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TECHNICAL POTENTIAL OF SOLAR THERMAL DRIVEN OPEN CYCLE ABSORPTION PROCESSES FOR INDUSTRIAL AND COMFORT AIR CONDITIONING

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ABSTRACT

The open absorption process is basically an air drying process. Applications for this process can be found in the sector of industrial and comfort air conditioning. In this investigation seven categories of applications are described and characterized concerning their specific requests for temperature and humidity.
Possible system configurations of an open absorption system are presented for each application category. Simulations are carried out for the absorber component taking into account the specific requirements of the applications and different designs for the absorber. The simulations consist of variations for mass flow ratios, geometrical and thermodynamical parameters and are evaluated concerning the absorber's effectiveness. As the main result a graph is derived from the collected and calculated data which helps to design an open absorption system and to choose the design for the absorber component and the type of liquid desiccant which matches the requirements of the application in question.

1. INTRODUCTION

Many applications in the industrial and comfort air conditioning sector require hygienic clean, dry and cooled or heated air. So far electrically driven vapour compression machines, electrical heaters or fossile fired burners are applied to produce dry and cooled or heated air. The wide use and high primary energy consumption of these conventional technologies result in ecological and sometimes even economical drawbacks. The solar driven open absorption process with aqueous salt solutions represents a promising alternative in cases where dehumidification is necessary.
The system evolving from the open absorption process is referred as a liquid desiccant system (LDS). Solar thermal driven liquid desiccant systems have many potential advantages and can provide a promising alternative to conventional vapor compression systems:

- LDS is driven by low temperature heat e.g. solar, combined heat and power plants, district heating, waste heat and therefore avoids peak electricity demand during the air conditioning season [Lowenstein 1998].
- The supply of solar energy and the demand for cooling and dehumidification usually in phase [Henning 2003].
- LDS results in drier ductwork to prevent mold and bacterial growth [Bland 2002].
- Since desiccants are able to attract and hold more than simply water vapor, they can remove contaminants from air streams to improve indoor air quality. Desiccants have been used to remove organic vapors, and in special circumstances, to control microbiological contaminants [Slayzak 2002].
- LDS have the potential to become more economic than solid desiccant and vapour compression technologies [Lowenstein 1998].

Figure 1 shows a schematic of the liquid desiccant air drying process in the dashed area. It presents possible driving heat sources (left), the coupling to different cooling technologies (center right) and possible applications where LDS can be technically viable and economically and ecologically useful (right).
In the absorber component of a LDS a hygroscopic aqueous salt solution e.g. lithium chloride (LiCl), calcium chloride ($CaCl_2$), etc. is brought in contact with a humid air stream. The moisture is absorbed by the salt solution. The absorption of moisture causes the release of evaporation heat, so that both, the air stream and the salt solution are heated in this process. The air leaves the absorber with a lower humidity ratio while the salt concentration of the liquid desiccant decreases.
Depending on the application a cooling process is coupled to the LDS. For this a direct or indirect evaporative cooler [Lävemann 2005], an absorption cooling machine [Simader 2005] or a vapour compression machine [Al-Jaafari (2003)] can be coupled to the process.

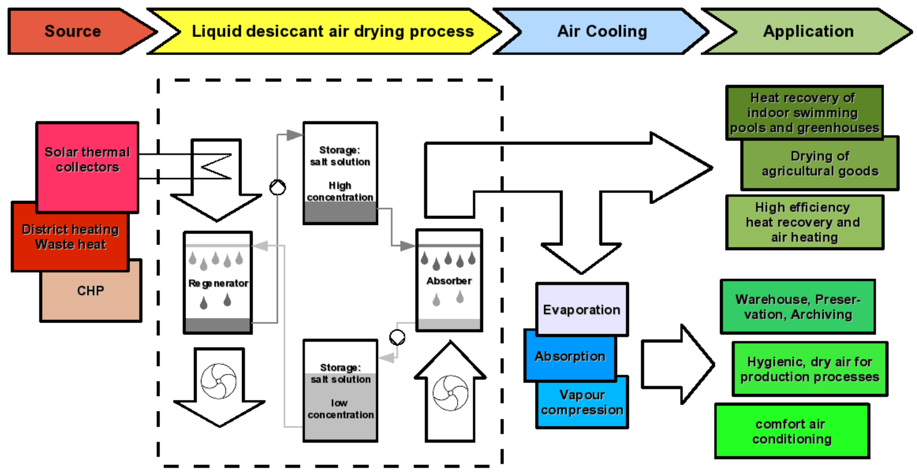

Fig. 1: Liquid desiccant air drying process: from source to application

The cooling process can be added either in serial to the dehumidification stage [Steimle 1998] or simultaneously [Saman 2002].

For a simulataneous cooling process it is necessary to have a cooling fluid cycle within the absorber. These absorbers are referred to as internally cooled absorbers while absorbers without the cooling cycle are referred to as adiabatic absorbers.

LDS coupled with cooling processes can be used for [Lowenstein 1998]:

- comfort air conditioning in offices, public and residential buildings
- warehouses and production halls for preservation and archiving purposes
- condensation protection to prevent mould and rust destruction from equipment
- production processes e.g. in the food production, pharmaceutic production, semi-conductor production, rubber industry, confectioneries

The air stream from the absorber can be used directly for:

- high efficiency heat recovery and indirect air heating in low energy buildings [Kerskes 2004]
- low temperature drying of agricultural goods and industrial products (“gentle drying”) [Rane 2005]
- high efficiency heat recovery and humidity control for indoor swimming pools and greenhouses [Waldenmaier 1998]

The aqueous salt solution needs to be regenerated after absorbing moisture. Similar to the absorber the salt solution in the regenerator is exposed again to an air stream. Either the desiccant or the air stream are heated by a low temperature heat source e.g. solar thermal air or liquid collectors, combined heat and power plants or waste and process heat. The regeneration temperature depends on the type of salt solution, the desired concentration and on the heat source. For solar thermal driven LDS an economical useful regeneration temperature ranges from 50 °C to 80 °C. Heat from fossile or waste heat sources may be used at higher values depending on the temperature available. Regenerators working on higher temperatures are constructed as 1½ – 2 stage boilers with multiple heat recovery stages [Lowenstein 1992], while regenerators working on a lower temperature level are often constructed similarly to the absorber. Like for the absorber internally heated or adiabatic regenerators can be used.

Therefore on one hand, the low regeneration temperature required to regenerate the liquid desiccant allows a broad variety of applicable heat sources and on the other hand, the process allows the parallel and serial combination with several cooling and heating technologies and reaches a high compatibility with different applications.

LDS allow additionally a lossfree chemical heat storage by utilizing the concentration shift of the aqueous salt solution. Especially in combination with exclusively solar driven LDS, this storage capability can be utilized to bridge day periods with insufficient radiation in comfort or industrial air conditioning applications, to run drying processes at night time or as a seasonal storage for heating purposes in low energy buildings.

2. <u>TECHNICAL APPLICATIONS FOR LIQUID DESICCANT SYSTEMS</u>

It can be distinguished between seen different application categories which are characterized in the following sections.

2.1 <u>Comfort Air Conditioning</u>

The classic application for LDS is comfort air conditioning in domestic and commercial buildings. Example applications are: airport terminals, shopping centres, offices and administration buildings, hospitals (surgery halls), fitness centres, hotels and restaurants, lecture rooms, exhibition halls. This application type is characterized by a strong demand for humidity control because of either outside weather

conditions or high internal latent loads. The space temperature and humidity requirements are regulated after international or national standards (ISO 7730, DIN 1946, ASHRAE 55) and depend generally on the outside conditions and on the activity level of the persons within the room. In the German standard DIN 1946 the comfort zone is defined in the range of 22 °C to 26 °C for the room temperature and from 30 % to 65 % for the relative humidity level.
For many buildings the sensible cooling load exceeds the capacity of the air conditioning system which is designed for the hygienically required air change rate. In this case an additional chilling system is needed.

2.2 Warehousing, Preservation and Archiving

Warehouses are no typical applications for dehumidification control. An usual storehouse has very low external and internal loads and beside that many products are not sensible to latent loads. However, there are some exceptions: wine depots, paper depots, textile and yarn depots, lumber yards, crop depots and munition depots. The product quality is highly sensible to latent loads as it either rottens or degenerates. A relative humidity level has to be kept between 30 % and 50 % at a highly varying application depending storing temperature between 5 °C and 30 °C [Bland 2002]. For conservation of historical buildings, art works, books, in museums and galleries it is recommended to keep also a humidity range between 30 % and 50 % at room temperatures between 14 °C and 22 °C [DIN ISO 11799].

2.3 Condensation Protection

Dehumidification is an essential method to ensure condensation protection and value conservation of equipment. Condensation will appear in processes with uninsulated pipes, pumps and tanks which are traversed by cold water and cause the formation of mould and rust. Example applications are breweries, steam power stations, freezing rooms, waterworks, ice rinks and milk filling stations. [Socher 1993] states that mould can be avoided below a relative humidity of 70 %. Rust can be essentially reduced below a relative humidity of 50 %. Below 35 % r. h. the formation of rust can be completely avoided.

2.4 Air Conditioning for Industrial Processes

Some examples where dry air is needed in industrial processes are the following: lacquering in the automobile industry, cement fabrication, drug production in the pharma industry, sugar conservation in large bakeries, meat processing, candy production, cosmetics production, wafer production in the semiconductor industry, micro mechanical production and plastic moulding and casting. The specific requirements for temperature and humidity differ strongly with the application. Extreme low relative humidities below 30 % have to be kept in some drug production and packaging processes, while the humidity requirements are restricted for lacquering only to 60 % r. H. [Oelsen 2001].

2.5 Gentle Drying

"Gentle" drying can be used for heat sensible products and substances. This is especially the case for medical plants, food products (fruits, vegetables, corn, fish) and flowers. These products have to be dried below a temperature of 60 °C to keep the substance or shape, in some cases even below 45 °C. Other examples where low temperature drying can be used is tobacco, gelatin, sludge or lumber drying. The relative humidity should be kept in all cases below 40 %.
There have been two systems proposed for drying applications: [Conrad 1996] studied the prototype of a solar sorption storage system for drying medical plants under Slovenian climate. The system worked as a dehumidifier and heat recovery system during night and times of insufficient irradiation. During sufficient irradiation the dryer was fed by hot air from a solar air collector. [Rane 2005] realized a laboratory prototype for an energy efficient liquid desiccant-based dryer with a two stage regeneration process driven by fossile energy. Experiments were conducted drying paper trays and a specific moisture removal rate superior to conventional drying technologies was found.

2.6 Heat Recovery and Humidity Control for Indoor Swimming Pools and Greenhouses

Indoor swimming pools and greenhouses have a very high energy consumption due to very high internal latent loads which are removed in general by fresh air exchange. Sensible heat recovery is mostly realized in these systems but a major part of energy is lost due to missing latent heat recovery which can be realized by a LDS [Waldenmaier 1998]. The typical indoor temperatures should be between 25 °C and 35 °C and a relative humidity below at least 60 %.

2.7 Heat Recovery in Low Energy Buildings

Latent heat recovery for low energy buildings can be realized by dehumidifying the exhaust air stream from a building [Kerskes 2004]. The more moisture is absorbed from the exhaust air the higher temperature shift can be realized up to 10 K above the room temperature.

3. COMPARISON OF ADIABATIC AND INTERNALLY COOLED ABSORBERS

A simulation study was undertaken to compare adiabatic and internally cooled absorbers for the application types discussed above. For both absorber types a parallel falling film design was assumed and the same geometries were applied. The model used was taken from [Mesquita 2006]. It is characterized as a two dimensional finite difference model which solves the governing equations for species, energy and momentum.

The specific air inlet conditions were taken the same for both absorbers. The inlet conditions for air are shown in table 1. For the applications “protection” and “process” the mass flow ratio between desiccant, air and coolant were adjusted to receive the same value for the air outlet temperature as for the inlet and a relative humidity at the outlet below 50 %. The mass flow ratios were adjusted in the “comfort” case to 23.5 °C and a relative humidity of 50 %. The applications “air heating” and “drying” were investigated only with an adiabatic absorber because no cooling is needed. The mass flow ratios were adjusted in these cases to an optimum between highest concentration shift in the desiccant and highest temperature shift in the air.

Both absorber types are compared concerning the efficiency of species and enthalpy:

$$\varepsilon_S = \frac{\omega_{a,in} - \omega_{a,out}}{\omega_{a,in} - \omega_{a,eq}} \quad , \quad \varepsilon_H = \frac{h_{a,in} - h_{a,out}}{h_{a,in} - h_{a,eq}}$$

Both equations are describing the actual change in absolute air humidity ω_a or enthalpy h_a between in and outlet of the absorber and the maximum possible shift.

Table 1 shows the resulting efficiencies for species and enthalpy. In the cases where the combination with a cooling technology is needed (protection, process and comfort air conditioning), the internally cooled absorber reaches slightly higher values for both efficiencies, species and enthalpy.

In case of comfort air conditioning the adiabatic absorber performs similar to the internally cooled. Due to the fact that a high desiccant mass flow is needed to reach the cooling effect, only a small concentration shift can be gained with the adiabatic absorber. In cases where heat storage with the aqueous salt solution should be realized, a batch operation can be used to reach a higher concentration shift.

For both cases in which heat recovery and air heating is required (air heating, drying) the adiabatic absorber shows low enthalpy efficiency because it is optimized for a high temperature and concentration shift. For heating applications the enthalpy efficiency can therefore not be taken as a process quality indicator. Temperature shifts of about 8 K to 10 K could be reached.

Tab. 1: Comparison of adiabatic and internally cooled absorbers for different applications

Application	**T**	**r.H.**	**Adiabatic**		**Internally Cooled**	
	°C	**%**	ε_H	ε_S	ε_H	ε_S
Protection	-10	100	0,36	0,83	0,87	0,91
Process	10	100	0,73	0,87	0,81	0,90
Comfort	32	40	0,83	0,88	0,84	0,88
Air heating	20	50	0,01	0,63	-	-
Drying	32	60	0,29	0,61	-	-

4. DERIVATION OF A DESIGN GRAPH

Figure 2 represents the summary of the collected information: In the lower part of the figure the requested humidity and temperature levels for the presented applications are

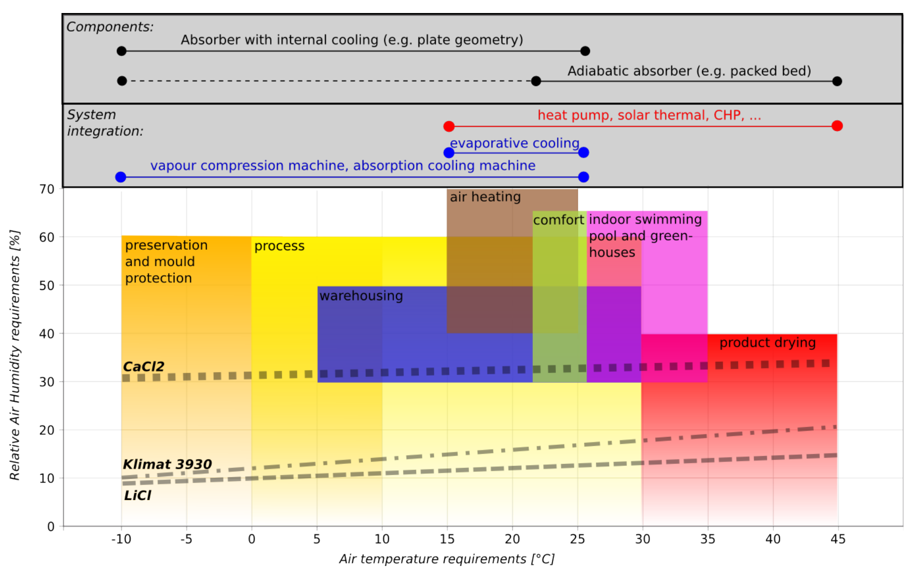

Fig. 2: Requested humidity and temperature levels for different applications

shown. Additionally, the absorption equilibrium curves of three different aqueous salt solutions i.e. lithium chloride, calcium chloride [Conde 2004] and Klimat3930 [Waldenmaier 1998] are showing the minimum achievable relative air humidity. In the upper part of figure 2 recommendations are given for the selection of the absorber component design depending on the temperature range. Below that the possibilities of coupling the absorber to different cooling and heating technologies are shown. The heating systems can be coupled with adiabatic absorbers as auxiliary devices in cases of insufficient performance of the absorber unit.

5. CONCLUSIONS

Seven application categories could be distinguished and described concerning their temperature and humidity requirements for LDS. Two general absorber designs were investigated for the applications. As the main result a graph was derived from the collected and calculated data which helps to design an open absorption system and to choose the design for the absorber component and the type of liquid desiccant which matches the requirements of the application in question.

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