# Air Conditioning

# with

# *ALDACS®*

# PREFACE

Work on liquid desiccant-based air conditioning systems at *M. Conde Engineering,* was started 2002, and has been pursued ever since. The motivation for this work followed from past activities in the development of closed absorption cooling machines, with both LiBr-$H_2O$ and $H_2O$-$NH_3$ working pairs, and on air handling units using solid desiccants combined with evaporative cooling (DEC Systems).

All the developed equipments, for a manufacturer of conventional DX air conditioning devices, were to be driven by solar thermal, CPC[1] type, collectors. Closed absorption air conditioning equipment require driving temperatures at, or well above 100 °C, to attain acceptable performance. Nevertheless, the energy efficiency of these devices is poor: – Air conditioning for human comfort requires only small temperature changes, about the ambient temperature, and the control of air humidity content may be done more efficiently, and at lower temperatures, by other, sorption-based, processes. The quest for higher energy efficiency process was, thus, open.

The initial steps in this quest, consisted of preparing the tools necessary to do both theoretical and experimental developments. The first evident need, was for a coherent property calculation tool, for the most interesting liquid desiccants. Data in the literature are plenty, but are spread in small, sometimes incongruent, bits, in sources published from the 1850,s to the end of the 1990,s. Two years of intensive search and work, led to a publication[1], that has been used by most researchers in the field, and cited several hundred times since. That paper offered to all researchers in this field a congruent set of methods for the estimation of the thermophysical properties of aqueous LiCl and $CaCl_2$, two of the most interesting liquid desiccants, the first for its extremely high affinity for water, the second with less affinity, but a much lower cost.

Above all, what problems did affect equipments, based on the 100 years old open absorption principle, and their diffusion on the market, that kept them out of the even more advanced thermodynamic courses, and thus out of sight? The answer is, some intrinsic, and a few more made by powerful interests. It shall be sufficient to remind that as Francis Bichowsky and Gilbert Kelley were publishing their first developments of open absorption systems[2] at the Surface Combustion Corporation, Thomas Midgley, Jr., and his team at the Frigidaire Corporation[3], were bringing out of a chemistry laboratory a group of substances that was to dominate mechanical refrigeration since. The consequences of this development for the following 80 years and beyond are well known to us all!

Sure, open absorption liquid desiccant systems do not appear simple: They use a binary solution as main operating fluid, and knowledge of the involved thermodynamics is necessary to design and understand them. The criterion to decide how to condition air for comfort or other purposes, is too simple minded however, if based exclusively on the more apparent than real complexity.

The work undertaken in the MemProDEC[2] Project challenged that criterion. In Phase I, concepts and solutions were developed to overcome the limitations of the hitherto used component technologies. Key parts of these developments were picked, and in some cases further developed, by a few research groups. Among those concepts and solutions, are methods to avoid desiccant aerosols in the supply air, and *simultaneous* cooling of the absorption as well as *simultaneous* heating of the desorption processes. Furthermore, the experimental results of Phase I showed that the techniques developed would improve the effectiveness of the air dehydration process by more than 30%. What was learnt as well from Phase I, was that the manufacturing methods required improvement, namely, replacing adhesive bonding techniques by others less vulnerable to failure at the temperatures of the regeneration process.

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1 Compounded Parabolic Collectors.

2 ***Mem***brane ***Pro***cesses-based ***D***esiccant and ***E***vaporative ***C***ooling

Phase II concentrated on the development of appropriate manufacturing techniques, their application, and test in a commercial sized air handling unit. The results obtained demonstrated that the *'trail we have been walking'* is the right one.

Manuel Conde-Petit

Zurich, Fall 2016

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# INTRODUCTION

The conditioning of air for comfort, manufacturing or other activities, requires the control of temperature, humidity content, particles, VOCs (Volatile Organic Compounds), germs and of harmful gases eventually present in atmospheric air. Particle control is mostly done through the use of suitable filters, and their regular maintenance. VOCs and germs may be done with in air washers and, particularly for germs, through UV irradiation. Harmful gases may be eliminated by ad/absorption in suitable beds or contactors. Changes in temperature and humidity, however, require the most of the energy used in the conditioning of air. The relative energy intensity for temperature and humidity control depends both on the local climate and on the particular application. The control of humidity content and temperature is the main subject of this work.

The control of temperature is done through cooling and heating, following the requirements of the particular application considered. There are various possibilities for carrying out both processes. While adiabatic evaporative cooling of the outside air (ODA), or a mixture of outside air with return air (ETA), may do in the climates such as those of Central Europe, it may not be adequate for the climates of other regions. It may also be problematic in terms of germ control, when the supply air (SUP) is cooled by direct evaporative cooling. Changing the temperature by direct evaporative cooling implies, mostly, no control over the humidity content, leading in many cases to discomfort situations. The control of humidity content is improved when indirect evaporative cooling is used, although systems operating along this principle require assistance from mechanical refrigeration to keep comfortable conditions in hot and humid days, or at high internal latent loads.

In those situations where additional cooling is required, both mechanical vapour compression and absorption refrigeration equipment may be used. Anyway, the use of mechanical refrigeration is far more widespread than evaporative cooling, even in climates where the late would represent the most suitable solution, from the energy efficiency point of view. Heating may require separate equipment, but in many cases integration with other systems available at the plant or building may provide for flexible and efficient solutions.

In the still most common process used to change humidity content, the air is cooled in contact with a surface at a temperature lower than its dew-point temperature, in order to condense the excess part of that humidity. These processes require mostly a heating step before the air is supplied to the conditioned space, and changing the temperature is not independent from changing the humidity content. On the other hand, there is a double energy loss due to cooling beyond the necessary level, and to reheating afterwards, although energy recovery is mostly possible. Despite all thermal losses and other similar arguments, the well proven and sturdy mechanical vapour compression equipment still continues to be preferred by many for providing the necessary cold source. Behind this lies a much more detrimental reality in thermodynamic terms: – The heating, cooling, and humidity control of air for building and process air conditioning requires only comparative small adjustments, at levels very near to ambient conditions. Driving the necessary processes with high grade energy is absolute nonsense! The overall thermodynamic efficiency of such processes is mostly less than 1%. As a supposedly intelligent species we ought to do better, for the general good.

The replacement of active cooling beyond the dew-point, with surface contactors, as a process for air dehydration, has been the subject of intensive research for many years. Practicable and well tested solutions have been found that decouple the control of temperature and humidity, and avoid the most, or all, of that double energy loss. For the climates of temperate regions, convenient and reasonably satisfactory solutions may be found through the combination of energy recovery and evaporative cooling. Although this particular process does not in most cases provide for an accurate control of humidity, it does however provide for acceptable comfort. For climates characterized by high ambient air humidity content, separating the control of humidity and temperature is an absolute necessity.

In the last thirty or so years, serious efforts have been undertaken to diversify the solutions applied to control humidity with air conditioning systems. Some of the ideas involved have been patented long ago[4], but only the perceived need to protect the environment and to minimize the depletion of fossil energy resources, has stimulated the development of new equipments implementing those ideas.

On the other hand, lower running costs and high reliability have increased their presence in air conditioning plants. Besides energy recovery, the essential of the systems being developed are characterized by separating the control of temperature (cooling and heating) from the control of humidity content (humidifying and dehumidifying). Most of these new systems involve sorption processes, using desiccants. Desiccants are materials with a high affinity for water. Solid Desiccants *adsorb* moisture *onto the surface* of their highly porous structure, while liquid desiccants *absorb* it *into their mass*. In both cases, the enthalpies of condensation and sorption are 'released' in the process. This change of state increases the temperature of the desiccant reducing its capability to take more moisture.

Besides the different nature of the sorption process in the solid and liquid desiccants, it is the relative simplicity of cooling the liquid desiccants during absorption that gives them a great advantage over the solid ones. Both kinds of desiccant have to be regenerated, when operating in a cycle, in order to preserve their air dehydration capability. The regeneration consists in stripping the water out of the desiccant. This is usually done by heating the desiccant to a point where water vapour may be stripped away, mostly by an air stream. Liquid desiccants are advantageous as they can be heated more efficiently (with liquid media instead of gaseous). Open absorption systems operate with liquid desiccants at atmospheric pressure. The atmosphere also functions as evaporator and condenser, when the system is compared with standard, closed absorption.

The technologies adopted initially for open absorption systems were the same as those used for closed ones, or in the process industry: direct contact gas-liquid packed columns, tube bundles and direct sprays. Two problems emerged from these choices:

– It is almost impossible to maintain a regular contacting surface, particularly at part load, with control and efficiency losses;

– The air contacting the desiccant transports aerosols loaded with corrosive salt solution, or desiccant vapour in the case of TEG. These aerosols not only corrode the plant downstream of the unit, but are also dangerous for people and other living organisms.

The corrosion effects of liquid desiccant aerosols are well illustrated in Figure 43, for a system operating with aqueous LiBr, [39]. Although corrosion may be well controlled in closed absorption systems, in the open ones, with conventional gas-liquid contactors, this is practically impossible due to the presence of oxygen. The system discussed in [39] used a reboiler as regenerator, and a condenser to recover energy from the vapour produced.

The study of the properties of aqueous solutions of alkali halides has shown that it is possible to operate open absorption air conditioning systems at relatively low driving temperatures. Temperatures in the range of 50 to 80 °C are sufficient to drive these systems efficiently. This range of temperatures can be easily attained with flat solar collectors, are available from district heating networks, are common in cogeneration systems, and as effluents in many industrial processes. Furthermore, improving the efficiency in all processes that involve any kind of energy transformation is a condition necessary to attain sustainability at all levels of economic activity.

Generating appropriate ambient conditions for living or productive work, requires large amounts of high grade energy with state-of-the-art air conditioning technologies. State-of-the-art air conditioning equipment (chillers, air handling units, cooling towers, and terminal units) require for their operation essentially electric power, generated in great part by thermal power stations (an estimated 95 % of all air conditioning systems in the developed world are based on electric power-driven vapour compression chillers). The remaining 5 % are mostly conventional thermally-driven absorption chillers with driving temperatures in the range 120 °C to 250 °C. Low temperature (50 °C to 80 °C) thermally driven equipments have up to now very low penetration in the market.

This general picture can be changed:

Low temperature thermally-driven systems can be made simpler and cheaper than conventional absorption chillers, without losses in efficiency;

Built as autonomous air handling units, they eliminate the need for further air handling and for cooling towers;

As driving energy resources, a variety of alternatives is possible:

Solar thermal collector arrays, district heating networks, waste heat in general, provided that temperatures in the range 50 °C to 80 °C are available.

Additionally, such equipment can provide loss-free chemical energy storage, allowing for a better accommodation of tariffs and loads. These systems, based on the open absorption principle, can provide cold, dry air and cold water, simultaneously or not, without increased system complexity. This makes them suitable for the retrofit market as well, particularly in combination with induction units as terminal units. To district heating network operators, they provide the opportunity to eliminate (or reduce) asymmetric annual loads by extending hot water demand beyond the heating season.

Early (and many recent) attempts to bring this technology to fruition have failed by not solving adequately its intrinsic problems such as corrosion, both internally in the equipment, and externally through aerosol transportation by the supply air. Conventional thermal design of the contacting surfaces (air to liquid desiccant) results in poor performance: Metallic surfaces are rapidly corroded and polymeric ones poorly wetted, thus requiring either frequent replacement, or very large components.

New concepts for the various components of open absorption systems shall contribute to overcome the remaining obstacles for their more extensive application. They are discussed in detail in this monograph.