

EXPERIMENTAL EVALUATION OF A PRE-INDUSTRIAL AIR-COOLED LiBr-H₂O SMALL CAPACITY ABSORPTION MACHINE

Joan Farnós, Jesus Castro, Eduardo García-Rivera, Assensi Oliva and Jorge Chiva

Centre Tecnològic de Transferència de Calor (CTTC)
Universitat Politècnica de Catalunya (UPC)
ETSEIAT, C. Colom 11, 08222 Terrassa (Barcelona), Spain
Fax: +34 93 739 89 20 e-mail: cttc@cttc.upc.edu

1. Abstract

The paper studies thermal design and describes the experimental set-up of a domestic-scale prototype experimental cooling system based on a 7kW of nominal capacity single-stage small LiBr-H₂O air-cooled absorption machine. The paper illustrates the characteristics based on a methodical procedure for the design and sizing of the small capacity air-cooled absorption machine.

2. Introduction

High initial investment is the main factor that impedes an extended use of solar absorption cooling system. Low capacity installations have the price of the absorption chiller as the most limiting factor. The development of air-cooled systems in order to explore the possibility of avoiding the cooling tower and therefore, to decrease the price of the whole installation, results very interesting. In the present research an air-cooled absorption machine will be developed, in this case driven by hot water below 100°C (suitable for solar cooling applications) with a single effect cycle configuration. The key aspect in the present development is the systematic application of advanced numerical tools and experimental techniques as usual methodology for an accurate design.

3. Methodology

The whole research is divided in three main steps (Castro et al., 2006).

- i) The first stage consists in the design, construction and test of a pre-industrial prototype.
- ii) New prototypes will be developed in the second stage. The main objective is to obtain a first experience in real-life application of an absorption chiller with an autonomous control and purge systems.
- iii) Development of a first small series of chillers with the definitive version of the control and purge systems.

In stage one thermal design is done using CTTC software as well as it will be described later. Mechanical design has been done using CAD and 3D software in order to avoid errors, saving hours of mounting and in order to do an easy serie fabrication as is described at third point before.

On the other hand this research is in parallel with project FERASOL which aim is obtaining new mathematical models in order to simulate falling film in vertical tubes in several regimes as well as creation of new facilities where heat and mass transfer phenomena can be observed and studied. An extended research is being carried so that results are being applied on air-cooled absorption machine design (Garcia-Rivera et al., 2008). It is expected to reduce the size of the whole chiller in the next future.

4. Numerical modelling

The whole system has been numerically analysed as well as each individual component, using a high level numerical detailed heat and mass transfer analysis. Absorber, desorber, condenser and evaporator are dimensioned using semi-empirical models that could use heat transfer and pressure drop correlations provided in the literature (Castro et al. 2008). Flooded evaporators are modelled taking account of heat and mass transfer coefficients as well as absorber and condenser are modelled using an own tube-fin high level numerical code; desorber is numerically modelled taking account absorption phenomena of heat and mass transfer as Castro et al. (2008) shown on their work recently.

Two types of heat exchanger have been considered: batteries of vertical finned tubes (absorber and condenser) (Oliet et al, 2000) and serpentine of horizontal tubes (generator and evaporator)(Castro et al. 2006). The solution heat exchanger is a commercial plate heat exchanger. The type of heat exchanger to be modelled consists in a serpentine of horizontal finned-tubes flooded by water. The resolution strategy has the following methodology (Castro et al., 2008): the heat exchanger is divided into control volumes along the tubes for both the solids (tube) and fluid (secondary flow). For the secondary flow (water stream in this case), in each control volume (CV) the equations of conservation of mass, momentum and energy are applied. The method of solution is a step-by-step procedure.

5. Description of prototype

5.1 General view

An absorption chiller is a type of thermal equipment quite complex. In order to make an optimal design of the absorption machine, it is interesting to develop numerical design tools for the cycle and heat exchangers (Castro et al., 2007) to avoid experiments. The evaporator of LiBr-H₂O absorption chillers normally is the second heat exchanger in terms of size and difficult of design. The typical configuration is the falling film type. They have many advantages: low-pressure drop in the primary stream, low amount of refrigerant, high heat transfer coefficients for small temperature differences, etc. However, this type of configuration requires usually an additional refrigerant pump to take the maximum advantage of the heat transfer area. In the case of small capacity absorption chillers results very interesting to remove the refrigerant pump because final price of the chiller can be decreased due to electrical expense. Flooded evaporators are an interesting alternative. They do not require any refrigerant pump, however, their design presents the main difficult of dealing with lower heat transfer coefficients with respect falling film evaporators. The main reason is because normally flooded evaporators do not work under boiling conditions, they work under natural convection regime, due to the small temperature differences between the primary and secondary streams (Castro, 2008).

5.2 Layout of absorption cycle

Comparison of the numerical predictions with the empirical results obtained of a experimental facility, in this case the laboratory prototype.

The arrangement between the air-cooled heat exchangers is in parallel flow (see Fig. 1). The absorber takes more than the 50% the total air flow, the same proportion as the frontal area. As can be observed in the two schematics views of figure 1, all the heat exchangers have been divided in two parts in order to keep the design as compact as possible. The arrangement of the heat exchangers forms a tunnel shape inside the machine.

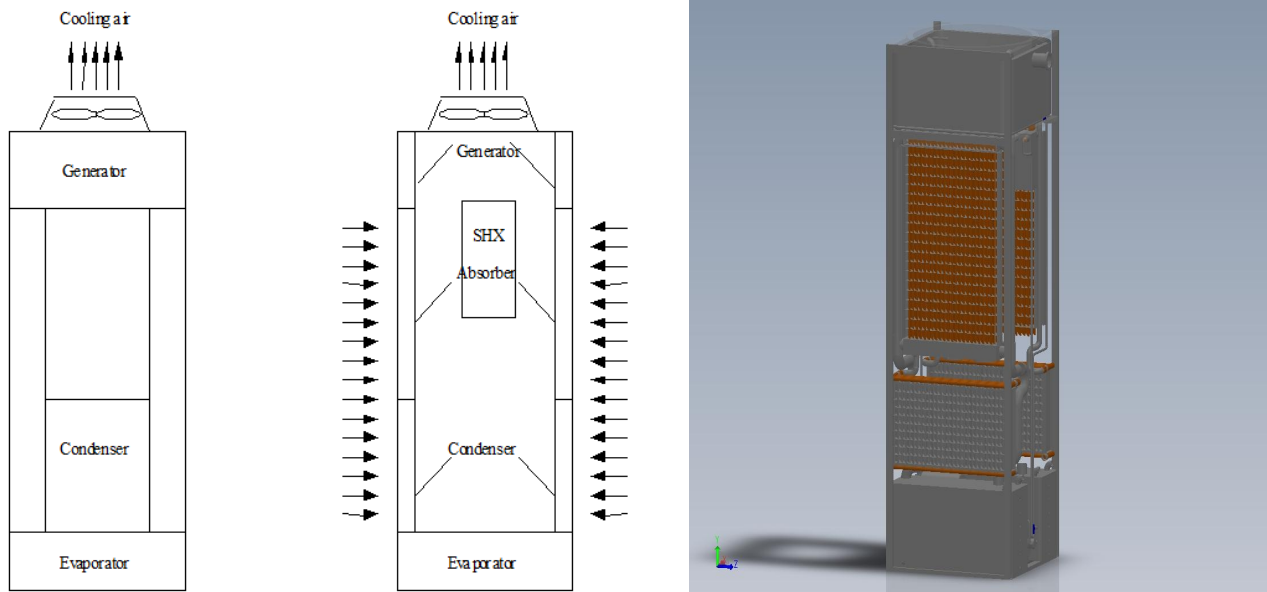


Fig. 1. Layout of the absorption chiller



Figure 2. General views of facility

Table 1. Equipment specifications and main results of the cycle simulation (* output value)

	<i>Units</i>		<i>Specifications</i>	
Nominal capacity	kW		7.0	
COP	-		0.7	
Dimensions	WDH, mm		800-800-2300	
Volume	m ³		1.5	
Electricity consumption	kW		0.37 (fan)+0.25 (pump)	
Hot water stream	°C	kg/h	88	1730
Cooling air stream	°C	m ³ /h	35	16500
Chilled water stream	°C *	kg/h	9	1200

5.3 Design of components

Evaporator

In this case the type of evaporator is of horizontal type. It consists in a battery of copper tubes with fins in order to enhance the heat transfer produced during the boiling process. In this case the evaporation process is produced outside the tubes and the secondary stream goes inside. Table 2 describes working conditions of the evaporator designed:

Table 2. Working conditions of the designed evaporator

<i>Working conditions</i>	<i>Units</i>	<i>Specifications</i>
Evaporation pressure	Pa	1092
Inlet temperature of the secondary stream	°C	14.07
Mass flow of secondary stream	Kg/s	0.17

Although the size of the evaporator is much higher compared with a falling film evaporator, its final price is lower than the mechanical pump needed for the recirculation of the refrigerant (Castro et. al, 2008).

Air-cooled Condenser

The condenser is also of falling film type. In this case, the liquid film/drops of condensed water are formed in the inner part of the tubes. It is also composed by two batteries made copper and fins.

Table 3. Working conditions of the designed condenser

<i>Working conditions</i>	<i>Units</i>	<i>Specifications</i>
Condensation pressure	Pa	7857
Inlet temperature of the secondary stream	°C	35
Mass flow of secondary stream	Kg/s	1.5

Air-cooled Absorber

The absorber is of falling film type. It is composed by vertical finned tubes where the LiBr aqueous solution goes inside where the absorption process is produced. It consists of two batteries.

Table 4. Working conditions of the designed absorber

<i>Working conditions</i>	<i>Units</i>	<i>Specifications</i>
Absorption pressure	Pa	1092
Inlet temperature of the secondary stream	°C	35
Mass flow of secondary stream	Kg/s	2.5

Desorber

The generator is of falling film type, where the LiBr aqueous solution goes outside the tubes and the secondary stream inside.

Table 5. Working conditions of the designed generator

<i>Working conditions</i>	<i>Units</i>	<i>Specifications</i>
Generation pressure	Pa	7857
Inlet temperature of the secondary stream	°C	88
Mass flow of secondary stream	Kg/s	0.48

Solution heat exchanger

The solution heat exchanger is a commercial component. The calculation has been done using standard methods in heat exchangers.

6. Instrumentation of prototype

A validation, which consists on comparing experimental versus numerical results, has to be done. In this way the facility aimed to analyse the performance of the air-cooled absorption machine contains a calorimeter so that global balances can be studied in high detail. The machine is supplied by 2 electrical boilers which have 3x2500W thermal impedances each one; it is possible to simulate several service conditions by varying the parameters of internal and external circuits, as the driving temperature, pressure and flow rate, all abled to be recorded in real time, i.e. varying the temperature and the flow rate of the supplying hot water; allowing to study energy performances of the machine.

Temperature is measured using Pt100 DIN 1/3 and a thermocouple matrix in order to study air inlet distribution temperature at secondary stream, mass primary flow using a Coriolis Flowmeter, volume flow using a Vortex flowmeter and pressure using an absolute pressure sensor. All data is being processed in order to check energy balances. On the other hand, power consumption of solution pump, secondary pumps and the fan is also measured by electronic instrumentation.

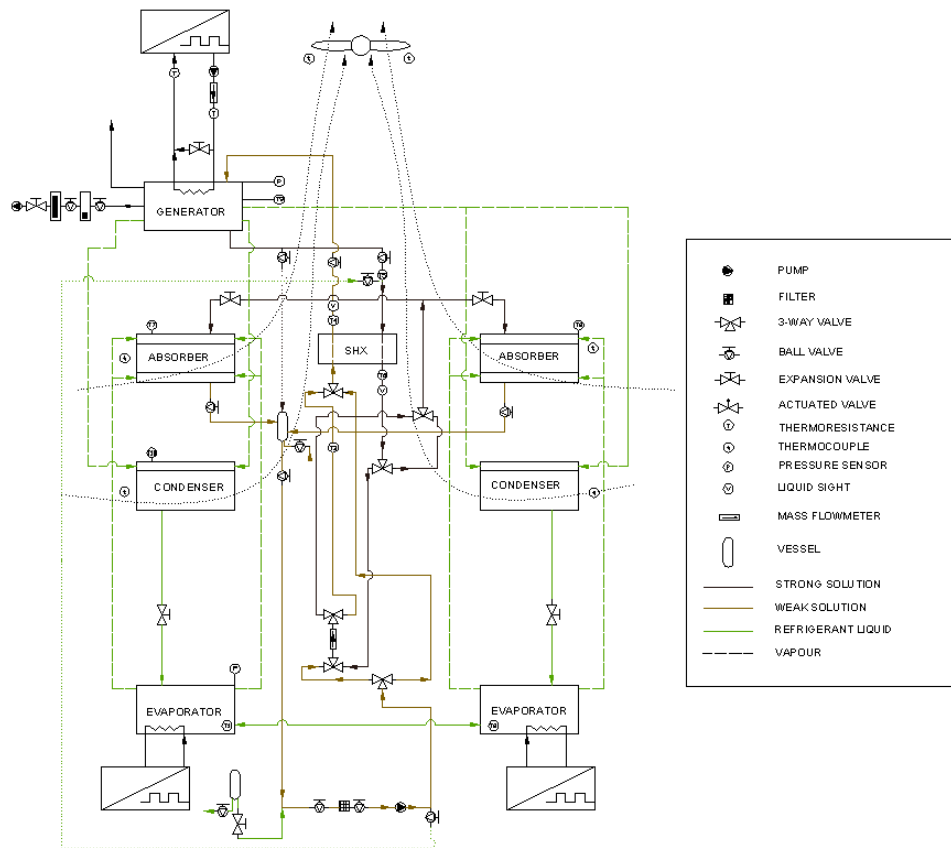


Figure 3. Instrumentation scheme.

In order to validate the air-cooled absorption machine described above some tests are performed. First tests that were done are vacuum tests. All components of the whole system were tested and validated with a very high requirement. The vacuum ratio F could be less than $1e-5 \text{ mbar} \cdot \text{l/s}$, where $F = (\Delta P \cdot V) / \Delta t$.

On the other hand, static tests are applied in order to obtain COP curves as dynamic tests are done describing a whole day performance and to study as many hours of performance it is possible. The main objective is to obtain a first experience in real-life application of an absorption chiller. Finally, it is important to incorporate the air-cooled absorption machine in a bigger facility which it is fed by solar energy. Now we are on this stage.

7. Conclusions

Industrial and basic research is being done in parallel in order to construct an air-cooled LiBr-H₂O absorption chiller. The critical point is being studied as water vapor absorption in vertical tubes, evaporation in flooded tubes, etc.

At the present, in most cases empirical based model overestimates heat transfer rate, it can be due by the limitations of the empirical information used. In order to avoid this kind of deviation in future more correlations that take into account more aspects (e. g. incondensables) for heat and mass transfer coefficients calculation will be employed for the absorber and also for the flooded evaporators.

The volume of the machine has resulted significantly bigger compared with the design of the referenced gas-fired machines, due to the use of a lower heat supply in the generator. It has been designed without taking into account the influence of additives or advanced surfaces that improve the heat and mass transfer. Moreover, it has to be taken into account the limitations of the single effect cycle in terms of maximum LiBr concentrations.

Next steps in this research are static analysis, which are performed in order to obtain COP curves. Then dynamic analysis will be done in order to describe a whole cycle day performance of the machine inside a calorimeter which allow varying conditions of analysis (flow mass rate of secondary streams, inlet temperature of secondary stream, fan flow rate, etc.) and

validating software developed previously. Finally a simulation of solar heating/ventilating system residence in the Mediterranean climate will be performed once the performance of air-cooled absorption machine components is widely analysed. This study will be used in order to validate numerical models applied on heat exchangers simulation. This work is also supported by FERASOL project, which is in parallel with the air-cooled absorption machine facility development project.

Finally, energy savings are going to be studied, as the ones achieved in water-cooled systems. In this way dynamic analysis are programmed in order to obtain a whole day performance of the whole solar cooling facility. A validation of the numerical simulation of the whole cycle solar air-cooled facility will be done allowing to improve numerical modelisation and to implement a virtual laboratory.

8. Acknowledgments

This work is financially supported by the “Generalitat de Catalunya CIDEM” (ref. VALTEC09-1-0009). This work was supported by a Scholarship Programme of the Spanish “Ministerio de Educación”.

9. References

- Castro, J., Oliva, A., Pérez-Segarra, C. D. and Cadafalch, J., 2007, Evaluation of a small capacity, hot water driven, air-cooled H₂O-LiBr absorption machine, *International Journal of Heat Ventilation Air Conditioning and Refrigeration Research*,13(1), p. 59-75.
- Oliva A., Pérez-Segarra C.D., Castro J., and Quispe M., (2002). Air-cooled water-LiBr absorption cooling machine of low capacity for air conditioning (ACABMA). JOULE-CRAFT Publishable Report, EU Contract JOE-CT98-7003.
- Oliet, C., Pérez-Segarra, C.D., García-Valladares, O. and Oliva, A.. Advanced numerical simulation of compact heat exchangers. Application to automotive, refrigeration and air conditioning industries. *Proceedings of the Third European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS)*, in CD format, 2000.
- Castro, J. (2005). Simulation of heat and mass transfer phenomena in the critical elements of H₂O-LiBr absorption cooling machines. Experimental validation and application to design., Ph. D. Thesis, Terrassa.
- Castro J., Oliva A., Pérez-Segarra C.D. and Oliet, C., 2008, Modelling of the heat exchangers of a small capacity, hot water driven, air-cooled H₂O-LiBr absorption cooling machine, *International Journal of Refrigeration*, 31(1), p. 75-86.
- Castro J., Oliva A., Oliet C., Pérez-Segarra C. D., 2006. Development of a pre-industrial prototype of an air-cooled H₂O-LiBr absorption chiller. 7th IIR Gustav Lorentzen Conference on Natural Working Fluids, Trondheim, Norway.
- Castro J., Oliva A., Oliet C., Pérez-Segarra C. D., 2006. Construction of a pre-industrial prototype of an air-cooled H₂O-LiBr absorption chiller for solar cooling applications. EuroSun 2006.
- Castro J., Farnós J., Oliva A., García-Rivera E., 2008. Flooded evaporators for LiBr-H₂O absorption chillers: modelling and validation. 8th IIR Gustav Lorentzen Conference on Natural Working Fluids.
- Churchill, S. W. and Usagi, R., 1972, A general expression for the correlation of rates of transfer and other phenomena", *AIChE Journal*, 18(6), p. 1121-1128.
- Pérez-Segarra, C. D., Oliet, C. and Oliva, A., 2008, Thermal and Fluid Dynamic Simulation of Automotive Fin-and-Tube Heat Exchangers. Part 1: Mathematical Model, *Heat Transfer Engineering*, 29(5), p. 484-494.