Heating And Cooling With Sun And Salt – A Thermo-Chemical Seasonal Storage System In Combination With Latent Heat Accumulation

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Abstract

As an alternative to the pure accumulation of sensible heat, this paper discusses the storage of latent heat with different methods. Possible disadvantages to these options include the relatively high costs for the storage media, which are required in large quantities for seasonal accumulation. Thermo-chemical storage media, like absorption systems, decrease this required volume because a great amount of latent heat is involved in the absorption process. Absorption systems are also considered a base technology for solar cooling applications.
The goal for the development of the "Watergy" technology described in this paper is to provide an economical absorption system for both competitive solar seasonal heat accumulation and for solar cooling, with consideration also for water efficiency. The resultant system integrates all components of a closed absorption machine, including all its potential benefits.

Keywords: solar thermal system, thermo-chemical seasonal storage, solar cooling, latent heat accumulation

1. Introduction

Heating and cooling buildings with solar energy relates to a tremendous, to date almost completely unexploited market. For the future success of this emerging industry, the total system, including solar collectors, low exergy heat transfer and energy storage must be envisaged in terms of costs, spatial flexibility and user acceptance. While solar thermal energy production for domestic hot water supply and space heating with short time energy storages are well established on the market, applications for seasonal heat accumulation and for solar cooling are still far from being competitive technologies. It is well known that domestic energy consumption comprises about 40% of the energy demand by industrialised countries, and that most of it is used for space heating- and cooling. Achieving further cost reduction and rapid market growth of these applications addresses the most realistic step towards lowered total energy consumption: compared with electricity, transportation or industrial production, the sector of space heating and cooling has the potential for rapid conversion from fossil to renewable energy sources.

Solar thermal systems, which are based on water as an energy transport medium, have disadvantages concerning the possibilities of **seasonal energy accumulation.** Large volumes of water and thick layers of insulation are needed to keep sufficient energy for building space heating from summer to winter. Given that only very large containers of water can achieve a beneficiary relation between volume and transmission loss of the surface, only large projects are relevant, which hinders investments on single smaller or middle sized housing units. Because of these problems of relatively high costs and necessary project size, the technology has not yet reached the point of market penetration. Indeed, only a few pilot plants have been built.

As an alternative to sensible heat accumulation, different methods of latent heat storage systems are being discussed. Thermo-chemical storages, such as **absorption systems,** allow a reasonable decrease of the required volume as the amount of latent heat involved in an absorption process is very large. Disadvantages to this method are the relatively high costs for the storage media that are needed in large quantities at seasonal accumulation. Absorption systems are also considered as a base technology for **solar cooling** applications.
For both seasonal heat accumulation and solar cooling, the energy needed to regenerate the working fluid must typically be provided at ~80°C (dependent on boundary conditions). For this reason, relatively expensive high performance solar collectors have been used until now. For seasonal heat accumulation, the components of the absorption heat pump (***absorber, regenerator, evaporator and condenser***) issue additional costs that must be calculated against the money saved on the smaller storage tank. Furthermore, seasonal accumulation requires the installation of an additional set of parallel working heat exchangers such that low tempered heat sources can be used during winter (e.g. from outside air or the ground soil).
Open absorption processes are well established within desiccant room air drying devices. The regeneration of working fluids in desiccant cooling systems on open surfaces have been partially investigated (e.g. Hawlander *et al*, Jahrgang), but have identifed the disadvantage that all the thermal heat and consequent evaporated water is lost to the environment.

2. Concept

The goal of the *Watergy Thermo Chemical Storage* project (figure 1) is to provide a significantly more economical absorption system for both systems, competitive **solar seasonal heat accumulation** and **solar cooling,** using the principle of combined air humidification and de-humidification.

Figure 1: Demonstration building with integrated humid air solar collector system at the site of Technische Universitaet Berlin, Chair Building Technology and Design.

The heating system is based on three directly integrated components:

- A **Humid Air Solar Collector** can be built out of cheap plastic or ceramic elements and will work below temperatures of 100° along the whole year. During summer it is used for the dehumidification of a salt solution. During winter, humid air is produced that will be absorbed by the concentrated salt solution, thereby providing usable low temperature heat.

- An **energy storage** with low volume compared to pure thermal storages is used for combined seasonal accumulation of the salt solution (thermo-chemical storage) and a short time accumulation of heat (thermal storage).
- A **low temperature heating system** is made out of very simple cooling tower packings, again made entirely of plastic. All heat transfer processes (i.e. 1) dehumidification of air during summer, 2) humid air vapour absorption during winter and 3) building heat supply) will be performed with direct contact to both air and liquid.

Cost reductions are possible within all three components, mainly by using cheap materials and simple processes. A further possibility for reducing the need for ventilation is the integration of a gravity/ buoyancy based air exchange system.

The integrated design also allows solar cooling applications based on combined de-humidification and humidification of air (desiccant cooling) with different variations regarding temperate, hot/ humid and hot/ arid climate. A specific application is the cooling of closed production greenhouses. Being based on the parameters of combined evaporation and condensation of water, this system also evaluates water efficiency, unlike that of any passive evaporative cooling system.

The working fluid of the system is an aqueous solution of water as the solvent and a salt as the solved matter/ solution. The thermal storage capacity sinks compared to the heat capacity of water. With sensible heat amplitude of 60K and an energy density of ~70 kWh/m³, a saline solution with a salinity amplitude (e.g. MgCl between 20% (diluted solution) and 33% (concentrated solution)) represents an energy density of 267 kWh/m³ storage volume. This results in a reduction of size for the storage system by a factor of 3.8. A secondary effect is reduced heat loss, as the storage medium is heated not only once to 90° but rather several times during winter with only low amplitudes. The problematic seasonal storage process from summer to winter is provided without any losses due to the thermo-chemical strategy of the system.

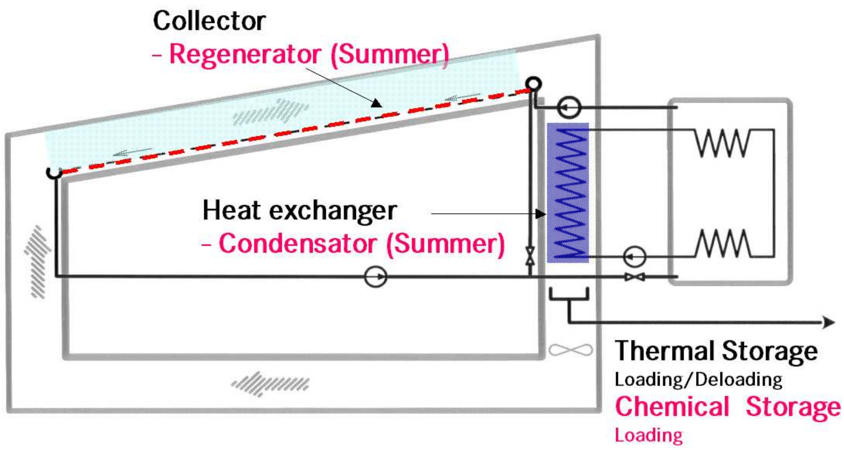

Figure 2: Simple loading phase during summer: the concentrated (de-watered) salt solution is transferred from the collector to the storage and allowed to heat up.

During summer a solar collector is used, such that the sun shines directly onto the solution which covers the radiated surface as a film (figure 2). This induces two different directions of energy flow. As the water in the solution is heated, it evaporates and the salt in the solution becomes concentrated. The concentrated solution accumulates in the storage tank for the entire summer period. Meanwhile, the wet film in the collector is heated by solar radiation, in turn heating the air inside the collector. The parallel evaporation of water leads to an energy flow, where hot and humidified air is directed to a colder heat exchanger surface which is in a duct outside the collector element. There, condensation occurs and the cooled and dehumidified air is redirected back to the collector, forming a closed air circuit. The latent heat that is released during condensation is transferred, together with the sensible heat of the air, to an open cooling water circuit which transfers the heat to the storage medium in the tank. The heat can be used for further dehumidification of the salt solution at night, as well as for domestic hot water supply.

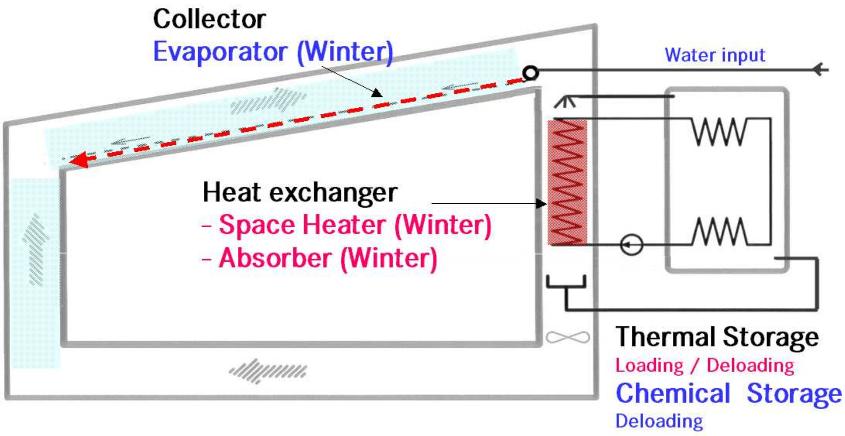

Figure 3: During winter: after using the heat in the storage for building supply, the strong solution is directed over the direct contact heat exchanger, absorbing water vapour from the collector to re-load the thermal storage for later building heat supply.

During winter, sensible heat is used by disposing the hot solution over the air-to-water heat exchanger in the duct (figure 3). The air is heated and can be directed into the building for heat supply. Due to a constant minimum of salinity water vapour is limited in the transport from fluid to the air inside the building, preventing the rates of relative humidity from becoming too high. Salinity also benefits the hinderance of hygienic problems in open water surfaces.

When the storage medium falls below the usable supply temperature, it can be re-heated even at relatively cold ambient temperatures thanks to the absorption process. For this, normal tap- or rain water is spread as a liquid film on the collector surface. Radiation or direct heat from ambient temperatures of warmer winter days (~10-35°C) produce warm and humid air that is transported to the heat exchanger duct. The concentrated solution is then directed over the open heat exchanger surface. Water vapour from the air stream of the collector is absorbed by the hygroscopic property of the strong solution. The phase change from vapour to liquid heats up the solution, and this can then be redirected to the storage for later heating purposes.

As analogy to a normal absorption heat pump, the collector element which is exposed to solar radiation is alternately used directly as the ***regenerator*** (concentrating the solution in summer) and as the ***evaporator*** (using low solar input or low temperate heat from the surrounding environment during the winter heating season,).

The direct contact heat exchanger in the duct is the **condenser** in summer, while also cooling the humid air stream and removing water from the system. During winter, the same heat exchanger is first used as a normal radiator to heat up the building with the stored heat from the storage. On sunny and warmer winter days, it is used as the **absorber**, again removing humidity from the air stream of the collector and thereby generating heat to re-load the thermal storage on the base of a lower temperate heat source.

3. Applications

3.1. Solar heating:

As the application of seasonal heat accumulation with the new system described above is the most complex task, it is investigated as an entire system here. The general objective is to reduce the costs of a solar heating device for seasonal heat accumulation. A further objective is the investigation of possible cost reductions with the system in different kinds of applications.

3.2. Solar cooling and solar water generation

For other applications, like solar cooling and solar desalination, the potential innovations proposed by this project include the parallel regeneration process of the working fluid in combination with the recycling of pure water in the condensation process. This allows a simple method of evaporative cooling in combination with improved water efficiency.

3.3. Using productive greenhouses as solar collectors

Special consideration is given to the concept of using greenhouses for the combined processes of regeneration/condensation. This can be effected by the isolated application of concentrated desiccants as commercially tradable fuels, and through the combined regeneration and evaporation process with façade greenhouses that are built in junction with building heating and cooling systems. In the Mediterranean region of Europe, it appears that greenhouses can provide the highest potential for energy cost reductions with this technology. Considering the low costs of greenhouses and the huge surfaces already in existence that could be retrofitted with the proposed technology (*Italy (61,900 ha), Spain (51,000 ha), Turkey (14,000 ha), Morocco (10,000 ha), Israel (5,200 ha), Algeria (5,005 ha), Greece (3,000 ha) and Portugal (2,700 ha), (AGR/DDGI, 1999))*, the required desiccants could be easily transported to neighbouring municipalities for cooling purposes.
A normal standard greenhouse in central Europe costs about 40 EUR /m², while a passive plastic greenhouse in the Mediterranean area costs about 5-10EUR/m². Compared with high performance solar collectors, this equates a difference of up to a factor of 100!

The results from Watergy, the precursor project, could prove that the water gained from the condensation process of this system, together with the collection of rainfall, may be sufficient for water sustainable agricultural production. The application of solar heating with greenhouses bears relevance in Central Europe, as well, where energy costs have reached the point of suffering competitiveness already for some time. An exception here is the Netherlands, where a long tradition of energy subsidies (natural gas) have allowed the continuation of horticultural production.

3.4. Solar desalination

The function of seawater desalination can be integrated in combination with the solar cooling process. Seawater can be directed into the evaporator of the evacuated system. As the salinity

of the induced working fluid is much higher, seawater can be concentrated up to the level of hygroscopic equilibrium of the two liquids, while at the same time gaining the evaporation effect which can be used for space cooling.
As the humidity from the sea water is absorbed by the working fluid, usable fresh water can be produced during condensation along the regeneration process. As desalination is only an additional effect, the potential investment costs for the entire system can be further lowered.

3.5. Water production from ambient air combined with space heating

At high levels of relative humidity during the night, potable water can be produced by directing ambient air into the solar collector and then forming it to an open air flow. If the concentrated working fluid is directed over the collector surface, the humidity of the air is absorbed and sensible heat is released by the phase change from vapour to liquid water. The outgoing air stream can be used for space heating. The water gained from the air, in turn, can be separated through the condenser during the regeneration of the working fluid.

4. Conclusions

The proposed system is more than just a further development of the common technologies of solar heating and cooling. It attempts to provide a set of different applications that are based on a relatively simple holistic principle but which can be adapted to specific demands.
In summarizing the potential applications described above, it may be stated that the concept of open absorption system in humid air solar collector systems is a significant enhancement to the state of the art, especially in terms of cost reduction.

Cost reductions can be achieved at all stages of the system, including:

- **smaller storage volume** (about 1/3rd to 1/5th, compared to water storages)
- **less storage insulation**, as sensible heat is only stored for a buffering period instead of a whole season.
- As a result of the two points above, **smaller units** (e.g. on the scale of one family houses) can be realised, for instance by installing storage units into existing cellar rooms.
- **less insulation needed on the collector transparent cover**, as the directly concentrated solution on the collector surface reduces losses, as does transporting most of the energy as latent heat (water vapour). During the winter heat pump mode and in the direct use of ambient heat, less insulation on the collector may also mean better heat transfer of sensible heat from the surroundings into the system.
- **cheaper material for the collector** (plastics or ceramics instead of copper or aluminium), as the energy travels directly from radiation to the open water surface and does not have to pass through a containing material.
- **radical simplification of the heat exchanger**: All transfer processes of sensible and latent heat between air and storage can also be performed in direct contact, allowing the use of cheap, unwoven fabric or simple packed bed columns rather than bundles of metal pipes.
- **cheaper working fluids** can be used in a wide range, as the air cycle is separated from the building volume and the air humidity can be very high. The thermal storage method requires a greater volume then the latent storage process, but with the merging of both items the necessary solubility of salt can be relatively low compared to closed absorption heat pumps. This in turn allows the use of a larger range of materials, like calcium chloride or magnesium chloride, which may be cheaper. For example, the price of water dissolved magnesium chloride costs less than 100 EUR/ton, while…!

The proposed technology can be envisaged as a technology platform for solar heating, solar cooling and potable water supply. It can be used in different modes, easily adapted to special demands and specific climatic conditions, whether seasonal, or day/ night accumulation of energy. This system can also be adapted to address the necessary issue of water efficiency, including the potential of implementing other available resources, like seawater or air humidity.

On global scale, the demand for electricity for space cooling applications is growing rapidly. Since water is a limited resource, technologies of passive evaporative cooling cannot be considered as universal alternatives to electric air conditioning. Furthermore, passive systems which use the thermal mass of construction materials represent a limited solution, as many existing houses are built under the preference of mass reduction and future architecture will be forced to use light materials in response to the issue of building energy demand.

In this regard, the “Watergy” project offers a technology that addresses three different points: use of solar energy, use of evaporative systems with recycling of water in a closed system, and reduction of costs with cheap materials and basic technology.

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Links:

www.watergy.de
www.cycler-support.net
www.a.tu-berlin.de/gte

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