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Application of an adapted single-/half- effect NH_3/H_2O absorption chiller in tri-generation and solar cooling systems

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ABSTRACT

Nowadays cooling loads make a considerable contribution of total energy consumption. Therefore, the focus has to be on the development of efficient sustainable cooling systems. This paper analyses the influence of different heat rejection units to a solar- or CHP-driven single-/half- effect ammonia/water absorption chiller.

A functional model of the chiller based on flat plate heat exchangers which is switchable between single- and half effect is built and measured. Chiller performance is evaluated in Hardware-in-the-Loop tests in terms of steady state and dynamic tests. Advanced component models based on lookup tables with dynamic behaviour are derived and used for annual simulations. TRNSYS simulation studies are used to analyse the annual impact on technical and economic performance of the new single-/half- effect concept in various configurations and boundary conditions.

The single/half effect chiller shows a good and stable performance over a wide range of operating conditions. It offers an operation up to 45 °C heat rejection temperature and enables the usage of a dry cooler in hot and arid climates. The application for solar- and CHP driven systems are reaching non-renewable primary energy savings of 30–70% at almost equal costs compared to conventional systems.

1. Introduction

There has been a tremendous increase in the global air-conditioning market. Global sales of room air-conditioners have increased dramatically within the last decade (Mauthner, 2016; JRAIA, 2017). In order to limit the negative impact on energy consumption, greenhouse gas emissions and electricity network infrastructure, solar (thermal or electric) driven air-conditioning is proposed as an environmentally friendly alternative to conventional fossil fuel based air-conditioning (Mugnier and Jakob, 2015). Promising back-up supplements for solar driven systems are tri-generation[1] (Naß et al., 2011) systems.

Tri-generation is the combination of combined heat and power plants (CHPs[2]) and thermal driven chillers. The necessary heat to be dissipated to run the CHP is used to drive the chiller. Such tri-generation systems provide a significant potential to assure sustainable heat-, cold- and electricity-supply to multifunctional buildings and urban settlements. According to Ramminger (2013) CHP systems in combination with absorption chillers (ACMs[3] – absorption cooling machines) with low capacities (approx. 50 kW_{th}) provide a great application possibility.

In the course of the Austrian research project DAKTris (Neyer and Thür, 2016) a commercial available single effect (SE[4]) absorption chiller is adapted to enable an optimal operation in combination with combined heat and power units. The general focus of the project is (i) on the chiller and its performance under the specific boundary conditions, (ii) the adaption of the chiller (PC19 – Pink chiller, chilled water capacity 19 kW (Pink and Halmdienst, 2017)) and (iii) system cost and primary energy performance under a wide range of profiles, configurations and system designs. Further investigation of the adapted chiller in solar thermal applications are conducted in the follow-up project SolarHybrid (Neyer and Thür, 2014). Focus in this project is the optimization of the hybrid operation of a NH_3-H_2O absorption and a

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1 tri-generation combined heat, power and cold.
2 CHP combined heat and power.
3 ACM absorption cooling machine/chiller.
4 SE single effect.

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Nomenclature

ABS	absorber
ACM	absorption cooling machine/chiller
C	costs
CAI	Cairo (Egypt)
CHP	combined heat and power
CON	condenser
CR	CostRatio
cRIO	compactRIO device
DLL	dynamic link library
el	electrical
EVA	evaporator
$f_{sav.NRE}$	non-renewable primary energy savings
GEN	generator
H_2O	water
HiL	Hardware-in-the-Loop
HT	high temperature circuit (generator)
IBK	Innsbruck (Austria)
LT	low temperature circuit (evaporator)
MT	mid temperature circuit (condenser and absorber)
NH_3	ammonia
PER_{NRE}	non-renewable primary energy ratio
prim	primary energy
Qc	Cooling load
ref	reference
SC	solar collector
SE	single effect
SEV	Sevilla (Spain)
SOL	solar thermal
sys	system
T_{amb}/T_{wetB}	ambient/wet bulb temperature
TEH	Teheran (Iran)
tri-generation	combined heat, power and cold
VCC	vapour compression chiller
VI	virtual instrument – LabVIEW sub program
ε	primary energy conversion factor

NH_3 vapor compression chiller for cooling but also heating applications.

The main challenge for a well accomplished tri-generation system is the adjustment of the absorption chiller and the system design and configuration. For a successful and efficient system solution, the ACM has to be adapted with respect to the CHP (this paper is focused on plants with small scaled combustion engines which usually have one combined cooling circuit for engine waste heat and exhaust heat) conditions of engine outlet (~90 °C) and inlet temperatures (~70 °C) at any heat rejection temperature.

Small capacity absorption systems often have problems with the heat rejection system if wet coolers are used. The ratio of capital and operating costs often leads to no or only inadequate water treatment for the wet cooling towers (Thür et al., 2010; Wiemken et al., 2013). Thus, the operation of the chiller cannot be guaranteed. Comparable dry coolers have a less intensive maintenance, but a temperature increase for heat rejection of the ACM is obvious (Fedrizzi et al., 2014).

The PC19 is working with heat rejection inlet temperatures up to 35 °C, this leads to less operating hours in case of dry heat rejection system (especially in dry and arid climates). According to Ziegler (1997), the single-effect cycles are rigidly integrated into the solution field, denoting that the temperatures of the heat source, sink and generator are interdependent. This restriction regarding the temperature spread can be enhanced by a Half-Effect-Cycle (c.f. (Alefeld and Radermacher, 1993; Herold et al., 2016), also called Double-Lift-Cycle (Schweigler et al., 1996) also for higher cooling water temperatures.

Performance comparison by means of mathematical models of different concepts (half-, single-, double effect, etc.) are carried out for water/lithium bromide (Domínguez-Inzunza et al., 2014b) but also for $NH_3/LiNO_3$ (Domínguez-Inzunza et al., 2014a). These investigations confirm that the HE concepts works better than any other concept when condensation and absorption temperatures are higher than 40 °C.

Very often H_2O/LiBr is the base for investigation and new developments either on 1.x effect cycles (Wang and Zheng, 2009; Xu et al., 2013) or on hybrid absorption/compression chillers (Schweigler et al., 2018). The concepts are analysed with various methods such as exergy analysis (e.g. (Maryami and Dehghan, 2017) or dynamic models (Kohlenbach and Ziegler, 2008) on component level but also on system level (Pietruschka, 2010). In terms of NH_3/H_2O based systems comparisons of air-cooled solar cooling are performed generally by Xu and Wang (2018). A prototype and experimental as well as model based performance date of a small capacity NH_3/H_2O double-lift absorption chiller is presented by Aprile et al. (2015).

Compared to the screened work the concept of this work is a market near approach, thus no experiments with other refrigerants are aimed and the development is based on long experience with NH_3-H_2O. The aim is to create a reliable and scalable chiller for a wide range of applications (e.g. air-conditioning, refrigeration, heat pump) and sources (CHP, solar, etc.). With its capacity of 20 kW the chiller is positioned at the higher end of small-scale systems. Therefor the chiller is designed not only stand-alone (directly air-cooled) but with focus to be integrated in parallel/serial to conventional systems.

2. Boundaries and concept for tri-generation in DAKTris

The target of the project DAKTris, derived from a market perspective, is on the combination of adapted NH_3/H_2O chiller and small-scale CHPs (< 50 kW_{th}). Thus, the focus is on combustion engines with combined cooling circuit (engine heat and exhaust heat) as in comparison large scale CHPs are often equipped with two separated cooling circuits to use the high temperature level of the exhaust circuit and guarantee engine heat rejection at lower temperatures (Schröder, 2012; ASUE, 2014). After analysing several CHP operating temperatures of specific products (e.g. (Lackner, 2013; Spaner RE2, 2013) but also more general overviews of CHPs like (ASUE, 2014) and heat rejection conditions for chillers (Henning et al., 2013; Fedrizzi et al., 2014) the following operation temperatures were defined. The generator temperature guarantees a reliable tri-generation operation, the heat rejection temperature (condenser, absorber) indicates the maximum possible temperature and the chilled water temperature is defined for standard air-conditioning temperatures (Eicker, 2012) although standard test conditions (e.g. (EUROVENT) are slightly different (12/7°C).

- CHP heat rejection → chiller generator (HT[5]): fixed 90/70 °C
- Chiller heat rejection, condenser and absorber (MT[6]): maximum 40/45 °C
- Chilled water, evaporator (LT[7]): 12/6°C

Up to now, tri-generation-systems are built up with market available absorption chillers. However, most absorption chillers are inappropriate for the operating conditions presented above. The SE-circuit (cp. Fig. 1, left) would disrupt under these conditions. For a successful and efficient system solution, the chiller must be adapted with respect to these conditions, thus the HE-concept (cp. Fig. 1, right) is one solution.

[5] HT high temperature circuit (generator).
[6] MT mid temperature circuit (condenser and absorber).
[7] LT low temperature circuit (evaporator).