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Research Paper

Performance of absorption chillers in field tests

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A B S T R A C T

Absorption chillers can use waste heat, solar heat, or excess heat by cogeneration facilities to supply chilled water. Therefore, absorption chillers are important components for poly-generation, which can improve plant utilization and efficiency of the overall energy supply system.

Currently, 27 new small and medium-scale (30–160 kW cooling capacity) absorption chillers with high efficiency in full- and part-load as well as low specific size and weight are the focus of two research projects sponsored by German Federal Ministries. The chillers are located in 20 different sites, four of them in Jordan and the rest in Germany. The main objective of these projects is to enhance trigeneration and solar cooling system efficiency.

The Jordan projects and more than 70% of the German installations use dry cooling towers. Combined heat and power (CHP) plants or district heating grids provide the driving heat for regeneration at the German installations. Solar thermal collectors drive one German and all Jordan installations.

Within the projects, the chillers are provided with an intelligent control algorithm that allows achieving several objectives at the same time. One of the objectives, of course, is to match the desired chilled water temperature as well as the cooling capacity. Another objective is, for instance, to fit the hot water outlet temperature. This is commonly essential in cogeneration to avoid emergency shutdowns of the CHP engine. The field operation shows that the deviation of said temperatures from the set point is usually less than ± 0.5 K in operation. In those operational hours in which the temperatures of the heat source or heat sink do not allow to reach all objectives, a set of hierarchical aims can be established within the algorithm so that the chiller can be controlled to match its prioritized objectives.

Furthermore, the designed absorption chiller performs dynamically and autonomously in a very large range of temperatures and flow rates. These can vary from 20% up to 150% of nominal conditions. This flexibility can be used to achieve up to 80% savings of electrical power consumption using speed-controlled pumps in part load conditions.

In contrast to the common opinion that small and medium-scale absorption chillers are not competitive as compared to compression chillers, this paper shows applications in which absorption chillers are advantageous because of synergies with and multiple benefits within the rest of the energy supply system.

1. Introduction

Although the demand for space cooling is increasing globally [1], it is an aim (and for sustainable energy use it is even compulsory) to decrease energy consumption for cooling. Compression chiller technology (which of course is improving over the years) dominates small to medium-scale installations (cooling capacity about 150 kW). Improving electrically driven solutions and basing them on alternative, green energies may be not enough to reach the sustainability goals, and may be economically unfeasible. Results of the Summerheat project [2] show that using large-scale absorption chillers in district cooling networks is energy efficient and reduces the electricity consumption. However, in terms of cost effectiveness small to medium scale absorption chillers are reported to be inappropriate up to now [2].

In the recent years, TU Berlin has been leading several projects to develop single effect water/lithium bromide absorption chillers within the said range of capacity with a smaller specific size and weight [3] to improve the cost-effectiveness. Based on one basic design, two differently sized absorption chillers have been designed, called Bee and Bumblebee (50 and 160 kW nominal cooling capacity, see Table 1). A third one, the Hornet with 500 kW nominal capacity, was just recently developed and therefore has not yet been part of the presented projects. The company W. Bälz & Sohn GmbH & Co. now markets the absorption chillers.

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Table 1
Absorption chiller specifications in nominal conditions.

Absorption chiller (water/lithium bromide) type			Bee	Bumble-bee	Example for a specific location (bumblebee)
	Description	Units	Nominal conditions		
t_{2Di}	Hot water inlet temperature	°C	90		85
t_{2Do}	Hot water outlet temperature	°C	70		70
V_{2Dx}	Hot water volumetric flowrate	m^3/h	3.2	10	6
Q_{2Dx}	Driving heat	kW_{th}	63	200	105
t_{1Ai}	Cooling water inlet temperature	°C	30		27
V_{AC1}	Cooling water volumetric flowrate	m^3/h	14	46	39
Q_{AC1}	Reject heat	kW_{th}	113	360	185
t_{0Eo}	Chilled water outlet temperature	°C	16		6
V_{0Ex}	Chilled water volumetric flowrate	m^3/h	8.6	28	14
Q_{0Ex}	Cooling capacity	kW_{th}	50	160	80
COP_{th}	Thermal coefficient of performance	kW_{th}/kW_{th}	0.79		0.74
COP_{el}	Electric coefficient of performance	kW_{th}/kW_{el}	20		

A large fraction of the investment cost in all cooling units originates from heat exchangers. In this respect, heat driven cooling technologies will always have a drawback. Therefore, there is no point in comparing absorption and compression chillers without discussing availability, price, and primary energy demand, which is different in every national and even local energy supply system. Fully standardized solutions will only reach part of the market. Hence, the economy of scale will only be strong when there is a technology that has a flexible operation and control adaptability to as much requirements as possible. A step towards these goals is reported in this paper showing at the same time an overview of the project scope and results.

Focusing on the driving heat circuit, this paper gives a brief description of the control methodology that allows the absorption chiller to perform flexibly in different operating conditions. Especially the operation with three types of driving heat (solar heat, centralized co-generated and decentralized co-generated heat) is discussed. Key data show how the absorption chiller performs in the given conditions. Finally, the paper reports first results to decrease the auxiliary electricity consumption.

In order not to overload the paper, only those details of the installations, which are necessary to understand the control issues, are provided here. Further information will be available in future papers and the final project reports.

2. Load control in different applications

2.1. Description of the control system

To work autonomously, reliably and endurably in the different operating modes, the control algorithms within the field tests run with an industrial programmable controller. The routines can be described by dividing them into two main independent tasks: process control and load control. The process control ensures safe operation. When exceeding preset limits, the process control first takes concrete actions to return to normal operation. If the problems persist and there is no actor to react appropriately, the absorption chiller will be shut down. This, however, is not topic if the paper at hand.

The load control is based on the steady state characteristic equation [4] using constant parameters (which are based on measurements in a test rig) characteristic to the designed chillers. The load control algorithms describe the process state by using external temperatures and flow rates, and determine two set points for the inlet temperatures of hot and cooling water (reject heat). These two set points are two degrees of freedom, which are used to adjust to one or more control objectives. They are conveyed to the PID-controllers of the valves and pumps. Additionally, to compensate for inaccuracies in the characteristic equation, thermo-physical parameters and heat flows are compared to measurements in order to make online corrections in the model working as an observer in terms of Lueneberger [5].

2.2. Solar thermal cooling

In regions like Jordan, where insolation is high, it is meaningful to use solar energy, either as electricity or as heat. Thermal collectors are interesting when a significant heat demand exists. However, this demand is never steady over the time and often emergency coolers have to be installed to release excessive heat during periods of high insolation and no complementary demand; otherwise, the high temperatures can damage the collector or the working fluid. This situation is convenient for cooling with absorption chillers as the cooling demand increases simultaneously with insolation. However, as another effect of high insolation the potential of the chillers to reject heat to the ambient is impeded. This commonly requires evaporative- or wet cooling towers, which means a drawback in locations with water scarcity.

In the Jordan installations, the chillers and their controls handle these extreme conditions properly even with dry cooling towers. In order to show this, in Fig. 1 the temperatures of the hot water (desorber inlet and outlet), cooling water (absorber inlet) and produced chilled water (evaporator outlet) are plotted in the top graph for one day in August. All sensors are located in thermowells near the chiller. The evaporator produces 10 °C all day long despite the ambient conditions, as this is the priority set in the control. The chiller starts operation at around 7 a.m. with a low driving heat temperature of approximately 50–55 °C. At noon, it operates at about 100 °C with the reject heat at a temperature of almost 40 °C. The cooling power is almost constant at 50–55 kW (see bottom graph), while the driving heat flow is larger in the beginning of the day than in the afternoon. The reason is the non-steady operation: in the morning, driving heat is used to warm up the installation additionally to the cold production. In the afternoon, when the temperatures are slowly falling again, the amount of driving heat is less than before noon, because the chiller also cools down a bit and uses its own heat capacity for desorbing. Consequently, the momentary COP_{th}[1] is better in the afternoon than in the morning.

2.3. Decentralized CCHP – using excess heat from power generation for cooling

Today, almost all available water/lithium absorption chillers have restricted operational conditions. Exceeding the nominal range of flow rates or temperatures leads to emergency shutdown of the chillers in order to avoid freezing of the evaporator and crystallization of the solution at high salt content. This limitation, however, is detrimental for working with other restricted technologies, e.g. CCHP (combined

[1] The thermal coefficient of performance COP_{th} is defined as the ratio between heat flow of evaporator and heat flow of desorber. This definition, however, is only valid in a strict sense for steady state operation. As the shown operation is never stationary, we do not show the COP_{th} in the figure.