ENERGY OPTIMIZED AND HYGENIC SOLUTIONS FOR WET RECOOLING SYSTEMS

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Abstract

The commercial use of Thermally Driven Cooling – TDC – machines (absorption, adsorption, desiccant, etc.) is bound to specific conditions concerning the recooling of the process. Low recooling temperatures as well as low auxiliary electricity consumptions are critical factors to reach sufficient efficiencies of TDC systems. Therefore wet recooling systems are used. With the use of wet recooling systems additional challenges such as water consumption and hygienic issues occur. An Austrian research project called InnoCOOL deals with these challenges. Therefore a cooling tower test rig was set up to investigate and optimize the pending issues. Thermal, electrical and hygienic investigations were carried out and the foundation for the development of an industrial product the cooling tower boy was laid.

1. Introduction

With the use of wet recooling systems mainly three challenges occur:

- The growth of harmful bacteria such as legionella can occur
- High water consumption
- High auxiliary electricity consumption

Large scale systems therefore are operated with the high effort of constant maintenance which has to be carried out by qualified persons. Small scale solar driven applications used in private households or small office buildings cannot effectively be operated with this high effort. A solution at low costs is needed. The growth of harmful bacteria has to be prevented and the water consumption has to be minimized as well as the auxiliary electricity consumption. The tests are carried out at a cooling tower test rig which is set up on the premises of JOANNEUM RESEARCH in Graz.

Figure 1 shows the hydraulic scheme of the cooling tower test rig which is set up at JOANNEUM RESEARCH in Graz. It features a 48 kW wet cooling tower, a special air handling unit and a heating system which simulates a TDC. The air handling system is used to set the supply air conditions. The temperature as well as the humidity of the supply air can be varied in order to simulate different climatic boundary conditions.

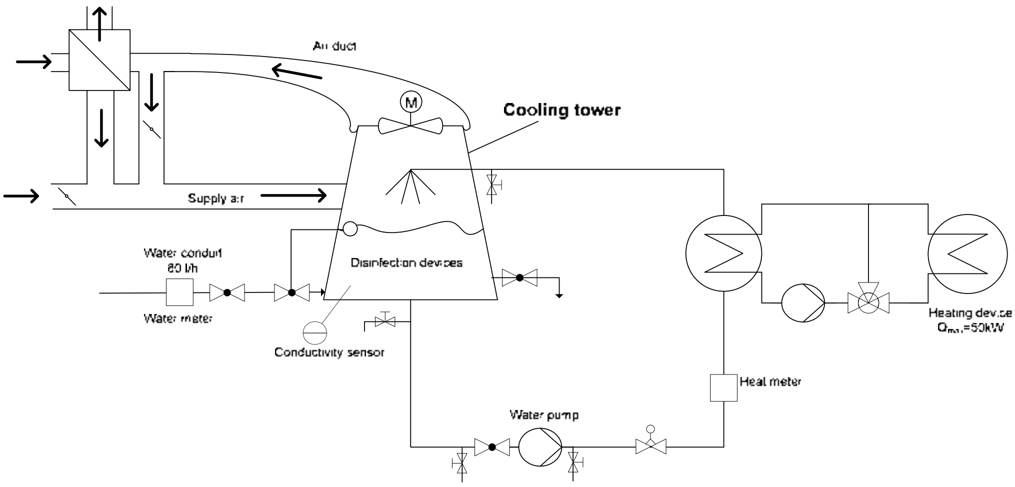


Fig. 1. Hydraulic scheme of the cooling tower test rig at JOANNEUM RESEARCH

2. Hygienic prevention strategies in wet cooling systems

2.1. Introduction

The legionella bacteria occur naturally in small amounts in every wet environment. They can be found in surface water, wet soil and tap water. In water conducting systems the legionella bacteria mostly find ideal living conditions to multiply. More than 70 species and 48 serotypes of legionellae are known. The most harmful species for humans is known as “Legionella Pneumophila”.

Cooling towers are considered to be man made amplifiers of Legionella ssp. and had been linked to many outbreaks of legionnaire’s disease in the past [1]. The mode of transmission of Legionellae is through the inhalation of aerosolized organisms. The concentrations of Legionellae associated with Legionellosis outbreaks are extremely variable and range between 103 and 106 cfu/mL [2]. So far there have been no relationships detected between concentrations of heterotrophic bacteria and Legionellae. In fact there are combined influences of organic, inorganic, antimicrobial and inhibitory formulations on the microbial community in cooling towers which make it difficult to find appropriate prevention strategies.

Thus the efficiencies of three different prevention strategies were investigated on laboratory scale. The strategies were: (1) Intermitted thermal disinfection, (2) Ultraviolet light disinfection and (3) Electrochemical disinfection based upon Silver/Copper Ionisation. The choice for these applications was driven by the criteria: low investment costs, low or no maintenance costs and automatic operation conditions.

First investigations on the pilot plant in operation concentrated from the hygienic point of view on the natural colonisation of heterotrophic bacteria in the cooling water circle.

2.2. Methodology

Pre-experiments were carried out using Standard I nutrient broth (MERCK) at a volume of 20 liters in batch reactors as growth media, which was sterilized in autoclave for 15 minutes at 121°C (pH = 7,5 ± 0,2 at 25° C). For the inoculation Pseudomonas aeruginosa was used as indicator organism because of their association with the acquisition of overt clinical disease from water-containing appliances.

During the application of various disinfection methods water samples were taken continuously out of the reactor and investigated for their biomass concentration. Quantifications of antibacterial effects were based on Agar plate counting and the use of a Bacteria Tracer Impedance Analysator. A microbiological multi-monitoring system based on a microbiological detection-system with electrical impedance measurement. Impedance is defined as the resistance to flow of an alternating current through a conducting material.

2.3. Results

2.3.1. Disinfection Strategies

a) Intermittent thermal disinfection

Heat treatment is a recognized method for bacterial disinfection. Significant effects of temperature to bacterial growth, depending on exposure time, have already been detected at 55 °C. 30 minutes of exposure to the heat at 55 °C significantly reduces the bacterial concentration in the system.

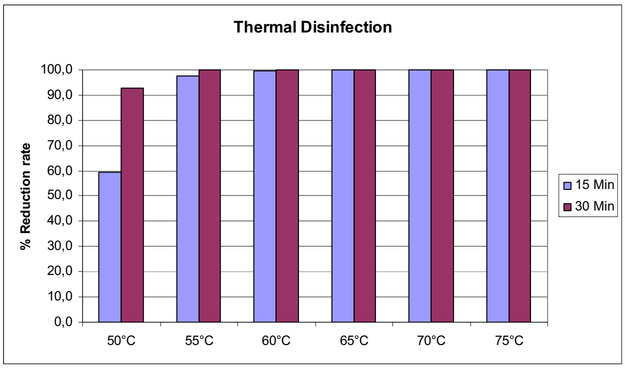


Fig. 2. Effects of Thermal disinfection on bacterial biomass concentrations in batch reactors

b) Ultraviolet Irradiation

The bactericidal effect of ultraviolet irradiation on the bacterial culture was expressed by reduced biomass concentrations up to 99.9 % after an exposure time of 45 minutes. Problems that occurred at regular intervals were reduced light intensities due to coating of the lamp surface with negative effects to the disinfection process.

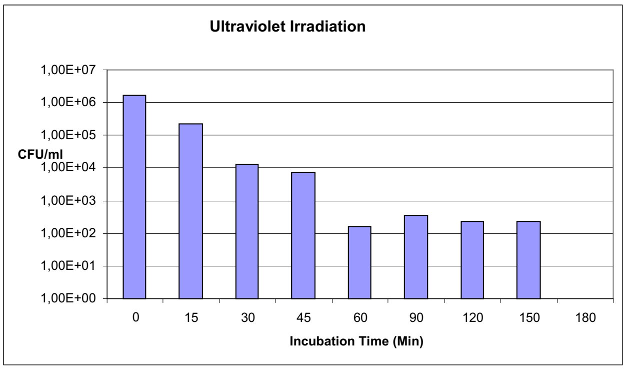


Fig. 3. Effects of Ultraviolet irradiation on bacterial biomass concentrations in batch reactors

c) Silver Copper ion disinfection

The best results show the tests with silver copper ion disinfection. In principle cooper ions penetrate the cell wall supporting the influx of silver ions, which are bound to various components of the cell system resulting in inhibition of cellular growth or cell division. Results show significant reduction rates of the bacterial concentrations within relatively short exposure times. Compared to the ultraviolet irradiation one advantage of this methodology could be the effective inhibition of biofilm communities through the homogenous distribution of the $Cu2+$ and Ag- within the water system. In general biofilm provides a mechanism that inhibits the penetration of biocides and other chemical treatments to the contained cells.

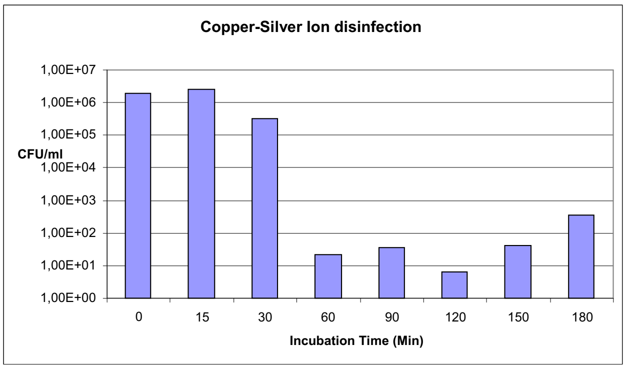


Fig. 4. Effects of Copper-Silver disinfection on bacterial biomass concentrations in batch reactors

2.3.2. Natural colonization of a wet cooling tower

After installation and commissioning of the pilot plant in spring 2010 the water flow of the cooling system continuously has been monitored with respect to water quality parameters and biomass concentrations. Micro-organisms enter cooling towers mainly through the water supply and the intake of air.

Within two weeks of operation the bacterial growth has reached its stationary phase. Influencing parameters to which the growth dynamic is correlated are ambient temperatures and the continuous increase of organic loadings within the water cycle. The concentration of anions and cations are underlying a steady accumulation process which under operating conditions will define the water management of the system.

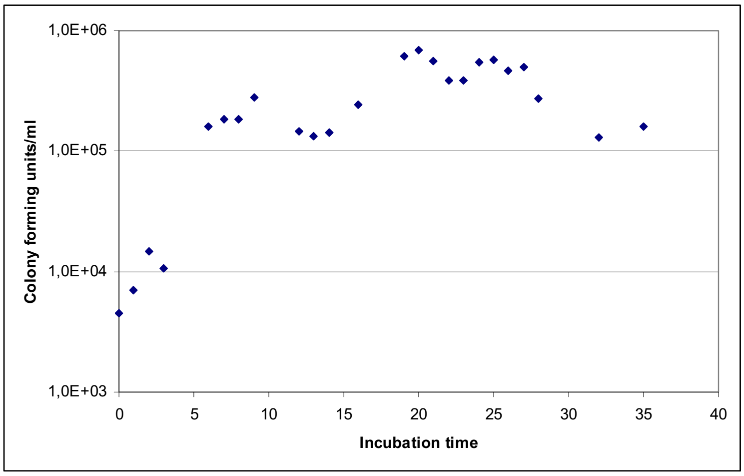


Fig. 5. Natural colonization of heterotrophic bacteria in a cooling tower pilot plant

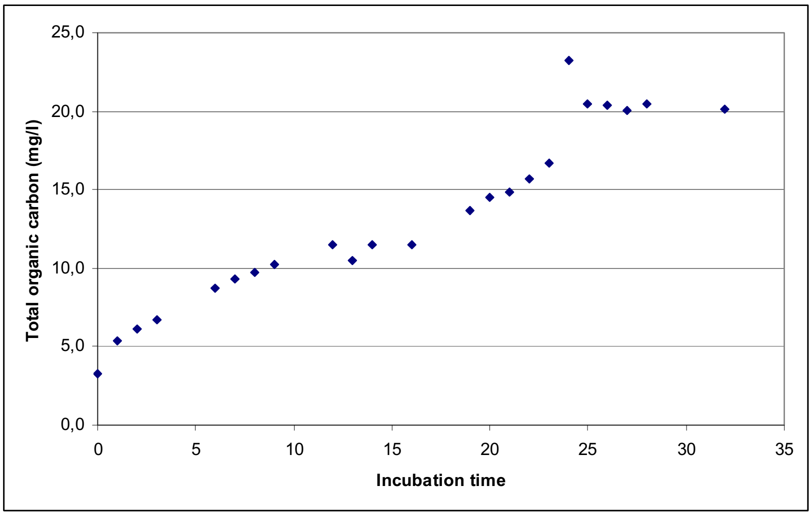


Fig. 6. Development of the total organic carbon concentrations (TOC) of the cooling water system after installation and commissioning of the pilot plant

Table 1. Development of the water quality in the cooling water system after installation and commissioning of the pilot plant

Operating Time (days)	Na [mg/l]	K [mg/l]	Mg [mg/l]	Ca [mg/l]	Cl [mg/l]	NO_3 [mg/l]	SO_4 [mg/l]	HCO_3 [mg/l]
0	6,5	11,8	14,4	82,3	13,6	8,4	36,5	283,1
1	14,4	5,3	32,7	105,1	21,0	18,4	90,6	356,4
2	24,0	9,1	53,8	99,9	44,1	28,2	144,9	368,6
3	29,7	8,9	70,3	106,1	51,8	37,2	200,0	380,2
6	54,8	20,3	143,3	54,9	100,1	84,9	403,6	286,8
7	59,6	21,6	157,9	35,7	108,0	92,5	436,9	237,4
8	61,8	21,6	161,7	46,9	112,9	94,4	449,4	276,4
9	66,8	49,1	175,1	42,1	126,3	104,4	492,1	271,5
12	72,1	24,7	183,2	44,8	128,8	112,1	527,7	288,0
13	77,9	22,8	185,0	65,4	138,6	108,4	518,0	381,4
14	82,3	22,0	198,0	44,7	140,7	112,0	526,0	299,0
16	80,2	26,0	192,0	43,7	143,9	111,0	529,0	290,5
19	83,2	21,5	226,0	23,4	146,5	114,1	528,0	331,3
20	99,6	26,6	229,0	44,8	171,9	134,9	617,0	333,8
21	103,0	26,0	236,0	47,6	176,3	138,4	632,0	349,0
22	106,6	25,4	246,0	46,1	183,4	147,1	666,0	348,4
23	118,2	27,6	270,0	44,7	208,0	165,5	745,0	369,8
24	142,3	31,7	325,0	31,8	254,7	207,6	906,0	366,1

2.3.3. Summary and Outlook

Findings of the short term experiments in general indicated the efficient application of all tested disinfection methods. Further investigations will focus on the evaluation of these results under operating conditions of a pilot plant on a long term schedule. The test design will cover continuously quantifications of inoculated heterotrophic bacteria and Legionella pneumophila in the water flow and aerosols deriving from the system.

3. Minimization of the auxiliary energy in solar absorption air-conditioning plants

3.1 Introduction

Thermal driven cooling systems need thermal energy to drive the thermodynamic process. But also a certain share of electric energy is necessary to operate the internal and external pumps and the electric control. The relation of the cold produced to the energy needed to drive the process is the characteristic number (ζ or COP – Coefficient Of Performance) for these cooling processes. The ratio between the produced cold and the driving heat is called “thermal Coeficient Of Performance (COP_{th})”. The ratio of the cold produced and the necessary electric energy for all auxiliary purposes is called “electric Coefficient of Performance (COP_{el})”. For all single lift, thermal driven sorption systems the COP_{th} lies between 0,30 to 0,75. The COP_{el} is especially important for all solar driven absorption systems and is found in test plants between 4 and 6. The desired number will be over 10.

3.2 Electric auxiliary drives in absorption cooling plants

The different cooling technologies have different characteristic auxiliary electricity consumptions. Table 2 shows the electricity consumption of a 10 kW absorption cooling plant for air conditioning with the working fluids ammonia/water and water/lithium-bromide. Due to the differences of the pressure levels within the two cooling processes also the working fluid pumps needs different amounts of electric energy.

Table 2: Necessary power for the auxiliary drives of a 10 kW-solar absorption air-conditioning

Drive	NH_3/H_2O	$H_2O/LiBr$	
	Watt	Watt	Remarks
Solar circuit pump	80	80	
Cold circuit pump	50	50	
Working fluid pump	450	50	pressure difference
Cooling tower pump	500	500	
Cooling tower fan	300	300	
Control	50	50	
Total electric consumption	**1.430**	**1.030**	

The total electricity consumption in the case of the 10 kW_{cold} solar absorption air conditioning system with the working fluid ammonia/water reaches 1.430 Watts. With such an electric drive a conventional vapour compression split system can produce already a cooling capacity of more than 4 kW of cooling. It is therefore absolutely necessary to reduce the electrical power consumed from the grid especially for solar absorption cooling plants.

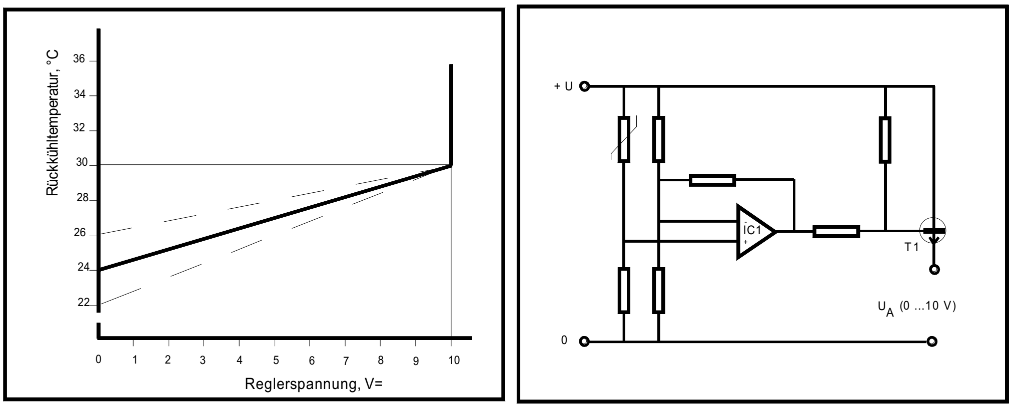
3.3 Potential for reduction of the electric consumption

For a first rough estimation of the annual cost of the electrical auxiliary energy the annual operation time of the solar cooling plant can be assumed with about 800 hours. Without a speed control for the drives the consumed electrical energy will reach about 1.100 kWh/a for the ammonia system and about 800 kWh/a for the low pressure system. The cost of the electric energy for these applications therefore lies in the range of 130 to 180 €/a. It is assumed that the electrical consumption can be reduced to 50% of the above mentioned cost by special technical measures. This example shows that the technical measures proposed have to be cheap and technically mature.

3.4 Technical solutions

The following items show technical solutions for the reduction of the electric energy consumption of the auxiliary drives.

Speed control of the cooling tower fan: For a 10 kW solar absorption cooling plant a 50 kW cooling tower is normally used. Following the calculation procedure for wet cooling towers in [3] the 50 kW cooling tower needs an air mass flow of about 1,38 kg/s. This air mass flow is necessary inside the wet cooling tower for the heat rejection. This means that the fan has to deliver an air mass flow of about 5.000 kg/h or 6.000 m3/h. This is in the case of part load to much and electric energy can be saved with a suitable, cheap speed control, which is lead by the heat rejection water temperature.



a

b

Fig. 6. Control curve (a) and principle analogue electronic circuit (b) for a speed control of the fan.

Figure 6 shows the principle of a very cheap electronic device for a speed control of the cooling tower fan. The fan has to be equipped with a frequency converter which can be controlled by a DC voltage of 0 to 10.

Speed control of the pumps: In case of part load of the solar absorption cooling device it is not necessary that all the pumps (collector water circuit, cold water circuit and heat rejection water circuit) work on full speed. A simple analogical electronic device can control the pump speed. The strategy of this control circuit could be a constant temperature difference of the water mass flow in the above mentioned water circuits.

Special emphasis has to be laid on the process behaviour of the cooling tower at reduced heat rejection water mass flow. It has to be tested seriously that the wet cooling process is reduced as a function of heat rejection water mass flow without an undefined breakdown.

4 Minimization of the of the water consumption

4.1 Introduction

The solar thermal driven cooling has a lot of advantages compared to the electric driven conventional technology. But one of the disadvantages is the higher thermal heat rejection load. Following the example of the mentioned 10 kW absorption air conditioning plant it can be shown, that the absorption system has a heat rejection load of 26 kW and the 10 kW vapour compression unit only about 13 kW. The heat rejection facility of a solar thermal driven system is therefore more expensive than that for a conventional vapour compression system. In addition to this disadvantage also the heat rejection temperature has to be as low as possible. Therefore a wet cooling tower with all its well known penalties is the best technical solution in most of absorption cooling applications.

4.2 Water evaporation and “blow down”

The cooling effect in an open wet cooling tower is managed by evaporating water. About 40 kg of clean water have to be evaporated for the heat rejection load of 26 kW.

Only clean water evaporates and all the chemical substances remain in the heat rejection water circuit and their concentration increases continuously. The water quality is determined by the amount of calcium and magnesium solved in the water. This is generally known as water hardness measured in degrees German hardness. If the water is hard the blow-down rate increases. So a decision has to be made: The investment cost plus the annual service of a water treatment device like an ion-exchanger has to be compared with the cost for the higher water consumption due to a high blow-down rate.

The blow down of the heat rejection water is normally realized by a constant water flow, independent of the heat rejection part load. If the cost of water is high, an electronic economizer could be considered to save water cost. The estimated savings of water for the above mentioned 10 kW-solar absorption cooling plant could be at about 20 l/h due to the part load of the plant. With a daily operation time of 8 hours a daily reduction of water consumption of 160 liters and an annual reduction of 16.000 liters could be expected. It depends strongly on the water cost if the additional cost for a blow-down economizer should be invested.

4.3 Technical solution

A cheap water conductivity measurement is proposed. Water conductivity sensors can be realized by two metal electrodes which are located in the water and a very small alternating currant flow between the electrodes through the water. The level of alternating current depends strongly on the number of ions in the water, which depends at first on the concentration of calcium and magnesium. In addition there is an interdependency between the conductivity and the water temperature. Therefore the measurement results have to be corrected by an electronic temperature signal.

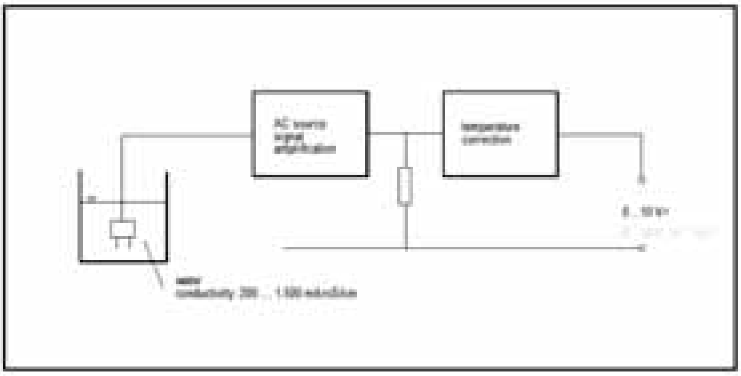


Fig. 7. Conductivity sensor for blow-down control

5. Cooling tower boy

An electronic unit is proposed especially for the application in solar absorption cooling plants. This device should be available as an economizer on a relatively cheap price. The cost of the electronic unit (CT-boy) has to be geared on the saving of electricity and water. A buy-back period of about 5 years should be guaranteed for this investment. The main tasks of the CT-boy are:

- Reduction of the annual electricity consumption for the auxiliary drives as described above in order to enlarge the COPel
- Minimization of the water consumption in case of wet re-cooling.

- Killing of all bacteria, algae and fungi through a newly developed silver/copper ion disinfection system within the heat rejection water.
- Excellent results have been gained with the silver/copper disinfection method on bacteria, like Legionella. Special investigations with fungi and algae are still missing.

References

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