LOW POWER ABSORPTION REFRIGERATION SYSTEMS, WITH STORAGE, FOR AIR CONDITIONIG, DRIVEN BY RENEWABLE ENERGY SOURCES

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Abstract. This paper presents the results of research on ammonia-water absorption refrigeration systems for small and medium powers, operated with renewable energy resources [solar energy, geothermal] and bivalent, with renewable energy and conventional sources. It were built two absorption refrigeration machine, one driven only with renewable energy sources, a 5 kW cooling capacity, and another 17 kW cooling capacity, driven bivalent. The equipment of the systems are compact heat exchangers, with mini and micro channels. Refrigeration systems are equipped with thermal energy storage. Such systems are designed for comfort and commercial climate. Absorption heat pumps and chillers with ammonia-water can save considerably fuel by using renewable heat sources or waste heat available at temperature that is low enough. A reduction of the carbon dioxide emission together with a global warming potential is resulting. Some performance data will be indicated emphasizing the viability of this system based on micro/mini channels heat exchangers.
Keywords: absorption ammonia/water, mini and micro channel, renewable energy.

1. INTRODUCTION

In Romania, it's topical the comfort cooling of small volumes, like offices, holiday homes, individual residential suites or luxury apartments, that require small values of air conditioning power ranging from 5 kW up to 50-60 kW. Cooling power is about 15-20 W/m^3, in areas corresponding to a microclimate for human comfort.

On the Romanian market are distributed more mechanical vapour compression machines but were imposed also absorption machines, considering the possibility of using the latest renewable and recoverable energy.

Absorption refrigerating systems are used with ammonia-water solution, as ROBUR systems, small power lithiumbromide-water solution systems, as Japanese manufacturing systems YAZAKY or Chinese manufacturing BROAD.

Ammonia is the most frequent used refrigerant for the industrial applications (food cooling mainly), but also for air conditioning.

An ammonia system has been used for the most important building used for social and cultural events, only compressors being imported, and the rest of the equipment being produced in Romania. After the sixties of the last century very high capacity (2-20MW) absorption ammonia-water systems have been conceived and produced, especially for the chemical industry. Some of these systems are still in operation where the industry still exists. In the same period research started to develop refrigeration systems using renewable energy. Professors and researchers from the Civil Engineering University of Bucharest – UTCB, and from the „Politehnica“ University of Bucharest (CHIRIAC et al., 1983) have realized a solar driven ice manufacturing system with a capacity of 20 000 kg ice/day. Figure 1 shows this installation using solar parabolic trough collectors. Such facilities, solar driven, have been designed and produced under the same supervising collective from the Thermodynamics Department, Civil Engineering University of Bucharest, and they operated until 1990, when re-industrialization of Romania began.

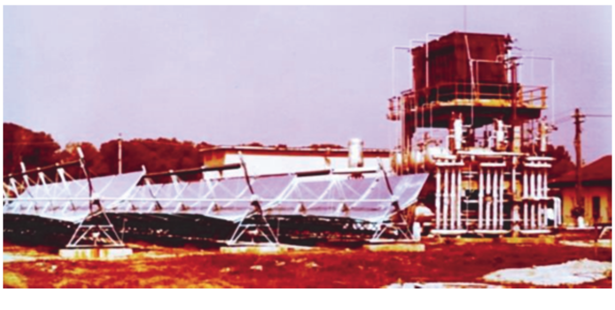
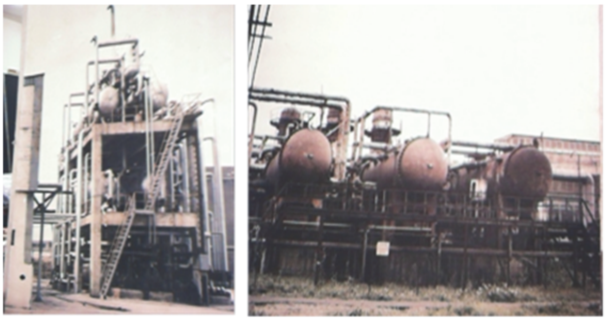


Fig. 1. Ammonia-water absorption refrigerator driven by solar energy, for cold water and ice preparation, Jurilovca-Tulcea, 1983, designed by Professor Florea CHIRIAC.

Consequently, high capacity absorption ammonia-water heat pumps have been designed and realized (Kim and Infante Ferreira, 2005), like:

- 2000 kW resorption system driven by conventional fuel and using waste warm-water having a temperature of 20 to 30 ^{o}C was able to produce 60-65 ^{o}C warm water;
- hybrid compression-absorption heat pump system, electric driven, with a heating capacity of 7000 kW, recovering heat from the warm water having 20 to 30^{o}C, and producing warm water of 60 to 70^{o}C;
- resorption heat transformer being driven by geothermal water of 35-40^{o}C, using it as a heat source also, and producing 55-60^{o}C warm water (Fig. 2).



a) b)

Fig. 2. Resorption heat pump, ammonia-water (a), and hybrid heat pump with mechanical compression and ammonia-water (b). Two factories, close to Bucharest, both projects designed by Professor Florea CHIRIAC.

After the year 1990 research in the field of the absorption refrigeration systems and heat pumps too, ammonia-water and LiBr-water solar/conventional driven was in progress both in the Thermodynamics Department, Civil Enginering University of Bucharest and in the HVAC&R Department of the "Transylvania" University of Brasov. Now research in Romania is focused on the improvement of the low power absorption systems, with storage, using renewable and recoverable energy, for air conditioning purposes. [1]

2. SOLAR COOLING WITH LITHIUM BROMIDE-WATER ABSORPTION

A 17.5 kW, YAZAKI, LiBr-Water system was installed inside the laboratory of the Building Services Faculty, on the Technical University of Civil Engineering Bucharest UTCB as shown in Figure 3.

The operation of the experimental setup: the 10% ethylene-glycol/water mixture circulating through the solar collectors, *1*, transfer heat to the water from the 4000 l tank *3*, by means of the plate heat exchanger *2*.

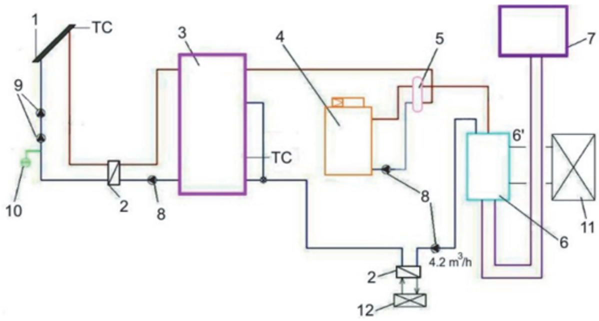


Fig. 3. Solar Cooling installation diagram:
1 – flat solar collectors; *2*- plate heat exchanger; *3* – warm water tank; *4* – boiler; *5* – distributor; *6* – absorption chiller Li Br/water; *7* – cooling tower; *8* – circulators; *9* – hydraulic unit; *10* – hydraulic unit control; *11* –chilled water consumer for air conditioning; *12* – hot water consumer; *TC* – temperature sensors.

The hydraulic unit 9, is controlled by the temperature sensors TC: only positive temperature differential between solar panels and storage tank keep in operation the circulator. The vapour generator inside the absorption chiller is drove by the hot water prepared in the tank 3. The system was designed for bivalent operation: if the solar radiation is not sufficient to heat the water at the temperature requested by the vapour generator then a back-up boiler 4, supplements the necessary thermal energy. The distributor 5, prepares the water at the requested temperature for the vapour generator. To improve the efficiency of the solar collectors the temperature of the hot water leaving the generator has to be lowered at approx. 30…35 °C, which is realized by the plate heat exchanger 2.

The system produces chilled water temperature at 7 °C, using a bivalent system to boil the solution, with flat solar collectors and classic gas fired boiler. In figure 4 we give some images of the solar cooling system. [2].

Fig. 4. Solar Cooling with BrLi-Water Absorption System on Building Services Faculty Bucharest.

3. ABSORPTION CHILLER WITH AMMONIA-WATER SOLUTION AND MICRO/MINI CHANNELS HEAT EXCHANGERS

Figure 5 illustrates the experimental plant with the major components and Figure 6 the schematics of a prototype ammonia-water refrigeration system connected to solar collectors, designed to produce chilled water 7/12 °C for air conditioning. The two economizers, the generator and the evaporator are mini channel heat exchangers and the condenser, together with the absorber are air cooled mini/micro channel heat exchangers with fins.

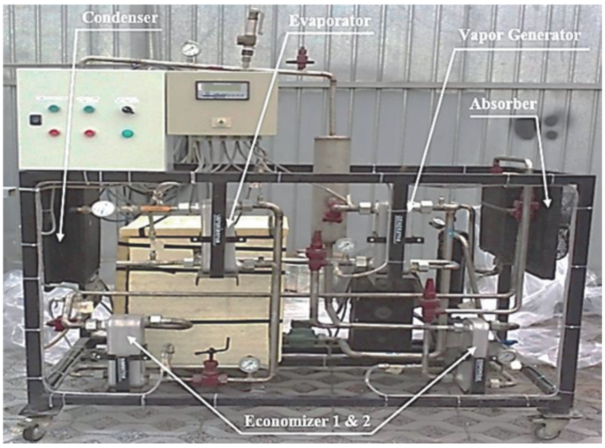


Fig. 5. Ammonia-water absorption chiller. Experimental plant.

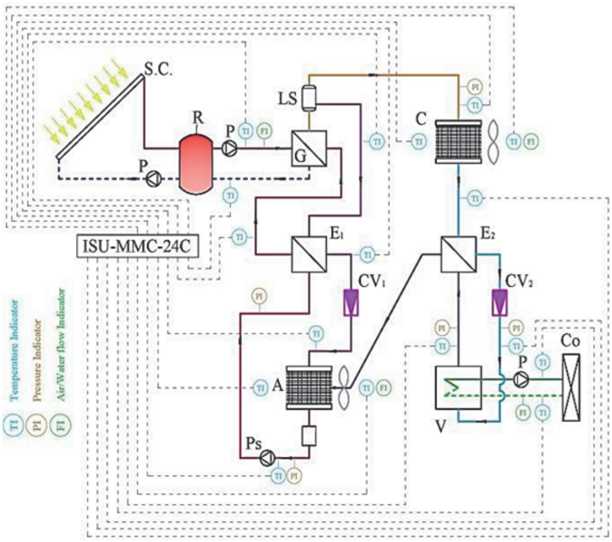


Fig. 6. Ammonia-water absorption chiller. The schematics.

Water cooling system is a solar plant with ammonia-water solution, operating on the principle of absorption and is calculated for approximately 7-10 kW. Hot water prepared by solar collectors, with temperature between 85-90°C is used at the generator for boiling the ammonia-water solution.

The vapour Generator consists of mini channels, with dimensions of 2×1 mm^2, construction material is aluminum. The absorber is an original construction, consisting of mini/micro channels, arranged in two vertical rows and have efficient finned outer surface, with superior distributor for the poor solution and lower collector for the strong solution; ammonia vapor injection, to be absorbed is done through the median distributor, connected to the mini/micro channels by individual connections. Evaporator has the same construction as the vapor generator and is from the same material. The economizers are the same type of construction with the generator and evaporator. The condenser is constructed of micro / mini channels, with efficient finned outer surface. The condenser is air cooled.

The use of heat exchangers with micro/mini channels in absorption refrigeration systems offers the possibility of low refrigerant charges as well as high heat transfer and compact design. Parts that are difficult for small refrigeration systems with powers of 2-10 kW are absorber and the ammonia-water solution pump. The presented system was tested using an original construction absorber with micro/mini channels of 1.5 mm equivalent diameter which had good results, and the system produces cold. In this stage were obtained in the evaporator vaporization temperatures, positive, producing chilled water for comfort air conditioning.

At these low cooling power can be made mobile refrigeration systems, that can use conventional energy, renewable [solar, geothermal] and recoverable, such as the hot gas fluids. Coefficient of performance, COP of the system is around 0.6 [3].

4. BIVALENT DRIVEN, SMALL CAPACITY ABSORPTION AMMONIA-WATER REFRIGERATION SYSTEM.

The solar driven ammonia-water, absorption system was studied by the research team from the Thermodynamics Department from UTCB (Calota, 2011). A ROBUR system having a 17.5 kW refrigeration capacity was modified by replacing the vapor generator with a plate heat exchanger that boils the ammonia-water solution by means of solar heated water. The rest of the system is kept in its original form. Figure 7 shows the modified system and in Figure 8 is presented the diagram of the experimental set-up.

The purpose of this study is to compare the temperatures values from different characteristic points, and so, to demonstrate that the modified plant, driven by the solar energy have the same temperature performance with the plant driven by the burner on natural gas.

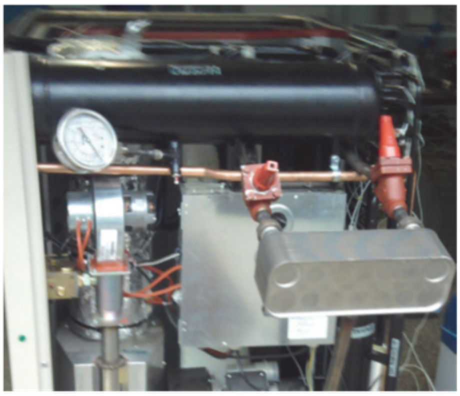


Fig.7. Image of heat exchanger mounted as steam generator.

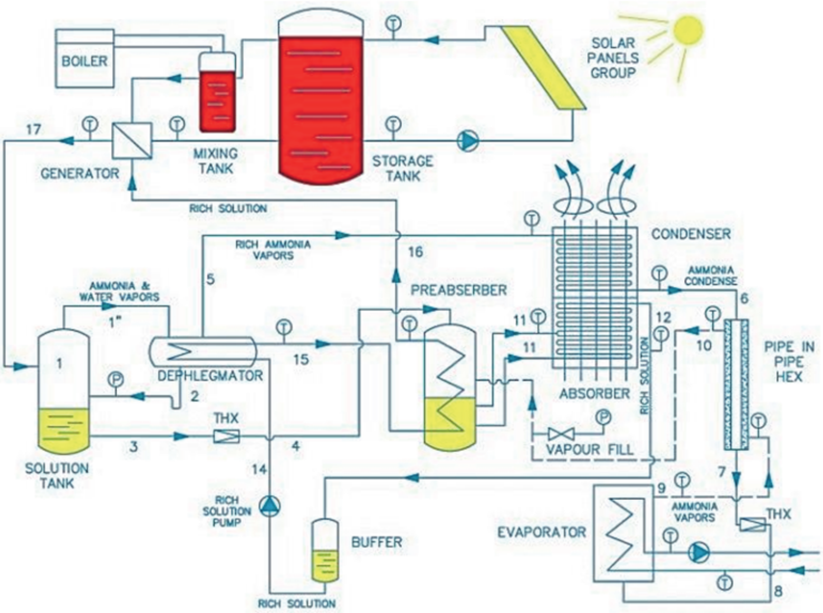


Fig. 8. Hydraulic setup and component denomination.

There are studied two cases as a function of the temperature of the chilled water at the outlet of the evaporator, 8/12 °C. During the testing, the outdoor temperature was the same for the two plants. Also, the pressure measured at the rectifier exit and at the absorber exit had the same values for both plants [1].

5. SMALL CAPACITY ABSORPTION AMMONIA-WATER SYSTEM WITH CHILLER AND HEAT PUMP

The Transylvania University Building Services Department has completed and now operates a complex HVAC system for cooling and heating of indoor spaces through the interconnection of two ammonia-water absorption systems (see Figure 9) manufactured by ROBUR Company.

Both equipment have been placed on a platform outside the building. This way the chiller fan noise (57 dB) and accidental ammonia contamination are avoided. The chiller is operated as refrigeration machine and the heat pump can be operated in a reversible mode as a chiller or as a heater using heat energy to provide cooling or heating. Both equipment are interconnected supplying with chilled or warm water the fan coils located into the faculty rooms depending on the seasonal requirements. The absorption heat pump is preparing warm water up to 60^{o}C recovering heat from the outside air. The ammonia is the refrigerant being absorbed by the water –the absorption fluid. For the balancing of the water circuits a hydraulic separator is used. The nominal temperature of the chilled water is 7.2°C returning back to the unit with 12.7°C for an outside air temperature of 35°C. A 150 l storage tank for hot water is installed in the underground room next to the heater. The rest of the equipment, circulation pumps, accumulators, filters, and the electrical wiring, direct measuring devices, and the loggers for the acquisition of data provided by the sensor are located in the adjacent room.

Two ROBUR absorption machines – single-effect gas fired – one operating only as a chiller and the other, reversible, working as a chiller or as a heat pump are connected as shown in Figure 10 [4].

Fig. 9. Small capacity Robur ammonia-water absorption systems with chiller and heat pump.

The chiller is an AYF 60-119/4 standard version having a cooling capacity of 17.49 kW at a nominal chilled water flow of 2735 l/h and a gas consumption of 2.51 m^3/h. The maximal sound pressure level is 57 dB(A). The complementary heating module supplying 2000 l/h of domestic hot water can be operated in both heating and cooling seasons. It has a capacity of 32.5 kW and is provided with a storage tank installed in the inside vicinity. To avoid the danger of possible freezing during the heating season the circuit between the heating module and the storage tank is filled with antifreeze solution [1].

The chilled water at 7°C provided by the chiller and by the heat pump operated as a chiller too is pumped into the fan coils placed inside the rooms. As a result the inside air is cooled and dried and the water returns warmer at approx. 12°C to the refrigeration units.

During the heating season the heat pump supplies the above mentioned fan-coils with warm water having a maximum temperature of 60 °C even at negative ambient-air temperatures, i.e. -20°C. But the heating performance is affected by the outside dry bulb temperature and also by the hot water temperature leaving the unit, This installation was realized to be used for different research studies at doctoral and MSc level but it is also useful for testing activities (AHU, cooling rooms, hydronic coils for heating/cooling, radiators) [4].

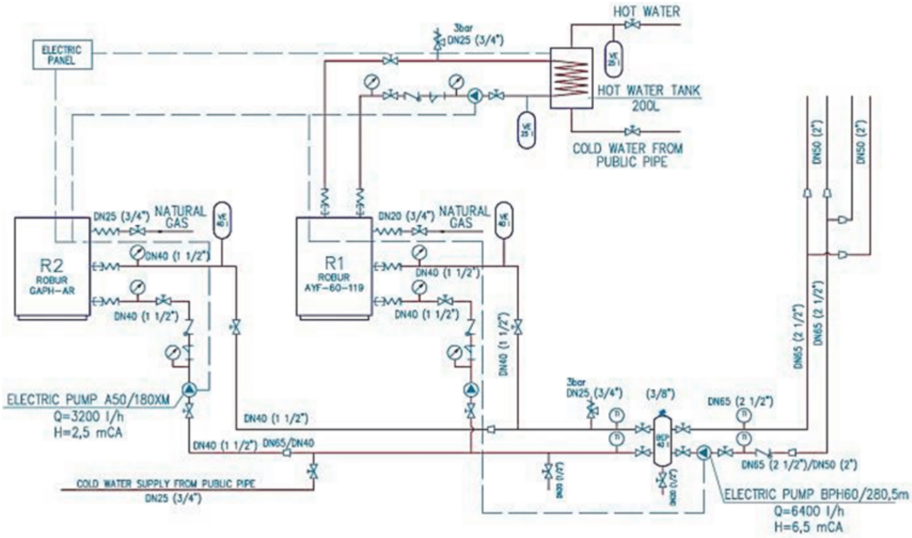


Fig.10. Hydraulic setup and component denomination:
R1 – Robur AFY-60-119 – Air cooled ammonia-water absorption chiller-heater, gas fired, cooling capacity = 17,7 kW, heating capacity = 32,5 kW;
R2 – Robur GAPH-AR – Reversible gas fired, air cooled ammonia-water, absorption heat pump, cooling capacity = 16,9 kW, heating capacity = 35,3 kW.

6. CONCLUSION

This paper presents refrigeration and air conditioning systems using natural refrigerants, powered by renewable energy sources, studied, performed and promoted by schools and research teams in Romania. Absorption refrigeration systems, powered by solar energy (hot water produced by solar panels) and water as refrigerant, are presented. Providing chilled water for air conditioning systems, these systems are realized either as experimentally pilot or promoted as implementing projects for different beneficiaries.

Presentation of these systems represents a call to the specialists also to promote cooling and air conditioning systems. Concerned about the introduction of new natural refrigerants and new refrigeration systems government, international institutions such as UNEP, IIR, and the Council of Europe adopt measures to amend the standards and norms of design, construction and operation of refrigeration, heat pumps and air conditioning systems. In developed countries, companies have switched to using natural refrigerants and cooling systems that uses renewable and recoverable energy sources, instead of transition refrigerants and classical cooling systems.

In our country professional and scientific societies should contribute to changing internal rules designed to protect the environment and conserve the energy.

Absorption heat pumps and chillers with ammonia water can save considerably fuel by using renewable heat sources or waste heat available at temperature that is low enough. A reduction of the carbon dioxide emission together with a global warming potential is resulting. In fact absorption systems exchange heat with three thermal reservoirs contributing to overall energy efficiency. The use of an absorption chiller during high summer-cooling demand periods or even in normal operating hours is economically beneficial especially in case of a favourable cost ratio of electricity to natural gas or by using the solar energy.

In the paper are presented some researches regarding the small absorption chiller driven by conventional or solar energy. Two small chillers installed in the laboratories of the Transylvania University of Brasov and of Technical University of Civil Engineering of Bucharest are used for PhD Thesis. It is demonstrated that small absorption chiller with ammonia-water is a good, economically and environmental friendly solution for the residential and commercial applications.

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