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Solar cooling with water–ammonia absorption chillers and concentrating solar collector – Operational experience

Christine Weber [a,*], *Michael Berger* [b], *Florian Mehling* [a], *Alexander Heinrich* [a], *Tomas Núñez* [a,1]

[a] *Fraunhofer Institute for Solar Energy Systems ISE, Department of Thermal Systems and Buildings, Heidenhofstrasse 2, 79110 Freiburg, Germany*

[b] *Industrial Solar GmbH, Emmy-Noether-Straße 2, 79110 Freiburg, Germany*

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This work is dedicated to Dr. Tomás Núñez who passed away abruptly in 2011. This project was one of his last achievements as an extremely committed, reliable and creative researcher. His vision was a future energy system based on renewable energies. Due to his work and experiences, he became one of the leading experts on solar cooling in Germany and Europe. We will always remember him as a very warm-hearted, inspiring and motivating person.

Keywords:
Solar cooling
Fresnel collector
NH_3–H_2O absorption
Ice storage
Process heat
Solar steam generation

ABSTRACT

Concentrating solar collectors provide high efficiency at high driving temperatures favourable for thermally driven chillers. Therefore, they offer applications for hot climates and industrial process integration, especially in combination with NH_3–H_2O chillers that provide refrigeration temperatures below 0 °C. The presented solar cooling installation comprises a linear concentrating Fresnel collector that provides the driving heat for two NH_3–H_2O absorption chillers at temperatures up to 200 °C. Chilled water temperatures are produced in the range between −12 °C and 0 °C. Collector capacities reached up to 70 kW at peak times and the total cooling capacity of both chillers showed peak values up to 25 kW. For good operating conditions, the thermal system EER was 0.8 and an electrical system EER of 12 was easily achieved. The system showed a sound operating behaviour. The performance of different operation and control strategies was analysed, evaluated and enhanced within the two year operation phase.

* *Corresponding author*. Tel.: +49 176 62016966; fax: +49 761 458 0.
E-mail addresses: christine.weber.de@gmail.com (C. Weber), peter.schossig@ise.fraunhofer.de. (P. Schossig)

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Nomenclature

CSP	concentrating solar power
DHW	domestic hot water
EC	European Commission
EER_{el}	electric energy efficiency ratio (cooling power/auxiliary electricity consumption) = cooling power to electricity consumption ratio
EER_{th}	thermal energy efficiency ratio (cooling power/driving power) (= COP_{th}) = cooling power to heat input ratio
IAM	incidence angle modifier
ISE	Fraunhofer Institute for Solar Energy Systems ISE
ISG	Industrial Solar GmbH
NH_3	ammonia
PID	proportional integral and derivative control
H_2O	water
TDC	thermally driven chiller

Nomenclature for performance data

A	area [m^2]
DNI	direct normal irradiation [$W\ m^{-2}$]
G	solar irradiation [$W\ m^{-2}$], in this context also DNI
$\dot{Q}$	power/heat flow [kW]
Q	energy [kWh]
T	temperature [°C]
V	volume flow [$l\ h^{-1}$]
c_p	heat capacity at constant pressure [$kJ\ kg^{-1}\ K$]
$\dot{m}$, m	mass flow rate [$kg\ s^{-1}$]
u_0; u_1	linear and quadratic heat loss coefficients [$W\ m^{-2}K^{-1}$; $W\ m^{-2}K^{-2}$]

Greek letters

α	Azimuth angle
η	efficiency
η_0	optical efficiency for sun in zenith position
θ	zenith angle
δ	angle between collector's absorber pipe and north–south direction
ϑ	temperature
$\Delta\vartheta$	temperature difference [$T_1 - T_0$]

Suffixes

aperture	collecting cross section surface
col	collector
loss	power loss
HT	high temperature, driving circuit
LT	low temperature, cold water circuit
MT	medium temperature, heat rejection circuit
out	outlet
in	inlet
1	chiller 1
2	chiller 2
l	longitudinal
t	transversal
sol	solar
tot	total, both chillers
load	thermal power measured in electric load circuit

Froid solaire avec des refroidisseurs à absorption d'ammoniac-eau et un capteur solaire à condensation – expérience de fonctionnement

Mots clés : Froid solaire ; Capteur solaire de Fresnel ; Absorption de NH_3-H_2O ; Accumulation de glace ; Chaleur industrielle ; Génération solaire de vapeur

1. Introduction

Worldwide there is an increasing energy demand, especially in industrialized countries and emerging countries with high economic growth. The cooling for buildings and industrial processes holds a significant proportion of this demand.

At first, energy efficiency measures and renewable energy usage need to be further developed and implemented. The goal is to develop systems with a low energy demand by energy-efficient measures coupled with a large proportion of renewably generated cooling power. Solar cooling provides a carbon-neutral and environmental protecting option to cover this demand and reduce greenhouse gas emissions.

Passive house standards and net zero energy buildings have become an important topic in the R&D work on buildings for the present future. In order to achieve a zero energy balance on annual level, energy saving and energy efficiency measures have to be fully exploited. Even though, a demand for active heating and cooling will remain in most buildings and under most climatic conditions (Henning and Döll, 2012).

Next to the cooling demand of buildings, process heat and cooling for industrial applications is an increasingly important topic, especially regarding energy efficiency and renewable sources to produce a carbon-neutral and environmentally harmless goods (Henning and Döll, 2012). Here, solar energy is the best and most available renewable energy source on the spot.

Regarding refrigeration, perishable goods, like food or pharmaceutics, require constant cooling. In this case, the fluctuating production of cooling power needs to be stored to maintain the product quality.