NEW ABSORPTION CHILLERS FOR CHCP OR SOLAR COOLING SYSTEM TECHNOLOGY

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Abstract: Sorption cooling technologies are well known as best practice energy efficient cooling supplying apparatus where heat as driving source is delivered by waste heat, trigeneration systems, solar thermal plants, etc. Recent European demonstration projects could not match this prospect due to parasitic electric consumptions.

A research project under participation of science and engineer researchers (TU-Berlin, ZAE Bayern) and an energy provider (Vattenfall Europe) was set up to develop high efficient absorption chillers in the range of 50-320 kW. System set ups for the entire cooling generation including reject heat and hydraulic components and control are within the focus. While a 160 kW absorption chiller is on the test bench, 50 kW absorption systems are already running in 2 demonstration plants.

The chiller operates in between 25 and 140% of load at thermal COP´s in the range of 0.80 and can stationary deliver cold down to part load of 5%. While driving heat can be used from 55°C up to 110°C at the inlet (standard operation point is at 90/72°C in/out), reject heat inlet temperatures up to 45°C are feasible for normal operation mode. Even higher reject heat temperatures are viable without crystallization, only limited by lower power density. Operation figures of new 50 and 160 kW absorption chillers as well as energy efficiency ratios of demonstration plants are presented. System layout, including market available dry reject heat systems, gains parasitic electric EER values lower than 6% of cooling load. New volumetric/energetic density benchmarks up to 23 l/kW are proven.

Results of 50 kW absorption system overreached thermodynamical targets while proposing a lower price than market available. System demonstration and development up to 320 kW cooling load systems are actually undertaken in Lab and will be lead to real estate installations in 2013.

Keywords: optimization, efficiency, control, demonstration, tri-generation

Supported by:

Federal Ministry of Economics and Technology

on the basis of a decision by the German Bundestag

1 INTRODUCTION

More than 25% of the space heating demand in some European countries as Germany, Sweden, Denmark or Finland is covered by district heat. Some cities in northern Europe even reach a ratio of more than 70% (Randløv 1997). In summer months, most of the district heating systems in Europe are running on low capacity as shown in Figure 1. On the other hand, there is an increasing demand of cooling supply for air-conditioning. Sorption chillers working with low driving temperatures are especially suitable for using district heat in summer to meet the demands of cooling loads. This way, the efficiency of district heating networks is improved, the provider of the heating networks encounters new key markets and the operator of the chiller obtains a cheap, reliable and ecologically worthwhile driving energy (Naß et al. 2010, Zegenhagen et al. 2010). But not only district heat networks can be used to drive absorption technology. Even solar thermal systems already used for heating tap water or support heating systems during winter period are viable to deliver the heat for producing cold in summer season (Petersen et al. 2006, Henning 2010). The main obstacle for sorption cooling by district heat is the lack of viable machines on a moderate price level on the market.

These considerations led to a collaboration project between the Technical University of Berlin (TU Berlin), the Bavarian Center for Applied Energy Research (ZAE Bayern) and Vattenfall Europe, who operates large district heating systems, to develop a low temperature driven water/lithium bromide absorption chiller. The focus was set on an efficient system for the whole cooling generation process, including heat rejection, hydraulic components (together with parasitic energy demand) and control.

An expedient capacity range was seen in 50 - 320 kW cooling power. This is suitable for average sized residential blocks. So, in a first step a 50 kW chiller was designed, built and installed in several demonstration sites. In a later step, a 160 kW machine is being developed.

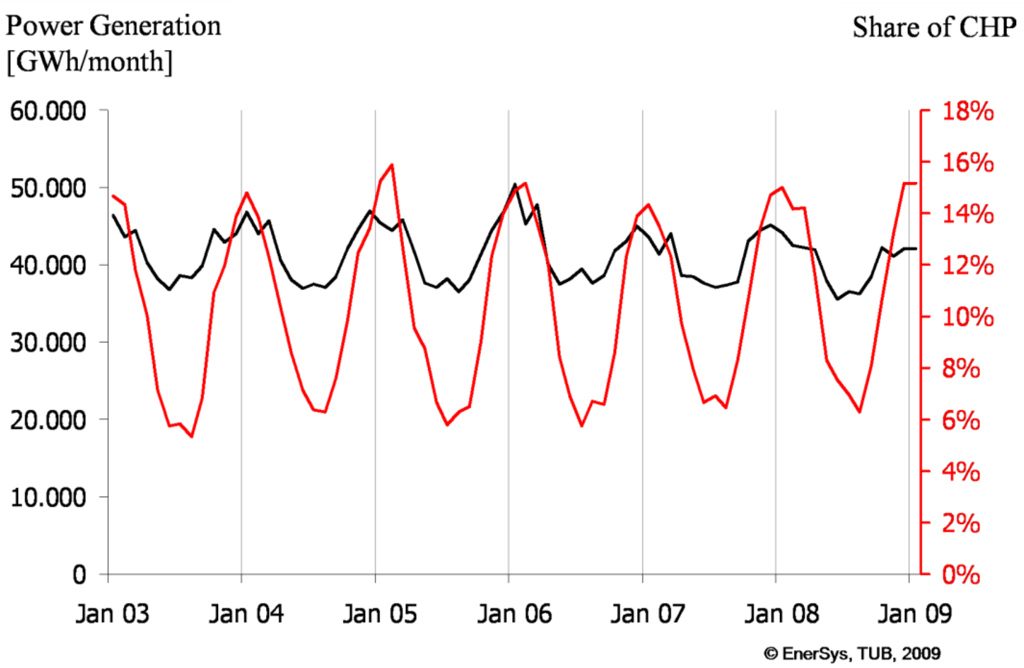

Figure 1: Share of CHP (combined heating and power) electricity in Germany 2003-2009

2 ABSORPTION CHILLERS

Main focus of the project as well as in market availability and necessity are single effect absorption chillers. In case of facility cooling water/lithium bromide is the most used working pair.

Most of the commercially available water/LiBr absorption cooling machines are working on a capacity range from 300 kW and up. Here, shell and tube heat exchanger are state of the art. Copper tubes are rolled into heavy front plates, assuring the inner refrigerant atmosphere to be vacuum proof. The direction change of the heat transfer medium is done by water boxes fixed outside onto the front plates. Transferring this technique on smaller capacity ranges below 200 kW leads to high specific cost, because with smaller tube lengths the fix costs of the fringe effects dominate (Estiot et al. 2007).

Other approaches, developed for small machines that are available from few manufacturers, like coiled tube heat exchangers, led to different problems including high size ratio and high external pressure drops. On the other hand, this pressure drops lead to high parasitic energy demands, reducing the advantage of heat driven cooling machines (Aprile 2010).

Another point is the part load behavior of common chillers. With fixed volume flows on the heat transfer medium side and a fix fan speed for the heat rejection unit (both set for nominal power), the resulting parasitic electric consumptions dominate at part load. Thus, again, the advantage of low electric energy consumption for sorption systems is reduced, leading to a low electric energy efficient ratio (electric EER).

Focusing on these aspects, the goals for a new development of an efficient and economic absorption chiller were set. Among those, a high COP on a wide capacity range was also set as target for the system. Inter alia, this can be achieved by low heat losses through reduced thermal bridges. Of course, also the number of working steps for construction (i.e. price), the compactness and the weight was to be looked at.

As a result, a new and promising idea of U-shaped bended tubes, arranged in a face-to-face adjustment for absorber and evaporator and cross-shaped parallel for generator and condenser, with a split condenser right and left of the generator, came to be.

3 NEW ABSORPTION CHILLER CHARACTERISTICS

Focus of the project has been the development of absorption chillers in small and medium capacity up to 320 kW. A first 50 kW lab functional model was erected in 2010 being analyzed for 18 month till late 2011. Based on these results conception studies for the 160 kW model were undertaken, gaining in a new 160 kW lab functional model which is actually analyzed at the test rig of TU Berlin.

3.1 50 kW lab model

Thermophysical characteristics of the first 50 kW chiller has been well described in 2011 (Petersen et al. 2011). It is stressed that the new chiller design, focusing on heat exchanger optimization due to pressure losses and surface usage combined with new control strategies can lead to efficiencies of 0.8 in cooling mode. The new absorption chiller overcomes limitations of low driving heat temperatures and can therefore start operation at 55°C up to 110°C.

New results do even claim to pull down a second prejudice. Designed for low maintenance costs there was a need to identify most expensive cost objects. Even in a country like Germany, where water is not really a limited source, costs for water treatment and bacteria treatment in evaporative reject heat cooling towers can be responsible for 30-40% of operation costs for small systems. Main concept of the new development has therefore been the combination with dry reject heat systems, taking into account that reject heat temperatures therefore do increase in normal load conditions. New benchmarks in reject heat temperatures have been reached not any more limited by 35°C as state of the art, and no crystallization problems at high reject heat temperatures. Even as there is no need for the chiller to shut down at high reject heat inlet temperatures as shown in Figure 2, capacity is limited if driving heat and used cold temperatures are kept constant and lead to 15 kW cooling capacity at 45°C. In part load there is a theoretical potential of saving pump energy in the reject heat cycle. As defined in European Seasonal Energy Efficiency Ratio (ESEER) around 40% of load hours are at 50% of installed capacity. Reducing volume flow while reducing pump speed will save up to 98.5% of electric consumption of the pump if efficiency of the pump keeps constant. Of course this is a scientific analysis, nevertheless it remains obvious that increasing reject heat temperature and therefore lowering fan speed simultaneously to control pump speed can lead to parasitic energy savings of 80-90% compared to full load if control strategies do system control and not each component on its own.

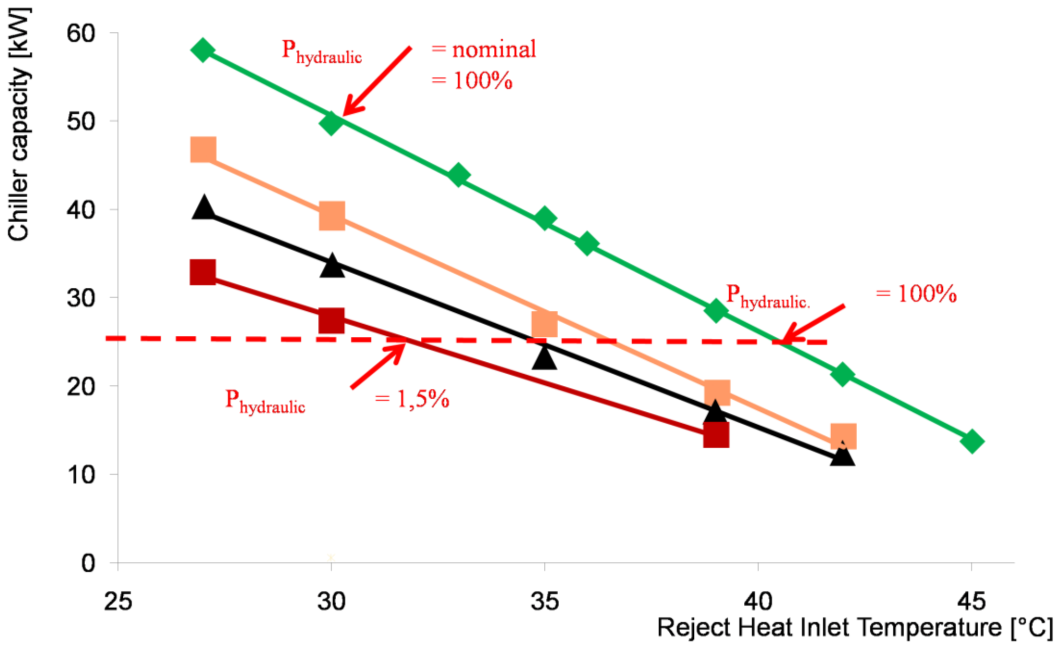

Figure 2: Reject heat variation

As a result of experimental characterization of the 160 kW functional model the 50 kW small capacity chiller was rearranged. The volumetric energy density was again increased by 30%. Results of an experimental characterization of the small size chiller should be available by late 2013.

3.2 160 kW “Bumble Bee”

Adapting and enhancing the heat exchanger concept of the 50 kW model the 160 kW model was established. Main goals, beside of the capacity, were keeping the weight of the chiller or the modules below 1000 kg (stair up- and downward transportability) and size limits below 1.9 m x 1.6 m x 0.88 m (floor transfer bottlenecks as doors and corner sizes) due to facility limitations. Finally, the new concept reached out to figures given in Table 1. As shown in Figure 3 the concept allows to divide the chiller into 2 main modules consisting each of 2 main heat exchangers, the low pressure part of evaporator, absorber, solution heat exchanger, pumps and base frame and the upper pressure vessel hosting desorber and condenser.

Figure 3: Modularized 160 kW "Bumble Bee"

Characteristic measurements started in April 2012. Results up to now fulfilled the expectations - not mandatory - but after particular on site construction changes. Chiller capacity varies in between 154 kW and 162 kW in nominal load conditions as shown in table 1, while COP is in the range of 0.79. Further thermodynamic characteristics will be analyzed till summer 2012. Simultaneous simulation models are varied to predict all kind of usage, temperature and volume flow conditions to discuss field tests, which should start in 2013. In figure 4 the new chiller is compared to top market available chillers. Even as one complete system it is lighter and smaller than "one vessel" market products which are pooled in the circle. One vessel chillers are not divisible, not in weight and not in size. Taking into account the possibility of modularizing the new chiller the advantage gets obvious. As a compact and complete chiller it is with only 0,86 m width the slimmest chiller of the capacity range above 15 kW nominal capacity and the first one passing through doorways.

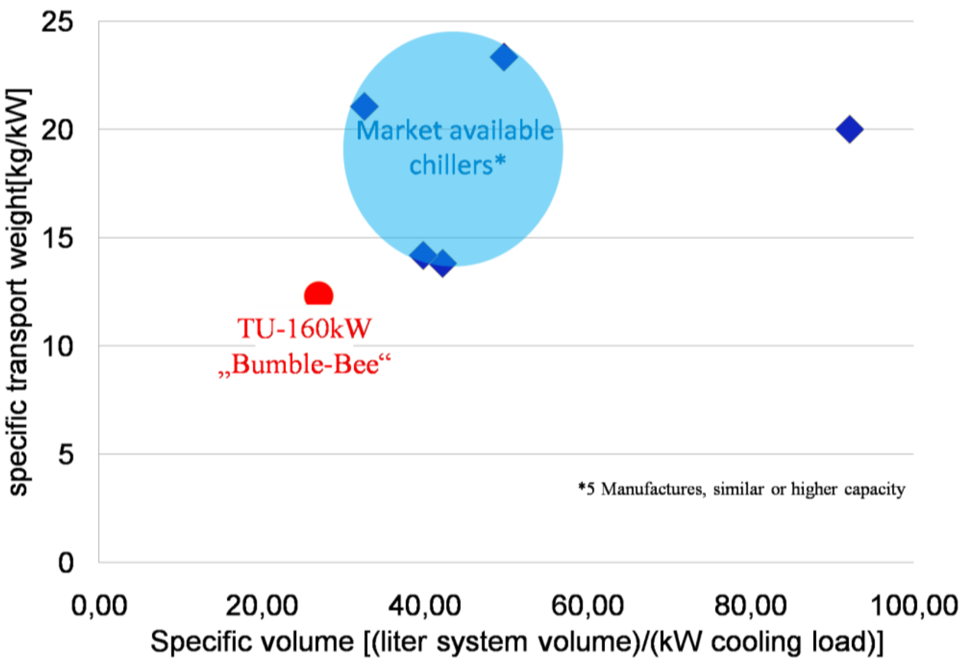

Figure 4: specific sizing benchmarks of absorption chillers

3.3 Results

First economic analyses propose system costs to be 50-70% lower than available by now. Figure 5 shows the expected costs in comparison to results based on a literature review given by IUTA (2002) for compression systems and absorption chillers. Considering the uncertainty due to system equipment the benefit of the new construction and system design is evident. System costs based on the new development including the absorption chiller, a dry reject heat system, supplying pumps and a system controller will be available at a reduced rate compared to market available absorption chillers. Compression chillers, still being price competitive or cheaper, loose significantly margin, which will finally lead to higher cold generation costs due to maintenance costs.

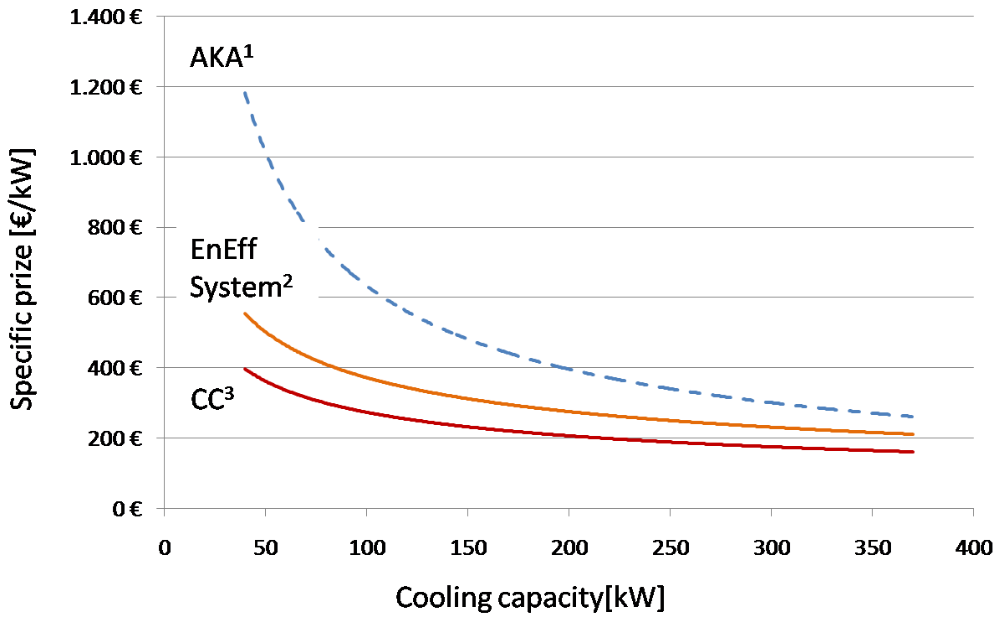

Figure 5: comparison of specific costs of cooling devices

In Table 1 geometrical data of the new absorption chillers are summarized. Beside of the compactness the modularity in terms of single module weights offers the opportunity to step with this chiller types not only in new building construction sites but also in the retrofit market which dominates the actual construction market all over Europe and where therefore the main necessities of energy saving heating and cooling devices are needed.

Table 1: Chiller size

	Bee Redesign (50 kW)	Bumble Bee (160 kW)
size of entire machine		
length [m]	1.75	1.95
width [m]	0.68	0.86
height [m]	1.59	2.05
total transportation weight [kg]	650	1750
max. modules	2(+4)	2+4
size of biggest module		
length [m]	1.75	1.82
width [m]	0.68	0.86
height [m]	0.98	1.21
transportation weight [kg]	< 350	<850

Table 2 gives an overview to operation standard conditions of the two models. Currently the 160 kW chiller is examined in the lab for its part load characterization. Both chillers provide chilled water in between 6°C and 25°C, using hot water from 55°C to 110°C, types for hot water temperatures up to 135°C will be viable. Hot water temperature spreads at standard flow rates of 0.014 l/s/kW (standard operation conditions, decentralized CHP) are in the range of 18 K but also spreads up to 40 K are feasible at low flow system flow rates of 0.006 l/s/kW as used in district heat networks or solar thermal systems.

Table 2: Standard operation conditions

		Bee	Bumble Bee	unit
Nominal cooling capacity		50	166	kW
Heat demand		63	208	kW
Reject heat		113	374	kW
COP		0.79		
Chilled water	temperature inlet	21		°C
	temperature outlet	16		°C
	volume flow	8.5	27.7	m³/h
	pressure drop	0.27	0.25	bar
	max. pressure	6.0		bar
Hot water	temperature inlet	90		°C
	temperature outlet	72		°C
	volume flow	3.0	9.7	m³/h
	pressure drop	0.12	0.36	bar
	max. pressure	16		bar
Reject heat water cycle	temperature inlet	30		°C
	temperature outlet	37	38	°C
	volume flow	14.4	39.0	m³/h
	pressure drop	0.70	0.57	bar
	max. pressure	6.0		bar

4 SUMMARY

The investigative development described in this paper shows up the potential for modernization of an old fashioned cooling technology. Sorption cooling or heat pump systems have been a niche-market during electrification period in Europe and northern American States. Within the actual discussion of energy usage efficiency, solar power usage and combined heat and power sorption cooling systems offer the possibility to make use of heat during summer season, diminish additional electric loads caused by compression cooling systems and with the goal of delivering cold. Within this topic market available systems suffer by volumetric size, efficiency and prize to be competitive. A new heat exchanger concept is elaborated.

With respect to research results of the last 15 years specific energy densities are increased by at least 30% for cooling capacities in the range from 30 kW to 320 kW. Cost reduction is expected to be in a range of 50% to 70% compared to current cooling costs.

The new generation overcomes conventional operating limits of absorption chillers. Former limitations regarding minimum hot water temperatures or maximum reject heat temperatures have been mainly based on construction parameters. Starting operation at 55°C hot water inlet there are no limitations to reject heat inlet temperatures up to 50°C. Nevertheless, system design will be different for high reject heat conditions than for lower ones.

The first 50 kW model is operating in two field tests in Germany, supplying cold for a 44 kW office cooling driven by district heat and a 35 kW solar cooled datacenter installation. Further field tests with the final developments in the range of 30 to 200 kW are expected to be set up in 2013.

5 ACKNOWLEDGEMENT

Authors wish to thank all supporting companies and the scientific community in the field of absorption technology. Special thanks do belong to our main project partner Vattenfall Europe and the German Federal Ministry of Economics and Technology represented by Project Management Jülich (PTJ) under the project number 0327460B.

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Part of

Thermally driven heat pumps for heating and cooling. – Ed.: Annett Kühn – Berlin: Universitätsverlag der TU Berlin, 2013

ISBN 978-3-7983-2686-6 (print)
ISBN 978-3-7983-2596-8 (online)

urn:nbn:de:kobv:83-opus4-39458
[http://nbn-resolving.de/urn:nbn:de:kobv:83-opus4-39458]