SOLAR COOLING

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ABSTRACT

Refrigeration driven by solar thermal energy is attractive because fossil fuels can be substituted by renewable energy whose availability usually is in phase with required cooling loads. In numerous applications this solar cooling has been realised for air conditioning, e.g. H_2O/LiBr-absorption cycles or desiccant evaporative open-cycle systems (DEC). In comparison, solutions for process cooling, i.e. cooling down to 0 °C and lower, are very scarcely realised, although there is a world wide and high demand for that to preserve food. The reason is, that until now suitable technologies meeting the demand for small cooling capacities ≤ 100 kW are not sufficiently available.

This report presents two developed solutions using refrigerant NH_3. The first refers to a 20 kW NH_3/H_2O-absorption system combined with high performance vacuum tube solar collectors. Starting from this pilot plant, a cold storage depot has been designed to store fruit and vegetables at 4°C, driven by solar energy only. Refrigeration load is 60 kW.

The second solution refers to very small cooling capacities like 1 kW and temperatures below 0 °C. An available gas fired diffusion-absorption heat pump has been modified by substituting the original heat input by transferring solar thermal energy from high performance collectors to the generator.

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ABSTRACT

Solutions for solar cooling down to 0 °C and lower are very scarcely realised, although there is a world wide and high demand for that to preserve food. Two systems are presented, which are powered by heat that is taken from solar vacuum tube collectors and which use absorption refrigerators and the refrigerant ammonia. Both have been designed to demonstrate that solar cooling can be economically competitive. They provide refrigeration for food stores with a demand meeting small cooling capacity. The first is an ammonia-water absorption system for cooling capacities from 20 to 60 kW, the second is a diffusion-absorption system for very small cooling capacities like 1 kW, which operates without any electrical input.

INTRODUCTION

Solar cooling is an attractive idea because cooling loads and availability of solar radiation are approximately in phase. As the refrigeration system operates – small pump work neglected - without the need for mechanical or electrical power, it is independent of electrical grids and thus may prevent in remote rural regions the spoiling of agricultural products in storage due to the lack of refrigeration. That is why there is a high demand for application of solar cooling for decentralised cold storage of food in the countries of the sun belt of the earth.

Solar cooling uses solar thermal energy to power a refrigerator, which in order to preserve food has to maintain temperatures lower than 5 °C in the storage room. Heat operated cooling systems are well known. Ammonia-water absorption refrigeration systems are normally preferred for low temperature applications. The heat input for this systems is required at temperatures higher than 90 °C. Therefore high performance solar collectors are needed to supply a sufficient solar energy input.

This report presents two designed solutions using ammonia as refrigerant. The first refers to a 20 kW ammonia-water absorption system combined with evacuated tube collectors, which has been designed and preliminary successfully tested. Starting from this pilot plant, a cold storage depot has been designed to store fruit and vegetables at 4 °C, powered by solar energy only. Refrigeration load is 60 kW.

The second solution refers to very small cooling capacities like 1 kW and temperatures below 0 °C. An available gas fired diffusion-absorption heat pump has been modified by substituting the original heat input by transferring solar thermal energy from high performance collectors to the generator.

PILOT PLANT

Within the framework of a R&D project an ammonia-water absorption chiller has been constructed as a pilot plant and tested throughout the past year (Fig.1). Beside 1 kW electrical energy input for the solution pump, another 32.4 kW energy input is transferred as heat to the generator via hot water, flow 100 °C and return 90 °C. The fluid being cooled is non-freezing brine, flow –2 °C and return +4 °C. With a cooling capacity of 20.4 kW the COP, the coefficient of performance, is 0.63. The cold is used to demonstrate comfort cooling, refrigeration for food preservation, and cold storage by ice (170 kWh capacity). The system is powered by solar thermal energy, which is supplied from vacuum tube collectors (absorber area 72 m²) via water heat pipes and dry couplers with 53% absorber efficiency. 52.8 kW heat that has to be rejected in the condenser and absorber is transferred to bore-holes heat exchangers from where it can be recovered via heat pump in wintertime.

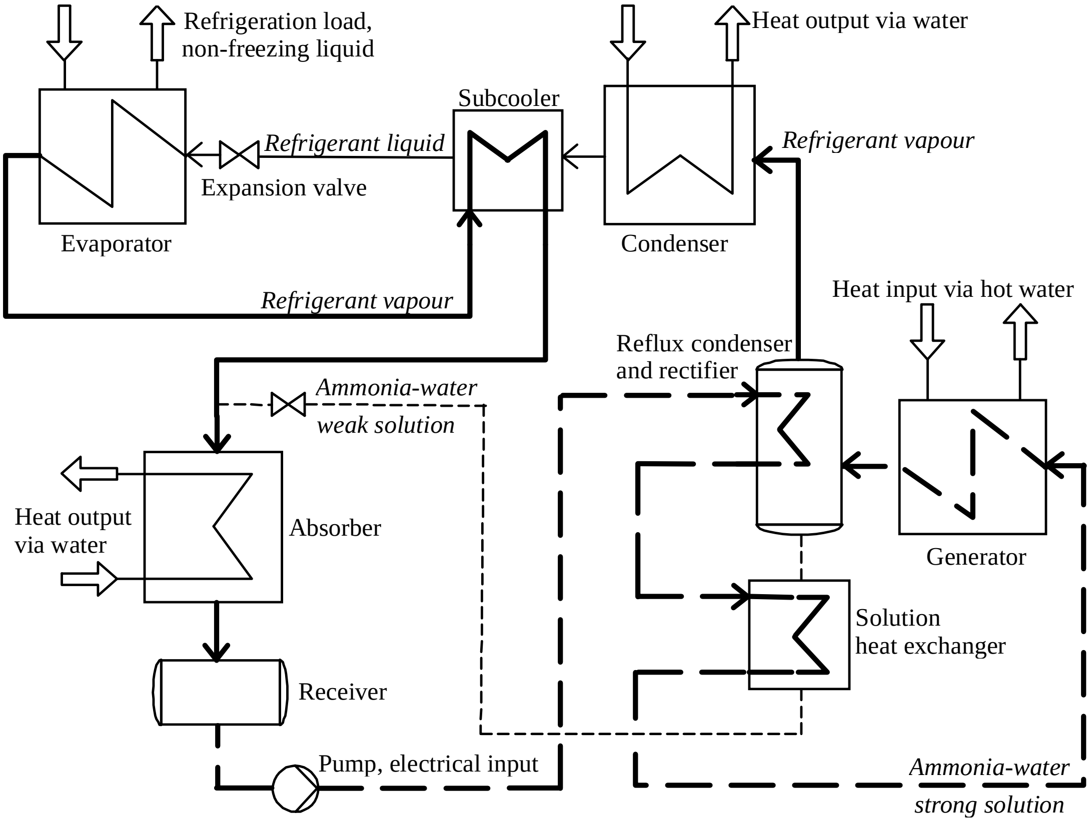

Figure 1: Schematic for ammonia-vapour absorption refrigeration plant

As to the cooling capacity of ammonia-water absorption systems maintaining temperatures below 5 °C, refrigerators with more than 100 kW are available for decades, whereas smaller ones are not. The objective of the pilot project is to qualify solar cooling to a demand meeting small cooling capacity which is capable to provide refrigeration for decentralised cold storage of food. The results gained of the project until now are, that the absorption refrigerator starts operation at 80 °C while the solar collector system supplies flow temperatures up to 110 °C, i.e. the solar cooling system is reliable and tough and leads one to assume that it is economically competitive.

DESIGN OF A COLD STORAGE DEPOT

To show that small solar cooling systems for decentralised cold storage of food can be marketable products, two solutions using ammonia as refrigerant have been designed. The first has been started with the knowledge gained from the 20 kW pilot plant described before and is intended to supply a cold storage depot, which stores fruit and vegetables at 4 °C, powered by solar energy only (Fig. 2). The refrigeration load is 60 kW. The advantage of solar cooling over conventional electrically driven compressor refrigerators is to produce refrigeration off-grid and with renewable energy, which substitutes the conversion of fossil energy to electrical energy. In order to find a solution that is ecologically and at the same time economically competitive, particular attention has to be paid to the rejection of waste heat, e.g. by using low cost heat sinks, and to possible surplus gains by domestic hot water heating. Table 1 compares the costing of solar cooling described in Fig.2 to the costing of a conventional cooling. Particularly noticeable are the very high initial investment costs of the solar cooling system, which result from very high, system dominating costs for the needed high performance solar collectors. Parameters used in the comparison are the total charge for electrical energy and possible proceeds from CO_2-emission trading. Example II shows that in the case of very realistic conditions solar cooling can be competitive, especially when located off-grid.

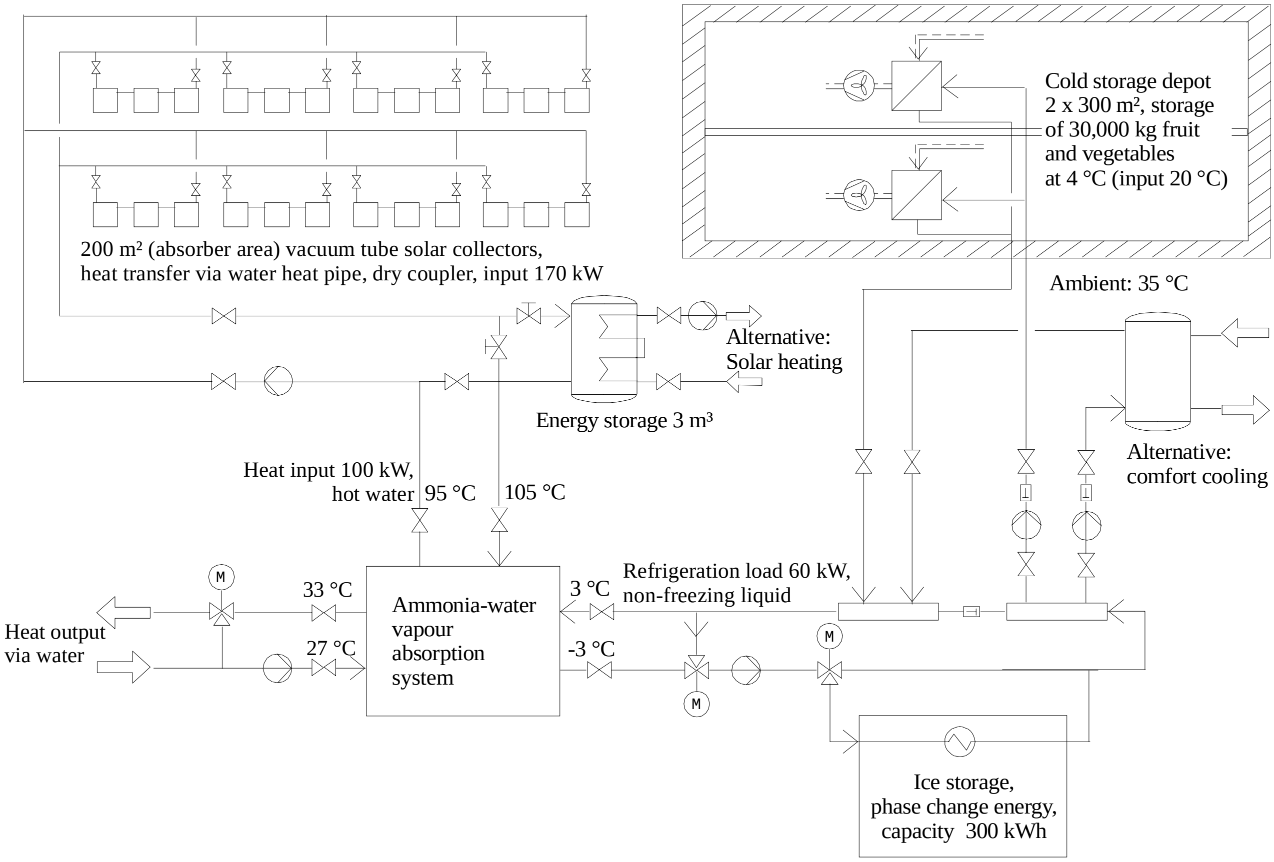

Figure 2: Schematic of a solar operated ammonia-water absorption refrigeration for food preservation

TABLE 1

COSTING OF SOLAR COOLING

		Costing [1]	
		Solar cooling [2]	Conventional cooling [3]
Initial investment costs (equipment and installation), Euro		245,340	61,360
Annual capital costs, interest and depreciation, Euro/a		18,615	7,777
Annual maintenance costs, Euro/a		770	770
Annual return on exported heat, Euro/a		5,361	0
Example I	Annual electricity costs (total charge 0.078 Euro/kWh), Euro/a	0	3.378
	CO_2-emission trading (7.67 Euro/t CO_2), proceeds, Euro/a	330	0
	Specific cooling costs, Euro/kWh	**0.137**	**0.119**
Example II	Electricity costs (total charge 0.127 Euro/kWh), Euro/a	0	5,500
	Specific cooling costs, Euro/kWh	**0.140**	**0.140**

[1] Data and assumptions:
- Cooling supply 60 kW — 100,000 kWh/a
- Fuel oil costs — 0.598 Euro/l
- Return on exported heat — 0.065 Euro/kWh
- Interest rate
  - Solar cooling, renewable energy — 4%
  - Conventional cooling — 8%
- Exported heat from collector plant — 82,480 kWh/a
- Electrical energy consumption, conventional cooling — 43,313 kWh/a

[2] Components of solar cooling:
high performance vacuum tube solar collectors, 60 kW NH_3/H_2O absorption refrigeration plant, ice storage, heat exchangers (waste heat and heat recovery), photovoltaic plant (auxiliary energy)

[3] Components of conventional cooling:
electrically driven compressor refrigeration plant, condensing equipment.

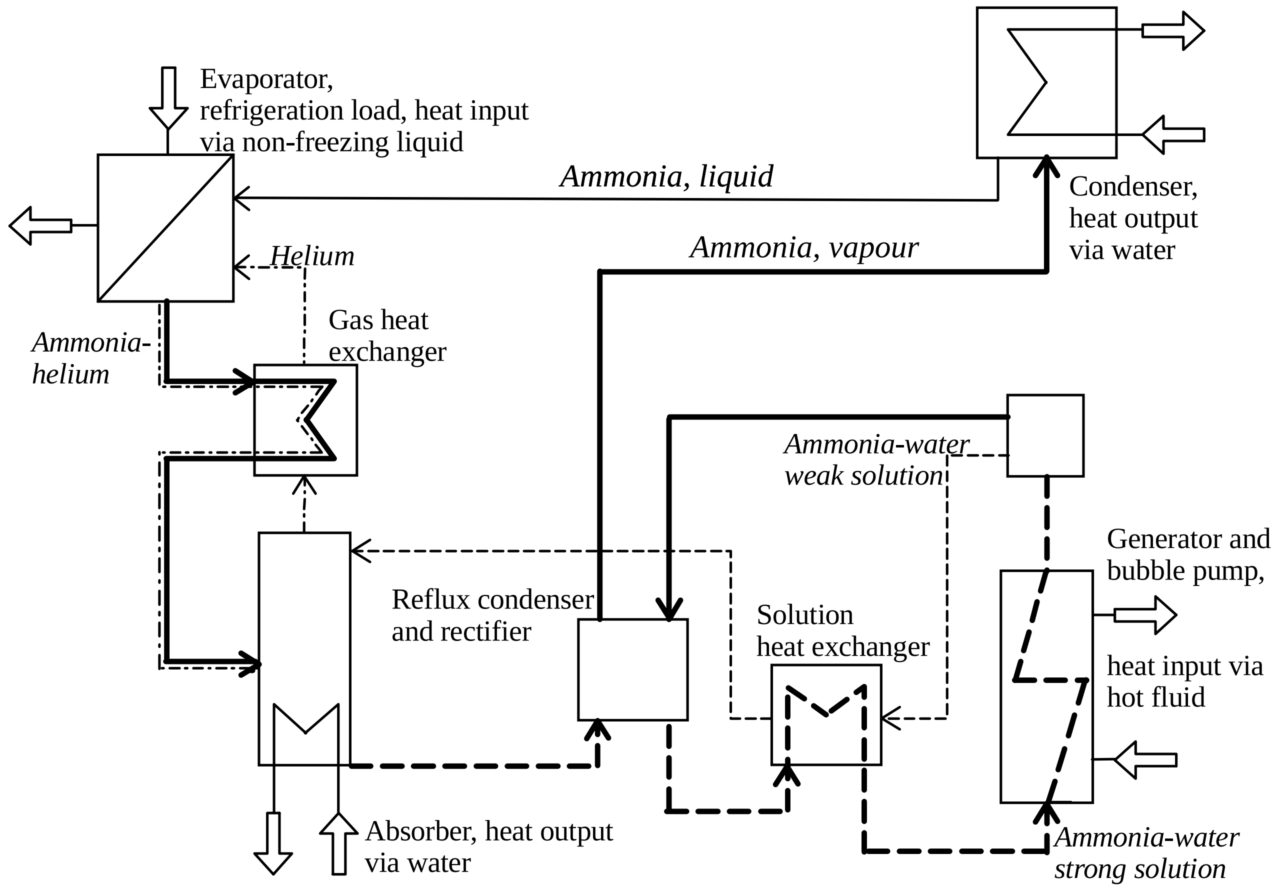

Figure 3: Schematic for Platen-Munters diffusion-absorption system

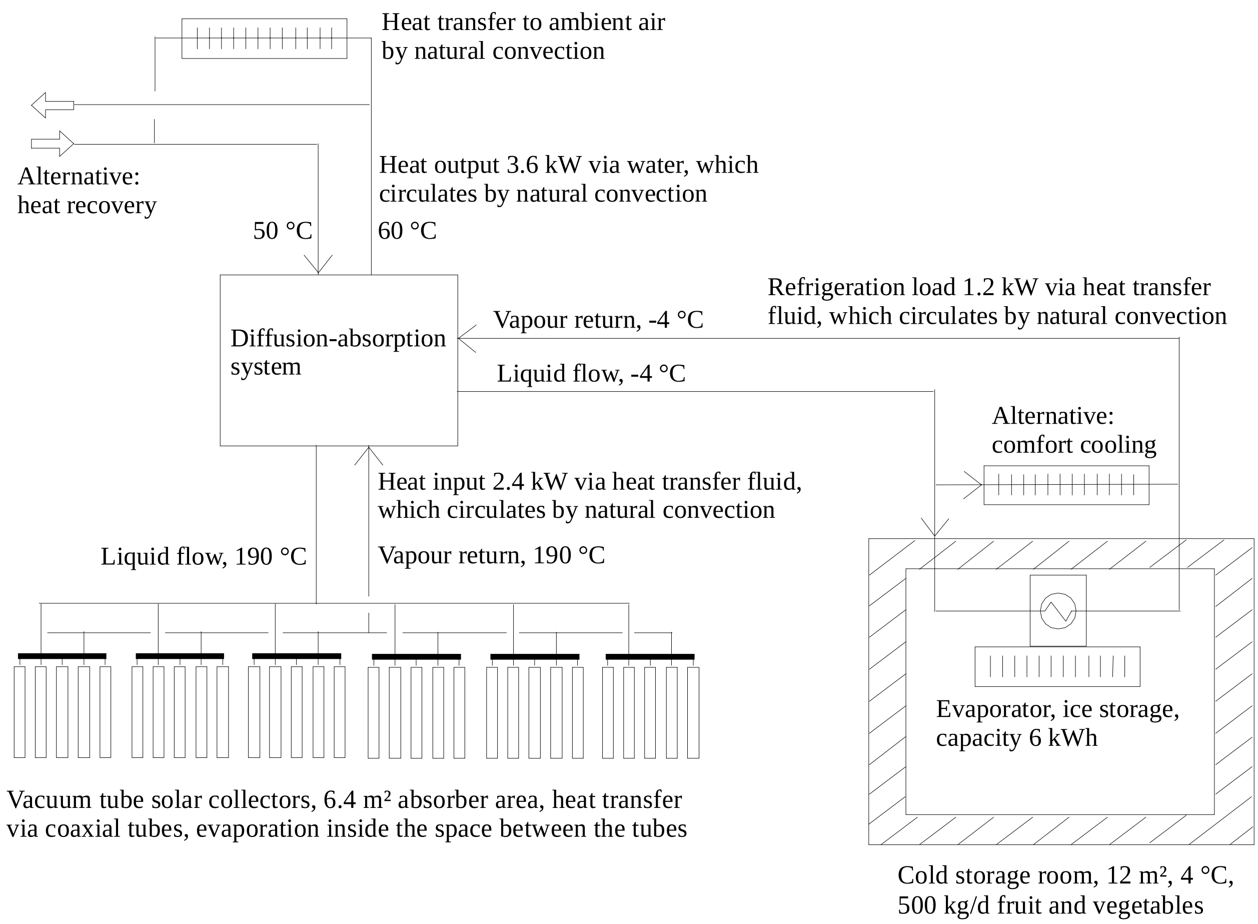

Figure 4: Schematic of a solar cooling plant,
operated with diffusion-absorption system, suitable for low refrigeration loads

SOLAR DIFFUSION-ABSORPTION REFRIGERATOR

The second solution refers to very small cooling capacities like 1 kW. An available gas fired diffusion-absorption heat pump (see www.heiztechnik.buderus.de) has been modified by substituting the origin heat input by transferring solar thermal energy from high performance collectors. Contrary to the previously presented solar cooling plant this small unit operates without any input of mechanical or electrical power, silently, without vibrations, and with less maintenance.

Based on Platen-Munters diffusion-absorption system (Fig. 3) the various working fluid loops are forced only by gravity circulation due to density differences. The liquid refrigerant ammonia leaves the condenser, enters the evaporator and evaporates into a helium atmosphere at low partial pressure. Helium is separated from ammonia in the absorber and returns to the evaporator. Inside the absorber ammonia vapour is absorbed by the weak ammonia-water solution. The resulting strong solution passes into the generator after cooling and rectifying ammonia vapour and being preheated by the weak solution. Inside the generator the strong solution is heated and due to this, ammonia vapour is separated whilst the remaining weak solution is pumped by a bubble pump. Solar energy is the only energy input.

The performance of the bubble pump depends on the temperature level and the heat flux density of the heat input. Insufficient values of both cause problems. These can be solved by using a heat pipe concept to achieve high heat transfer rates and low temperature differences between the bubble pump as heat sink and the solar collectors as heat source (Fig. 4). A heat transfer fluid evaporates inside the space between coaxial tubes of the vacuum tube solar collector and condenses inside the bubble pump and generator.

A refrigeration load of about 1.2 kW at a temperature level of –4 °C needs about 2.4 kW of heat input to the bubble pump and generator. 6.4 m² absorber area of vacuum tube solar collectors cover heat supply. The coefficient of performance of the refrigerator approaches 0.5, if the temperature level of the heat output in the condenser and absorber is close to 55 °C. The heat output can be used for heat recovery, e.g. hot water supply, otherwise heat has to be transferred to water, ambient air or ground. The refrigeration load of the diffusion- absorption system supplies cold storage refrigeration for about 500 kg fruit and vegetables down to 4 °C, including ice storage with a capacity of 6 kWh. An alternative application may be comfort cooling. Additionally, it is an important potential for further applications that inside the diffusion-absorption system ammonia evaporates at a very low temperature level down to –18 °C.

CONCLUSIONS

There is a world wide and high demand for decentralised cold storage of food operated by solar cooling at storage temperatures below 5 °C. As yet, economically competitive refrigeration techniques meeting the demand for small cooling capacities below 100 kW are not sufficiently available. Nevertheless, adequate solutions, using ammonia as refrigerant, seem to be feasible as proved by the pilot project. A very promising technique is given by a modification of a diffusion-absorption heat pump, which will be available as a mass product.

Characteristic of solar cooling is the very high initial investment cost, half of which results from the needed high performance solar collectors. The feasibility study has shown that solar cooling systems for cold storage of food can be realised competitively if

- particular attention is paid to efficient rejection or better to recovery of waste heat
- the total charge for electricity, which has to be taken into account, is high enough, being the case with off-grid situations.

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