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Technische Gebäudeausrüstung – Gebäudetechnik

UV-Disinfection of Cooling Towers

Reliable Control of Legionella and Biofilm for safe and efficient operation

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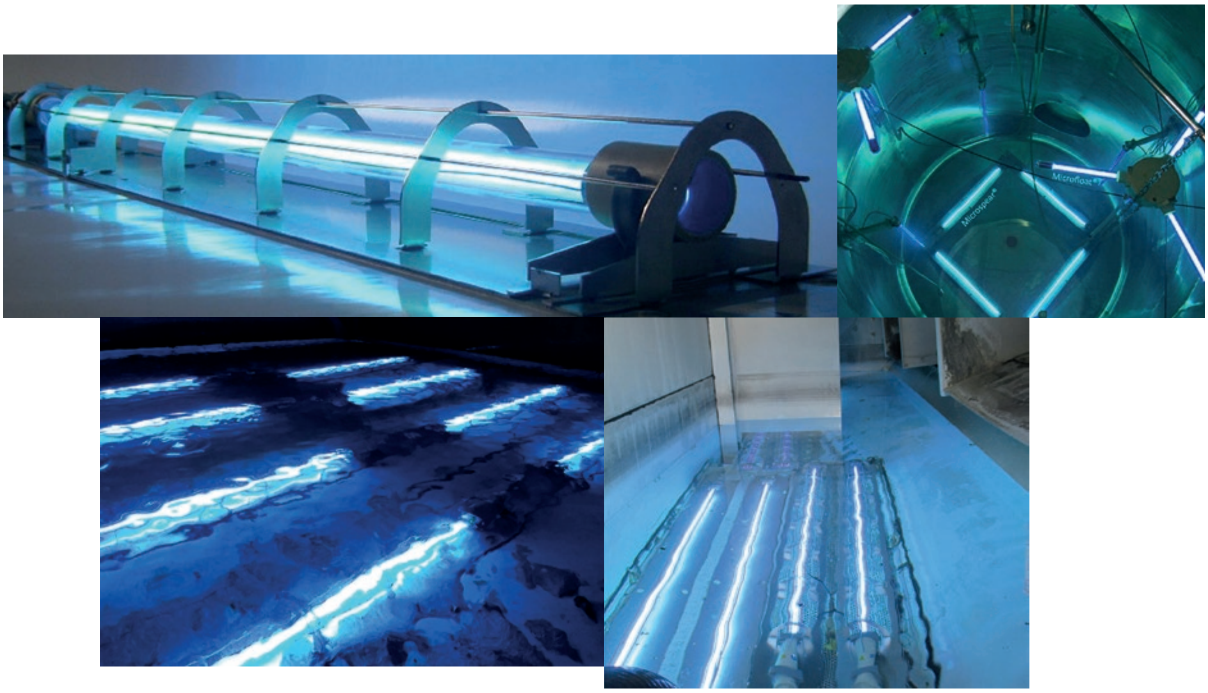


Picture 1: Cooling Tower with Installed UV-Lamps, Type Microfloat® & Microspear®

The growing number of cooling towers for process heat removal have led to an increasing number of suspects that pathogens are multiplying and expanding. Actual examples from a series of suspects are the Legionella disease cases in Ulm (2010)[1,2] and in Warstein (2013)[3] that were possibly caused from cooling towers, whereas in Ulm alone an illness outbreak was reported causing 5 death and 65 insured people. At that location, Legionella infection from cooling towers on top of a building was discovered and that is when an efficient disinfection system based on UV-H_2O_2 technology from a.c.k. aqua concept GmbH was implemented.

For preventing in the future more such cases in Germany, the VDI-Guideline 2047 page 2 is in effect since January 2015 for achieving a hygiene-proof performance of the atmospheric evaporation type cooling systems. The guideline gives the operator directions for the technically correct operation and is valid for existing and newly planned installations of atmospheric evaporator cooling systems. It is also the operator's responsibility to ensure safety for the operation of the system[4].

For an efficient and safe performance of industrial cooling towers the recirculated water must be proficiently conditioned and disinfected. Also, the water quality must be regularly checked. Currently, the conditioning/disinfection process of the recirculated water is predominantly provided by means of partially toxic chemical dosing, which is detrimental and, ultimately, will have a negative influence on cooling tower operation (e.g. corrosion caused through biocide).

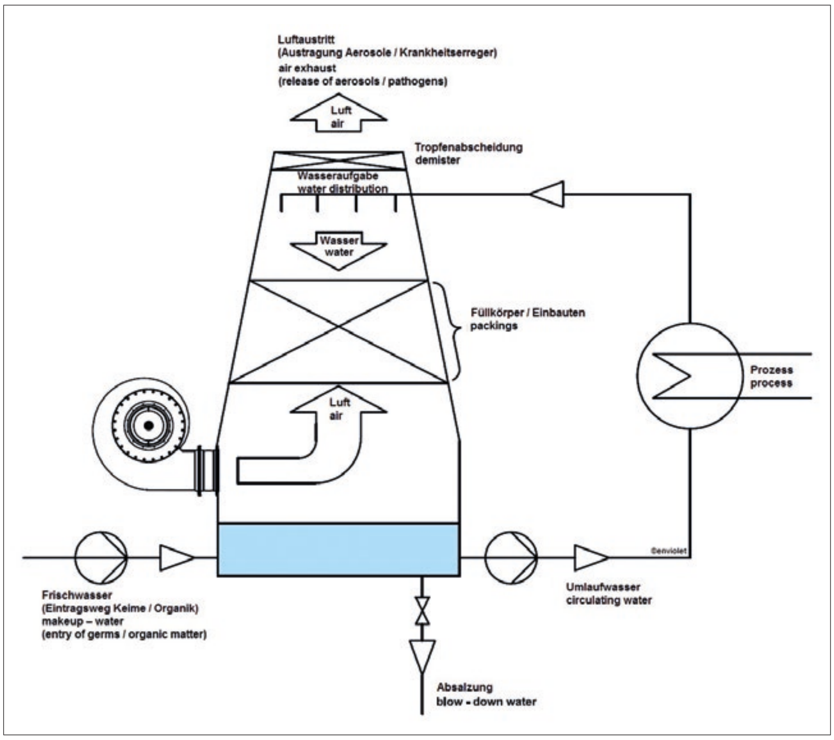
Next follows a general function description of a cooling tower and its correlation of the observed parameters during operation.
The established procedure for the control of these parameters will be described and its impacts analyzed. Alternatively, "Enviolet" GmbH will present its developed concept for disinfection and stabilization of cooling towers based on UV-irradiation in combination with H_2O_2. Advantages of this process will be compared with the conventional approach by illustrating and comparing operating data of the cooling towers (total bacteria growth, Legionella bacteria growth, corrosion rate, operating costs).

BASICS OF COOLING TOWER OPERATION

Cooling towers are semi-enclosed cooling systems in which the cooling effect is achieved through evaporation of water. See Picture 2: Air and water move in counter-flow direction thus a fraction of water is evaporated and the extracted vaporization enthalpy is generating a cooling effect on the remaining water within the system.

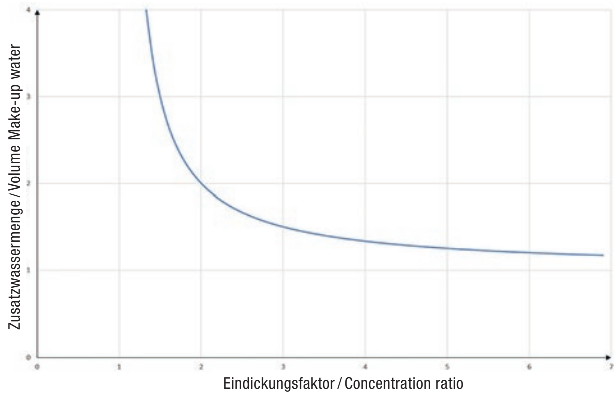
As only pure water evaporates in a cooling tower dissolved solids concentration will increase, e.g. mineral salts, thus solubility limit of the dissolved solids will ultimately exceed and consequently resulting in inorganic mineral deposition (hardness) in the cooling system, which must then be removed again by a rather time consuming and costly effort.

$$\text{Contentration Factor} = \frac{\text{Mineral Salt Content of Recirculating Water}}{\text{Mineral Salt Content of Water Supply}}$$



Picture 2: Cooling Tower Flow Schematic

To prevent this concentration buildup, a portion of the recirculated water must be replenished with fresh water to prevent exceedance of the solubility limit of the dissolved solids. Typically, such a process is controlled via conductivity measurement. However, depending on the dilution demand, this replenishing process for maintaining the required volume of the recirculating water is an increase in operating cost of the cooling system.



Picture 3: Fresh water demand with increasing concentration (recirculating water volume constant)

Picture 3 shows the relationship between concentration factor and fresh water supply demand. It is worth noting how the fresh water demand is decreasing with increased concentration (dissolved solids concentration) by constant recirculating water volume. With an increase of concentration from 1.5 to 3 fresh water supply is basically reduced to half. Since water costs are typically higher than chemical costs an increase of concentration can result in substantial cost savings. Cost savings above the concentration factor 4 are rather negligible and other interfering effects are having a negative system impact.

Thus, an additional increase of the concentration factor is not practical since a higher dissolved solids concentration would only increase the boiling point of the recirculated water and decrease the vapor pressure (ebullioscopy effect), which would reduce evaporation rate and resulting in a loss of cooling performance.

PROBLEMS WITH MICROORGANISMS

Accumulation of dissolved solids in cooling towers coupled with typical temperatures of approximately 25 – 35 °C are promoting ideal conditions for the germination of microorganism e.g. Pseudomonas aeruginosa and Legionella spp... Bacteria are constantly introduced into the cooling tower from either the surrounding air or fresh water supply, which requires proper disinfection and microbial control.

Biofilm buildup (fouling) on surfaces with contact of water are particularly problematic as this not only affects heat transfer but also promotes corrosion and impairs with the hygienic condition of the cooling tower.

Since the recirculated water is in direct contact with air and is subsequently exhausted to the environment, it exists the possibility that, despite the use of demisters, water droplets entrained by the air stream escapes the cooling tower in form of an aerosol. It is due to this fact that health hazards are caused because of excessive bacteria growth in the cooling tower as bacteria carrying aerosol is the ideal pathogen for infectious diseases such as Legionella.

The microbiologic conditions of a cooling tower are, therefore, primarily from environmental circumstances impacted:

- Temperature (→ seasonal impact)
- Drag-in of sedimentary deposits (dust etc. → climatic impact)
- Fresh water supply composition
- Drag-in of environmental pollutants, pollen (e.g. pollen → seasonal impact)

For that reason, not all cooling towers are suffering equally as local environment plays a significant role and influencing its operation accordingly, requiring customized conditioning of their recirculating water. For instance, the farther north the geographical location of a cooling tower is the less problematic is its operation regarding microorganism, which is primarily due to tendentially lower temperature of that climate. Furthermore, a cooling tower operation in a dusty and dirty environment is more problematic than in a clean air environment.

For recognizing system changes in time, it is critical that regular bacteria and Legionella tests are performed. Therefore, the VDI 2047 guideline is recommending stringent (e.g. monthly) control intervals.

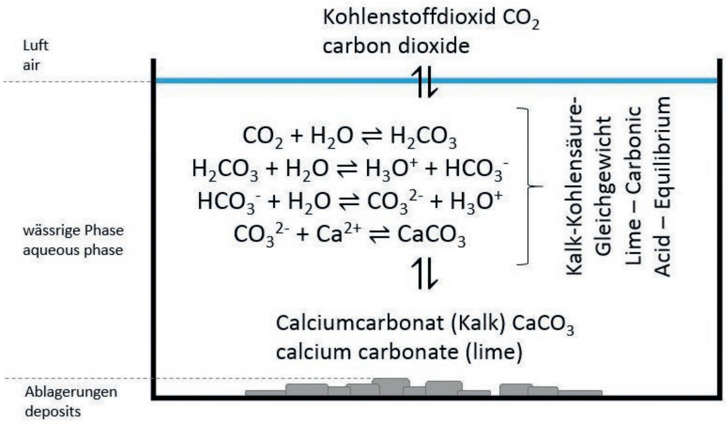
Parameter	Action Required Limit
Total bacteria count (GKZ)	~ 10000 KBE/ml
Legionella ssp.	100 KBE/100ml
Pseudomonas aeruginosa	100 KBE/100ml

Table 1: Action required limits for commonly tested microbiologic parameter per VDI 2047 page 2 (KBE = colony forming units)

Table 1 lists three basic tested parameters for evaluation of the microbial condition and first level action required limits. When first level limits are exceeded the guideline VDI 2047 requires for special action to be taken, e.g. shorter test periods or specific identification. Exceedance of additional levels calls for more action and may ultimately lead to immediate shutdown of the system.

LIME-SCALE DEPOSIT PROBLEMS

Calcium carbonate – carbonic acid equilibrium is of essence for understanding buildup of undesirable lime-scale deposit and corrosion in cooling towers by making it an additionally important parameter for the cooling tower operation.

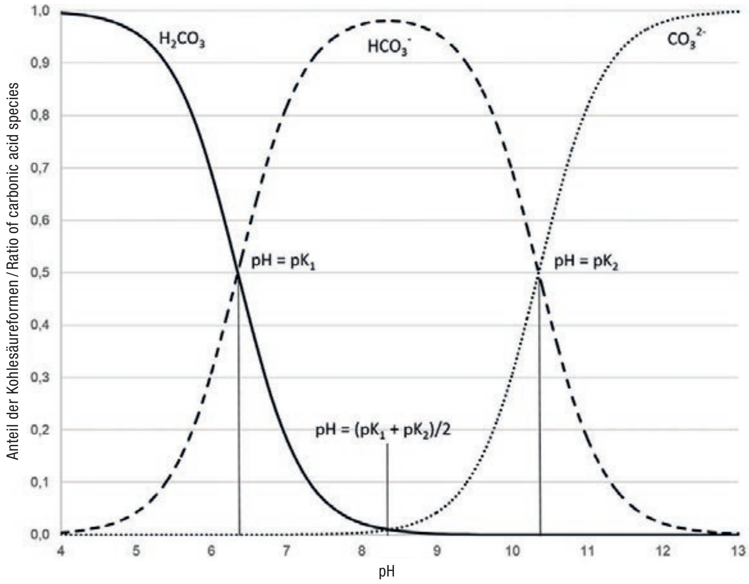


Picture 4: Schematic illustration of the Calcium Carbonate-Carbonic Acid-Equilibrium

As shown in picture 4, small amounts of carbon dioxide are introduced into the recirculated water from contact with air. A small fraction from it is reacting and thereby forming carbonic acid (H_2CO_3). As shown in picture 4 and 5, the formation of calcium carbonate occurs via multiple dissociation steps of the dissolved carbonic acid in the system.[5]

Ultimately, the calcium carbonate – carbonic acid equilibrium is determining how materials (surfaces) in contact with the water is reacting. If a small amount of carbonic acid is present, then the system is in balanced condition. However, if there is too much carbonic acid the water reacts aggressively by forming lime-scale and causing corrosion for metal and concrete materials. On the other hand, a lack of carbonic acid in the system causes precipitation of low soluble calcium carbonate which can also cause interference with the cooling tower operation. Therefore, both off-limit conditions must be avoided to ensure optimal cooling tower operation.

Since cooling towers are complex systems influenced by many possible factors (e.g. fresh water supply or pH value, see picture 5), calcium carbonate – carbonic acid equilibrium must be evaluated and controlled case by case. The problem is especially critical when water supplies of different sources get mixed together, e.g. demineralized water and city water. Calcium carbonate – carbonic acid equilibrium of one supply may be acceptable while another one is not.



Picture 5: Proportion of Changing Carbonic Acid Compositions Depending on pH-Values

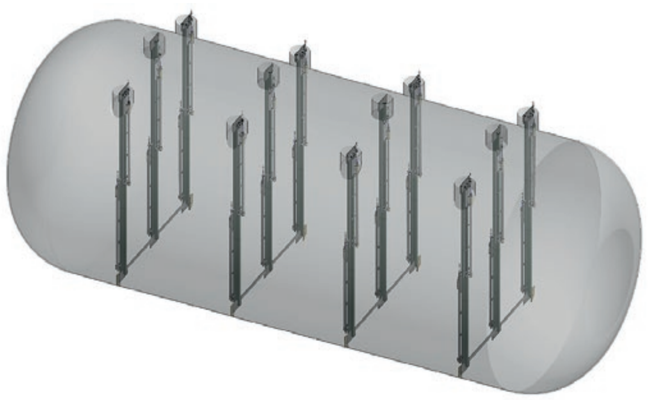
COOLING TOWER OPERATION WITH UV-H_2O_2 COMBINATION

The most common approach to control recirculated water of a cooling tower is by dosing various chemicals, of which some are rather toxic, and the complex interaction of these chemicals require a major effort. Biologic pollution may be under control and biofilms dissolved with conventional biocides, however, equipment materials (surface passivation) in contact with these chemicals become corroded followed by a new biologic attack, resulting in additional corrosion inhibiting chemicals to be added into the system for combating side-effects. All these added chemicals combined with the ongoing evaporation process, the recirculated water becomes so concentrated with dissolved solids that the use of hardness stabilizers is necessary to avoid mineral deposition.

Many of the applied chemicals are unfortunately needed only to combat negative side-effects of another added chemical. The resultant chemically loaded water (e.g. AOX, phosphates) requires periodic replenishing and must be discharged to the wastewater treatment system for subsequent treatment.

For these reasons, an environmental friendly and economically effective method is UV-irradiation combined with completely disintegrating hydrogen peroxide (H_2O_2). Enviolet GmbH has supplied hundreds of industrial cooling towers with that treatment concept and has gained the experience together with positive customer reviews.[6]

The UV-disinfection application is also approved by the previously mentioned VDI-guideline, although their requirement for UVsensors for this application reveals some lack of practical knowhow. Enviolet GmbH has developed some alternate solutions since UV-sensors in cooling towers do not provide reliable monitoring data.



Picture 6: Example of mounting bracket systems for submerged UV-lamps in KTC-Tanks

Envielot GmbH has set varies goals for the treatment standard of cooling towers:

- Reliable and high efficiency of the cooling tower operation
- Total bacteria count and Legionella limits should be below the required action limits
- Lower operating cost and less labor intensive
- The cooling tower may not form slurry, nor any lime-scale buildup, nor become corroded
- The operating mode must be user-friendly and environmentally as safe as possible

The necessary steps for the implementation and achievement of this goals are described in the following paragraphs.

INTEGRATION OF UV-LAMPS

Considering the specific portion of the UV spectrum UV-Irradiation has a strong germicidal effect by killing microorganisms/pathogens. The highly energetic irradiation effect from these UV-lamps kills microorganisms by penetrating their cell membranes and destroying the DNA, making them unable to reproduce and effectively killing them.

Contrary to biocide products, no bacterial resistance can be formed and disinfection in the surrounding area of the UV-lamps occurs without feeding of any additional chemicals. Typically, the recirculated water of the cooling tower is stored in a buffer tank where UV-lamps can be positioned inside that tank. Here is where effective bacteria control and reliable disinfection of most water in the system is achieved. With this kind of setup, a UV-reactor is created and integrated into the cooling tower buffer tank, whereas, with relatively high retention time of the closed-loop water, the UV-lamps are providing a very high and penetrating UV-dose.

Therefore, the first step for implementation of the UV-H_2O_2 system is the correct placement and number of the legally protected Microspear® & Microfloat® units inside the cooling tower tank as shown in picture 1.

The placement and number of UV-lamps are customized depending on the specific operating parameters of the cooling tower. A highlighted feature of the system is the UV-lamp, Microfloat® (floating on the water surface) which, together with the UV-lamp Microspear®, can be combined to a tailor-made modular concept. Besides disinfecting the water, by placement of the floating UV-lamps on the water surface, the surrounding air and moist and wet walls above the water level will also be simultaneously disinfected.

The UV system is delivered as a complete package including a control panel manufactured to industrial standards. System functions and life cycle time of the UV-lamps are all integrated and monitored in the control panel. These provided systems deliver by far more reliable control and useful information than the VDI 2047 required cooling tower UV-sensors.

The modular concept and customized bracket systems design allows for cooling towers with various tank sizes and cooling performance to be easily equipped. To ensure optimal arrangement of the UV-lamps in the cooling tower tank or other auxiliary tanks, there are assorted, legally protected, systems available:

- Stainless steel base plates with protective cage (see picture 1)
- Cable-bracket systems (stainless steel cable, affixing of Microfloat® and Microspear® per special brackets for optimal maintenance)
- Bracket systems for KTC-Tanks and similar (see picture 6)
- Customer specific systems, assuring a technically optimal integration

UV-H_2O_2 COMBINATION

UV-Irradiation is simply not enough for a reliable operation of the cooling tower as some system components, pipes and other blind spots are not irradiated and, UV has no residual effect. For that reason, step two is necessary by metering small amounts of completely disintegrating hydrogen peroxide (H_2O_2) into the recirculating water loop.

Hydrogen peroxide is a disinfectant and weak oxidant which, depending on the conditions can also have deoxidizing effects. Under the influence of UV-irradiation hydrogen peroxide is decomposed into two hydroxyl-radicals that act as a strong oxidizer, but, as described later, due to its transitory effect it causes no corrosion and thus considered harmless:

$$H_2O_2 \xrightarrow{\text{UV-Irridiation}} 2\,OH^{\cdot}$$

The resultant hydroxyl radicals through this synergy ensure the disinfection as well as combating biofilms in those areas where UV-irradiation is not accessible (piping, heat exchanger, other auxiliary system components). Simultaneously, the radicals re-

	Advantages	Disadvantages
UV	Resistance buildup is impossible	No residual effect; blind spot areas in the system without UV-irradiation may not be disinfected
H_2O_2	Disinfection effect also in blind spot areas with no UV-irradiation, residual effect present	Resistance buildup is possible at prolonged low concentration levels (same as with all disinfecting agents); Catalase effect rather critical
	Combined Concept	
H_2O_2	Synergy: Decomposition of H2O2 to radicals; all system components will be disinfected; Risk of resistance buildup is virtually impossible with the combined concept; Reduction of organic (AOC); Substrate for microorganism will be deprived; Forming of small organic carbonic acids (with minimal AOC); Small organic carbonic acids act as natural complexing agents, therefore, minimal calcium carbonate deposition due to forming of complexes and positive pH influence	

Table 2: Technical Advantages and Disadvantages with UV-H_2O_2; AOC = (from Microorganisms) Assimilable Organic Carbon

act with organic compounds present in the water by reducing the AOC level (Assimilable Organic Carbon), i.e. breeding ground for microorganisms/bacteria.

Table 2 describes advantages and disadvantages of the UV and H_2O_2 treatment system and its effect when applied in combination. It clearly shows how the two treatment steps complement each other by combining them into one-of-kind treatment concept that is ideal for microbiologic control of cooling towers.

There is no additional concentration increase when feeding H_2O_2 and no chemicals are discharged during replenishment of the recirculating water, resulting in a major advantage since this water can be discharged without any further treatment requirement.

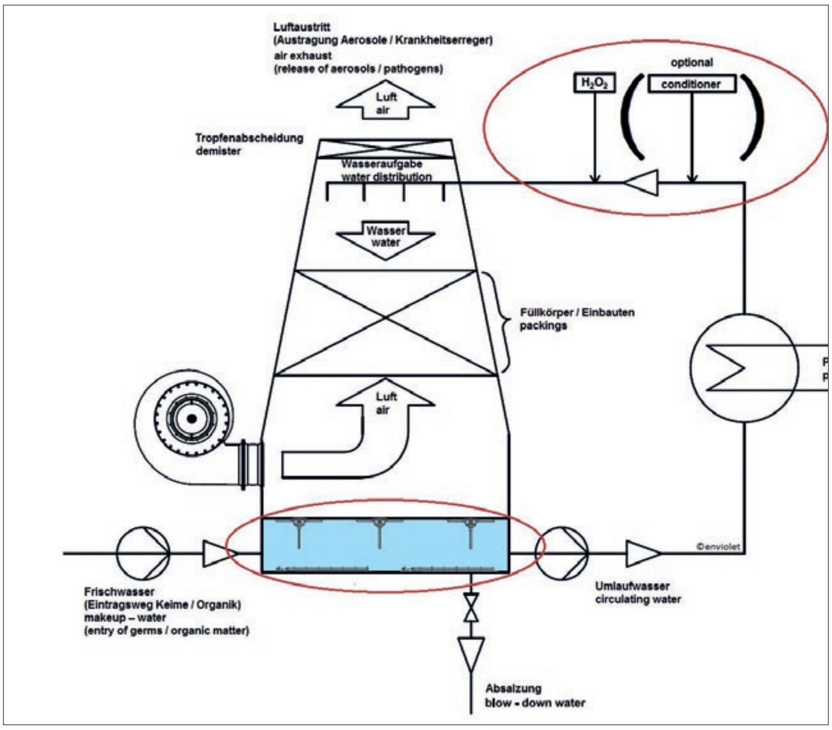
Furthermore, the clean water quality not only improves the cooling tower performance but is also advantageous from disposal and environmental aspects. Due to lower dissolved solids concentration, the vapor pressure of the closed-loop water will also be reduced and increase the cooling tower's evaporation rate and cooling performance (ebullioscopy effect).

If removal of lime-scale is necessary, a third step is provided by intermittent metering of completely degradable non-corrosive conditioning agents.

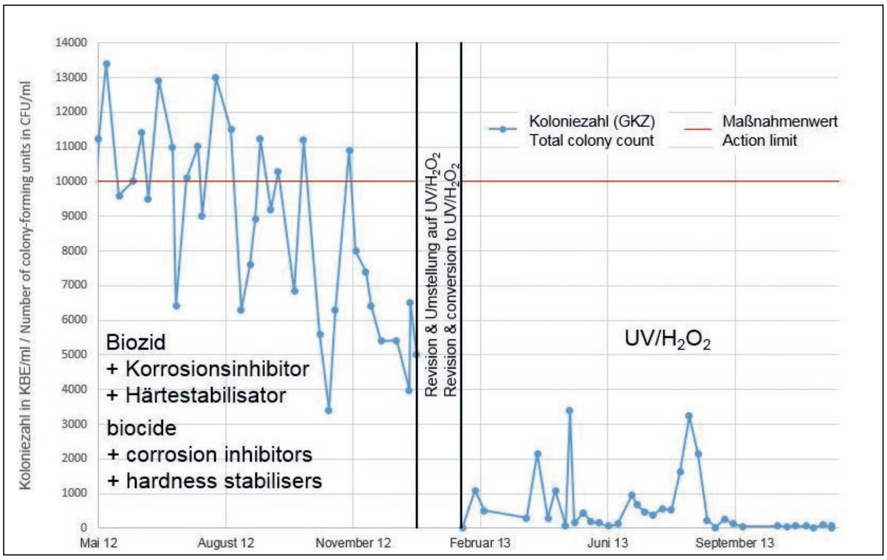
REVIEW AND RESULTS

As described above, the combination of the three treatment steps is a complete concept resolving all problems of microorganisms and the calcium carbonate issue (lime-scale build-up). Furthermore, the treatment concept has already been proven multiple times. Picture 7 illustrates the typical integration of a UV-disinfection system into the cooling tower water recirculation tank and the H_2O_2 feed into the water recirculation loop. For reference purpose please also refer to system flow schematic, picture 2.

The data shown in picture 8 are based on regularly performed bacteria growth tests from a strongly affected cooling tower. Due to continuously over-the-limit values, specifically during summer season, the operation of a totally chemical fed (biocide, hardness stabilizer and corrosion inhibitors) cooling tower was converted to UV-H_2O_2 disinfection. The required operating limits



Picture 7: Conceptual Flow schematic with integrated UV-Disinfection and H_2O_2 Feed



Picture 8: Bacteria growth, total bacteria count/year (GKZ), KBE/ml = Colony Building Units per ml (prior to UV-H_2O_2 system installation of a biologic strongly affected cooling tower)

were after conversion, including summer season, successfully and reliably maintained. Bacteria count tests (GKZ) were performed from water samples taken from the cooling tower with incubation in a culture medium of 5 days at 22 °C.

Table 3 shows Legionella test results of five step by step converted cooling towers from conventional chemical to UV-H_2O_2 treatment over a period of 2–3 years. The color change of the cells from white to blue indicates the time frame of the conversion. The data demonstrates that Legionella growth is in all cases reliably below the required limits of VDI 2047, page 2. In four out of five cooling towers, after conversion from chemical to UV-H_2O_2 treatment, is midterm an improvement clearly noticeable.

Table 4 shows corrosion rates based on the identical material of the cooling towers as listed in table 3. One can notice that cooling tower 1 with UV-H_2O_2 operated has a low corrosion rate even without use of a corrosion inhibitor. However, cooling towers 2–5 attained in comparison a noticeably better result while operating with chemical treatment during those periods.

Table 5 illustrates operating costs of a converted cooling tower from conventional chemical treatment to UV-H_2O_2. It demonstrates in this comparison that for just the conditioning portion of the cooling loop (H_2O_2 + power consumption + UV-lamp) operating costs were reduced by over 50%. Also, by a constant remaining concentration factor a reduction in water consumption can normally be expected. And, ultimately, wastewater treatment costs were eliminated by achieving a substantial operating cost savings with a more environmental and user friendly operation of the cooling tower at Lemken GmbH & Co. KG, Alpen, Germany (327 Million, Sales 2015[7]). After implementation of the UV-H_2O_2 system the periodic discharge of the concentrated water from the cooling tower could be directly discharged as seepage water since it was chemical free water quality.

Data shown in table 3, 4 and 5 (Legionella test results, corrosion rate and operating costs), were supported from several UV-H_2O_2 converted cooling towers of the SNF Floerger Group. SNF Floerger is a worldwide chemical producer with yearly sales (2015[8]), of over 2 Milliards Euro (or 2 US-Billions Euro). After conversion of the first few cooling towers the remaining others were also step by step converted. The demonstrated positive results in the respective tables above are certainly prove of this excellent system quality applied in praxis.

SUMMARY

Because of the VDI-guideline 2047 page 2, it is now the cooling tower owner's liability committing for a safe and efficient system operation. In comparison to a common standard solution – conditioning of the cooling water with chemicals – UV disinfection combined with H_2O_2 offers as an alternative in many ways an advantageous solution by providing a more efficient and environmentally safer cooling tower operation.

The previously defined goals for the system were achieved as follows:

- Reliable cooling tower operation at high efficiency
- No resistance buildup possible with UV+H_2O_2 combination
- Improved cooling performance with applied UV+H_2O_2 (ebullioscopy effect)
- Total bacteria count and Legionella bacteria should remain below required limits
- The treatment concept has been successfully implemented in many cooling towers and can also be applied for disinfection in air
- Conditioning systems, humidifiers or air handling systems. The demonstrated results confirm the many advantages of the applied
- Treatment concept. Typically, the UV-H_2O_2 system can easily be integrated in existing systems
- In a time where companies request process optimization for the achievement of cost savings, higher efficiency and
- Total bacteria count as well as Legionella bacteria limits were consistently within the required limits or were
- Lowered in comparison to chemical treatment
- Operating and labor cost saving
- Substantial operating cost savings were achieved with a system conversion to UV-H_2O_2
- No slurry or lime-scale buildup nor corrosion in the cooling tower
- Slurry buildup will be minimized with proper disinfection

Date of Sampling	Legionella Test Results in KBE/100ml (Values per VDI 2047 Blatt 2 = 100 KBE/100ml)				
	Cooling Tower 1	Cooling Tower 2	Cooling Tower 3	Cooling Tower 4	Cooling Tower 5
29.05.2013	< 50	< 50		< 50	< 50
27.06.2013	< 50	< 50		< 50	
27.07.2013		< 50		< 50	< 50
22.08.2013	< 50	< 50		< 50	< 50
19.09.2013	< 50	< 50		< 50	< 50
20.12.2013	< 50	< 50	< 50	< 50	< 50
13.02.2014	< 50	< 50	< 50	< 50	< 50
13.03.2014	< 50	< 50	< 50	< 50	< 50
10.04.2014	< 50	< 50	< 50	< 50	< 50
06.05.2014	< 50	< 50	< 50	< 50	< 50
05.06.2014	< 50	< 50	< 50	< 50	< 50
03.07.2014	< 50	< 50	< 50	< 50	< 50
31.07.2014	< 50	< 50	< 50	< 50	< 50
28.08.2014	< 50	< 50	< 50	< 50	< 50
08.09.2014		< 50	< 50		
25.09.2014	< 50	< 50	< 50	< 50	< 50
23.10.2014	< 50	< 50	< 50	< 50	< 50
20.11.2014	< 50	< 50	< 50	< 50	< 50
18.12.2014	< 50	< 50	< 50	< 50	< 50
15.01.2015	< 50	< 50	< 50	< 50	< 50
12.02.2015	< 10	< 50	< 50	< 50	< 50
10.03.2015	< 10	< 50	< 50	< 50	< 50
16.04.2015	< 50	< 50	< 10	< 50	< 50
20.05.2015	< 10		< 10	< 10	< 10
28.05.2015		< 10			
18.06.2015	< 10		< 10	< 10	< 10
23.06.2015	< 10				
09.07.2015	< 10	< 10	< 10	< 10	< 10
23.07.2015				< 10	< 10
29.07.2015				< 10	< 10
06.08.2015	< 10	< 10	< 10	< 10	< 10
10.09.2015	< 10	< 10	< 10	< 10	< 10
23.09.2015				< 10	< 10
08.10.2015	< 10	< 10	< 10	< 10	< 10
05.11.2015	< 10	< 10	< 10	< 10	< 10
10.12.2015	< 10	< 10	< 10	< 10	< 10

Table 3: Legionella test results of several from chemical to UV-H_2O_2 converted cooling towers over a period of several years, the color change (green = conversion to UV-H_2O_2) indicates time/date of conversion to UV-H_2O_2, KBE/100ml per ISO 11731-2: 2004

Cooling Tower	Period of Measurement	Operating Mode	Corrosion Rate Micrometer/Year
Cooling Tower 1	28.02.2014 – 09.07.2014	UV/ H_2O_2	1,9
Cooling Tower 2	13.03.2014 – 03.07.2014	biocide, corrosion inhibitor and hardness stabilizer	2,8
Cooling Tower 3	28.02.2014 – 03.07.2014	biocide, corrosion inhibitor and hardness stabilizer	7,2
Cooling Tower 4	28.02.2014 – 09.07.2014	biocide, corrosion inhibitor and hardness stabilizer	2,1
Cooling Tower 5	28.02.2014 – 09.07.2014	biocide, corrosion inhibitor and hardness stabilizer	0,4

Table 4: Corrosion rates of the cooling towers listed in table 3; same reference material in all cooling towers; test strips immersed in recirculated water for corrosion rate evaluation

	UV/H_2O_2	Biocide, Corrosion Inhibitor and Hardness Stabilizer
H_2O_2	77,00 €	—
Biocide + Corrosion Inhibitor + Hardness Stabilizer	—	1439,00 €
Fresh Water Makeup	1750,00 €	1750,00 €
Power Consumption	105,00 €	10,00 €
UV-Lamp	523,00 €	—
Treatment of Replenished Water	—	1319,00 €
Operating Cost (6 Months)	2455,00 €	4508,00 €

Table 5: Cooling tower operating cost comparison during a 6-month period before and after conversion to UV/H_2O_2

- Lime-scale buildup will be removed with a biodegradable conditioning agent if necessary
- Corrosion could be held at a minimum without use of corrosion inhibitor
- Operating condition should be as environmental friendly as possible
- H_2O_2 and conditioning agent are completely degradable. Cooling tower water discharge does not require any treatment

The treatment concept has been successfully implemented in many cooling towers and can also be applied for disinfection in air conditioning systems, humidifiers or air handling systems. The demonstrated results confirm the many advantages of the applied treatment concept. Typically, the UV-H_2O_2 system can easily be integrated in existing systems. In a time where companies request process optimization for the achievement of cost savings, higher efficiency and maintained sustainability, this presented treatment concept offers an alternative for the future with powerful arguments!

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