DYNAMICAL STUDIES WITH A SEMI-VIRTUAL TESTING APPROACH FOR CHARACTERIZATION OF SMALL SCALE ABSORPTION CHILLER

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Abstract

Within the ABCLIMSOL project, a dynamical and semi-virtual testing approach for the characterization of absorption chillers has been developed by CEA/INES in order to have a better understanding of the small absorption chiller,. A methodology has been developed in order to select three representative summer days. These days generate the different functioning conditions met by a solar cooling system (variability of solar energy resource and cooling loads). The development of this test sequence has been done with a complete system modelled within TRNSYS 16 using a simplified model of absorption chiller. Validations of this test sequence have been done using the experimental facilities of CEA/INES and EDF R&D. Three H2O/LiBr chillers have been tested according to this method. Moreover static tests results from EDF R&D and CETIAT have been used in order to develop three simplified models of these absorption chillers. For defined virtual system (building loads, heat and cold storage volume, collector area …) and climatic conditions, the combination of dynamic and steady state experimental results provides important information regarding the operating limits, the inertial times and the performances of these chillers.

1. Introduction

Last years, several small scale absorption chillers (between 5 and 15 kW cold) have been introduced on the market. These products are the industrial results of the preceding generation of prototypes designed by several companies and research institutes during the last decade. In general, precise feed back information dealing with the functioning of these chillers or valid experimental data of solar cooling systems using these products are not yet available. This technical knowledge and validation are crucial to integrate these chillers in a solar cooling system and to optimize it.

Indeed, solar cooling systems with absorption chiller are organized according to three hydraulic loops (one for the generator, one for the absorber/condenser and one for the evaporator) around the chiller that implies a lot of boundaries and working conditions to the system. These requirements mean that the well functioning of such systems depends partly on the good knowledge of these parameters.

The main objectives of these tests are to facilitate the design of solar cooling systems with these chillers, to optimize the performance and the control unit of the installation and to validate the detailed numerical models. The methodology developed, the numerical models used and the results obtained are described in this paper.

2. Principle of the test method

In order to be representative, the characterization of the absorption chiller must be realized under operating conditions equivalent to those of a real solar cooling system. For this, a semi virtual testing method is used and is based on the use of

- a solar cooling system model under TRNSYS 16 [1], which defines at each time step the operating conditions (temperatures and flow rates) applied on the chiller,
- a dynamical test bench able to transform the numerical information of the system model in real physical values at each time step.

2.1. Description of the semi virtual test bench

The semi-virtual test bench consists mainly on a boiler room able to supply hot (54 kW at 180°C) and cold (150 kW at -10°C) water with two distribution loops, and on test modules of 25 or 50 kW able to reproduce the desired dynamical thermal loads within these range of temperature, Fig. 1.

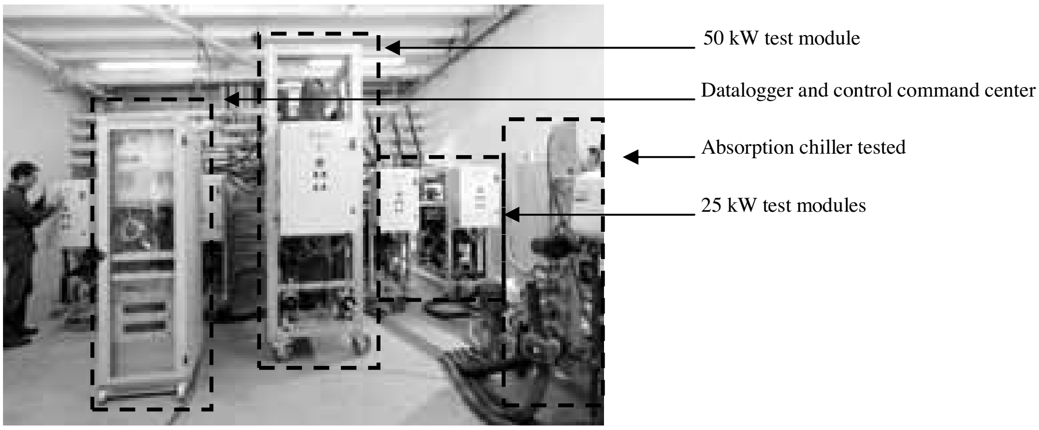

Fig. 1. Picture of INES semi-virtual test bench during an EAW chiller test

This test bench allows testing of various thermal systems for space heating, air conditioning and DHW preparation for different kind of applications (single or multi family houses, small industry, small tertiary buildings). The operating conditions of each module are representative of all or part of a system and their behaviour is controlled by a TRNSYS numerical model linked. With this method, a component or several components are characterised in a semi virtual environment, in fact by emulating some of the components of the system and the climatic conditions to which it is subjected.

In this study, climatic conditions, the solar loop, the heat rejection loop and the building are emulated.

2.2. Description of the TRNSYS reference system

The Fig. 2 shows the absorption solar cooling system defined under TRNSYS 16.

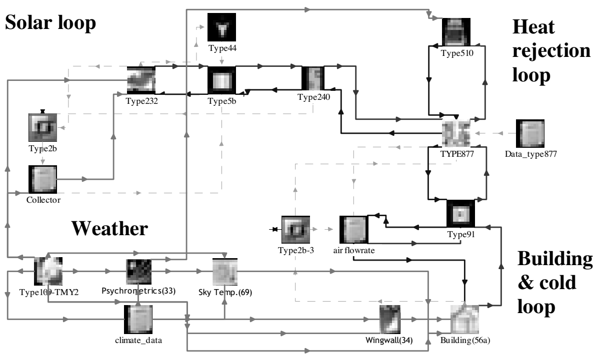

Fig. 2. Solar cooling system defined under TRNSYS

The hypotheses of the numerical model defined are the following:

- the solar loop, used for the alimentation of the thermally driven chiller, comprised flat-plate collectors, a plate heat exchanger and a hot water storage,
- the heat rejection of the chiller is connected to a closed circuit cooling tower, designed at nominal values provided by the chiller manufacturer,
- the cold loop uses a heat exchanger like fan-coils able to transfer the cold water power provided by the chiller into cold air power introduced in the building,
- the climatic conditions and the building used for the simulation have been defined by the IEA-SHC Task 32 [2]: Carpentras (FRANCE) and a 60 $kWh.m^{-2}.year^{-1}$ single family house (SFH 60) with a air change rate of 0.4 volume per hour,
- two controls are used, one on the solar heat production (comparison between the solar collector temperature and the storage tank temperature with two hysteresis of +5°C and of -2°C) and one on the internal temperature of the building (26°C with a hysteresis of -1°C).

2.3. Definition of the adjustment parameters

In order to adapt the system to different absorption chiller (with different cooling power), three uniformity parameters are defined on the three hydraulic loops:

- heat rejection loop: for each test or each simulation, the closed cooling tower model is designed at the nominal operating conditions provided by the manufacturer,
- cold loop: in order to adjust the cooling power provided by the chiller to the cooling demand of the building, the cooling power dissipated by the fan-coils into the building (P_{cool}) is calculated using the maximal cooling demand of the building (P_{SFH60}), the nominal cooling power of the chiller (P_N), the effective cooling power of the fan coils (P_{fc}) and the effectiveness of the fan coils (η_{fc}), with the following equation:

$$P_{cool} = \left(P_{SFH\,60} \cdot P_{fc}\right) / \left(\eta_{fc} \cdot P_N\right) \qquad (1)$$

- solar loop : in order to fix the right collector area and storage size, a parametric study have been done on the range described in Table 1, for the 4.5 kW ROTARTICA absorption chiller,

Table 1. Parametric study for sizing the solar loop

Parameters	Minimal value	Maximal value	Step	Unit
Collector area *A*	5	30	5	[m^2]
Hot storage volume *V*	50	400	50	[l]
Sizing temperatures for the cooling tower	32/28	52/48	10	[°C]

The optimization criteria chosen to use the results are the following:

- the specific cost of the solar collector loop (€.kWh^{-1} of cold energy) with a ratio of 375 €.m^{-2} for the solar collector area and a specific cost for the hot storage volume between 3600 and 5000 € for a range of storage volume of 0.1 to 1 m^3,
- the average operating time per day,
- the thermal performance coefficient of the absorption chiller.

The results of the parametric study are presented on the Fig. 3.

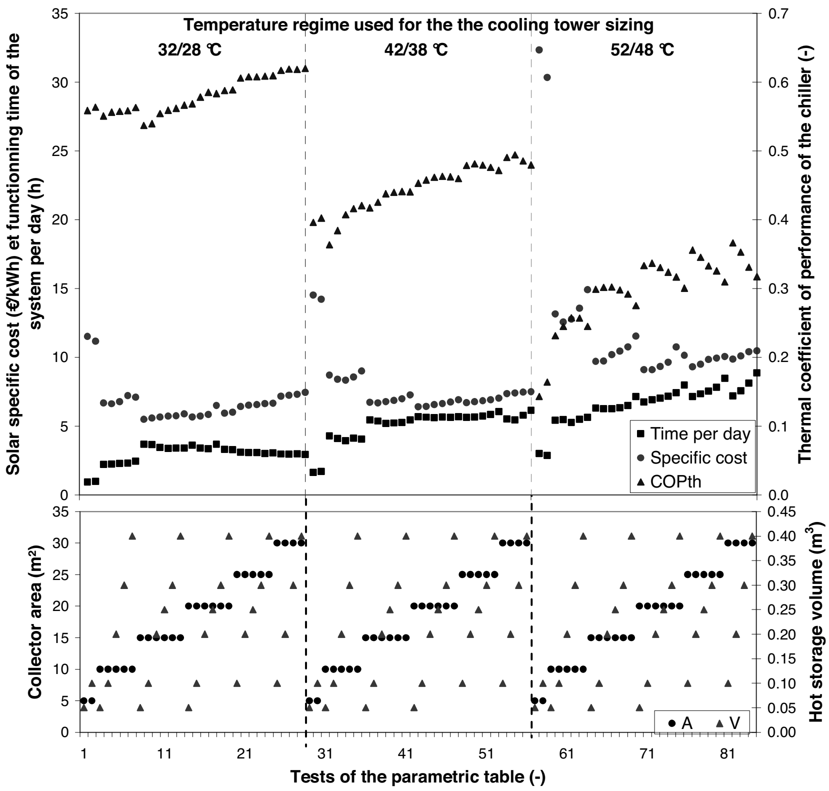

Fig. 3. Results of the parametric study for the uniformity parameters of the solar loop

The parametric study shows that the optimum value (high thermal COP, low cost and average functioning time) for the different sizing temperature of the cooling tower are obtained for the following couples: 15 m^2 & 300 l, 20 m^2 & 250 l and 25 m^2 & 200 l. The average value can be calculated by the following criteria for the solar loop: 4.5 m^2/.kW$_{cold}$ & 55 l/kW$_{cold}$. These values are upper than those given by Henning [3] which are 2.5 m^2/kW for absorption chillers and 3.4 m^2/kW for adsorption chillers, but allow the optimal performances under the fixed conditions.

2.4. Methodology of test

The methodology used for the dynamical characterization of the absorption chiller is based on the dynamical study of solar combi-system (SCS) developed at INES. This protocol estimates the SCS performances on 12 days representative of the 12 months of a year [4].

Despite the fact that this methodology is difficult to transfer directly to solar cooling system, it is possible to test the solar cooling system on three representative days of the different conditions met during the summer period and corresponding to a day with a high cooling demand and a medium irradiation (day 1), a day with a high cooling demand and a high irradiation (day 2) and a day with a low cooling demand and a high irradiation (day 3).

These three days are chosen between June the 1st and September the 30th in the Carpentras weather data file, used for the test of the system. For each test day (8 hours between 10h00 and 18h00), absorption chiller is tested and the rest of the system is simulated with TRNSYS, Fig. 4. During the other period, the complete system, including the absorption chiller, is simulated.

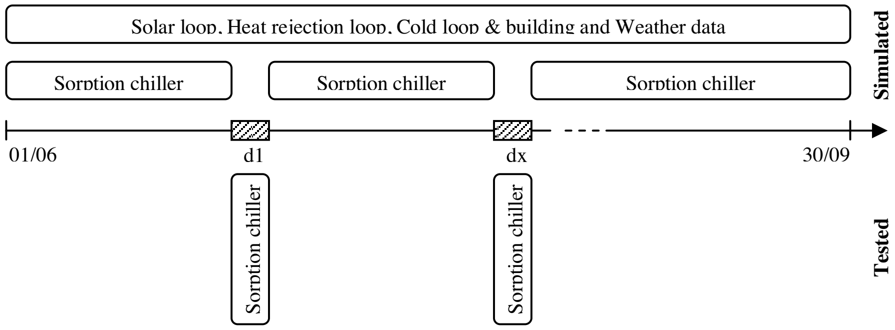

Fig. 4. Methodology of test

One advantage of this methodology is that it is able to define good initial conditions of the system (building, storage, etc.) at the beginning of the physical test of the chiller. But for this, it's necessary to have a numerical model of the tested chiller.

3. Characterization of the absorption chillers

3.1. Presentation of the tested chiller

Three absorption chillers have been tested in accordance with the previous methodology: a 4.5 kW ROTARTICA chiller Solar45, a 10 kW SONNENKLIMA chiller Suninverse provided by PHOENIX Solaire and a 15 kW EAW chiller LB15 provided by SCHUCO.

3.2. Numerical model of the absorption chillers

The numerical model used for the absorption chillers was proposed first by Ziegler [5]. This simple method is based on the definition of a characteristic temperature function $\Delta\Delta t$ [6].

$$\Delta\Delta t = t_G - (1+R)\cdot t_{AC} + R\cdot t_E \qquad (2)$$

In this expression, t_G, t_{AC} and t_E are the external arithmetic mean temperatures at generator, absorber-condenser and evaporator and R is a factor in the range of 1.1 for single-effect H_2O/LiBr absorption chiller. The different calorific powers can be expressed as linear function of the characteristic temperature function $\Delta\Delta t$.

$$P_X = A_X \cdot \Delta\Delta t + B_X \quad (3)$$

A_X and B_X are coefficients defined with experimental results in steady state conditions for each calorific power P_X of the chiller.

3.3. Statical test of the absorption chillers

By the use of static tests realised by CETIAT for the 15 kW EAW chiller, EDF R&D for the 4.5 kW ROTARTICA chiller and INES for the 10 kW SONNENLIMA chiller, the coefficients A_X and B_X have been determined for the three absorption chillers and are presented in the Table 2.

Table 2. Value of the linear coefficients for the absorption chillers tested

Absorption chiller	A_E	B_E	A_G	B_G	A_{AC}	B_{AC}	R
Units	[W/°C]	[W]	[W/°C]	[W]	[W/°C]	[W]	[-]
ROTARTICA 4.5 kW	316.20	-1864.46	383.42	658.86	-681.41	752.12	1.1
SONNEKLIMA 10 kW	302.69	-143.28	306.46	2561.43	-778.17	-1459.97	1.1
EAW 15 KW	677.32	-2311.72	842.84	3168.6	-1549.56	116.34	1.1

The Fig. 5 shows a comparison between the experimental thermal COP and the numerical thermal COP for the three chillers.

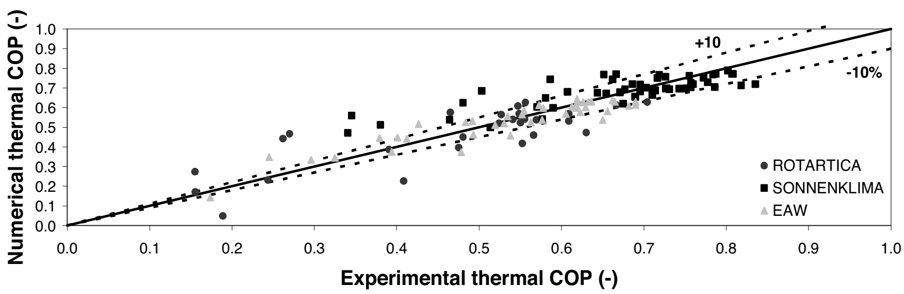

Fig. 4. Comparison of the experimental and numerical thermal COP for the three chillers

The numerical model provides numerical values in agreement with the experimental results (more or less 10%). Only few points for the ROTARTICA chiller are out of this range, but correspond at low thermal COP values obtained under bad working conditions for the chiller.

3.4. Dynamical test of the absorption chillers

For the three absorption chillers, the dynamical tests have been done. The Fig. 5 shows the behaviour of the EAW chiller for the three different days defined. The experimental results showed the different operating conditions for the three test days. During day 1 and day 2, the chiller runs continually. During day 3, due to on/off cooling demand for the building, seven start/stop cycles are observed. The high operating temperatures at the generator during day 2 give better performances results than those of day 1.

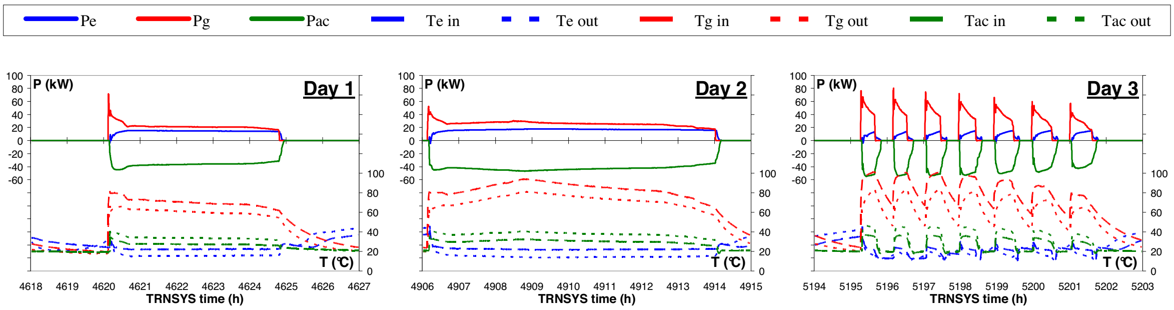

Fig. 5. Comparison of the experimental and numerical thermal COP for the three chillers

The Table 3 shows the mean operating characteristic for these three days of tests for the three chillers.

Table 3. Results of test on the three different days for the three chillers

Chiller	**Day**	**Thermal COP**	**Functioning time**	**Average P_E**	**Cooling energy**	**Average P_G**	**Solar energy**
Unit	[-]	[-]	[h]	[kW]	[kWh]	[kW]	[kWh]
EAW	1	0.65	4.68	14.14	67.23	21.95	103.15
Nominal COPth ~ 0.71	2	0.63	7.88	16.84	129.97	25.42	204.98
at 90/30/17 °C [7]	3	0.27	3.54	10.62	37.56	28.43	138.04
SONNENKLIMA	1	0.64	5.73	10.57	61.05	16.54	95.02
Nominal COPth ~ 0.75	2	0.60	7.91	14.18	112.54	23.86	189.12
at 90/27/18 °C [6]	3						
ROTARTICA	1	0.71	3.11	3.89	12.10	5.50	17.10
Nominal COPth ~ 0.73	2	0.56	7.65	5.18	44.00	9.18	78.00
at 90/30/18 °C [5]	3	0.47	3.2	3.41	10.90	7.31	23.4

During the dynamical tests, the SONENNKLIMA chiller has met some vacuum leaks. Day 3 was not realised for this reason and the thermal COP obtained seem to be low compared to the manufacturer nominal thermal COP.

In addition to the experimental results obtained for a nominal configuration, other tests have been done with variation of collector area ratio (± 1 m^2/kW), storage volume ratio (± 10 l/kW) and sizing temperatures for the closed cooling tower (± 10°C). The results are showed by the ratio of the experimental power and the manufacturer nominal power of the chiller as a function of the operating time, Fig. 6.

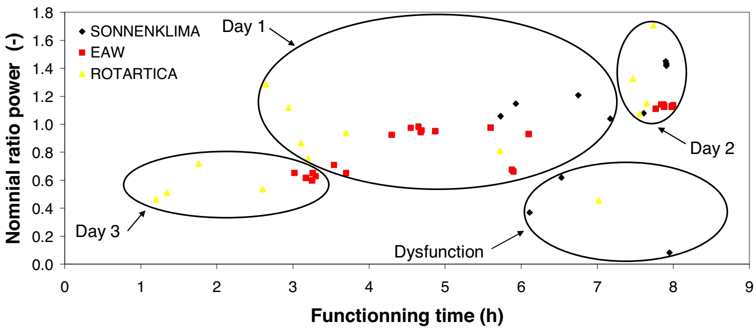

Fig. 6. Ratio between the average experimental power and the nominal power of the three chillers as a function of the running time during different experimental days and for different configurations of tests

During the ideal operating days (day 2), the performance of the chillers are consistent and superior to the nominal powers indicated by manufacturers. For less sunny days (day 1), the performances are equivalent to those announced, although more disparate because of the influence of the sizing system. The performances during the days with on/off cooling demand are low, reflecting the fact that these chillers are not provided for discontinuous operation. A dysfunction area (low cooling power) appears for the machine SONNENKLIMA due to the vacuum leaks and for one point of the ROTARTICA chiller.

5. Conclusion

The semi-virtual testing approach developed for the absorption chillers has been validated on three commercial systems. This protocol has highlighted the gap between the manufacturer nominal performances and the experimental performances during dynamical operation. These differences are particularly important for an adapting design of solar cooling systems.

In addition, the static tests (CETIAT and EDF R&D) and dynamic tests (INES and EDF R&D) will be used to fix the values of the heat exchange coefficients and the inertial masses of these chillers in order to adjust the parameters of detailed numerical models.

Finally, the dynamic test of sorption chillers is the first step towards a complete characterization of solar cooling systems on a test bench with a view to predictive performance.

References

[1] TRNSYS 16, A Transient System Simulation Program, TRNSYS 16.0.1.0002, Solar Energy Laboratory, University of Wisconsin-Madison, http://sel.me.wisc.edu/trnsys

[2] Heimrath R., Haller M. (2007) "Project Report A2 of Subtask A: The Reference Heating System, the Template Solar System", A Report of IEA SHC – Task 32, May 2007.

[3] Henning H.M. (2004) "Solar-Assisted Air-Conditioning in Buildings – A Handbook for Planners", SpringerWienNewYork editions, 2004.

[4] Albaric, M., Nowag, J., Papillon, Ph. (2008) "Thermal performance evaluation of solar combisystems using a global approach", Eurosun 2008, October 7-10, Lisbon, Portugal.

[5] Ziegler F. (1997) "Sorptionswärmepumpen, Forschungsberitchte des DKV", Nr. 57. Habilitattionsschrift, Erding, 1997.

[6] Khün A., Ziegler F. (2005) "Operational results of a 10 kW absorption chiller and adaptation of the characteristic equation", Proceeding of the first International Conference of Solar Air Conditioning, Bad Staffelstein, 2005.

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