Test Procedures for Sorption Chillers Based on the Working Mode

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Abstract

Up to now, thermally driven chillers have been classified on the base of number of effects (single or double effect), driving technology (direct or indirect fired) and sorbent physical properties (liquid: absorption; solid: adsorption); the few dedicated existing standards for their testing and evaluation have been developed on this classification. Nevertheless, the introduction on the market of new machines technologies and the necessity to test and evaluate them for a reliable marking as well as for having a deep understanding of their working, have shown in many cases the inapplicability of standards' prescriptions and the inadequacy of the parameters used for their classification. For this reason, a new way to classify thermally driven chillers based on their working modes (continuous, semi-continuous and batch mode) has been identified and, based on it, dedicated test procedures have been developed. The present work concerns with the development of the test procedures and with their application to a prototype of CW10 chiller .

1. Introduction

Given the huge electricity consumption due to the summer air-conditioning - about 90 TWh of electricity are used in EU15 for satisfying this demand [1] - the introduction on the market of thermally driven sorption chillers, using renewables as driving energy, could represent a valid solution to significantly reduce such consumption and the related CO_2 emissions.

Following this concept, in the last few years, several companies have invested in this technology, introducing new sorption chillers on the market. Nevertheless, an equal updating of the normative scenario has not followed the market development, leaving manufacturers without useful tools and references for marking their products before releasing them on the market. In fact, the tests prescribed by the standards for the evaluation of the sorption chiller performance are, in many cases, inapplicable: they treat all machines as continuous ones and classify them only on the base of the heating phases – i.e. single or double effect -, driving technology – i.e. direct or indirect fired - and sorbent physical properties – i.e. liquid: absorption; solid: adsorption-.

The need of having common references induced the authors to assess a test methodology applicable to all chillers technologies. A new way to classify thermally driven chillers based on their working mode - i.e. continuous, semi-continuous and batch mode - has been identified and, based on that, a new test procedure has been developed. In the present document the newly developed test procedure is described and applied to a prototype of CW10.

2. State of the Art

An analysis has been carried out on the most relevant existing on the base of their:

- ***Purpose*** – i.e. only those standards containing test requirements, test procedures and rating conditions have been selected and used for the analysis

- ***Scope*** – i.e. all standards applying to devices for space heating and/or cooling have been considered even if they are not directly related to sorption chillers
- ***Performance Figures*** – i.e. those standards having the focus both on the sole machine without considering its interferences with the external ambient (stationary tests) and on their combinations with climate and loads have been considered

and summarized by groups in Table 1 as a function of the main performance figures calculated considered.

Table 1 Relevant existing standards for chillers and heat pumps

PERFOMANCE FIGURE	NAME	SHORT TITLE
COP/EER		
	ANSI/ARI 560	Absorption Water Chilling and Water Heating Packages
	EN 14511	Air conditioners, liquid chilling packages and heat pumps with ….
	EN 12309	Gas-fired absorption and adsorption air-conditioning and/or heat pump..
	prEN255-3	Testing and requirements for marking for domestic hot water units
SCOP/SEER		
	ANSI/ARI 560	Absorption Water Chilling and Water Heating Packages
	VDI 4650-1	Short-cut method for calculation of the annual effort figure for the heat..
	prEN14825	Air conditioners, liquid chilling packages and heat pumps with ………
	EN 15316-4-2	Heating systems in buildings –Method of calculation of system energy
SPF/PER		
	EN 12309	Gas-fired absorption and adsorption air-conditioning and/or heat pump..
	EN 15316-4-5:	Heating systems in buildings –Method of calculation of system energy..

The analysis showed that:

- They refer mostly to electrically driven chillers and heat pumps with the only exceptions of EN 12309 and ARI/ANSI 560/2000 which refer to gas-fired absorption and adsorption chillers and water/gas fired absorption chillers.
- Being commercial standards, they supply test procedures for probing the unit only externally (***black-box approach***) – i.e. only coolant temperatures, coolant flow rates and power input are measured and recorded during the tests - only at stationary conditions. This last aspect is quite limiting since, often, sorption chillers are combined with unsteady heat sources, like in solar cooling plants.
- They treat all chillers (and heat pumps) as continuous without taking into account their real working modes. Even the standard EN 12309, although having some references to adsorption units – i.e. discontinuous –, doesn’t make any clear distinction from those continuous.

The main limitation is encountered with discontinuous chillers for which stationary conditions cannot be established. A clear view of this aspect is given in Figure1 in which it can be seen that the temperature profiles - at generator, condenser and evaporator - of a discontinuous chiller strongly depart from stationary conditions.

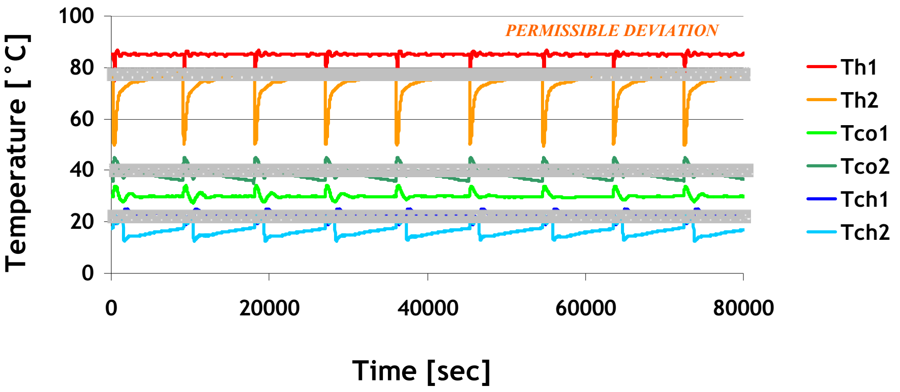

Figure 1 Temperature profiles at generator, condenser and evaporator of a discontinuous chiller vs. time – Source: EURAC

The same holds for the methodology used for calculating COP and chilling (or heating) power which is not clearly specified for discontinuous chillers.

- Finally they give quite different test restrictions concerning sample time and test duration – e.g. UNI 14511 prescribes a sample time not larger than 30sec; while EN 12309 prescribes a sample time not larger than 2 minutes –. Aanalogue remark can be done about the time necessary for establishment the stationary conditions.

2. Method-Development of dedicated test procedures

From the previous analysis, it emerged that the inapplicability of the existing standards to the sorption chillers currently present on the market, is mainly due to the fact that they treat all chillers as continuous. For this reason, the authors have introduced the working mode as a new distinctive parameter– i.e. the way in which the four phases of the sorption cycle are processed – and, based on that, they have defined:

Continuous Chillers as those chillers in which the four phases are processed continuously and by dedicated components within the machine

Semi-Continuous Chillers as those chillers in which the four phases are periodically shifted among the internal components (i.e. the heat exchangers) producing a discontinuous operation. The shifts, usually called “swap”, occurs between couples of phases - i.e. desorption/condensation and sorption/evaporation – which are processed simultaneously. This aspect implies that two or multiples of two units, each processing one couple, are needed.

Batch Mode Chiller as those chillers in which the four phases are processed by couples and periodically shifted among the internal components (i.e. the heat exchangers) determining also in this case a discontinuous operation. The difference with semi-continuous chillers is due to the fact that they might be processed once at a time. This implies that also one unit can operate the four phases.

These last two chillers’ types are characterized by a cyclic operation. Representative quantities are therefore cycle times, swaps and swapping periods - i.e. time, after a swap, needed to reach the equilibrium and in which the machine doesn’t deliver any chilling (*or heating*) power. Figure 2 shows the classification of sorption chillers on the basis of their working modes.

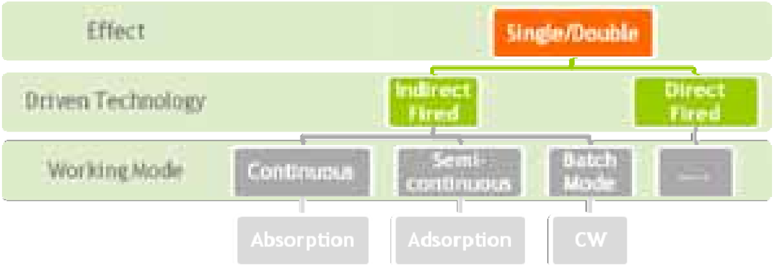

Figure 2 Classification of sorption chillers using as new criteria the working mode

2.1 Subintervals A and B

One of the most critical points of the test procedures is the definition of the Stationary Conditions. To that purpose, the proposed procedure makes use of two subintervals – i.e. A and B.

Sub-Interval A consists of all data collected during each cycle time, i.e. the time between two consecutive swaps; while ***Sub-Interval B,*** consists of the data collected during each cycle time with the exception of those relative to the swapping period. In Figure 3 they are shown on a discontinuous chiller since it represents the most general case. Obviously all remarks done for discontinuous chillers can be extended to the continuous ones.

The reason of such subdivision is based on the nature of the fluctuations of the controlled quantities. In particular, the Sub-Interval B contains only the data corresponding to stationary inlet conditions to the machine; here measured temperatures' variations in time are due the machine behavior (mainly for outlet temperatures) or to the measuring apparatus (fluctuations of the inlet temperatures, mass flows and pressures).

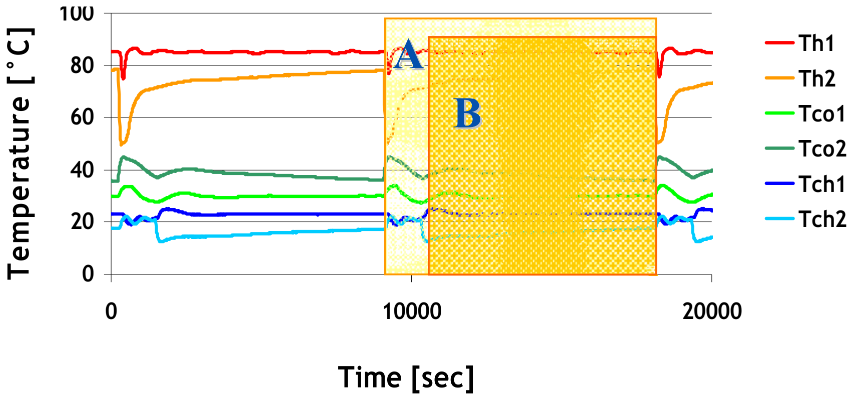

Figure 3 Sub-Intervals employed in the new stationary conditions definitions

2.2 Stationary Test Conditions

Since stationary test conditions cannot be assured as a whole, in case of discontinuous and batch mode chillers, conditions for stationary tests were only defined at inlet of the machine.

In particular, conditions were fixed for:

- Cycle Time
- Inlet Temperatures
- Static Pressure Differences
- Volume Flows

The cycle time was considered constant when not varying more than 10% in the test cycles.
The stationary behavior of the other parameters was checked within sub-Interval B, since here it depends only on the measuring apparatus. The tolerances used (reported in Table 2) refer to UNI EN 14511. Dedicated values should be defined on the basis of sorption chillers on the market.

An additional assumption has to be stated regarding the generator inlet temperature: since the thermal COP computed is a function of the heat supplied to the chiller along the whole cycle (sub-Interval A) the generator inlet temperature is to be fast brought back to its set value after every swap. To formalize this concept it was establishes that, in sub-Interval A, the ratio of coefficient of performance, computed using the average of the real temperatures divided by the coefficient of performance calculated using the set inlet temperature shall be equal or higher than 0.95. This condition can be formulated as follows for:

Equation 1

$$R_{COP} = \frac{COP_{real}}{COP_{set}} = \frac{\overline{\Delta T}_{h,real}}{\Delta T_{h,set}} = \frac{\overline{T_{in,real} - T_{out,real}}}{T_{in,set} - \overline{T}_{out,real}} \geq 0.95$$

At this point it’s possible to state that the stationary conditions are obtained and maintained when, all the monitored quantities remain constant for a minimum duration of four cycles, with respect of tolerances given in Table 2: in this way each unit constituting the chiller performs at least two entire cycles. Moreover, four pre-conditioning cycles shall be carried out before test to slake the influence of the former working condition on the present (see Figure 4).

Table 2 Stationary boundary conditions for a discontinuous chiller

Measure Quantity		***Permissible deviation of the arithmetic mean values from set values***		***Permissible deviation of individual measured values from set values***	
		A	***B***	***A***	***B***
Generator	Inlet Temperature	**R_{COP}>95%**	±0.2K	**R_{COP}>95%**	±0.5K
	Mass Flow	**R_{COP}>95%**	±2%	**R_{COP}>95%**	±5%
	Static Pressure Diff.		-		±10%
Condenser/ Evaporator	Inlet Temperature		±0.2K		±0.5K
	Mass Flow		±2%		±5%
	Static Pressure Diff.		-		±10%
Cycle Time		±10%			

In case of continuous chillers, they shall be thought as if they were characterized by a single-cycle operation, whose swapping time is equal to zero: the two subintervals A and B coincide. In this case, the stationary conditions are obtained and maintained when, all the monitored quantities remain constant for a minimum duration of one hour, with respect of the tolerances given in subinterval B of Table 2.

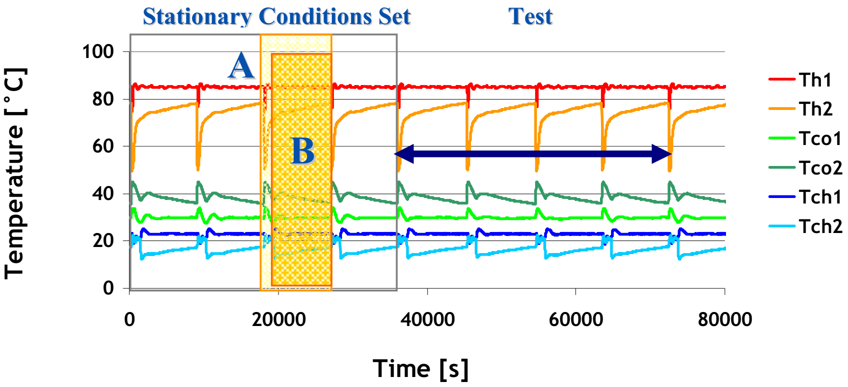

Figure 4 Cycles used for carrying out a test at specific rating conditions: 4 cycles for establishing the stationary conditions; and 4 cycles for performing the test itself.

2.3 Test Duration and Performance Equations

Once the chiller is at stationary conditions, the test can be performed. In order to collect enough data to be representative of chiller operation, the test shall last:

- 0.5 hour in case of Continuous Chiller
- 4 cycles in case of Discontinuous Chiller

and the sample time shall be, at least, equal to 10 seconds to capture the smallest meaningful data. The choice of 10 seconds is based on the swapping times of the smallest chillers available on the market.

For assessing chiller's performances, mean values shall be calculated. Here, as an example, the Mean Thermal Power, expressed in kW, is reported. It can be obtained as the average of all instantaneous thermal powers calculated for each cycle and for each sample carried out during the test.

Equation 2

$$\bar{\dot{Q}} = \frac{1}{n_{total,sample}} \cdot \sum_{j=1}^{n^\circ_{cycle}} \cdot \sum_{i=1}^{n^\circ_{sample/cycle,j}} \cdot \left(\dot{m}_{i,j} \cdot c_{p,i,j} \cdot \Delta T_{i,j} \right)$$

The thermal COP is calculated as the ratio of chilling power divided by the heating power – i.e. effective input to the chiller - expressed in kW/kW.

Equation 3

$$COP = \frac{\overline{\dot{Q}_{ch}}}{\overline{\dot{Q}_h}}$$

Results-Application of the test procedures

The developed test procedure was validated on a prototype of ClimateWell 10, classified as a batch mode (i.e. discontinuous) absorption chiller [2]. In particular, a series of test was carried out varying the inlet temperatures at generator - i.e. 75-85-95 °C-, condenser/absorber - i.e. 25-30-35 °C- and evaporator – i.e. 12-23°C -, while the mass flows have been maintained constant at the nominal values indicate by the manufacturer - 900l/h, 1800l/h and 900l/h respectively -. The tests were performed at EURAC [3,4].

With the achieved data, the performances of the chiller at the different working conditions were assessed. In particular, it was observed that the powers at the three heat exchangers decrease over each cycle as the sorption and desorption rates decrease (see Figure 5): they start from a maximum just after a swap and reach the minimum at the swap after. The chilling power shows the same behavior, translated by a period equal to the swapping time.

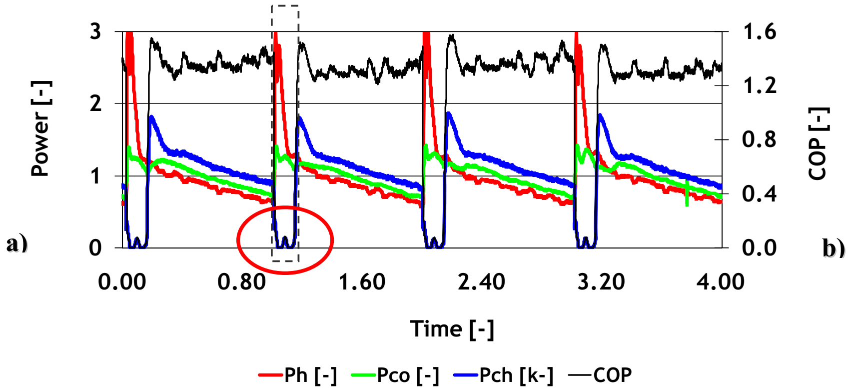

Figure 5 a) Non-dimensional Heating, Cooling and Chilling powers vs. Time; b) Non-dimensional COP vs. Time (reference conditions: 85-30-23°C)

This results in a null COP during the swapping time: the incidence of the null values of COP and chilling capacities on the chiller performances depends on the working temperatures since they influence the sorption and desorption rates and therefore the cycle times –i.e. the cycle time is shorter when the inlet temperature at the generator increase and those at condenser and evaporator decrease. Table 3 shows non-dimensional Cycle Time, COP and Chilling Power at the rating conditions (reference conditions 85-30-23°C).

Analyzing Table 3, it’s can be seen that the chilling capacity increases when the temperature at the generator and condenser decrease, for given evaporator temperature. The COP increases when the temperature at the generator decreases and the one at the condenser increases.

Table 3 Non-dimensional Chilling Capacity and COP calculated at different rating conditions

		Chilling Capacity [kW]			COP [-]		
		Condenser [°C]			*Condenser [°C]*		
		25	30	35	25	30	35
Generator [°C]	75	**0.62**	**-**	**-**	**0.90**	**-**	**-**
	85	**0.30**	**0.47**	**-**	**0.25**	**0.63**	**-**
	95	**0.37**	**0.12**	**-**	**0.22**	**0.22**	**-**
Evaporator		12			12		
		25	30	35	25	30	35
Generator [°C]	75	**0.90**	**-**	**-**	**1.06**	**-**	**-**
	85	**1.22**	**1.00**	**0.75**	**1.01**	**1.00**	**1.00**
	95	**0.72**	**1.01**	**0.89**	**0.50**	**0.74**	**0.90**
Evaporator		23			23		

5. Conclusion

A new way to classify thermally driven chillers based on their working mode was identified and, based on it, a dedicated test procedure was developed. In order to validate the procedure, a prototype of ClimateWell CW10 was extensively tested in laboratory.

The test procedure developed takes into account stationary conditions with regard to the temperatures and mass flows at the inlet of the machine. This is not the case if Solar Combi Plus systems are regarded though: in this application the inlet temperatures are continuously varying, mainly as a function of the sun radiation and the ambient temperature. The performance of the chiller is also strongly affected by those fluctuations, due to their notable thermal inertia. Therefore, further test procedures should be developed in the future for chillers to be used in this kind of applications. Unsteady, reality-like boundary conditions should be considered that reliably simulate meteorological conditions of representative locations placed on the market addressed.

Acknowledgements

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