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SMALL SIZE ABSORPTION REFRIGERATORS: A COMPARISON AMONG DIFFERENT SOLUTIONS IN SOLAR FEEDING APPLICATIONS

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ABSTRACT

Absorption refrigerating machines represent an interesting alternative to compression machines, especially when waste heat or heat produced by solar energy is available; the market is beginning to propose small-size absorption machines especially designed for air conditioning in residential buildings. A recognition of small size absorption refrigerators is reported, with particular emphasis on their performances in the case that the thermal source is constituted by solar energy. The examined machines cover different chilling powers (from 4 to 15 kW) and have different working principles. The study is conducted through the data supplied by manufacturers and collected in the experimental set-up available at the Labs of the University of Perugia; different refrigerators are compared taking into account the most significant parameters such as hot source and chilled water temperature, cooling circuit characteristics, coefficient of performance, weight and dimensions. Energy and environmental advantages deriving from the solar supply are also evaluated.

1. INTRODUCTION

The summer air conditioning demand is growing continuously, not only in the tertiary sector but also in residential applications; the correspondent request of electric power may cause crisis of the electrical net, that must cover higher and higher load peaks. Absorption refrigerators represent an interesting alternative to compression machines, especially when waste heat or heat produced by solar energy is available [1, 2, 3 and 4], therefore, they could represent a solution to the energetic-environmental matters linked to the respect of international agreements, such as Kyoto Protocol for CO_2 emissions reduction, or the United Nations Framework Convention on Climate Change (FCCC) and the Montreal Protocol, whose aim is to abandon the use of CFC in cooling cycles. Absorption cooling systems, in fact, do not employ CFC but solutions with low environmental impact. The market is beginning to propose small-size absorption machines especially designed for air conditioning in residential buildings; the present work is aimed to give a recognition of these solutions, with particular emphasis on their performances in the case that the thermal source is constituted by solar energy.

2. FEEDING ABSORPTION MACHINES WITH SOLAR ENERGY

Nowadays, the huge potential of the residential buildings cooling market is almost completely covered by electric refrigerators, heat pumps and (with lower success) gas fired absorbers. Main problems linked to solar fed absorption plants should be summarized as follow:

– strict plant dependence on environmental parameters such as external air temperature, solar irradiation level and wind speed;
– high initial cost;
– efficiency of solar contribution limited to the central hours of the day.

Besides, an intrinsic characteristic of the plant limits the global performance: although absorption cycles reach highest efficiencies when heat sources are available at a high thermal level, solar panels behave exactly in the opposite manner: both flat and evacuated tubes collectors present efficiencies that decrease with the raise of the circulating fluid temperature.

Finally, even if the cooling load and the solar irradiation appear reasonably at the same time of the day, there can be many occasions when the ideal coupling between the sun and the absorption machine is not present: hot days with scarce irradiation, morning or late evening cooling load and sunny days without cooling request.

Plant layouts must tend to reach the best efficiency, combining flexibility, cheapness and installation easiness; the perfect installation does not exist: each answer aims to satisfy different properties, so the fitting solution has to be found from time to time. Starting from the simplest connection (Figure 1) solar collectors are linked directly (or by an external heat exchanger) to the generator of the absorption machine.

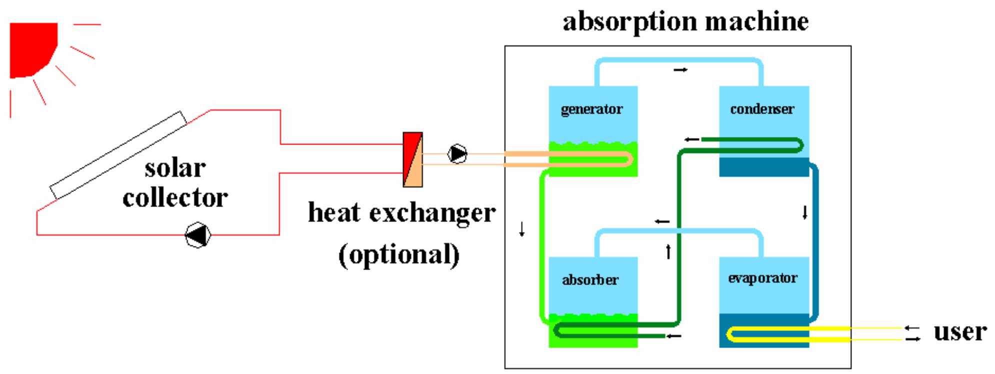

Figure 1. Scheme of direct connection between solar collectors and absorption machine.

This solution gives the possibility of transferring the whole energy gathered by the collectors straightly to the machine, without the passage by a storage tank. The experimental campaign conducted at the Labs of University of Perugia showed (as expected) that, although the generator is fed with high thermal level energy, the regulation possibilities remain strongly limited. Therefore, each variation of the solar input is transmitted to the chilled water and than to the user; besides, in case of low irradiation, it was found a transient effect characterized by continuous ON-OFFs, with consequent efficiency decrease and unwanted intermittent behavior of the absorption cycle.

The first step to better regulate the plant functioning consists of positioning a hot storage between the collectors and the refrigerating machine (Figure 2).

With this solution a series of heat losses is introduced: the dispersion through the tank surface, the energy wasted in the heat exchanger between the solar circuit and the hot storage as well as the coils between the generator feeding circuit and the storage itself. On the other hand, the presence of the hot tank allows a minimum regulation, storing the energy when the production exceeds the chilling load and feeding the generator also when the solar radiation is not enough.

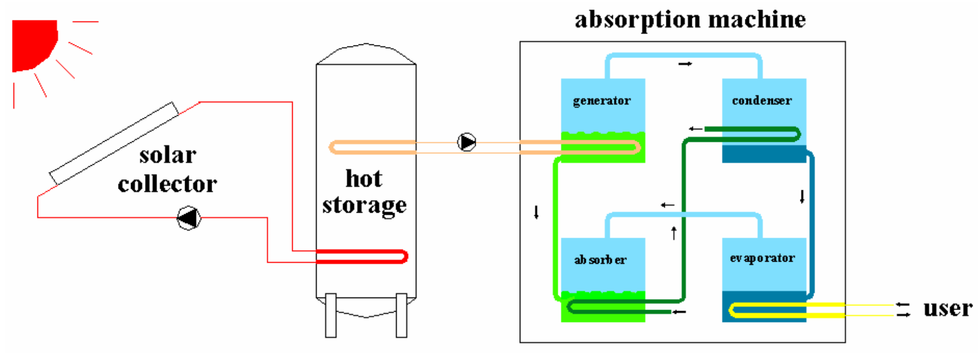

Figure 2. Scheme of solar fed absorption machine with hot storage.

Regarding the possibility of installing a cold storage, one of the available solutions is showed in Figure 3. The effect consists of giving a higher inertia to the load, avoiding the intermittent functioning of the absorption machine.

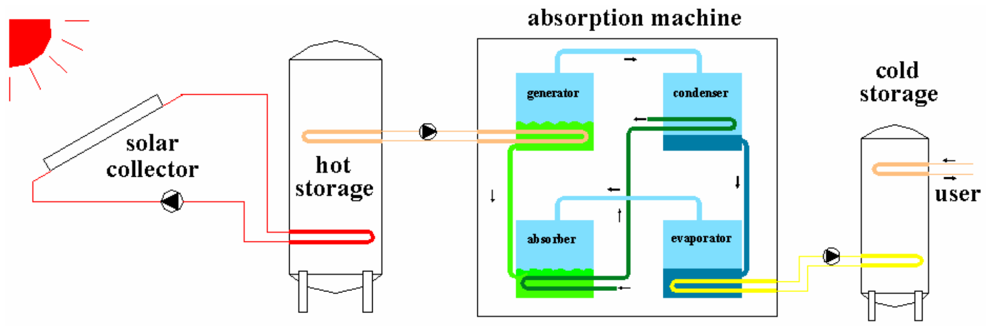

Figure 3. Scheme of solar fed absorption machine with hot and cold storage.

Finally, it is worthwhile to underline that the plant has to be connected to an evaporative tower removing the heat released by the condenser and the absorber of the refrigerating machine; the amount of this energy is about the sum of the heat given to the generator and the one released in the evaporator.

3. INVESTIGATED SMALL-SIZE ABSORPTION REFRIGERATORS

Small size absorption refrigerators market seems to be scarcely developed, probably because of the cutthroat competition of electric refrigerators and heat pumps; nevertheless, it has been possible to find and analyze five absorption machines, built by different manufacturers even if most of them should be considered more as prototypes rather than commercially available items.

3.1. Machine A

The first sample is constituted by two separated steel units where are placed respectively the couples evaporator-absorber and generator-condenser (Figure 4).

The refrigerant-absorbent couple is water - lithium bromide, evolving inside a classical single stage absorption cycle with a regenerator (plate heat exchanger) between the absorber and the generator. The circulation between the absorber and the generator is guaranteed by two electric pumps. The chilling power at fixed conditions (see paragraph 4) is about 11 kW an the heat extraction tasks in all conditions are fulfilled by a 35 kW cooling tower [5].

3.2. Machine B

The second absorption machine analysed results similar to the previous one as far as construction: it follows the normal Li-Br single stage absorption cycle, with only one electric solution pump to overcome the pressure difference between the absorber and the generator, divided by the heat regenerator (Figure 4). The chilling power at fixed conditions is about 10 kW and it is necessary a cooling tower of 25 kW [6].

Figure 4. External view of samples A and B.

3.3. Machine C

The main characteristic that distinguish this machine (Figure 5) from the others is the absence of the electric solution pump: the circulation from the absorber to the generator is realized by a bubble pump that does not need electric supply. The machine operates with a single stage Li-Br absorption cycle with a plate heat exchanger as a regenerator; the fixed conditions chilling power of 15 kW needs the coupling with a 45 kW cooling tower [7].

3.4. Machine D

The fourth sample has the peculiarity of presenting a rotating generator: the chamber that hosts the generator rotates with a speed of 260 rpm; according to the manufacturer, this characteristic enhances the heat and mass transfer process inside the generator itself, permitting a consistent size reduction. The rest of the cycle reflects the normal Li-Br single stage absorption cycle, with a difference on the dissipation device that is wet – type integrated in the machine (Figure 5). The nominal chilling power is about 5 kW [8].

3.5. Machine E

The last sample (Figure 5) employs a triple-state absorption technology with a water - lithium chloride solution. It works intermittently with two parallel accumulators (barrels) each comprising a reactor and a condenser/evaporator: in the charging period, the input heat is converted into chemical energy by drying the salt (Li-Cl), afterwards, the cooling effect is obtained by inverting the cycle. Both sequences need a heat sink that could be constituted by a standard dissipation device such as a cooling tower. The nominal chilling power is about 4 kW [8].

Figure 5. External view of samples C, D and E.

4. COMPARATIVE ANALYSIS

Starting from the manufacturers' rating and functioning curves, a comparison between the five different absorption machines was carried out, imposing, as far as possible, the same working conditions. The choice of these parameters was dictated by data availability considerations and taking into account that the devices are fed by solar collectors; the following values are fixed:

- generator inlet temperature $T_{g,i}$ = 85 °C;
- machine outlet chilled fluid temperature $T_{c,o}$ = 9 °C;
- tower outlet cooling fluid temperature $T_{t,o}$ = 30 °C.

Performances are evaluated in terms of chilling power, thermal Coefficient Of Performance (the ratio between chilling power and heat given to the generator) and global Coefficient Of Performance (the ratio between chilling power and the sum of the heat given to the generator plus the electric energy absorbed). The electric energy necessary for the functioning of the machines includes the generator-absorber pumps (when applicable), the pumps for the circulating fluids of the cooling tower and the solar circuit, the energy for the engine of the evaporative tower and, for the sample D, the energy needs for the generator rotation. The energy consumption of external circuits pumps are considered equal to 20 W/kW of fluids transported (considering a direct connection between solar collectors and absorption machine, without cold storage, as shown in Figure 1) plus 10 W/kW elaborated by the evaporative tower engine; this value are considered the same for each absorption machine analyzed, so that they do not influence relative performances.
Table 1 resumes the results, along with the overall dimensions and the weight of each absorption machine.

Table 1. Comparison between the characteristics of the investigated absorption machines.

Position	Parameter	M.U.	Sample A	Sample B	Sample C	Sample D	Sample E
Chilling circuit	Power	kW	10.6	10.0	14.9	5.2	4.0
	$T_{c,o}$	°C	9.0	9.0	9.0	9.0	9.0
Heating circuit	Power	kW	15.4	14.5	26.1	7.5	10.4
	$T_{g,i}$	°C	85.0	85.0	85.0	85.0	85.0
Cooling circuit	Power	kW	26.0	24.5	41.0	12.7	14.4
	$T_{t,o}$	°C	30.0	30.0	30.0	30.0	30.0
Electric absorption		kW	1.4	1.1	1.8	0.7	0.6
Thermal COP		-	0.69	0.69	0.57	0.69	0.39
Global COP		-	0.63	0.64	0.53	0.63	0.36
Weight		kg	700	350	325	290	740
Overall dimensions	Length	mm	1500	855	750	1092	380
	Width	mm	750	653	716	760	680
	Height	mm	1600	1847	1750	1150	1850

In figure 6 the chilling power of each sample is sketched as a function of the chilling circuit outlet temperature, fixing the generator inlet temperature at 85 °C an the tower outlet cooling fluid temperature at 30 °C.

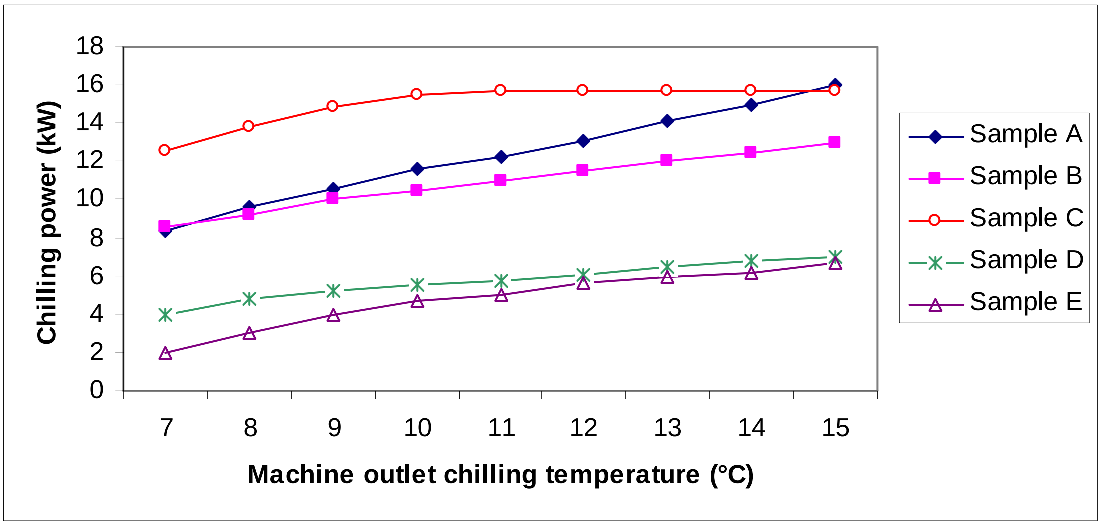

Figure 6. Samples' chilling power as a function of $T_{c,o}$: $T_{t,o}$ = 30 °C, $T_{g,i}$ = 85 °C.

With the same conditions, in figure 7 the COP is sketched as a function of the chilling circuit outlet temperature.

Apart from the differences between the samples chilling power which depend on construction choices of the manufacturer, the first consideration that emerges from the two graphs is the net difference in terms of performances between samples C and E and all the others. Sample C probably suffers the age of the project that dates back to more than twenty years ago while Sample E shows poor performances at low chilling temperatures because of its intermitting functioning that decouples the heat feeding conditions by the chilling power production environment. Besides, it appears that the sample D pays a tribute to its unquestionable compactness, more in terms of limited chilling power than from the comparison of global COP that remains significantly lower than the sample A and B ones, only at low outlet chilling temperatures. Samples A and B behave similarly, reflecting their common construction philosophy, it's only worthwhile to underline that the sample A weights the double of all the other absorption machines investigated.

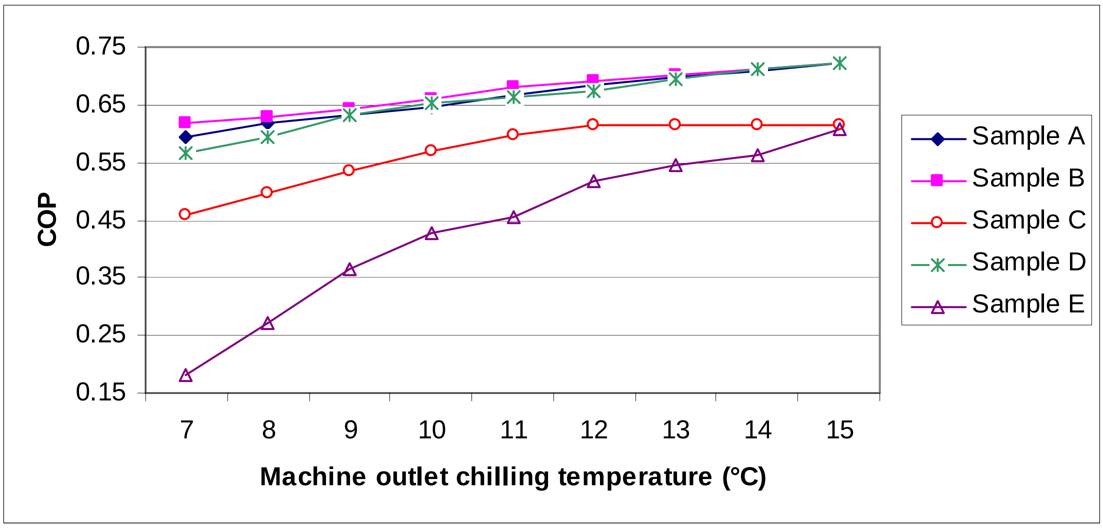

Figure 7. Samples' COP as a function of $T_{c,o}$: $T_{t,o}$ = 30 °C, $T_{g,i}$ = 85 °C.

5. ENERGETIC AND ENVIRONMENTAL CONSIDERATIONS

The previous paragraph showed that to obtain a complete vision of solar fed absorption machines, all the losses and energy expenses have to be taken into account. Nevertheless, it is useful to take a look on the difference between absorption machines and compression refrigerators or electric heat pumps, in terms of energy consumption and environmental impact. Considering, for example, the sample B that has a chilling power of 10 kW in the conditions above stated, using 1.1 kW of electric energy, we may calculate that, for each chilling kWh produced, the needs of electric energy amount to 0.11 kWh. On the other hand, an average compression refrigerator with a COP equal to 3 produces 1 chilling kWh with 0.33 kWh of electric energy. That brings to an electric energy saving of 0.22 kWh per kWh produced, reducing by a factor 3 the global consumption.

Assuming for a standard thermoelectric plant an emission rate of 700 $gCO_{2\text{-}eq}$/kWh, we find that, for each chilling unit of 1 kWh power produced, absorption machines fed with solar collectors avoid the atmosphere emission of 154 $gCO_{2\text{-}eq}$, respect to electric refrigerators.

6. CONCLUSIONS

A recognition of five small size absorption refrigerators fed with solar energy is reported. The analyzed machines cover different chilling powers (from 4 to 15 kW) and have different working principles and design. The performances study has been conducted starting from the manufacturers' rating and functioning curves, imposing the same working conditions: in terms of COP the machines show similar behavior, apart from two of them presenting lower performances because of the old-fashioned project (Sample C) and the intermitting functioning (Sample E). Besides, the most compact machine produces a limited chilling power, although the global COP seems not to be affected by the refrigerator size. The energetic and environmental comparison with compression refrigerators or electric heat pumps shows a reduction by a factor 3 in terms of equivalent CO_2 emission rate, so confirming the sustainability of this technology, whose higher margins of improvements consist of the costs' abatement.

NOMENCLATURE

T	temperature	(°C)
rpm	revolutions per minute	(s^{-1})
M.U.	Measurement Unit	(-)
COP	Coefficient Of Performance	(-)

Subscripts

g	generator
i	inlet
c	chilling
o	outlet
t	tower
eq	equivalent

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