Absorption cooling R&D in Europe

This article reviews absorption cooling R&D in Europe from the viewpoint of fundamentals, cycle development and applications.

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Abstract

The review contains information on R&D, predominantly of public projects in the field of sorption cooling. We report on research which is performed in Europe with some stress on Germany. There is progress in fundamentals, thermodynamic cycle design, and also applications. In the fundamentals part the discussion about thermodynamics, working pairs, and heat and mass transfer is reflected. Today' s discussion on thermodynamic cycles is not very strong. Main focus is on special solid sorption cycles, compression-sorption hybrids, and open cycles. In the applications part the chilling business is the main issue. Some interest is given to the improvement of efficiency on and the adaptation to low temperature waste heat use, but the stress is on the use of solar energy as heat source. The area of heat pumping for heating purposes is less prominent but not at all negligible. Finally, industrial heat pumping involves the reverse cycle (heat transformer, heat pump type II) also, but there is no significant activity.

KEYWORDS
Sorption, heat pump, chiller, refrigeration, research, experiments, application

Introduction

It is well known that there are two large fields for application of absorption technology: one is air-conditioning with mostly Water-Lithiumbromide chillers, the other is deep freezing with predominantly Ammonia-Water refrigerators. The market of the former is much larger than the latter; it is well taken care of by manufacturers in the Far East. Up to now, only a small fraction of specially designed chillers and some refrigerators (Bassols et al., 2001) and heat pumps are manufactured in Europe. In spite of this, European R&D has always been relatively strong in this field. Probably, this fact can be attributed to the theoretical and practical achievements from the first half of the last century, especially of German engineers such as Altenkirch (1913 - 1914) and Niebergall (1959) in the first half of the last century. In the time of the oil price crisis there was renewed interest and new progress in the fundamentals (e.g., Alefeld, 1983). This interest has leveled of but still prevails today.

We will give our view of what is going on today. The relative freedom from noise and vibrations is an argument for using absorption technology, but in Europe, above all, the possibility to use waste heat or solar energy to energize the systems as well as the freedom from CFCs and the like are the important arguments in favor of sorption systems. In the near future, the problem of the mid-afternoon peak in electricity consumption will emerge in Europe, also.

This paper, of course, continues or complements other reviews published earlier (Meunier,1999). The reader should also refer to the proceedings of the Absorption Heat Pump Conferences. (Nikanpour and Hosatte, 1996). Other, more European-oriented information can be achieved by consulting the Proceedings of the Heat Powered Cycles 2001 (Neveu, 2001) and Eurotherm 2003 (Corberan and Royo, 2003).

We suppose that the basics of sorption heat pumping are well known. For more basic information the reader can use the books by Alefeld et al. (1994), Herold et al. (1996), or other textbooks.

We can distinguish three different areas of R&D within the field of sorption heat pumping: fundamental research, simulations or experiments with more or less sophisticated cycles, and applicational topics.

Fundamentals

Within the fundamental′s part, there are always three blocks: the thermodynamical considerations, the working pair development, and the heat and mass transfer research.

In the thermodynamic section, a very fundamental discussion of more or less idealised models can be recognized worldwide. Tozer and Agnew (1999) refresh paths which have been initiated by Eber (1968) and thus creates new possibilities for the analysis of multistage systems. Morosuk et al. (2002a) look first at multistage compression systems. They try to find new cycles by ordering and classification, and also study heat transformers (type II heat pump) (Morosuk et al., 2002b). By the way, there is - to the best of our knowledge - no other significant activity in this field of technology! Another very basic model which works by looking at the entropic effect on the environment, and which is useful for both simple or more complex cycles is presented by Neveu (2002).

Similarly, better understanding of open sorption systems by using new methods of analysis is sought by Pons and Kodama (1999) who model these cycles as closed ones.

Of course, there are always attempts to improve models of real cycles in steady state, part-load, or dynamics (Tozer and Lozano, 1999). Cerkvenik et al. (2001) discuss the effects of the dead thermal mass in solid sorption systems in order to compare their performance to that of liquid sorption systems.

There are many rationales to choose a **working pair**: temperature and pressure range, thermodynamic efficiency (COP), experience, complexity in handling, safety, environmental concerns etc., and there is a large number of potential working pairs; however, none fulfills all requirements at the same time. There are still only two working pairs which dominate the market: Water-Lithiumbromide for water chillers and Ammonia-Water for refrigeration.

The research in organics is well established in Israel (e.g., Jelinek and Borde, 1999). For the time being, there is more research in prototyping and components than on basic thermophysical data of these systems.

A radical change away from the standard pairs is the switch to solid sorbents. The technical use of the physically necessary storage feature is in most cases taken into consideration, for instance by Hauer (2002) using Zeolites, by Jänchen (2002) who compare a variety of sorbents; complex compounds of Ammonia are being used by Nahrendorf (see Gbt, 2003). Composites of solid sorbents and salts are being investigated by Aristov et al. (1999) and they are addressed also by Jänchen (2003) and Mugele (2004). Finally, there is a long lasting activity in the field of metal hydrides, which is reported on by Klein and Groll (2001). A review is given by Groll et al. (2002). Some years ago many of these investigations have been collected in a special issue of the International Journal of Refrigeration (Ziegler, 1999) and are compared in that issue of the journal by Pons et al. (1999).

When we come back to liquid sorbents, there is some activity in variation of the salt (Venegas et al., 2003). Moreover, research in acids starts again (Riebow, 2004).

An effective **heat and mass transfer** is of utmost importance in all thermal systems. To some extent, almost all applied research in solid sorption is dedicated to this problem. However, in absorption the related activities in Europe are not too strong. There is a small cluster in Spain in Valencia (Soto, 2000), and Tarragona (Salcedo et al., 2000) where falling films of different solutions have been investigated. Especially by Soto (2000) the effect of additives was studied by using stability criteria. In Germany there has been a very detailed analysis and simulation by Hackner. More experimental work (Sahin, 2004) is going on with stress on additives and the problem of non-condensables (Petersen, 2004). Additives have been studied in depth by Glebov (2002) with the aim of finding thermally more stable alternatives to the short-chained alcohols. Heat and mass transfer in plate heat exchangers with Ammonia-Water is examined by Nordtvedt (2002).

We can also find research on the bubble pump (thermosyphon) at several places: by Koyfman et al. (2001), by Jakob et al. (2001), and by Albers and Ziegler (2003). Thermosyphon pumps are an hermetic alternative to standard solution circulation pumps. Differently from the latter, thermosyphon pumps rely almost totally on the mechanism of heat and mass transfer.

Cycle Development

It is useful to group the discussion about cycles into five different topics:

- multistage absorption cycles for low temperature driving heat or high lift
- highly efficient multistage cycles
- compression-sorption hybrids
- specific solid sorption cycles
- open cycles

There is not much recent activity on **multistage cycles for low temperature driving heat**. We should mention the incorporation of a jet ejector which boosts the absorber pressure (Eames et al., 1999) and some very recent work on dedicated compression sorption hybrid (Ghiasi, 2004). In the field of **highly efficient multistage cycles** there was a lot of work in former years which is continued only on a low level. A new triple-effect prototype has been proposed by Henning (ISE, 2004). Also the work on acids (Riebow, 2004) is aimed at high-efficient (triple-effect) cycles. Bruno et al. (2003) report on experiments with a GAX cycle (Generator-Absorber-Heat Exchange or overlapping temperatures).

A substantial development of **compression-sorption hybrids** is going on since some years in Norway (Baksaas and Grandrum). It is composed from basic topics such as heat and mass transfer and prototyping, with well established links to industrial use. Other prototypes are being investigated by and Ghiasi (2004).

The work on **solid sorption cycles** is mainly done in the basic field and has been reported of above. Additionally, since some years, there is steady development of a peculiar cycle by Critoph which is reported on by, e.g., Critoph and Tamainot-Telto (2003). It is a regenerative (heat wave) cycle using activated carbon and Ammonia.

It is obvious that in dry regions evaporative cooling is energetically the best solution, as long as water is at hand cheaply. Thermodynamically speaking, the gradient of the water concentration in a humid air stream and that of the relatively dry ambient air can be used as a driving potential for a sorption chiller. As in all multistage concepts, we have the possibility to use this gradient for improving the COP on the one hand (multi-effect concept) or for lowering the temperature of the driving heat (multi-lift concept). These **open systems** are demonstrated in several places in Europe using Zeolites (Hauer, 2002), circulating salt solutions (Kessling et al., 1999) or desiccant wheels (Henning et al., 1999). The aim of the research is increase in performance on the one hand, and optimization of storage features on the other hand. The main use is solar cooling.

Application

We can distinguish between the application of air-conditioning, deep freezing, and heat pumping on the one hand, and between the kind of heat sources, namely natural gas, waste heat, or solar heat, on the other hand.

There is no remarkable activity in the field of **deep freezing** in recent years. In **heat pumping** there is an ongoing effort by the company Vaillant using Zeolite (Lang et al., 1999) and by the company Buderus (2004) using Ammonia-Water. Both companies seem to be near the marketing or at least the field-testing stage.

Most of the applied work is dedicated to **air-conditioning** or water chilling. One specific form of air-conditioning is the pre-cooling of the compressor inlet air of gas turbine power stations (Prelipceanu, 2003). It is achieved by absorption chillers which are fired by the flue gas of the gas turbine. This increases both power density and efficiency of the system.

The most prominent area of application of absorption systems worldwide is providing chilled water for air-conditioning by **direct-fired** Water-Lithiumbromide absorption chillers. This, however, is not very significant in Europe. Here, the main application is the use of heat from **combined heat and power** production in - small or large - district heating systems for cooling purposes. During summertime an exploitation of this energy source for air conditioning with the consequence of increased utilization of the district heating networks contributes to both energy savings and better economics. This is common sense and state of the art. The development will lead into the direction of improving the COP and increasing the cold to power ratio by multistaging. Along this line, one of the long-lasting topics is the waste heat (exhaust gas etc.) driven air-conditioner for mobile application. There is no significant progress up to now. In the recent years an additional problem arose: with the engines becoming more efficient year by year, the waste heat which is available to operate the sorption chiller decreases and the whole idea may become obsolete.

Primary energy saving can be achieved when regenerative energy is being used as driving input to the chiller, partly or in total. In addition, considering the problem of the mid-afternoon peak in electricity consumption due to electric chillers, the idea of solar chilling is intriguing from a demand-side consideration: the chilling demand at least to a significant extent goes parallel to the availability of solar irradiation. Therefore, the interest in **solar cooling** by sorption systems prevails since several decades. European R&D is quite strong in this area. Specific reviews on that topic have been written earlier by Lamp and Ziegler (1998), and, more recently, by Florides et al. (2002) and Papadopoulos and Kyriakis (2003). An overview about a dozen installations of commercialized systems in Germany can be found on a homepage of the IEA (2003).

In some places the 35 kW chiller by Yazaki is tested. But there is also progress in new chillers on the prototype or laboratory scale. A 10 kW Water-Lithiumbromide chiller which is in a pre-market stage has been presented by Storkenmaier et al. (2003). Another chiller of about the same size is being developed by the company EAW (2003). Smaller prototypes are reported on by Florides et al.(2002), and Sözen and Usta (2002). Also a small Ammonia-Water system is in development (Mendes and Collares-Pereira, 1999). There is also research on pumpless hermetic units using Ammonia, Water, and Hydrogen or Helium (Jakob et al., 2003). Last but not lest, several open systems are being installed and monitored as discussed above (ISE, 2004).

Conclusion

We will conclude this review with a personal view on the future of sorption systems: As for the working pairs, we think that Water-Lithiumbromide and Ammonia-Water will continue to dominate, however, a change to alternative pairs will happen for special applications.

Sorption chilling will stay strong where it is strong today, i.e. in the countries which suffer from a heavy mid-afternoon peak. As this will happen in Europe too, more sorption cooling will emerge here as well. However, sorption systems will not become mainstream in Europe but they will fill large niches, e.g. in total energy systems, and, probably in solar cooling. Much of the research on fundamentals or cycles is also devoted to this end.

Eventually, large selling numbers will be attained for heating systems when the step beyond the condensing boiler will be done.

References

Alefeld G (1983) Wärmeumwandlungssysteme. Skript zur Vorlesung, Lehrstuhl E19 des Physik Departments der Technischen Universität München. (partially published as Alefeld and Radermacher, 1994).

Altenkirch, E (1913-14): Reversible Absorptions-maschinen. Zeitschrift für die gesamte Kälte-Industrie, No. 1/1913, pp. 1-9; No. 6/1913, pp. 114-119; No. 8/1913, pp. 150-161; No. 1/1914, pp.7-14; No. 2/1914, pp. 21-24.

Aristov Y-I, Tokarev M M, Parmon V-N, Restuccia G, Burger H-D, Mittelbach W, Henning M-H (1999) New working materials for sorption cooling/heating driven by low temperature heat: properties. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 247.

Baksaas S, Grandum S (1999) Initial tests of high temperature absorption/compression heat pump. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 477.

Bassols J, Kuckelkorn B, Langreck J, Schneider R, Veelken H (2001) Trigeneration in the food industry. Proc. of the 2nd International Heat Powered Cycles Conference, Paris 6-7 September 2001, Conservatoire national des arts et métiers, 7 September, CD-Rom.

Bruno J C, Rivera W, Velázquez N, Best R, Coranas A (2003) Thermodynamic analysis of a directly couplet gax chiller/micro gas turbine combined system. Proc. of the Eurotherm Seminar 72 March 31-April 2, 2003, Valencia, Spain, pp. 369-374.

Buderus (2004) http://www.heiztechnik.buderus.de

Cerkvenik B, Poredos A, Ziegler F (2001) Influence of adsorption cycle limitations on the system performance, Int. J. Refrigeration, vol. 24, no. 6, pp.

475-485.

Corberán J M, Royo R (eds.) (2003) Thermodynamics, Heat and Mass Transfer of Refrigeration Machines and Heat Pumps. Proc. of the Eurotherm Seminar 72 March 31-April 2, 2003, Valencia, Spain.

Critoph R E, Tamainot-Telto Z (2002) Laboratory Demonstration of a Multiple Bed Regenerative Adsorption Cycle Air. ISHPC ' 02, Proc. of the International Sorption Heat Pump Conf., Shanghai, China, September 24-27, Science Press, New York, p. 571.

Eames I, Everitt P, Georghiades M, Tucker R (1999) Manufacture and testing of a prototype 30 kW combined ejector-absorption cycle refrigerator. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 585.

EAW (2003) private communication.

Eber, N (1968) Die Darstellung und Analyse von Absorptionskreisprozessen mit Hilfe des Temperatur-Entropie-Diagrammes. PhD thesis no. 4229, ETH Zürich.

Florides G A, Tassou S A, Kalogirou S A, Wrobel L C (2002). Review of solar and low energy cooling technologies for buildings. Renewable and Sustainable Energy Reviews, vol.6, pp. 557-572.

Ghiasi C (2004) Absorption-compression hybrid for solar cooling. Homepage of the Department of Energy Conversion Technology, Institute for Energy Engineering, Technical University Berlin: http://www.tu-berlin.de/fb6/lfmw/info.html.

Glebov D, Martin V, Setterwall F (2002) Heat transfer model of the single-effect absorption chiller. ISHPC ' 02: Proc. of the International Sorption Heat Pump Conf., Shanghai, China, September 24-27, Science Press, New York, pp.152-156.

Groll M, Klein H-P, Srinivasa Murthy S (2002) Metal hydride based thermal systems: a review. Proc. World Renewable Energy Congress VII (ed. A A M Sayigh), Elsevier Science Ltd.

Hauer A (2002) Thermal Energy Storage with Zeolite for Heating and Cooling Applications. ISHPC ' 02, Proc. of the International Sorption Heat Pump Conf., Shanghai, China, September 24-27, Science Press, New York, pp. 385.

Henning H-M, Erpenbeck T, Hindenburg C, Santamaria I-S (1999) The potential of solar energy use in desiccant cooling cycles. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 109.

ISE (2004) http://www.ise.fhg.de.

Jänichen J, Ackermann D, Stach H (2002) Adsorption Properties of Aluminophosphate Molecular Sieves-potential Applications for Low Temperature Heat Utilisation. ISHPC ' 02, Proc. of the International Sorption Heat Pump Conf., Shanghai, China, September 24-27, Science Press, New York, pp. 635

Jakob U, Schneider D, Eicker U (2001) Entwicklung einer solar betriebenen Kältemaschine basierend auf dem Diffusions-Absorptionsprinzip. Forschungsbericht 2001 des Joseph-von-Egle Institut für angewandte Forschung. Veröffentlichungen der Fachhochschule Stuttgart - Hochschule für Technik, vol. 55, pp. 7-11.

Jelinek M, Borde I (1999) Working fluids for absorption heat pumps based on R125 (pentafluoroethane) and organic absorbents. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 205.

Kessling W, Laevemann E, Peltzer M (1999) Open cycle liquid desiccant dehumidifier: Theoretical Potential, Experimental results, Applications. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 137.

Koyfman A, Jelinek M, Levy A, Borde I (2001) A study on bubble pump performance for absorption diffusion refrigeration system with organic working fluids. Proc. of the 2nd International Heat Powered Cycles Conference, Paris 6-7 September 2001, Conservatoire national des arts et métiers, CD-

Rom, 5 September.

Labidi J, Stitou D, Spinner B (2002) Cycle à sorption pour la production et le transport d'énergie thermique. Congrès Français de Thermique "Du moteur à explosion à la pile à combustible", SFT 2002, Vittel, France, ISBN 2-84299-375-6, pp. 691-696, 2002.

Lang R, Roth M, Stricker M (1999) Development of a modular zeolite-water heat pump. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 611.

Mendes L F, Collares-Pereira M (1999) A solar assisted and air cooled absorption machine to provide small power heating and cooling. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 129.

Meunier F (1999) Adsorption heat pump technology: possibilities and limits. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 25.

Neveu P (ed) (2001) Proc. of the 2nd International Heat Powered Cycles Conference, Paris 6-7 September 2001, Conservatoire national des arts et métiers.

Niebergall W (1959) Sorptionskältmaschinen. Handbuch der Kältetechnik Band 7. Springer Verlag, Berlin.

Nikanpour D, Hosatte S (1996) Towards Sustainable Technologies, Proc. of the 1996 Absorption Heat Pump Conf., IAHP, Montreal, Canada, Sept. 17-20.

Papadopoulos A M, Kyriakis S O N (2003) Perspectives of Solar Cooling in View of the Developments in the Air-Conditioning Sector. Renewable & Sustainable Energy Reviews, vol.7, pp. 419-438.

Petersen S (2004) Non-condensables in absorption heat pumps. Homepage of the Department of Energy Conversion Technology, Institute for Energy Engineering, Technical University Berlin: http://www.tu-berlin.de/fb6/lfmw/info.html.

Pons M, Kodama A (1999) Second law analysis of the open cycles for solid desiccant air conditioners. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 389.

Pons M (2003) A non-dimensional irreversibility balance for analysing energy conversion cycles. Proc. of the Eurotherm Seminar 72 March 31-April 2, 2003, Valencia, Spain, pp. 161-166.

Prelipceanu A (2003) The cooled gas turbine. http://www.ltk.mw.tu-muenchen.de/default.htm

Riebow D (2004) Absorption heat pump with sulfuric acid. Homepage of the Department of Energy Conversion Technology, Institute for Energy Engineering, Technical University Berlin: http://www.tu-berlin.de/fb6/lfmw/info.html.

Salcedo J, Nogues M, Leyva R, Coronas A (2000) Análisis dinámico de una enfriadora de agua por absorción en un banco de ensayos, 14th Congreso Nacional de Ingeniería Mecánica, Madrid.

Sahin D (2004) Study of absorption in a quasi-commercial LiBr-water chiller. Homepage of the Chair of Energy Conversion Technology, Institute for Energy Engineering, Technical University Berlin: http://www.tu-berlin.de/fb6/lfmw/info.html.

Storkenmaier F, Harm M, Schweigler C, Ziegler F, Albers J, Kohlenbach P, Sengewald T (2003): Small-Capacity Water/LiBr Absorption Chiller for Solar Cooling and Waste-Heat Driven Cooling, in Proc. of the 21st International Congress of Refrigeration, Washington DC, 17-22 August 2003, CD-Rom.

Sözen A, Usta D A H (2002) Development and testing of a Prototype of Absorption Heat Pump System Operated by Solar Energy. Applied Thermal Engineering, vol. 22, pp. 1847-1859.

Soto V M (2000) Transferencia de calor y masa en absorberedores de tubos horizontals que trabajan con la mezcla LiBr-H_2O. Universidad Politécnic de Valencia, PhD thesis, Valencia.

Tozer R, Lozano M-A (1999) Thermo-economic optimisation of a single effect absorption chiller and cooling tower. ISHPC' 99, Proc. of the 1999 Sorption Heat Pump Conf., München, Germany, March 24-26, pp. 417.

Venegas M, Rodríguez P, Lecuona A, Izquierdo M (2003) Spray absorbers in absorption systems using lithium nitrate-ammonia solution. Proc. of the Eurotherm Seminar 72 March 31-April 2, 2003, Valencia, Spain, pp. 19-24.

Ziegler F (ed) (1999) European research on solid sorption refrigeration. Special issue of the Int. J. Refrigeration, vol. 22, no. 1