Solar thermal absorption cooling - heat rejection by pulsed water spraying on a hybrid cooler

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Abstract

A hybrid cooler was installed for heat rejection in the mid temperature range of the absorber condenser unit of a LiBr-H_2O solar thermal driven absorption cooling system. The heat rejection efficiency generally is increased by continuous water sprinkling on the heat conducting surface of the heat exchanger and the water evaporation thereof e.g. because of latent cooling. To reduce the water consumption the cooler heat exchanger was pulse-sprayed through nozzles. By decreasing the pulse cycle time the return fluid temperature to the absorber condenser unit of the absorption cooling machine could be lowered and finally reached the fluid temperature of the open cooling tower for comparison. On the contrary the water use is increased by a lower pulse cycle time because the total water spraying time is increased. A strong inhomogeneity of the temperature distribution on the hybrid cooler heat exchanger could be observed.

Keywords: solar thermal absorption cooling, heat rejection, hybrid cooler, pulsed water spraying

1 Introduction

The increased need of air conditioned working and living rooms leads to a higher thermal and electrical energy consumption. The regional dependence of the climatic conditions allows the use of water operated open cooling towers for efficient heat rejection from the absorber condenser unit of the thermal driven absorption cooling machine. In these open cooling towers the cooling effect is mainly affected through the evaporation of water out of the cooling water flow e.g. latent cooling. The cooled water can reach the air wet-bulb temperature of the entering air plus the approach of 2K to 3K [1]. While water is evaporated the same amount of water has to be added to keep a constant water level in the cooling tower sump. To avoid the accumulation of lime scale, debris and the contamination of the water with dust, pollen and growing algae the cooling water has to be replaced and to be treated with biocides [2] or ultra violet light. To avoid hazardous legionella growth in the sump of the cooling tower a chemical treatment of the water has to be done periodically. Fresh water as valuable resource should be saved and sustainably used. In a hybrid cooler for heat rejection the efficient latent cooling effect can be applied by a continuous water sprinkling on the heat conducting heat exchanger surface. In the following an alternative system of continuous operating sprinkling system, namely heat rejection by pulsed water spraying on a hybrid cooler heat exchanger in a LiBr-H_2O solar thermal absorption cooling (STAC) system is presented.

2 Experimental

2.1 System boundaries

The 10 kWR SK Sonnenklima LiBr-H2O STAC machine is usually equipped with an open cooling tower type wct23kW for heat rejection [3][4][5]. An absorption cooling machine of this type is installed at SPF-HSR for investigations. To reduce water consumption a dry cooler [6] was installed at SPF-HSR in addition to the cooling tower. This dry cooler was equipped with spray nozzles. In Fig. 1 the heat rejection subsystem of the STAC system is shown and in Fig. 2 a photo shows the lamella heat exchanger of the dry cooler and the position of the installed nozzles. By switching the valves (Fig. 1) in the pipes the heat rejection can be done either through the open cooling tower or through the dry/hybrid cooler. With the water sprayed on the lamella of the heat exchanger through the nozzles a higher heat rejection efficiency of the dry cooler can be achieved because of the additional latent cooling effect. In this hybrid heat rejection mode a reduction of the water use / consumption can be reached by increasing the OFF period in spray cycle time. The spray cycle time consists of the sum of the ON and the OFF times of the magnetic valve – open and closed water supply pipe. In Fig. 3 a photo of the magnetic valve and the clock timer which controls the valve is shown.

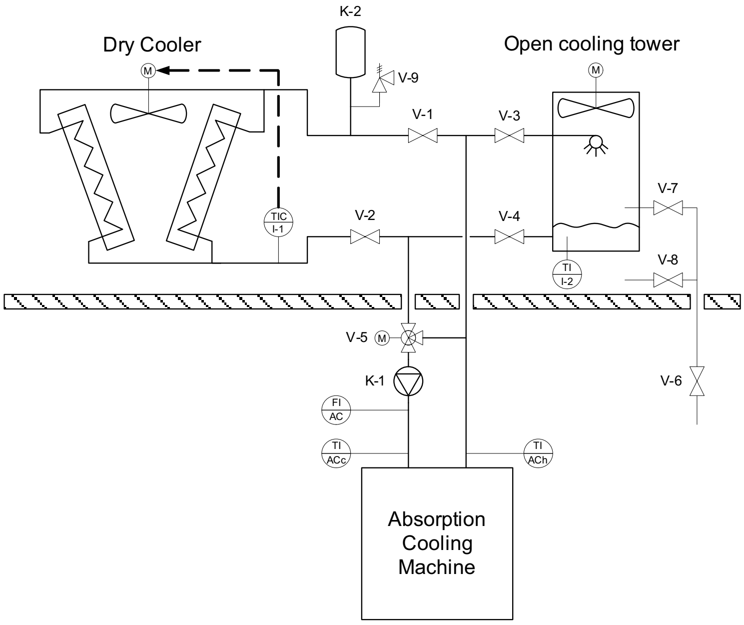

Fig. 1: Schematic of the heat rejection system.

Nomenclature:

K-1 Circulating pump.
K-2 Expansion tank.
V-X Valve (X=1, 2, 3, 4).
V-5 Mixing valve.
V-6 Main valve osmotic water.
V-7 Valve osmotic water open cooling tower.
V-8 Valve osmotic water hybrid cooler.
V-9 Pressure relief valve.
I-1 (TIC) Temperature sensor at return fluid of the hybrid cooler – ventilator speed control.
I-2 (TI) Temperature sensor in the sump of the open cooling tower.
$AC_{h,c}$ (TI) Temperature sensor.
AC (FI) magnetic flow sensor.

Fig. 2: Installed and operating dry cooler lamella heat exchanger equipped with 11 nozzles on each side of the V-shaped heat exchanger.

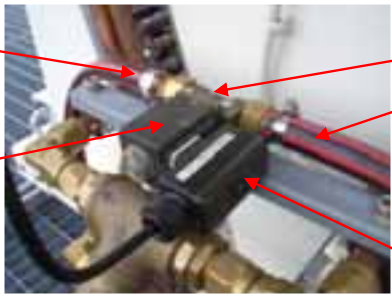

Fig. 3: Magnetic valve and clock timer of the water supply system to the spray system of the hybrid cooler.

The convective heat rejection in a hybrid cooler is increased through evaporation of water sprayed pulse-wise on the lamella of the heat exchanger. To avoid calcinations of the heat exchanger surface osmotic water was used in the experiments. Below the hybrid cooler no basin was installed to collect the excess water and for this reason no circulating pump was needed. The spray time could be reduced to several seconds and so the water use can be optimized. Table 1 shows the cycle time branches ON and OFF as they were fixed in the experiments and the determined volume flow dV/dt of the spray cooling system:

t_{ON}	t_{OFF}	$dV/dt_{Spray\ System}$
5s	5min 12s	8.60 l/h
5s	2min 20s	18.80 l/h
3s	1min 28s	19.81 l/h

Table 1: Spray cycle time ON / OFF and sprayed water volume.

The water consumption of the open cooling tower is in the range of 30 to 38 liters per hour.

The photo in Fig. 4 shows a zoomed sector of the 0.2 thick Aluminum lamellas of the dry cooler heat exchanger and a heat transfer fluid (water) containing pipe can be seen. For an increased heat transfer the lamellas are corrugated.

Fig. 4: Sector of the lamellas of the dry cooler heat exchanger. In the middle one of the fluid carrying pipes can be seen. The corrugated aluminum lamellas have a thickness of 0.2mm.

In the OFF valve position the water of the upper nozzles and flexible tube rows flows out through the lower nozzles and is lost for further use. Because of this reason a smaller diameter of 4.6mm for the flexible tubes was installed. The lower nozzle rows were directly installed on the 13mm diameter flexible tubes.

The objectives to reach in the heat rejection system are the temperature T_{ACc} of the returning fluid, which in our case is water, and the power P_{ACth} = dQ/dt which is the product of the mass flow

($\dot{m}$ = dm/dt = (dV/dt)*ρ(T)) and the heat capacity c_p(T) of the cooling fluid multiplied by the temperature difference between the higher cooling water temperature (h) and the colder return temperature (c) $\Delta T = T_{AC,h} - T_{AC,c}$: to the absorber condenser unit:

$$P_{ACth} = dQ/dt = \dot{m} * c_p(T) * \Delta T = (dV/dt) * \rho(T) * (T_{AC,h} - T_{AC,c}) \quad (1).$$

The temperatures were measured with Pt100 sensors and the volume flow was measured with a Krohne magnetic inductive flow sensor. Although osmotic water was used in the heat rejection subsystem, from the previous experiments the ion concentration in the water was high enough for a electrical conductivity of 30 μS/cm and a strong enough signal for the flow sensor. A comparison was made to the returning fluid temperature $T_{AC,c}$ in case of operating the system with the open cooling tower.

2.2 Selected Results

In Fig. 5 the return temperature $T_{AC,c}$ to the absorber condenser unit of the thermal driven absorption cooling machine is shown. For comparison the return temperature $T_{AC,c}$ of the open cooling tower is shown because heat rejection in this equipment is most efficient but related with high water consumption. The results will be presented and discussed in detail in the paper. The most efficient cooling principle is reached by fluid evaporation e.g. a phase transition from liquid to vapour, because the latent heat of evaporation Δh_v is generally several times higher than the specific heat capacity c_p(T) of the fluid. To reduce the amount of used water in this evaporation cooling decreasing the time t_OFF relative to t_ON shows a reduction of the temperature $T_{AC,c}$ and by this reduction the heat rejected power is increased. By adjusting the wetted heat exchanger surface through an appropriate relation of t_ON to t_OFF and an optimized geometric arrangement of the nozzles the process can be optimised. In Fig. 5 the return temperature $T_{AC,c}$ to the absorber condenser unit of the thermal driven absorption cooling machine is shown. For comparison the return temperature $T_{AC,c}$ of the open cooling tower is shown because heat rejection in this equipment is most efficient but related with high water consumption.

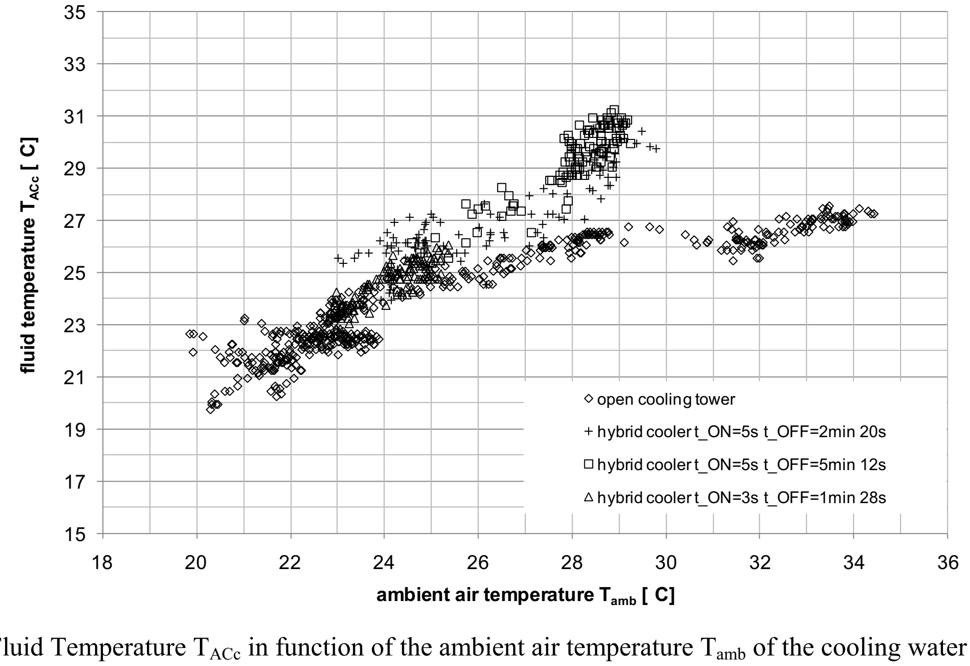

Fig. 5: Fluid Temperature T_{ACc} in function of the ambient air temperature T_{amb} of the cooling water entering the absorber condenser unit of the absorption cooling machine. For comparion T_{ACc} of the open cooling tower is shown. “t_ON” describes the spraying time (electromagnetic valve open), “t_OFF” describes the time interval with no spraying (electromagnetic valve closed).

In Fig. 6 $T_{AC,c}$ is shown in relation to the relative air humidity rh which influences the wet bulb temperature $T_{wet\ bulb}$ at a given ambient temperature T_{amb} at the geographic location of the system.

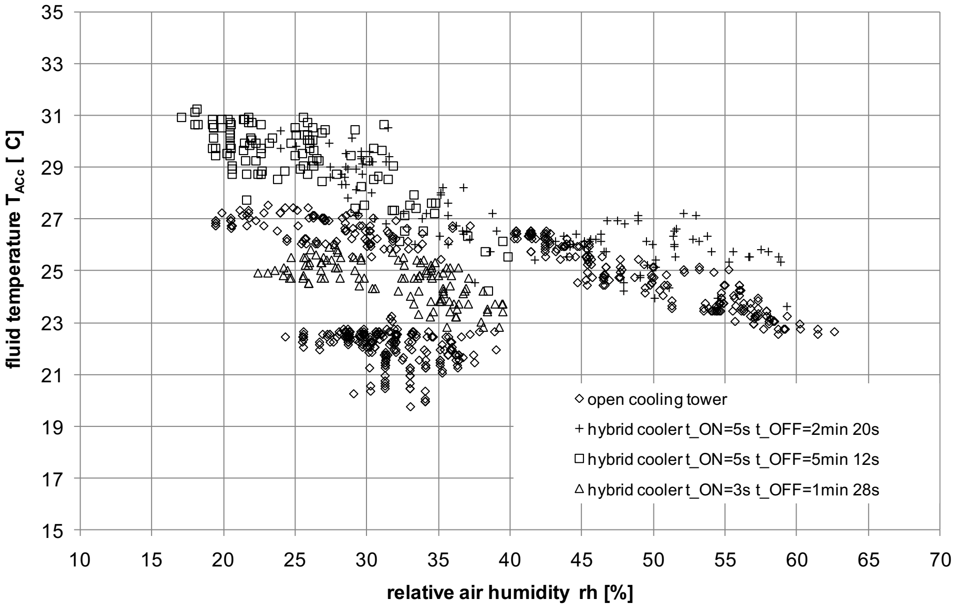

Fig. 6: Fluid Temperature T_{ACc} in function of the relative air humidity rh of the cooling water entering the absorber condenser unit of the absorption cooling machine.

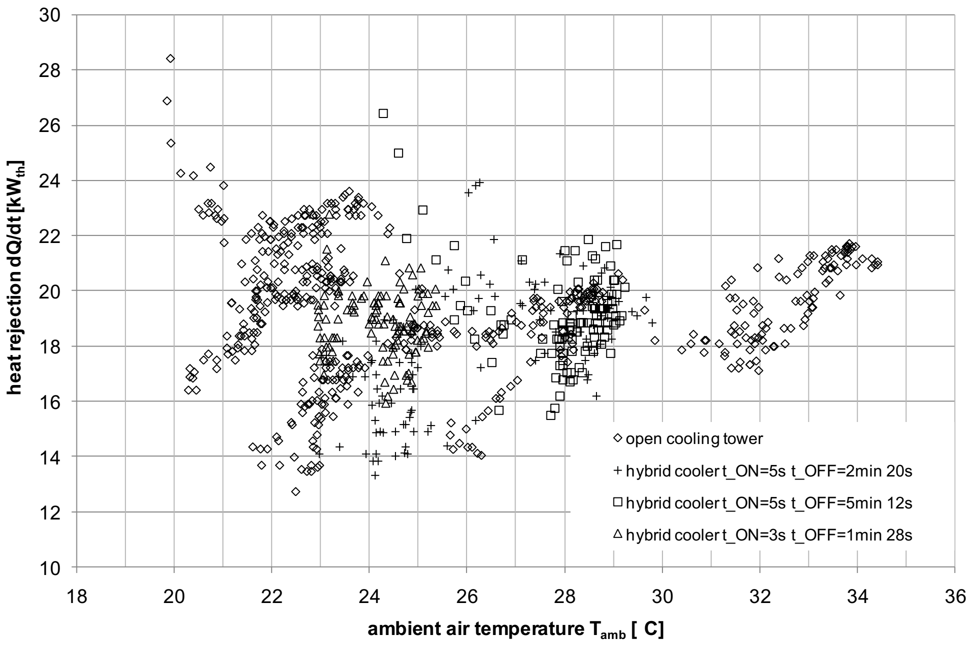

Fig. 7: Heat rejection dQ/dt through the pulse sprayed heat exchanger hybrid cooler in function of the ambient air temperature T_{amb}. The data of the heat rejection power of the open cooling tower are shown for comparison.

Through the heat rejection subsystem the total power (thermal + electrical) of the STAC has to be transferred to an appropriate heat sink, which in our case is the ambient air. The cooling power of a STAC is strongly influenced by the temperature level T_{amb} and the relative humidity rh of the ambient air. In Fig. 7 the rejected power dQ/dt of the pulse sprayed hybrid cooler depending of the ambient air temperature T_{amb} is shown. The thermal power dQ/dt rejected via the hybrid cooler is in the range of the data behaviour of the open cooling tower.

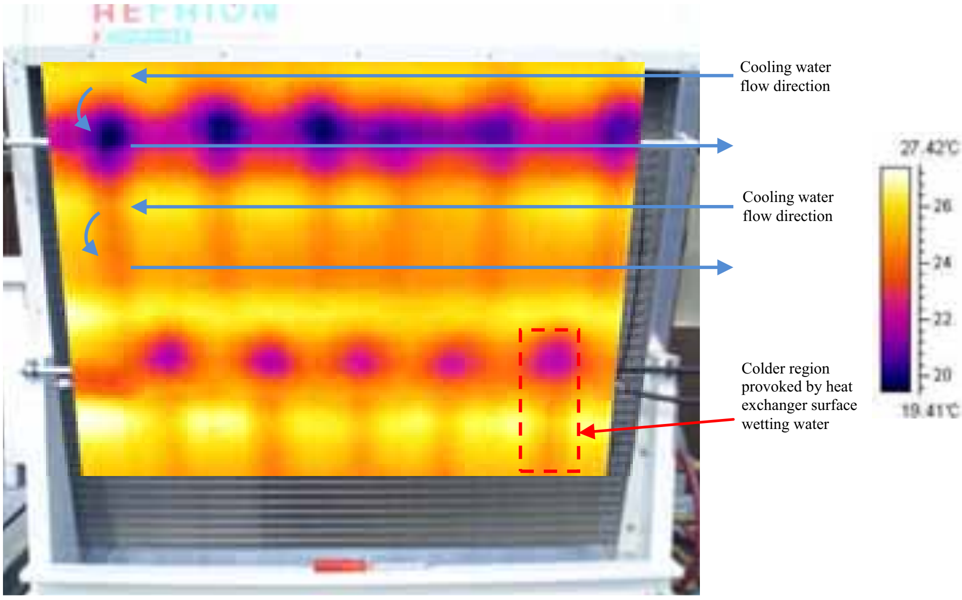

Fig. 8: Infrared photo superimposed on a visible light photos of the hybrid cooler after spraying water on the lamellas. The highest temperature is in the range of 27°C while the dark blue areas reach a temperature as low as 20°C. A strong temperature inhomogeneity over the heat exchanger can be seen.

An indication of the heat transfer efficiency is shown in the infrared photo (IR) of the dry / hybrid cooler of Fig. 8. A clear cooling effect can be seen in wet regions on the lamellas (dark blue) of the heat exchanger. But also a strong temperature inhomogeneity occurs through the wetting (and water droplet size) of the surface of the heat exchanger. At the time the IR photo was taken the outdoor temperature was T_{amb} = 21°C and the relative air humidity was in the range of rh = 38% to 44%. For these values of the temperature T_{amb} and the relative air humidity rh the wet bulb temperature is $T_{wet\ bulb}$ = 12°C to 14°C.

3 Conclusions and outlook

In a heat rejection system open cooling towers can be replaced by hybrid coolers. The rejected heat power has the same level in both system types but the temperature of the return fluid to the absorption cooling machine is slightly higher in case of the hybrid cooler. The temperature difference can be reduced by decreased spray cycle times e.g. shorter OFF time periods. In contrary the water consumption is increased and the advantage of low water use holds no longer. A higher return fluid temperature has the consequence of a decreased cooling power by 0.7kW/°C [3] of the absorption cooling machine.

A better dispersion of the sprayed water on the lamellas of the heat exchanger would increase the heat rejection power and a lower cooling fluid temperature should be reached. In further experiments the effect of a homogeneous wetting of the heat exchanger surface on the return fluid temperature has to be examined and has to be compared to the effect of reduced magnetic valve cycle time. Ideally, an optimum can be found.

Nomenclature

General

Δh_V	heat of evaporation, kJ/kg
$\dot{m}$	mass flow (water), kg/s
P_{th}	thermal power, kW
Q	energy, thermal, kJ
ρ	density (water), kg/ m^3
t	time, s
dt	time step,s
T	temperature, °C
dV	differential volume, m^3

Subscripts

amb	ambient (air temperature)
AC	Absorber-Condenser (fluid temperature)
c	cold (temperature)
h	hot (temperature)
p	pressure (heat capacity at constant p)
th	thermal
V	vapour (heat of evaporation)

Greek letters

Δ	difference (temperature / heat of evaporation)
ρ	density (water), kg/ m^3

Acknowledgments

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