “stand alone“ preventive measure but high efficiency drift eliminator are able to reduce the release of micro-organism significantly. Furthermore the evaporative cooling equipment should be positioned such that it is away from occupied areas or where drift can enter directly into the windows or air intakes of buildings in the vicinity of the installation. The prevailing wind direction should be taken into account wherever possible EUROVENT 9/5 (2002)

## 2.5 Electricity Consumption

The electricity consumption of a cooling tower is mainly determined by the electricity demand of the pumps and fans. As discussed, compared to the cooling capacity of a thermally driven heat pump the cooling capacity of the heat rejection system is approx. 2 to 3 times bigger. This leads to a significant electricity consumption of the heat rejection system in solar cooling applications. In order to reduce this demand variable speed controlled pumps and fans can be considered.

## 2.6 Anti Freeze

Solar cooling applications are not in operation during winter season and cooling towers will be drained during this period of time thus no freezing problems occur. However, if there is a risk of freezing appropriate counter measures are needed e.g. electric immersion heater in the collection basin.

## 2.7 Part Load Operation

Typically the speed of the fans can be controlled in two steps. Alternatively it is possible to equip the fan with frequency control in order to control the required cooling capacity.

During part load operation the reduction ratio of the water flow rate must not exceed 1:5 to avoid clogging, whereas it is even possible to switch off the fan when running at about 10% cooling load. (Henning, 2004)

## 2.8 Maintenance

The key requirements for maintaining system efficiency are adequate control of the recalculating water quality and a programme of maintenance to keep the equipment clean and in good condition.

Maintenance requirements are given in manufacturer's instructions or in Guidelines e.g. EUROVENT 9/5 (2002) or VDMA 24649 (2005).

A typical mechanical maintenance schedule is shown in Table 2-1

*Table 2-1 Typical mechanical maintenance schedule (EUROVENT 9/5,2002)*

| Description of Service | Start–Up (see Note 1) | Monthly | Every six months | Shut- Down | Annually |
|---|---|---|---|---|---|
| Inspect general condition of the system | X | | | X | X |
| Inspect heat transfer section(s) for fouling | X | | X | | |
| Inspect water distribution | X | | X | | |
| Inspect drift eliminators for cleanliness and proper installation | X | | X | | |
| Inspect sump | X | | X | | |
| Check and adjust sump water level and make-up | X | | X | | |
| Check chemical feed equipment | X | X | | | |
| Check proper functioning of blow-down | X | X | | | |
| Check operation of sump heaters (if applicable) | X | | X | | |
| Clean sump strainer | X | | X | | |
| Drain sump & piping | | | | X | |

Note 1: Initial start-up and after seasonal shut-down period.

# 3 Wet Cooling Tower - Process Calculation

The need of special information of wet cooling tower technology begins with the purchase of a wet cooling tower. The owner and later on the user are interested in the technical behavior of the cooling tower. Therefore this chapter contains information according the process calculation of wet cooling towers. With the help of these knowledge the commissioning, adaptations and also changes of the technical features of wet cooling towers can be executed.

## 3.1 General Aspects

The heat transferred from the heat sources (solar collectors or other heat sources and the air conditioned rooms) to the sorption process have to be rejected to the ambient due to the requirements of the continuous thermodynamic process.

If a dry heat rejection system is used, the return temperature of the cooling water will be about 7 to 10 °C higher than the dry temperature of the ambient air. This causes cooling water temperatures in the Mediterranean countries in the range of 40 to 55 °C. This requires for the operation of sorption cooling machines temperatures of the heat source of 110 °C and more, which can not be managed by relatively cheap flat plate collectors.

If a wet heat rejection system is used, the return temperature of the cooling water will be about 3 to 8 °C lower than the dry temperature of the ambient air. In these cases of application flat plate collectors can be used.

This calculation procedure for a wet cooling tower is used above all for commissioning, adaptations and changes of the technical features. In addition to this the formulas and graphs can be computerized and used for several kinds of simulations of changing the mass flows of water and air.

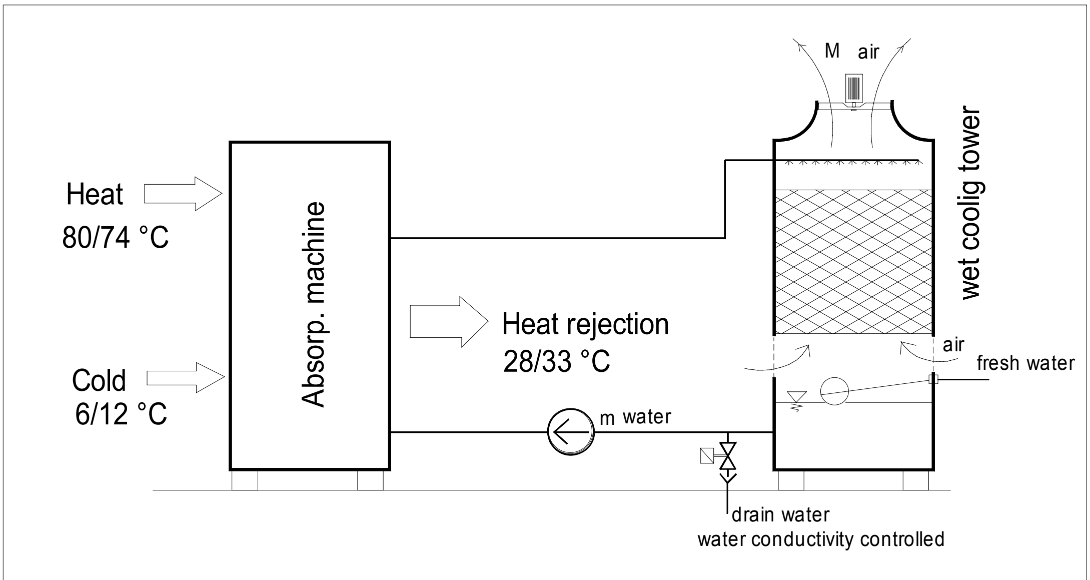



*Figure 3-1: Principle of a thermal driven cooling with wet heat rejection*

## 3.2 State of Air and Temperatures Inside the Cooling Tower

The following equation describes the heat balance at the wet cooling tower.

$$m * c * (\vartheta w1 - \vartheta w2) = M * (h1 - h2) \qquad (3\text{-}1)$$

<u>Legend</u>

m………………… mass flow of the cooling water ………… …kg/s

M…………………mass flow of the air…………………………......kg/s

c …………………..specific isobar heat capacity kJ/kg K

$\vartheta\ w1, \vartheta w2$ ……….cooling water temperature (inlet/outlet)………°C

$h2 - h1$ …………..…enthalpy difference of the air (inlet/outlet)…..kJ/kg

Figure 3-2 shows the temperatures of the cooling water between inlet and outlet in the cooling tower and also the state of the air on the way from the entrance to the outlet.

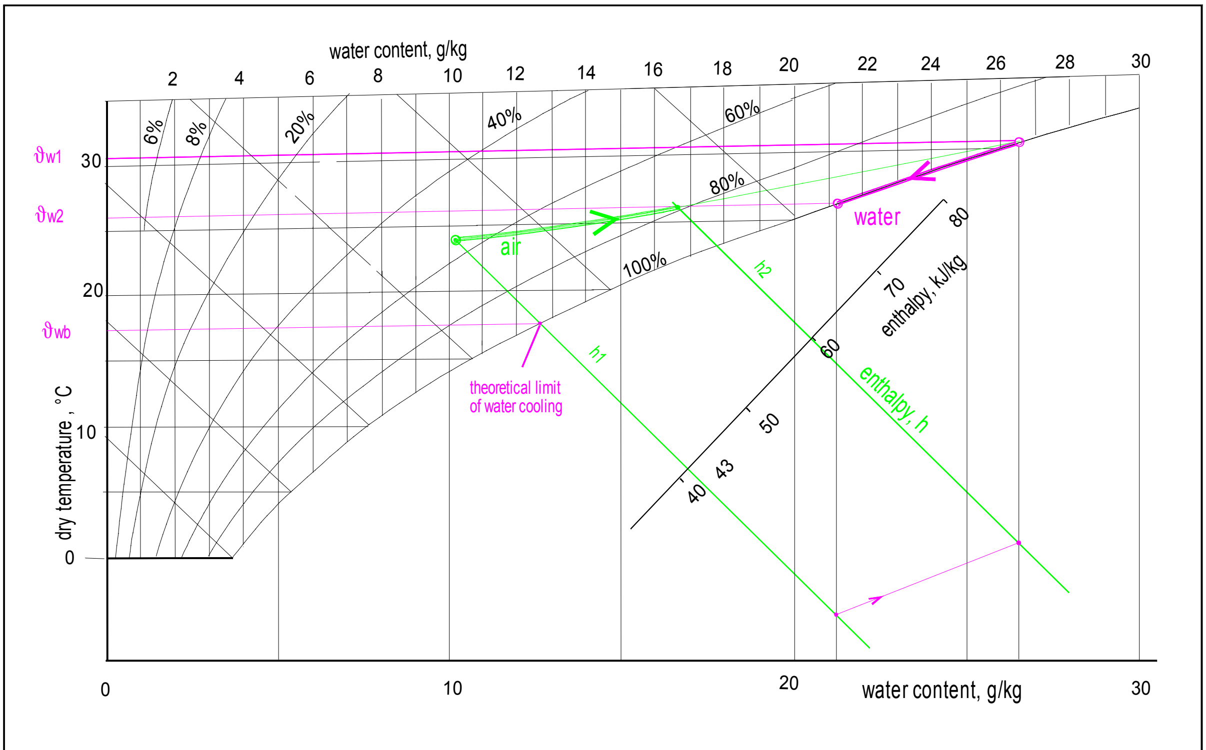



*Figure 3-2: States of the air and temperatures of the cooling water inside of the cooling tower*

The theoretical limit of water cooling is given by the wet bulb temperature of the air. In this case the contact area between air and water has to be infinite. In practice only a part of the theoretical water cooling gradation is realized due to economical reasons of the dripping body and air flow. The "water cooling gradation" η describes this part of the theoretical possible water cooling.

$$\eta = \frac{\vartheta w1 - \vartheta w2}{\vartheta w1 - \vartheta wb} \qquad (3.2)$$

η ………… water cooling gradation …………………… -

$\vartheta wb$ ……..wet bulb temperature ………………………°C

Following the information in Recknagel Sprenger (1997/98) the water cooling gradation (η) can be calculated with the aid of the cooling tower operational data (M, m), the cooling tower constant ($C_K$) and the state of the ambient air at the location of the cooling tower. The important result is the return temperature of the cooling tower, which can be determined with the cooling ratio η.

In a first step the *relative minimum quantity of air ($l_{min}$)* is determined with the aid of the diagram in Figure 3-3 and the state of the ambient air at the site. A typical state of the ambient air is assumed with $\vartheta\ w1$ = 33 °C, and φ = 54% at noon on a sunny summer day. Out of the h,x-diagram the wet bulb temperature can be determined with 16,5 °C. With the aid of the wet bulb temperature and Figure 3-3 now the relative minimum quantity of air can be found.

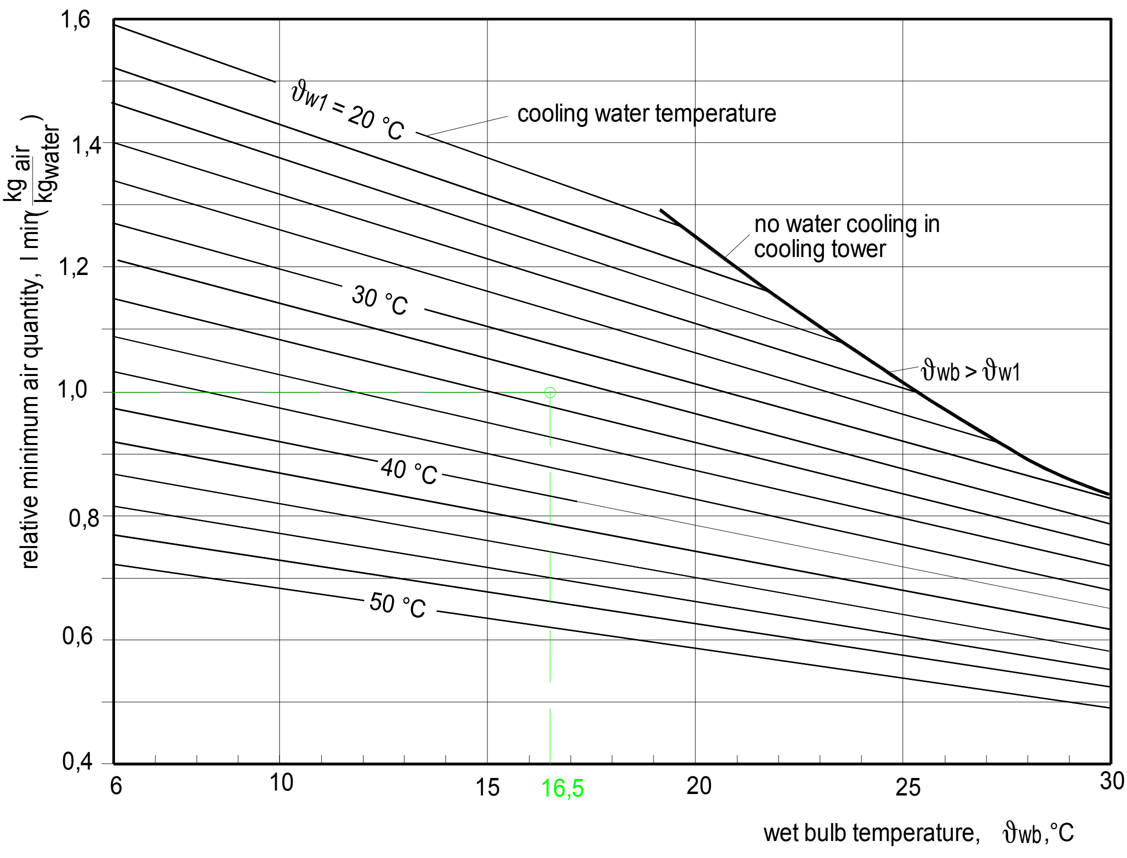



*Figure 3-3: Relative minimum quantity of air (Recknagel Sprenger, 1997/98)*

The relative minimum air quantity is determined with $l_{min}$ = 1,0

For the further calculations the equations below are used:

$$l_{\min} = \frac{M_{\min}}{m} \tag{3.3}$$

$$l_0 = \frac{M}{m} \tag{3.4}$$

$$\lambda = \frac{l_0}{l_{\min}} \tag{3.5}$$

$l_{\min}$ ……………relative minimum air quantity……… ……………………..…..-

$M_{\min}$ …………..minimum air quantity, corresponding to (h2 – h1) ………kg/s

($M_{\min}$ is the minimum air quantity for an ideal cooling tower to cool down the water from $\vartheta_{w1}$ to $\vartheta_{wb}$

$l_0$ …………….. relative real air quantity ………..…………………………..-

$M$ ……………..real air quantity ……………………………………………kg/s

$\lambda$ ……………. air ration of a wet cooling tower ……….. ……………. –

The next step is the calculation of the cooling tower constant. This can be managed by a relation between the water cooling gradation and the air ratio. Equation 3.6 shows this.

$\eta = C_k * (1 - e^{-\lambda})$ ………………………………………………………………………..3.6

$C_k$ ……………...cooling tower constant ………………………...………-

$C_k$ can be determined by a diagram which is provided by the cooling tower producers and is shown in Figure 3-4

The water cooling gradation (η) can now be read out of the diagram in Figure 3-5

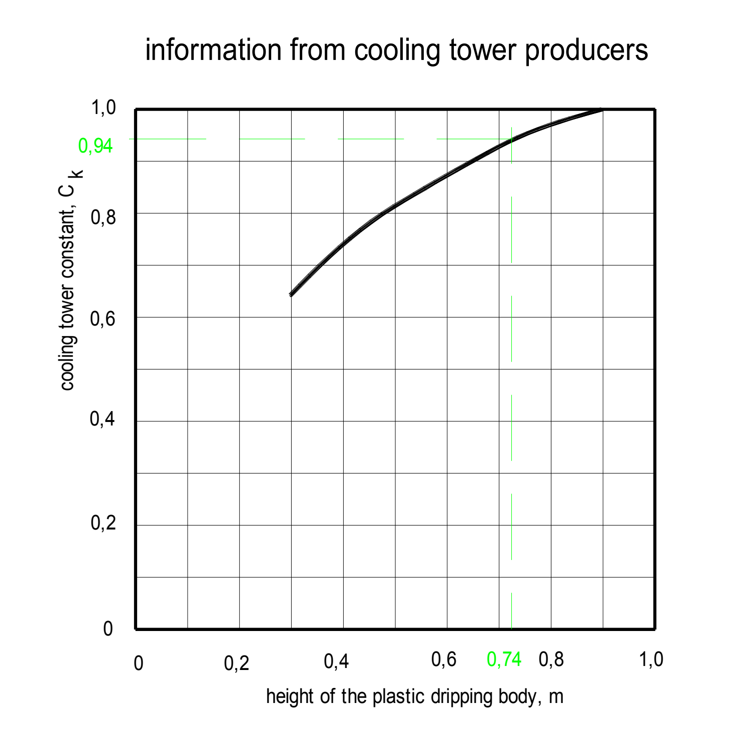



*Figure 3-4: Cooling tower constant as a function of the height of the dripping body (on the basis of Recknagel Sprenger, 1997/98)*

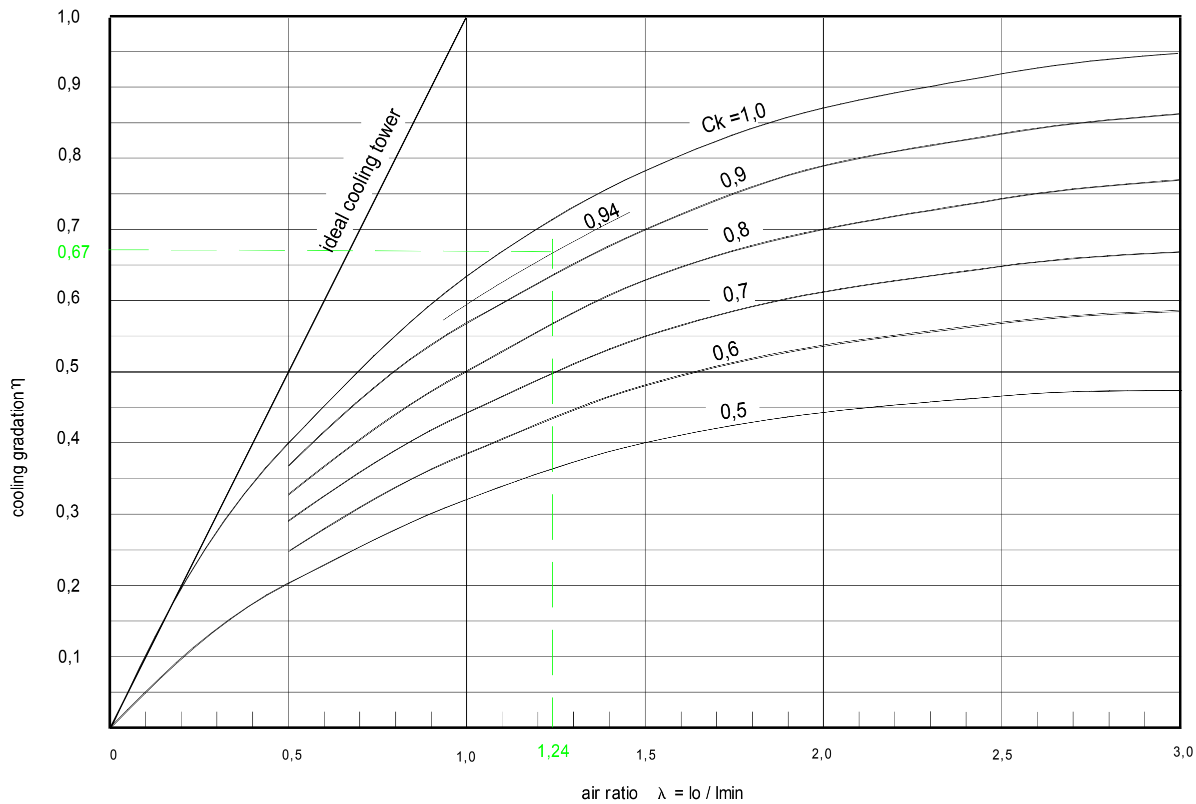



*Figure 3-5: Cooling gradation η as a function of the air ratio with the parameter of the cooling tower constant (Recknagel Sprenger, 1997/98)*

## 3.3 Example

| | |
|---|---|
| Cooling water: | $\vartheta_{w1}$ = 33 °C |
| Cooling water mass flow | $m$ = 1,11 kg/s = 4.000 kg/h |
| Air flow rate | $M$ = 1,38 kg/s (information of the producer) |
| Wet bulb temperature | $\vartheta_{wb}$ = 16,5 °C |
| Ideal minimum air ratio | $l_{\min}$ = 1,0 |
| Real air ratio | $l_0$ = 1,243 |
| Air ratio of a wet cooling tower | $\lambda = \frac{l_0}{l_{\min}} = 1{,}24$ |
| Cooling gradation | $\eta =$ 0,67 (out of figure 3.5) |
| Result: Cooling water $\vartheta_{w2}$ | $\vartheta_{w2} = \frac{\vartheta_{w1} - \vartheta_{w2}}{\vartheta_{w1} - \vartheta wb}$ = 0,64 $\rightarrow \vartheta_{w2} = 22{,}09°C$ |

# 4 Legionella

Due to the fact, that limitation of micro-organism and especially Legionella is an important issue in many applications like water supply, domestic hot water systems, spas, cooling technologies etc. a lot of corresponding literature can be found.

According the risk of contracting to Legionnaires' disease associated with cooling towers the following guidelines have been found and reviewed:

- EUROVENT 9/5 (2002)
- VDMA 24649 (2005)
- ASHRAE Guideline 12-2000
- CTI Guideline WTB 148 (2008)
- IIR 18th Informatory Note on Refrigeration Technologies (2005)

In Austria the following national standards dealing with hygienic aspects in "Heating Ventilation and Air Conditioning" equipment were found:

- ÖNORM H6021 (2003) Lüftungstechnische Anlagen – Reinhaltung und Hygiene
- ÖNORM H6020-2 (2007) Lüftungstechnische Anlagen in Krankenanstalten – Betrieb, Instandhaltung, technische und hygienische Kontrollen,
- ÖNORM B5019 (2007) Hygienerelevante Planung, Ausführung, Betrieb, Wartung, Überwachung und Sanierung von zentralen Trinkwassererwärmungsanlagen

The ÖNORM H 6021 states that wet cooling tower need to have regular blow down and at least twice a year mechanical cleaning and water quality monitoring. If the water quality is not sufficient the period of time between cleaning and monitoring measures has to be reduced.

The description in the subsequent sections is manly derived from these guidelines and shall give a short overview how it is generally intended to avoid a too high contamination of Legionella bacteria in the cooling water system. The values given below should only be used for orientation; some local or national regulations may differ from these values.

## 4.1 Legionellosis

Legionella is a family of bacteria, commonly present in low concentrations, in natural and man-made aquatic environments. Most of them are not virulent. However, pneumophila causes legionellosis, which have two distinct clinical forms:

- Legionaire´s disease is a form of pneumonia. The fatality rate is estimated by 10 to 20%.
- Pontiac fever is an easily treated flu-like illness.

Legionnaires' disease is an uncommon but serious form of pneumonia. Although healthy people can develop Legionnaires' disease, but mainly people who are susceptible to an infection of this kind like smokers, patients with cancer etc. are affected. People are contracted by inhaling contaminated aerosols deeply into there lungs and not by drinking contaminated water.

Over 40 species of Legionella are known. The Legionella Pneumophila (LP) appears to be the most virulent and is associated with approx. 90% of cases of Legionnaires' disease. The bacterium is commonly found in surface water and is likely to exist in low concentration in most water systems (ASHRAE Guideline, 12-2000).

## 4.2 Conditions of Legionella Growth

Legionella and similar bacteria develop in ground, surface water and mud. They grow in slime and biofilms, which are layered groups of microbial populations. The biofilms protect the bacteria from inactivation agents and provide nutrients. If the conditions for the growth are well, the proliferation of the Legionella and also of other bacteria may increase significantly.

Legionella growth is sensitive to the prevailing temperature level of the water. The following temperature ranges can be distinguished:

- 70 - 80°C  Disinfection range
- 60 °C  90% of Legionella die within 2 minutes
- 20 - 50°C  Legionella growth range
- 35 - 46°C  Ideal growth range
- < 20 °C  Legionella can survive but do not grow

In solar cooling systems the cooling water temperatures will be at a critical level for Legionella growth most period of operation time.

Furthermore a ph-value between 5.5 and 8.5 and the presence of nutrients like sediments, sludge, corrosion debris, untreated wood or natural rubber support microbiological growth. Biofilms, algae, slimes and fungi also provide nutrients and protection for Legionella multiplication especially in stagnant water e.g. in hydraulically dead ends which can provide a haven for the growth of Legionella. Legionella can invade and replicate within other organisms like amoeba which protect them e.g. from disinfectants – compare Figure 4-1.

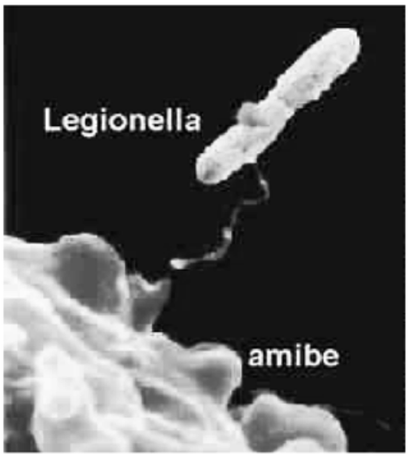



*Figure 4-1 Picture of a Legionella growing on a amoeba (Aquaprox, 2007)*

Water is essential for the survival of the bacteria; if the water evaporates and the Legionella dry out it will die.

### 4.3 Monitoring of Legionella and Micro-Organisms

The simplest method to monitor the bacteriological levels in water is to measure the total aerobic bacteria (TAB) concentration by the use of dip slides. Therefore dip slides are immersed in the cooling water and stored in an incubator for 24 - 48 hours. Depending on the concentration of total aerobic bacteria (TAB) in the water the colour of the dip slide changes and by comparison of the dip slide with a colour chart supplied by the producer the amount of total aerobic bacteria can be determined. The results are indicated in colony forming units of TAB per millilitre (cfu/ml)

Weekly monitoring of the total aerobic bacteria levels in cooling water is recommended by many legislators and professional authorities (e.g. EUROVENT 9/5, 2002; VDMA 24649, 2005) as a visual performance indicator to both system and treatment regime.

Beside dip slides ATP-based technologies can be used for real-time assessment of microbial populations. ATP is the abbreviation for “Adenosine-5'-triphosphate” which is a multifunctional nucleotide, that plays an important role in cell biology for intracellular energy transfer. The ATP-based measurement device measures the light produced when enzyme reagents react with ATP and the amount of light production correlates with the amount of ATP in the sample, which in turn is a relative measure for the microbial activity. The advantage of this system is the short determination time of several minutes.

It should be noted that dip slides and ATP-based measurements alone do not detect Legionella as a select micro-organism. However it is generally accepted that overall bacteria levels (TAB) are considered able to support Legionella and therefore are an indicator of serious risk for Legionnaires’ Disease.

Unless otherwise specified by local regulations, a concentration of total aerobic bacteria up to $10^4$ cfu/ml mean the system is under control. Between $10^4$ and $10^5$ cfu/ml the test should be repeated and if the concentration is confirmed the biocide treatment should be increased. Concentrations of more than $10^5$ cfu/ml require immediate corrective actions to reduce the bacterial level.

Most of professional and governmental agencies that have issued Legionella position statement and guidelines do not recommend testing of Legionella bacteria on a routine basis. According to CTI Guideline WTB 148 (2008) the reasons derive from difficulties in interpreting Legionella test results and the following aspects are mentioned:

- Not all Legionella serogroups are associated with Legionnaires’ Disease
- Culture-based testing methods to quantify Legionella have a 10 to 14 day turnaround for results which is too long for effective treatment control
- Legionella can repopulate within a few days and can be released from biofilms etc.
- An infectious dose level for Legionella has not been established

However, testing of Legionella is needed if:

- Legionella contamination is suspected
- The TAB concentration remains above $10^4$ cfu/ml after corrective measures have been taken

EUROVENT 9/5 (2002) specifies that, if the level of Legionella bacteria has been separately tested and the result are below $10^3$ cfu/l, no action is required, otherwise the test should be repeated and corrective measures are necessary. If the concentration is above $10^5$ cfu/l immediate cleaning and disinfection is required.

Two international standards should be mentioned which describe cultural methods for isolation of Legionella organisms and estimation of their numbers in environmental samples. The ISO 11731 (1998) method is applicable to all kinds of environmental samples including potable, industrial and natural waters and associated materials such as sediments, deposits and slime. The ISO 11731-2 (2004) is intended for water for human use (e.g. hot and cold water, water used for washing). It is especially suitable for waters with prospected low numbers of Legionella.

The EUROVENT 9/5; 2002 guideline suggests a Typical Water Quality Monitoring Schedule shown in Table 4-1. For a specific application the local regulations has to be reviewed.

*Table 4-1: Typical Water Quality Monitoring Schedule (EUROVENT 9/5; 2002)*

| Control Activity | Time of Execution |
|---|---|
| Check operation of water treatment system | Initial start-up & after seasonal shut-down period. Thereafter monthly. |
| Check stock of chemicals | Initial start-up & after seasonal shut-down period. Thereafter weekly. |
| Monitor TAB concentration | Weekly |
| Monitor recirculating water quality against Control Parameters | Monthly |
| Visual inspection for algae, biofilm formation | Every 6 months (see text) |
| Check LP concentration | If TAB remains high (see Table 5) after corrective action (see text).<br>If LP contamination is suspected. |
| System cleaning & disinfection | Prior to start-up, annually, after a shut-down longer than one month.<br>If TAB is above $10^5$ cfu/ml.<br>If LP concentration is above $10^4$ cfu/l.<br>If excessive growth of organic material is noticed. |

Note: Microbiological molecular methods for enumeration of pathogenic and other troublesome microbes are now commercially available. These methods are based on oligonucleotide probes that target the specific microorganisms of interest. For specific analyses of *Legionella* sp. a new method based on quantitative polymerase chain reaction (real time PCR or qPCR) is now commercially available and normally analyses can be conducted within a day. This tool can be used on a routine basis and is suitable for monitoring increased growth of Legionella in cooling systems. However, guidelines are still using the culture based method for detection of *Legionella* to determine the risk of *Legionella* in a cooling system. This includes also decisions for weather cooling systems should be closed down and disinfected.

# 5 Avoidance of Legionella and Micro Organisms

This chapter describes measures to avoid uncontrolled Legionella multiplication in order to operate the system safe. The conventional biocides for water treatment like Chlorine or Ozon are state of the art technologies and therefore described hereafter very briefly only.

Based on a survey of water treatment technologies it seems to be worth to look more in detail to two possibilities of water treatment, ultra violet light and silver copper ions. For small scale wet cooling towers these technologies seem to be promising, thus the focus of this chapter is on these two technologies. However these technologies can not be seen as state of the art and further investigations are strongly needed.

## 5.1 Chain of Events

An outbreak of Legionnaires' Disease associated with a cooling tower requires a 'Chain of Events' with all events in the chain linked together and occurring in sequence (comp. Figure 5-1)

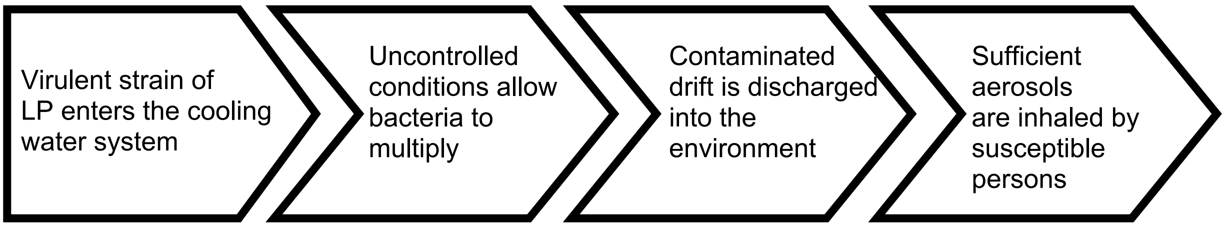



*Figure 5-1: Chain of Events for the outbreak of Legionnaires' Disease associated with a cooling tower (EUROVENT 9/5, 2002))*

To effectively prevent the risk of Legionnaires' Disease, it is necessary to break this chain of events at any link. There are three chain links, which can be broken by good design and correct operation of the cooling system:

1. prevent conditions that encourage multiplication of bacteria
2. minimise drift or aerosol effect in the discharge air stream
3. reduce chances of inhalation by people through equipment location and/ or personal protection.

The measures mentioned above are not equally effective in terms of prevention. By far the most important measure is to prevent uncontrolled conditions that allow the bacteria to multiply.

## 5.2 Design and Operational Measures to Avoid Legionella

Proper system design, regular inspection and, if required, cleaning and disinfection are needed to minimise Legionella bacteria within the cooling system. With respect of the design and installation of evaporative cooling systems a large number of items should be considered:

- Easy and safe access to the cooling tower should be included for inspection and to take samples.

- Regular maintenance and cleaning should be scheduled.
- The open Cooling device should be located as far as possible from the fresh air intakes of a building the areas with organic intake, like kitchen exhaust fan.
- As far as possible remote from out door public areas.
- Reduction of the water droplet rate by high performed separator without a hindrance for inspection and maintenance

Additional to the design active measure are necessary like injection of biocide. A possible alternative could be the installation of UV-C disinfection facility including the necessary control measures and the installation of suitable metal ion electrolysis, e.g. silver-copper ion method which is discussed hereafter.

The above mentioned measures together with a regular maintenance will avoid the growth of virulent bacteria like Legionella pneumophila.

## 5.3 Water Treatment with Disinfectants

In wet cooling towers different water treatment chemicals are used for scale and corrosion inhibition, anti-foaming, cleaning, biofilm control and disinfection. Many different commercial products are on the market which uses different chemical substances. Within this section only a very short overview on the used biocides for Legionella control should be given. Good information on commercially available products can e.g. be found on the web pages of the companies

- Lenntech (http://www.lenntech.com/water-treatment-chemicals.htm) and
- Accepta (http://www.accepta.com/water_treatment_chemicals/biocides.asp)

In principle the biocides for Legionella control can be divided up into oxidising biocides and non-oxidising biocides.

The commonly used oxidising agents are:

- Chlorine
- Chlorine dioxide
- Ozone
- Hypochlorite

Every disinfection technique has its specific advantages and its own application area. The company Lenntech assigns the following advantages and disadvantages to different technologies (compare: Table 5-1)

*Table 5-1: Pro and Cons of different water treatment technologies (http://www.lenntech.com/water-treatment-chemicals.htm, 07.04.2009; 14:53)*

| Technology | Environm. friendly | Byproducts | Effectivity | Investment | Operational costs | Fluids | Surfaces |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **Ozone** | + | + | ++ | - | + | ++ | ++ |
| **UV** | ++ | ++ | + | +/- | ++ | + | ++ |
| **Chlorine dioxide** | +/- | +/- | ++ | ++ | + | ++ | -- |
| **Chlorine gas** | -- | -- | - | + | ++ | +/- | -- |
| **Hypochlorite** | -- | -- | - | + | ++ | +/- | -- |

From the table above it can be concluded, that ultra violet light (UV) and Chlorine Dioxide are the most promising technologies for the application in small scale wet cooling towers because the investment and operational cost of the used technology are moderate or low and the effectivity against Legionella is high. Chlorine Dioxide offers further the advantage to be effective against biofilms. For large installations Chlorine Dioxide is usually manufactured on site because it is an unstable gas that dissociates into chlorine gas ($Cl_2$) and oxygen gas ($O_2$). For small applications Chlorine Dioxide is also commercial available in stabilized form as powder, tablet or solution.

For the water treatment with Ozone an expansive reactor for production of the Ozone on site is necessary, thus this technology is applicable for high quantities of water only. The treatment with Chlorine or Hyperchloride is less effective compared to other options and does not act against biofilm formation.

## 5.4 Disinfection by UV-Radiation

This chapter describes the principle structure of bacteria and the mechanism how they can be destroyed by ultra violet light (UV). Furthermore the design of market available lamps and there possible application are discussed.

### 5.4.1 General

For a better understanding of the destruction mechanism in case of disinfection by UV-radiation, of water or air, the Figure 5-2 shows the principle structure of bacteria. It consists of a cell nucleus, the cell fluid and the cell wall. The cell wall consists of a Murein membrane and an additional Lipid membrane. Murein is a biochemical strong net of Polysacharine chains and Peptide chains and build up a strong protection around the cell fluid. The chemist Gram discovered, that there are two groups of bacteria. The group 1, he calls it “negative”, do have a thin Murein membrane around the nucleus. The Murein membrane is lower than 10 % of the wall dry mass. The group 2, he calls it “positive” do have a Murein membrane with 30 to 70 % of the dry wall mass.

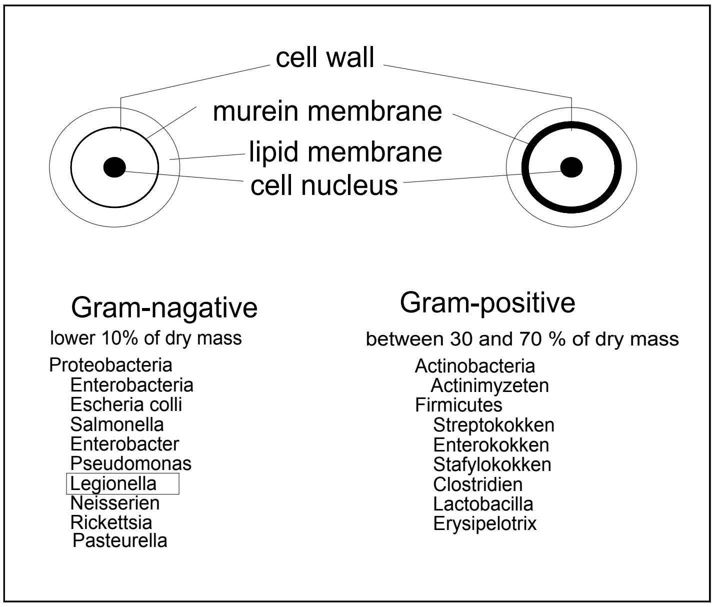



*Figure 5-2: Principle construction of Gram positive and Gram negative bacteria.*

Figure 4.1 characterizes a lot of well known bacteria which are assigned to the Gram-positive and Gram-negative groups. The Legionella bacteria belong to the Gram-negative group and have therefore a thin protecting Murein membrane which opens the possibility to kill the dangerous bacteria by UV-disinfection.

The ultraviolet (UV) radiation is an electromagnetic wave with a wave length in the range of 100 to 380 nm, or a frequency of more than 789 THz. Generally it is known that ultraviolet radiation is able to destroy bacteria.

Especially the Gram-negative bacteria, which have only a relatively thin Murein membrane, can be destroyed by UV-radiation with a high lethal rate. Figure 5-3 shows the range of the ultraviolet radiation and the curve of effectiveness of destroying the Gram-negative bacteria. The highest effective destruction can be detected at 254 nm in the range of UV-C radiation (200 to 280 nm)

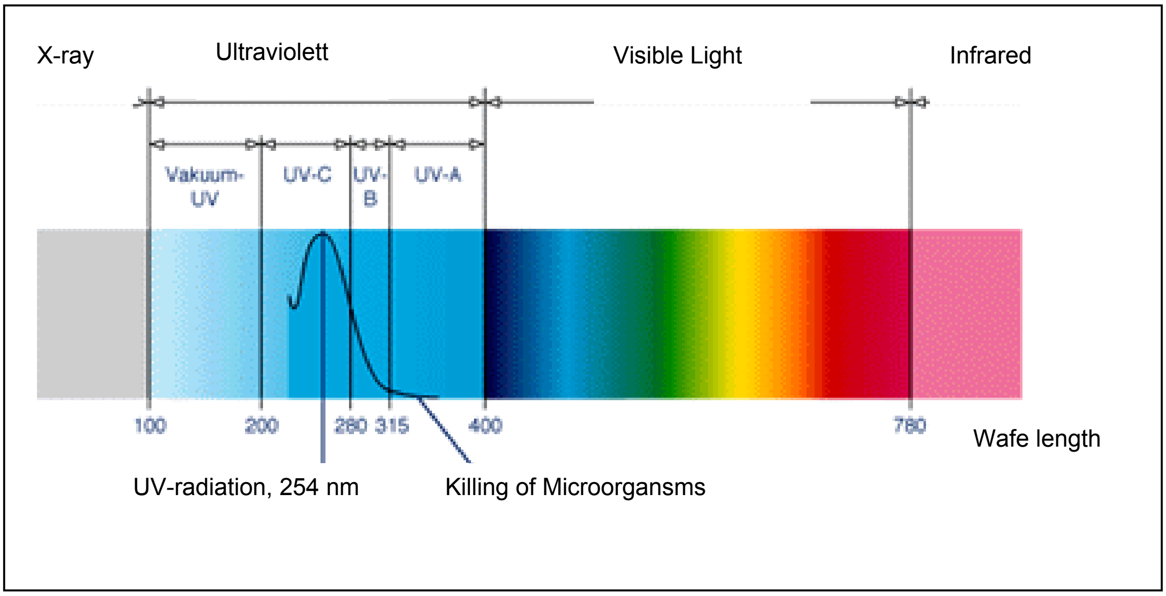



*Figure 5-3: Position of the UV-C radiation in the frequency band from 100 to 750 nm*

### 5.4.2 Mechanism of Destruction

All microorganisms contain the Nuclein Acids (DNA), which carries their genetic information. The general shape of the Nuclein Acids is displayed in Figure 5-4. It is similar to a double helix with connecting rods. The Nuclein Acids absorbs the energy of the UV-radiation at 254 nm, due to their resonance frequency. The energy absorbed destroys the molecule structure and the proliferation of the Gram-negative bacteria, like Legionella, is stopped suddenly.

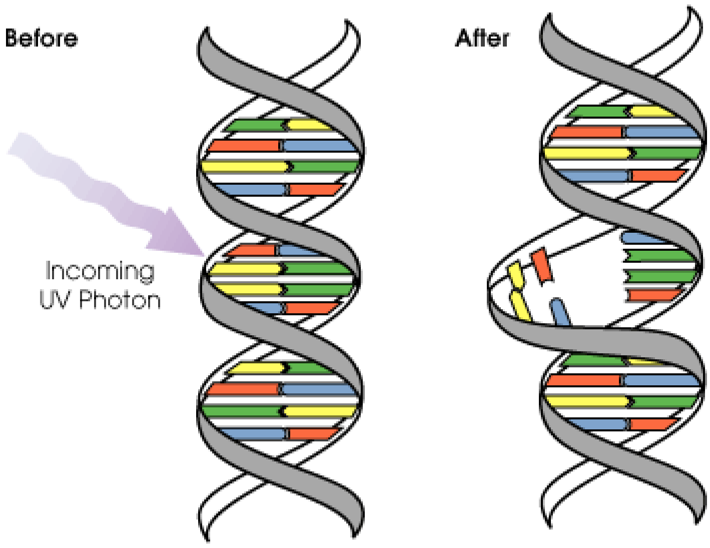



*Figure 5-4: Schematic shape of the Nuclein Acid (DNA) before and after radiation treatment (http://waterecotechnology.com/?page_id=414, 09.12.2009)*

### 5.4.3 UV-C Light Production

The construction of UV-C lamps needs a special technology: the "mercury vapor low pressure technology". An important component, a quartz glass tube, is necessary to envelop the mercury vapor low pressure process, which generates the UV-C radiation. Quartz glass has the important property that UV-C can pass the quartz glass wall without significant losses.

Some companies offer UV-C lamps with the above mentioned technology. Normally lamps with 18, 20, 30 and 36 Watt are available. For the production of UV-C radiation the lamp itself has to be equipped with additional electrical components, which consumes additional electric energy too. The UV-C radiation drops after an operation time of about 10.000 to 12.000 hours down to 75%. After 12.000 operation hours the change of the lamp is recommended.

### 5.4.4 Market Available Products

Figure 5-5 illustrates a product of company sterilAqua, which is besides of other similar products available on the market. The UV-C lamp including the additional components is waterproof and ready for a use in a water basin, like the basin at the bottom of a wet cooling tower. The effective penetration of the UV-C light is for relatively clean water about 30 cm. The cost of a UV-C unit regarding figure 4.5 lies in the range of 250 to 350 Euro excl. VAT.

*Figure 5-5: Waterproof UV-C lamp (http://www.albkoi.de/upload/files/1-AQT-018-PDE.pdf, 09.12.2009)*

A lot of other similar UV-C products are available on the market produced by several companies. Figure 5-6 shows an UV-C product for integration in a tube system, which is on a higher cost level.

The maintenance for the UV-C unit belongs to the change of the lamps after 10.000 to 12.000 operational hours and the cleaning of the quartz glass depending on the purity of the water.

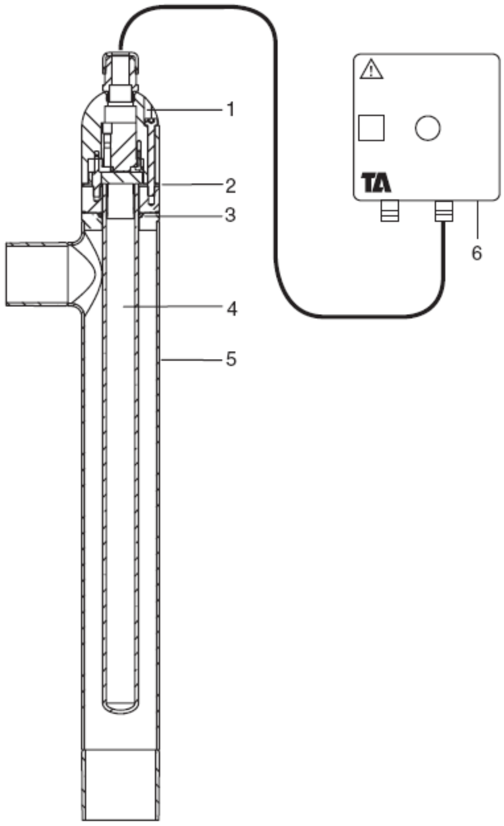



*Figure 5-6: UV-C disinfection facility for integration in the installation (http://www.hydroteam.gr/pdf/TA-Aqua.pdf, 09.12.2009)*

## 5.5 Water Disinfection by Metal Ions

The technology of metal ion disinfection is well known since some thousand years. Already the old Egyptians used silver vessels for the drinking water, in order to keep it sterile. The old Greeks and Romans know the disinfecting effects of silver and copper too. Also the settler of North America put into the drinking water barrels silver and copper coins, which produce by the motion of the water in the barrels silver and copper ions, and the water remains potable.

In order to verify, if the disinfection effects of silver and copper ions can also be used in open wet cooling towers this old knowledge and the experience of water treatment in swimming pools has been reviewed and further investigated. The aim of this work is to make a step forward in finding a simple and cheap method to kill Gram-negative bacteria and especially Legionella bacteria in the open cooling water circuits.

This sub-chapter describes the results of a pre-test which has been carried out in order to verify the feasibility of the disinfection method with silver and cooper ions. Furthermore a method for production and control of silver and cooper ions in a water system is discussed and a test device is presented in order to show a possible technical realisation.

### 5.5.1 Pre-Test of the Method

From the river Mur in Graz, Austria, contaminated water was taken out without a cleaning up for the test of the disinfection method with silver and cooper ions. The contamination of the Mur water was tested with the method of Petri shells. With the aid of the Petri shells the number of germs of 1 $cm^3$ water can be determined. The Petri shell consists of a plastic housing and a culture medium at the bottom. One $cm^3$ of Mur water was distributed continuously across the culture medium of the Petri shell and taken into a warm atmosphere for about 24 hours with temperatures of 33 °C, which is near the optimum for the growth of bacteria like Legionella.

Figure 5-7 illustrates the effectiveness of killing the bacteria by the silver/copper ion disinfection method.

*Petri shell a)* shows the bacteria, which are grown up without a treatment of the contaminated Mur water. 370 germs (bacteria) could be determined in 1 $cm^3$ of contaminated water by this Petri shell method.

*Petri shell b)* shows that after a treatment of only 6 hours with the silver/copper ions method the water seems to be dead and all bacteria killed. The same can be said for the Petri shells c) and d).

This simple test indicates that the silver/copper ions could be used obvious successfully in the open water cycles of wet cooling towers.


a) b) c) d)

*Figure 5-7: Test of the content of bacteria in the Petri shell*

a … contaminated water with out silver/copper ion treatment
b … contaminated water after silver/copper ion treatment of 6 hours
c … contaminated water after silver/copper ion treatment of 12 hours
d … contaminated water after silver/copper ion treatment of 18 hours

### 5.5.2 Production of Silver Ions and Copper Ions

The Faraday equation and the measurement of the electric current allow calculating, how many metal ions are produced in a certain period of time. With the help of the Petri shell tests series can be detected that a concentration of about $10^{-9}$ (mass of ions per mass of water) results in a satisfying bacteria dead rate. The chemical analysis of the water used in the cooling tower cycle is furthermore very important for a successful implementation of the metal ion disinfection.

The control of the silver/copper ions disinfection works in two stages. After filling or refilling the cooling water cycle with fresh water the main task of the control is the production of those number of silver ions, which enables a concentration of around $10^{-9}$. After this stage one the electric current has to be reduced, so that only that quantity of the silver/copper ions are produced, which correspond to the replaced water in the cooling water cycle.

Important is also the presence of calcium, chlorine, magnesium or other kind of anions in the water. With the help of a suitable computer program like *phreeqc*, which can be cost free downloaded from the internet, and the above mentioned chemical water analysis it is possible to calculate the saturation concentration of silver ions and copper ions in the ambient of several anions The chemical analysis for the water from the river Mur in Graz was used as an example to calculate the limits of concentration. The results show that the limits of concentration for the active copper ions lies at 0.58 µg/liter, which is very low. In contrast to this the limit of the concentration of active silver ions is much higher and reaches 87 µg/liter. These results show that the silver ions can meet very easily the necessary concentration of 20 to 30 µg/liter, which lie in the range of a satisfying bacteria dead rate.

The limits of concentration of silver and copper ions depend on the kind of used water and on its chemical balance.

### 5.5.3 Realization of the Method

A suitable concentration of silver/copper ions can be produced with the help of electric current. Only some milliamperes of electric current are necessary to produce the required quantity of silver/copper ions for the disinfection of the open water circuit of wet cooling towers. An electronic device produces this necessary electric current on a low voltage level. The electronic device is designed in such a manner that also the personal safety of the people making the maintenance is secured. Figure 5-8 and Figure 5-9 displays the realized device for the test described.


*Figure 5-8: Test device for silver/copper ions production (courtesy of ECONICsystems)*


*Figure 5-9: Silver/copper electrodes for cooling tower basin (courtesy of ECONICsystems)*

The silver/copper electrodes are also available for integration in the cooling water pipe system.

In summary it can be said, that the first results are promising to the development of a suitable disinfection method for small scale wet cooling towers. However, further research on the disinfection method and tests in real heat rejection applications are necessary to verify the effectiveness of the disinfection method in long term tests and for different chemical composition of the cooling water. This shall be carried out in near future.

## 5.6 Cost Comparison

After analysis and description of the two physical water treatments for a hygienic operation of small wet cooling towers, it is also worth to compare the estimated cost of the proposed measures. In the table below the investment and operation cost are listed over an operation period of 15 years.

*Table 5-2 Annual cost of hygienic measures for a small cooling tower (30 kW) over a operation time of 15 years*

| | Investment | Operational cost | Maintenance & replacement | Remarks |
|---|---|---|---|---|
| | Euro | Euro/a | Euro/a | |
| UV-C disinfection | 450[1)] to 1000[2)] | 90 | 65 | Cleaning, lamp |
| Silver/copper ions disinfection | 100 to 300 | 0,5 | 27,5 | Inspection |

Note[1)]: Equipment according to Figure 5-5

Note[2)]: Equipment according to Figure 5-6

The numbers in the Table 5-2 are calculated for a small wet cooling tower with cooling capacity of 30 kW under the following conditions:

*UV-C disinfection*

| | |
|---|---|
| ➢ Annual operation time: | 1.500 h/a |
| ➢ Electricity demand of a 30 W UV-C lamp: (40W consumption) | 60 kWh/a |
| ➢ Electricity cost: (0,16 €/kWh) | 9,6 €/a |
| ➢ Maintenance: Change of UV-C lamp every 6,6 years (cost: 200 €/lamp) | 40 €/a |
| ➢ Maintenance time/a: 30 minutes (50 €/h) | 25 €/a |

*Silver/copper ion disinfection*

| | |
|---|---|
| ➢ 0,5 W in sum with 1500 h/a | 0,12 € |
| ➢ Maintenance silver/copper electrodes 15 €/piece, once in 6 years is | 2,5 €/a |
| ➢ Maintenance time/a: 30 Minutes | 25 €/a |

# 6 Conclusion

Heat rejection for thermally driven heat pumps is a crucial subsystem especially in solar assisted air conditioning, because:

- The necessary temperature level of the driving heat and the efficiency of the system depends on the temperature level of the heat rejection system significantly
- The amount of heat to be rejected is about twice to triple bigger than the cooling load
- The electrical energy consumption as well as the initial and operating costs of the heat rejection system are significantly high

In order to minimize the temperature level of the heat rejection wet cooling towers can be used. Wet cooling tower are able to cool down the cooling water to a significantly lower temperature than dry coolers. The typical cooling water temperature of a dry cooler and a wet cooling tower has been calculated for different climates. E.g. when the maximum cooling load is required the dry cooler delivers cooling water with a temperature level of 42.4°C and the wet cooling tower of 30.5°C in Madrid which represents a difference of 11.9 K. In Palermo the dry cooler delivers a temperature of 40.7°C and the wet cooling tower of 34°C thus the temperature difference is still 6.7 K.

Furthermore the electricity demand and investment costs are much lower for wet cooling towers than for dry coolers. The main drawbacks of wet cooling towers are water consumption, hygienic problems and linked to that high maintenance costs.

Large wet cooling towers are normally integrated in power stations or industrial production lines and well educated people are available for the necessary service work at the site. In contrast to this is the necessary service at small wet cooling towers below 100 kW not every time secured, due to the lack of suitable workers and owner´s technical information. Therefore a more or less automatic maintenance system for small cooling towers is highly desirable.

The need of special information of wet cooling tower technology begins with the purchase of a wet cooling tower. The owner and later on the user are interested in the technical behavior of the cooling tower. Therefore this report contains a small but easy written chapter of “Wet Cooling Tower – Process Calculation”. With the help of these knowledge the commissioning, adaptations and also changes of the technical features of wet cooling towers can be executed.

The main task of an automatically working maintenance system of a wet cooling tower is the secure hygienic operation. It seems that a physical disinfection might be better than biocide injection or other chemical water treatments. Therefore especially the UV-disinfection and also the not so well known silver/cooper ion disinfection were analyzed and even tested. Due to the simple installation and low cost operation, the silver/copper disinfection method seems to be a recommendable disinfection technique for small open water cycles, like there are in small wet cooling towers. However, further research on the disinfection method and tests in real heat rejection applications are necessary to verify the effectiveness of the disinfection method in long term tests and for different chemical composition of the cooling water. This shall be carried out in near future.

Other important tasks of an automatically working maintenance system are the minimization of the water consumption and also the electric energy consumption. The measurement and the limitation of the conductivity of the water by an automatic drain valve can guarantee low water consumption. In addition to this also the speed of the cooling tower fan should be controlled and leaded by a temperature signal of the cooling water. The water temperature generates a control signal, which can be used by a broad variety of market available frequency converters for the fan.

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