LIQUID DESICCANT-BASED AIR-CONDITIONING SYSTEMS — *LDAC*S

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ABSTRACT

This communication concerns *Liquid desiccant-based air-conditioning systems* - *LDACS*, or open absorption air-conditioning systems. The background of the technology is discussed, in a historical and engineering perspective, along with reviews of products already on the market, and recent and current research and development activity. A statement on the past, present and future of this technology reiterates the various conditions to make it successful.

Keywords: Open absorption; Liquid desiccant; Air-conditioning; Environment.

INTRODUCTION

It is an irony of our age that research work in concurrent but related fields, that started at about the same time, would evolve to commercial products at so different paces, and at so distant times. During the 1930s and 40s, while Thomas Midgley, jr. [1] and co-workers, working for the Kinetic Chemical Company, were revolutionizing the chemistry of operating fluids for refrigeration, Alexis Berestneff [2] was busy developing LiBr-H_2O systems for the Carrier Corporation, Edmund Altenkirch [3] and Francis Bichowsky [4], [5] were putting forward concepts and technical solutions for open absorption systems that are now, almost 80 years on, seen as advantageous for the conditioning of air, from the energetic and environmental points of view.

While the new refrigerant fluids of Midgley successfully replaced the toxic and dangerous refrigerants used at the time in vapour compression systems (methyl chloride, sulfur dioxide, ammonia, etc.), thus advancing the expansion of the recently born air- conditioning industry, closed absorption systems for use in air conditioning struggled for another thirty years, until LiBr-H_2O units were successfully used, though not widespread. Open absorption systems started to be used in industrial applications by the end of the 1940s, although they handled mostly only the latent load (air dehydration), leaving the sensible load to be handled by the then already traditional vapour compression systems. The removal of the sensible heat load needs not be done by an active system, such as a vapour compression refrigeration device. Evaporative cooling, preferably indirect evaporative cooling, may effectively remove this load, if the supply air is first dehumidified to the right point. This is possibly the most important strength of an open absorption-based autonomous AHU.

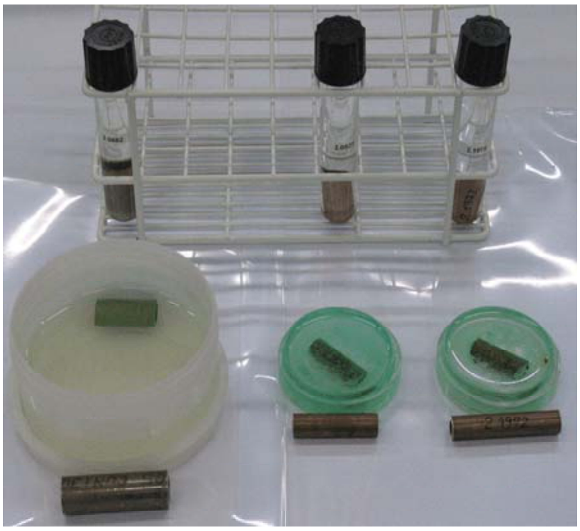

Figure 1. Corrosion of CuNi tube samples by aqueus LiCl solutions in the presence and in the absence of air.

Figure 2. Corrosion damage to the air supply channel of a large auditotium by LiCl solution aerosol

Open absorption systems are, theoretically, simple to build, require driving energy at relatively low temperatures (flat-plate solar collectors, co-generation effluents, district heating, etc.), and are efficient air dehumidifiers. So, why are they not ubiquitous?

The problem is corrosion. Almost all metall alloys are corroded by the most effective liquid desiccants, e.g. aqueous solutions of lithium chloride, particularly in the presence of oxygen. Our own experience shows that even high nickel content copper-nickel alloys are significantly corroded within a short time, as documented in Fig. 1. Beyond the components of the system itself, other parts of air conditioning plants are also affected by corrosion when state-of-the-art open absorption equipment is used, as shown in Fig. 2 [6]. What is necessary are machines designed to avoid contact of the desiccant solution with metallic surfaces, on one hand, and avoid aerosol formation on the other. This is where most of recent research and development efforts have been made, with a couple of manufacturers venturing to the market with their last developed solutions.

Once a suitable and economical solution, in terms of materials and design, is found for these problems, *LDACS* will certainly play a very important role in air conditioning for both industry and comfort, requiring only driving temperatures in the range 60 to 90 °C. In this communication I shall concentrate particularly on these two aspects, besides looking at the main requirement, that is to generate supply air (SA) at the right conditions, out of outside air (OA), or a mixture of this with return air (RA).

A conventional, central air conditioning system consists mostly of the four main subsystems depicted in Fig. 3.

LDACS vs other AC systems

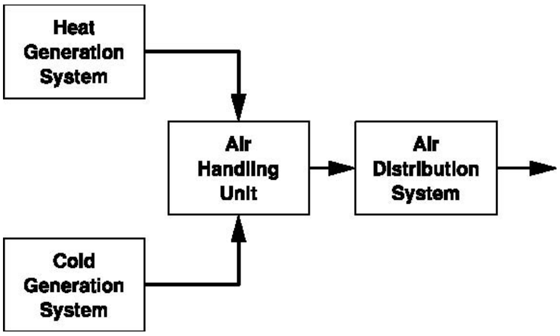

Figure 3 -Block-diagram of a conventional central airconditioning system.

The Air Handling Unit (AHU) concentrates the essential operations on the air, e.g. filtration, hydration (dehydration), cooling (heating),de-ionization, etc. Heat is commonly generated in a boiler, although the condensation energy of the chiller, necessary to generate cold, may sometimes be used. Most of the times however, this condensation energy is dissipated directly to the atmosphere, either in a cooling tower, or in a directly air-cooled condenser. The cold producing chiller may be a vapour compression type, or a closed absorption unit, in which case the heat generator may be the only thermal component requiring external energy supply. The dehumidification of the air is mostly carried out contacting the air with a surface at a temperature below its dew-point. This requires the chiller to deliver a cooling fluid at a temperature even lower than the dew-point of the air. This common method of dehumidification, usually requires a re-heating step in order to give the air the required supply temperature. Heat and humidity recovery may reduce the intensities of these processes, but does not permit avoiding them in general.

The energy required to drive conventional air-conditioning systems is mostly electricity, or thermal fluxes at temperatures above 100 °C, to be economical. In contrast, open absorption-based air conditioning systems dispense with the chiller, and driving thermal energy may be supplied at temperatures down to 60 °C. This allows for the use of alternative thermal energy sources, such as solar thermal energy from cheap flat solar collectors, effluents of co-generation plants, and district heating when available. District heating plants burning urban waste are particularly favourable, since urban waste has to be burnt year round, the heat being mostly dissipated through cooling towers in the Summer season. Open absorption-based air conditioning systems also offer very interesting possibilities for lossless energy storage as concentrated liquid desiccant solution, instead of loss-prone, as sensible or latent heat storage.

Now, the large majority of the so-called air conditioners (window units, multi-split units, mobile units, etc.) are not central systems. These, mostly small systems, represent by their sheer number perhaps the worst challenge for the electricity generation and transport system. For us, developing engineers and researchers working on open absorption systems, the greatest challenge is to come up with technological solutions able to compete, effectively, on an open and unregulated market with these small, mass-produced units.

LDACS ON THE MARKET

Several open absorption-based products for air conditioning have made their way to the market place. Some represent whole air conditioning system solutions, while others have a more limited scope, such as handling the latent load alone. Let us make a *‘tour d’horizont’* about them.

Kathabar (Kathabar Inc., New Brunswick, NJ, USA)

The *Kathabar* systems are on the market since the 1940s, following the development work of Francis Bichowsky in the preceding decade. They are mostly to be found in industrial applications. Essentially, the *Kathabar* systems consist of two vertical contact columns, one operating as absorber (conditioner), and the other as desorber (regenerator), with heat recovery between concentrated and diluted solutions. Cooling of the concentrated solution and heating of the diluted solution take place separately and before the absorber and the desorber, respectively, Fig. 4.

The liquid desiccant used is Kathene, a proprietary mixture of halide salts in aqueous solution.

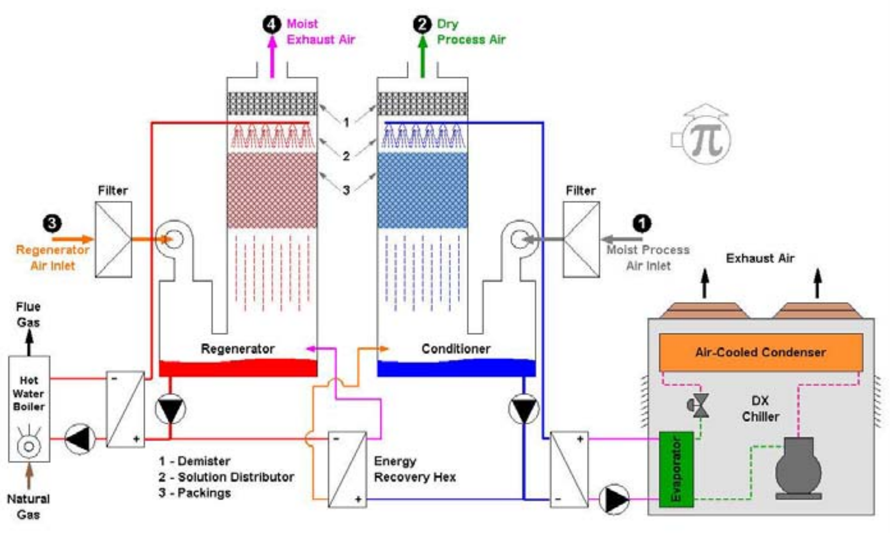

Figure 4 -Author's representation of a typical Kathabar system.

DryKor® (DryKor® Ltd., Atlit, Israel)

The *DryKor*® units use aqueous lithium chloride as desiccant. Absorber and desorber are relatively compact, where the desiccant and the air contact directly by means of cellulose contacting pads of the type found in many air humidifiers. The concentrated desiccant is cooled, before entering the absorber, by the evaporator of a heat pump, which condenser provides the energy necessary to regenerate the diluted solution before the desorber. This is a clever idea [7], since the heat pump operates at a high COP, but the units have mostly had a short life due to corrosion problems at the condenser and evaporator. *DryKor*® equipment ceased to be manufactured in 2006. Fig. 5 depicts schematically a typical *DryKor*® air dehumidification unit.

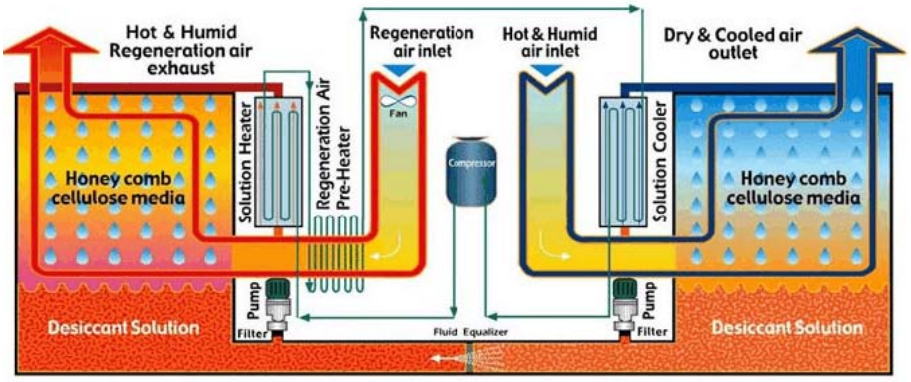

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Fig. 5 -Schematic representation of a DryKor® air dehumidifier.

***Ficom* (Ficom Pty Ltd., Glenelg, Australia)**

Ficom has developed [8] and brought to the market what they called a *Dual Indirect Cycle Energy Recovery (DICER-D)* unit. The system combines air dehydration with indirect evaporative cooling in a single unit, Fig. 6. The regeneration of the desiccant solution takes place in a separate unit, Fig. 7. This concept allows for distributed air handling, with its inherent flexibility, and centralized desiccant regeneration. Demand management, particularly when using solar energy to drive the regenerator, is done by storing concentrated aqueous LiCl solution. The exhaust air of the process is dehumidified in one first contactor and cooled by re-humidification to provide indirect evaporative cooling to the supply air.

This air washing step warrants that no aerosols come out of the AHU, the supply air never contacting water or the desiccant solution. On the other hand, this air handling method forfeits the potential benefit of the bacteriostaticity of the aqueous LiCl solution, and does not really control the humidity of the supply air, since indirect evaporative cooling, as used in the unit, is not able to control both simultaneously.

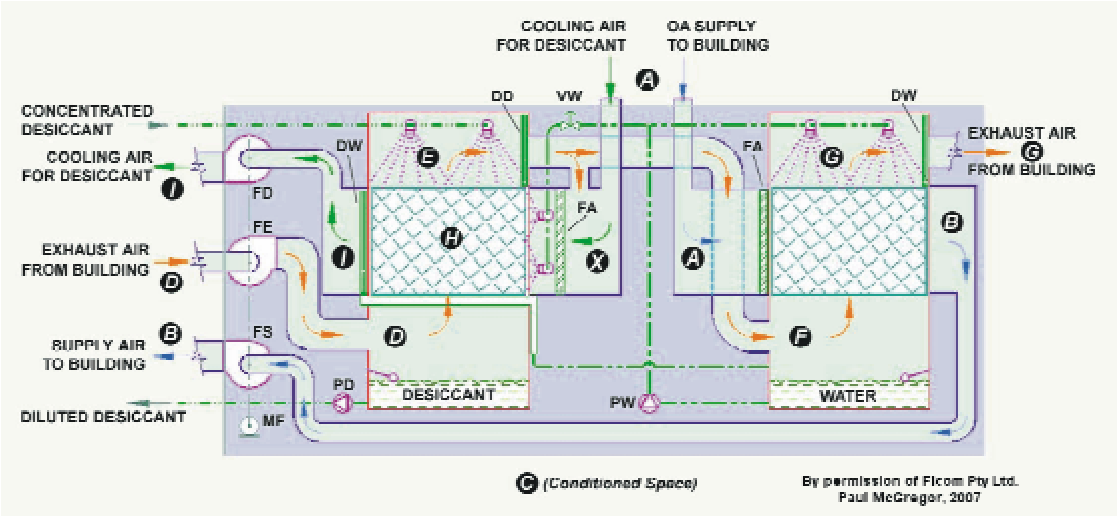

Fig. 6 -Schematic representation of Ficom's AHU.

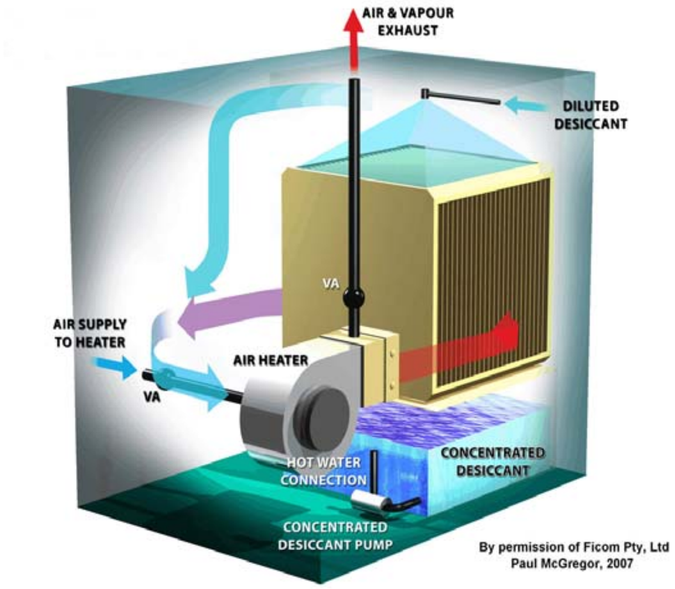

Figure 7. Schematic 3-D view of Ficom's dessicant regenerator.

L-DCS (L-DCS Technology GmbH, Ismaning, Germany)

L-DCS, Liquid Desiccant Cooling System, is an off-spring of the Bavarian Center for Applied Energy Research (ZAE Bayern). The *L-DCS* on purpose designed systems combine decentralized air handling (dehydration + evaporative air cooling) with central regeneration and desiccant storage, Fig. 8.

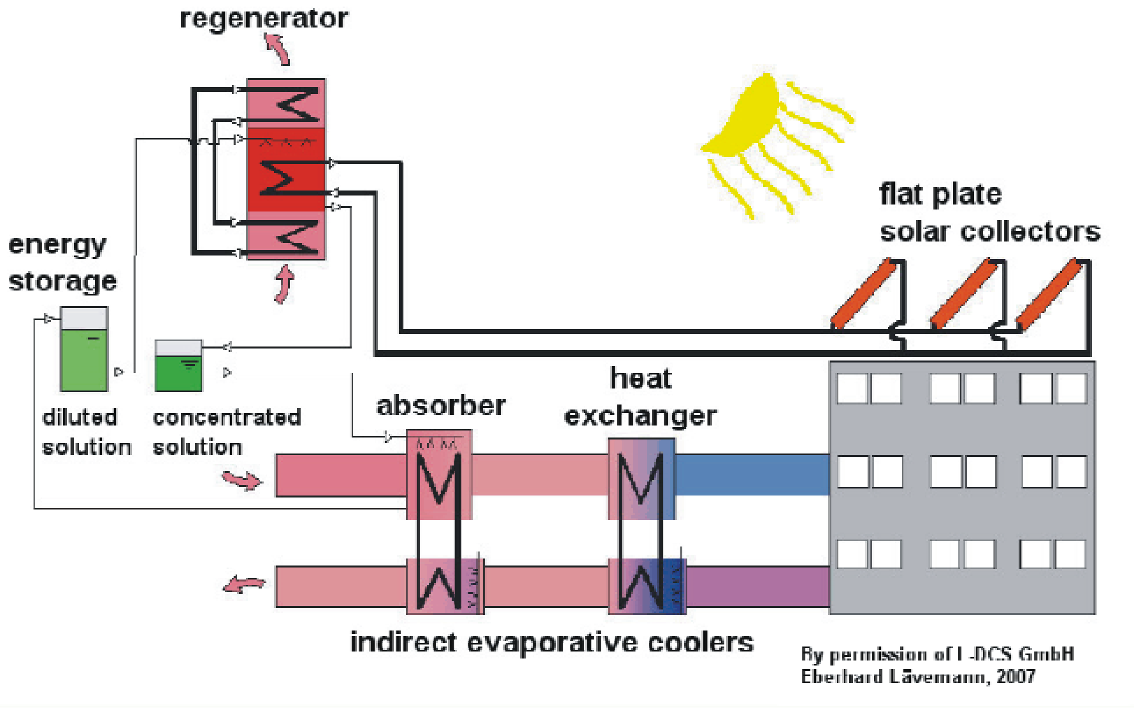

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Figure. 8 -Schematic representation of a solar-driven L-DCS plant.

Air-desiccant contactors use a patented distributor [9] for micro-quantities of liquid, to ensure a good wetting of the contacting surfaces. The absorber is internally cooled by water and the desorber is internally heated by hot water at a temperature in the range 60 - 80 °C. The direct contact of process air with the LiCl aqueous solution warrants the benefits of the bacteriostaticity of the desiccant, although the generation of LiCl containing aerosols is also probable. No reports are available to the author in this respect at this point, though. Fig.8 depicts the schematic of a solar-driven plant using *L-DCS* equipment.

***AIL Research, Inc.* (AIL Research, Inc., Princeton, NJ, USA)**

The sole AIL Research unit (OA6000) on the market, Fig. 9, is a result of early research carried out in cooperation with the Gas Research Institute (GRI) [10] and with the National Renewable Energy Laboratory (NREL) [11] in the 1990s.

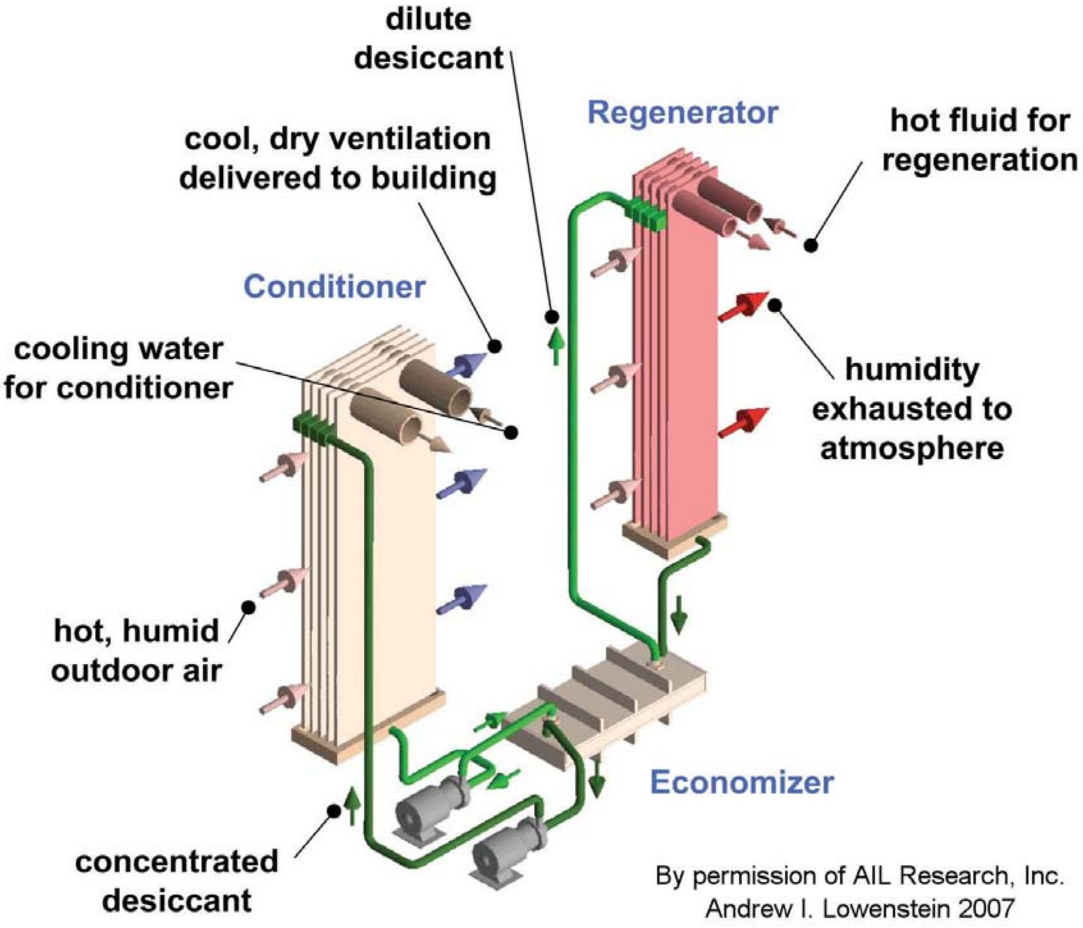

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Figure 9. 3-D schematic of an AIL Research Liquid Desiccant dehumidifier.

The main aspects addressed in that collaborative research were desiccant solution carryover and material compatibility. This has been what might be considered a relatively long evolution of the technology of this manufacturer, which is documented both in the open literature [12] [13] [14], and in several patent applications [15] The unit is intended to handle the latent load only (dehumidifier) and to operate upstream of the evaporator of a conventional air cooling system, although it might as well deliver supply air directly in some cases. Since both absorber and desorber operate in direct contact with air, it is questionable whether, with ageing of the contactor surfaces, the carryover problem is definitely solved.

AEX (American Energy Exchange, Inc., Holland, MI, USA)

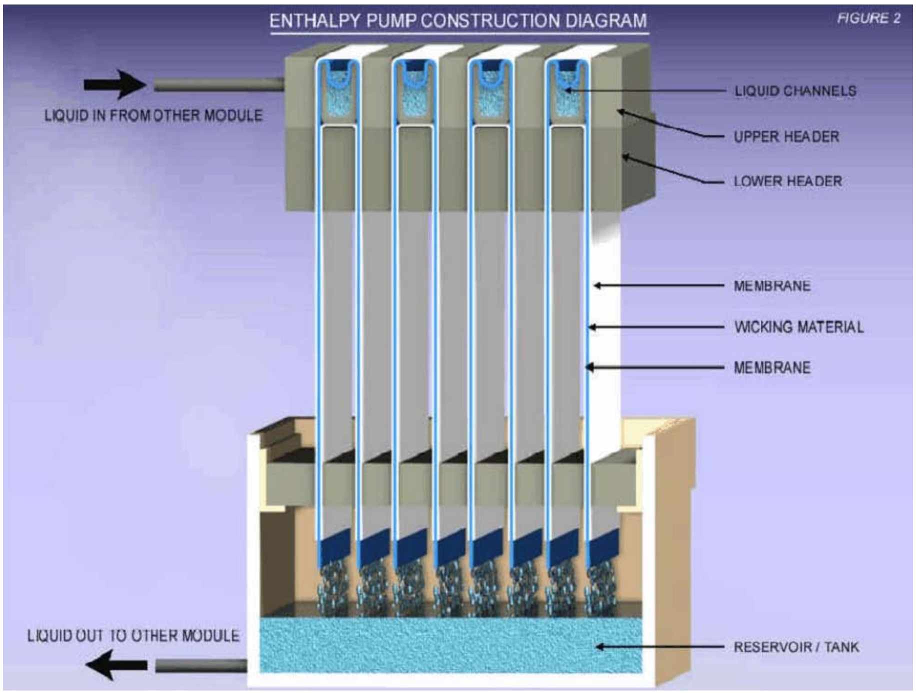

Figure 10. Schematic representation of the AEX Enthalpy pump. (Image from product sheet of AEX, Inc.)

AEX has been on the market with the so-called *enthalpy pump* [16],which is conceived as a dehumidifier to be placed upstream of the evaporator of a conventional chiller or air conditioning unit. Interesting in this product is that it effectively solves the carryover problem by placing a micro-porous membrane between the desiccant solution and the air, Fig 10. The absorber part may be used in a decentralized way, multiple modules, with a central desorber.

Menerga (Menerga Apparatebau GmbH, Mülheim an der Ruhr, Germany)

Menerga has been field-testing open absorption-based air handling units for some time. These units have been developed on the basis of research work done at the UGH Essen [17]. In this research the desiccant used was a proprietary solution produced by Solvay (Klimat 3930s). For their field tests *Menerga* has resorted to aqueous LiCl solutions. The tested air handling units combine air dehydration with indirect evaporative cooling. *Menerga* is well known for the effective use of this technology in many of its products for comfort air conditioning. Fig. 11 shows a schematic of a liquid sorption-based *Menerga* AHU.

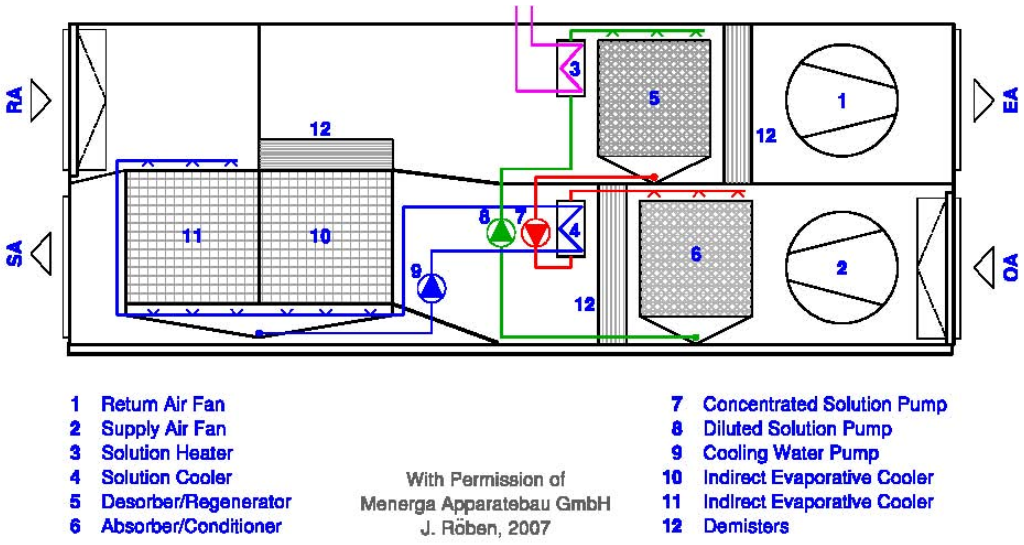

Fig. 11 - *Menerga* air handling unit using liquid sorption technology.

R&D on *LDACS*

Research and development on *LDACS* continues, in some cases at a relatively basic level, despite the great efforts and the profusion of ideas put forward

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Fig. 11 -Menerga air handling unit using liquid sorption technology. Biel, S., et al. 1997. Sorption Entfeuchtung unde Temperaturabsenkung bei der Klimatisierung, Final Report

already some eighty years ago. This research has had various motivations: While until shortly the gas industry in the US was the pulling force, the SARS crisis has driven the far-East research in recent times, particularly in China, in Europe it is the use of renewable resources, in particular solar energy, and other environmental reasons.

Several directions and objectives of this R&D can be identified:

a) Solve basic problems of the system, such as avoiding corrosion of the system and plant components;

b) Improve the transport processes in the contacting columns (absorber and desorber), particularly at part load;

c) Combine open liquid absorption systems with conventional refrigeration, to reduce defrosting energy costs, for example, in food conservation and transport;

d) Combine open liquid absorption systems with conventional air conditioning systems to reduce, or eliminate, the latent load on the chiller;

e) Combine open liquid absorption systems with mobile air conditioning systems to reduce CO_2 emissions due to the operation of such systems in cars, busses and trucks;

f) Develop compact and modular components allowing the construction of autonomous (no chiller, no cooling tower) air handling units.

One good measure of these efforts, at least in Europe, may perhaps be given by the direct EC funding in the last seven years: ~ 10 M€, for total budgeted project costs of ~ 17 M€. Research work in Europe, outside of the EC Framework Programs, has also been taking place, for example at the University of Padova, in Italy [18], and at the Haute Ecole d’Ingénierie et de Gestion du Canton de Vaud, in Switzerland [19].

Research and development in the US [20] [12] [13] [14], Australia [21], the middle East countries [22], China [23] [24], India [25] and elsewhere are also taking place, as is apparent from the open literature.

Our own research in Switzerland (M. Conde Engineering and EMPA [26]), is described essentially by a) and f). We have developed the design procedures and the manufacturing techniques to build generic, corrosion-free, membrane-based air-liquid contactors, that may be used to contact air with a liquid desiccant (absorber, desorber) or with water (evaporative coolers), Fig. 12. These modular building blocs allow the construction of autonomous all-air handling units (supplying dry, cold air to the distribution system), or air-water units (supplying dry air combined with cold water, or cold water only, to the distribution system). Dry air combined with cold water may be used with great advantage together with induction units, Fig. 13, or with fan-coil systems, although induction units are economically and energetically superior. Cold ceilings may naturally also be served. These membrane contactors may as well be used for the purposes described by c), d) and e), although, in my opinion, this makes little sense in comfort air conditioning in buildings.

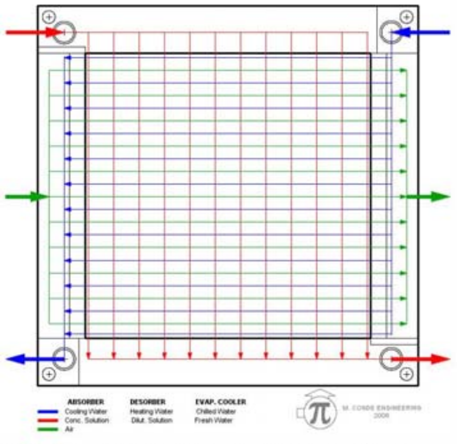

Fig. 12 - Schematic illustration of the flow paths in a generic contactor.

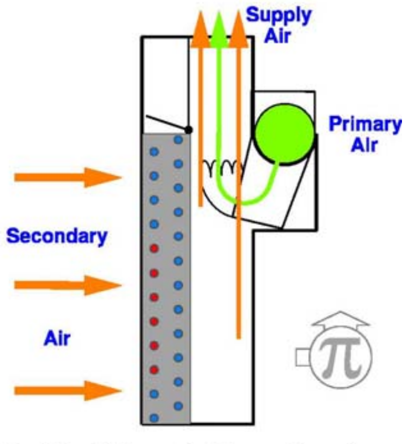

Fig. 13 - Schematic illustration of an induction unit.

CONCLUSIONS AND OUTLOOK

Already in the early work of E. Altenkirch one basic preocupation was how close air dehydration processes could be to thermodynamic reversibility, thus how could the energy requirements be minimized. Francis Bichowsky fought with the cumbersome equipment he was able to build at the time. And all through the past eighty years much research has been carried out to promote a technology that, despite its many theoretical advantages, has not made it to the top. So, is anything gone wrong?, what was the problem to be solved, to start with?

The answers are perhaps bewildering, but nothing is gone wrong, and there seems to have been no problem requiring an urgent solution: Plenty of electric power has been available, and air conditioning devices were around to satisfy all conceivable and perceived needs! Has anything then changed in recent times that might require a review of these answers? I fear yes! Plenty of power is still available almost everywhere, though not at all times: consider the blackouts in many places in the industrialized world. On the other hand, unintended consequences of the solutions adopted before now, and used in today’s systems, are apparent today. This changes radically the terms we used to reason with, and carries as a consequence that air conditioning devices are neither available in many circumstances for even life critical applications, nor are they as safe as we used to believe them to be. Add to this the growing environmental constraints we now face, and shall continue to face in the future, and the picture is dramatically changing in a very short time, even at the human scale.

Air conditioning is, and shall continue to be needed

- to improve living conditions (in some cases to make living at all possible) in many parts of the world;
- to warrant safe hygienic conditions in hospitals and sports facilities;
- to improve productivity everywhere;
- to make many manufacturing processes at all possible;

- to avoid material losses in long term storage of some goods, not the least nuclear waste, for example;

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This list could be longer, but it is difficult to shorten.

The development of liquid desiccant-based air-conditioning systems has attained a stage where it is reasonable to state that they are here to stay and their market share to grow. Although the manufacturers already on the market are not among the 'front pack' in the field, they are, nonetheless, the leaders of a 'new-old' technology, that brings along much needed new impulses and solutions to a real problem: Safe, reliable and environmentally sound satisfaction of our society's needs.

R&D on *LDACS* is further required, as are educated people, familiar with the principles of these systems, from the design board through the shop floor, down to the installer.

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