ACTIVITIES IN THERMAL DRIVEN COOLING AT FRAUNHOFER UMSICHT

Peter Schwerdt, Fraunhofer UMSICHT, Department of Energy-Efficiency-Technologies
Osterfelder Str. 3, D-46047 Oberhausen, Germany, peter.schwerdt@umsicht.fraunhofer.de

Abstract: Thermally actuated cooling processes have reached a promising maturity to offer an environmentally acceptable solution to the growing demand for air conditioning. Using solar thermal energy, district heating or waste heat from cogeneration or industrial processes avoids the large electricity of conventional compression chillers, prevents grid overloads in summer and helps to save primary energy.

Several thermal driven refrigeration processes have been investigated and realized by Fraunhofer UMSICHT since the 1990s, with cooling capacities of 1 to 1000 kW. Some examples of steam jet ejector chillers, an adsorption system set up in Egypt and a novel membrane-absorption process as well as thermal storage with PCS/PCM are presented.

Key Words: Thermal driven cooling, Solar cooling, Steam-Jet-Ejector chiller, Absorption cooling, Membrane pervaporation, Water-Lithium bromide

1 INTRODUCTION

In most OECD economies buildings account for about 40% of all energy use and are the largest single usage sector, more than industry or transport. Therefore, with respect to climate change and declining fossile energy resources, strong efforts have to focus on the improvement of energy efficiency and savings of primary energy in the building sector. In residential and commercial buildings the provision of thermal comfort and air quality accounts for the greatest energy use. Beside better insulation of the building envelope, improvements should focus on HVAC equipment and utilize non-electric energy sources such as solar energy, district heating water or waste heat of small CHP-plants.

2 REFERENCES AND PROJECTS IN THERMAL DRIVEN COOLING

Fraunhofer UMSICHT develops applied and custom-made process engineering technologies. Assuming a leading position in the fields of environmental and material technologies, process engineering and energy technology, Fraunhofer UMSICHT is committed to sustainable economic development and environmentally friendly technologies. The department Energy-Efficiency-Technologies focuses on the intelligent integration of energy systems into existing and new supply structures as well as their efficient utilization. Besides strong activities in Energy Efficiency, Renewable Energies and Electric Energy Storage there is continuous R&D work in the fields of thermal energy storage and thermal, resp. solar cooling.

In the 1990s researchers at Fraunhofer UMSICHT worked on several thermally driven refrigeration processes. In 1998 a first steam jet ejector chiller system (SJEC) with a maximum cooling capacity of about 600 kW was put into operation in the city of Gera, driven by steam of a municipal power station and serving a district cooling network in the city centre (Figure 1).

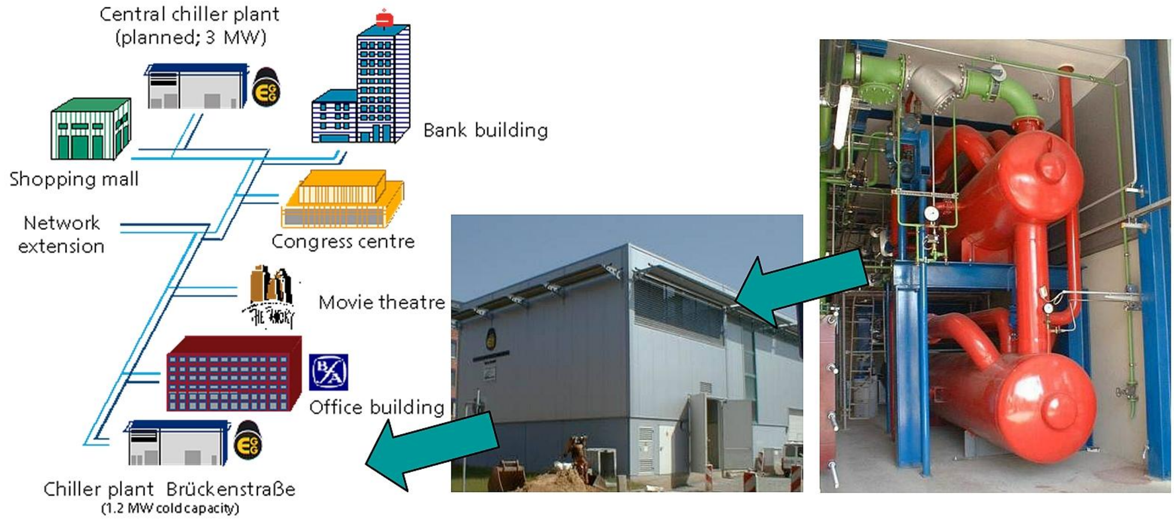

Figure 1: District cooling in the city of Gera with 600 kW steam jet ejector chiller

This system was also included in the "Study on Measurements of operational Optimization of Solar-thermal Driven Plants for Cold Generation", which was embedded in the IEA Task 38 "Solar Air-Conditioning and Refrigeration". Later on a SJE cooling system with a cooling capacity 1000 kW was designed and realized at a paper mill in Germany, driven by waste heat from a combined heating power plant.

Since 2002 a solar driven cooling system with vacuum tube collectors is being operated as a demonstration project at UMSICHT itself, feeding chilled water into the institutes air-conditioning (AC) network (Figure 2). The system consists of a collector field of about 100 m², supplying a 35 kW Yasaki WFC10 absorption chiller, and buffer tanks for heating water and chilled water. The system also allows free cooling and direct supply of hot water for heating purposes in spring or fall.

Figure 2: Solar Cooling demonstration plant at Fraunhofer UMSICHT with Yasaki WFC10 absorption chiller

Other projects focused on the development of a prototype SJEC with a small cold capacity of ~1 kW (with support by the Deutsche Bundesstiftung Umwelt), and two similar processes with ~5 kW (Pollerberg et al. 2009) and about 80 kW cooling power, see Figures 3 and 4 (supported by the Bundesministerium für Bildung und Forschung). The principle process diagram of a solar driven SJE chiller is given in Figure 5.

Figure 3: SJE chiller with 5 kW by Fraunhofer UMSICHT, as a contribution to the German-Austrian demonstration project "Solar Cooling" at Gleisdorf, Austria (Source: AEE Intec)

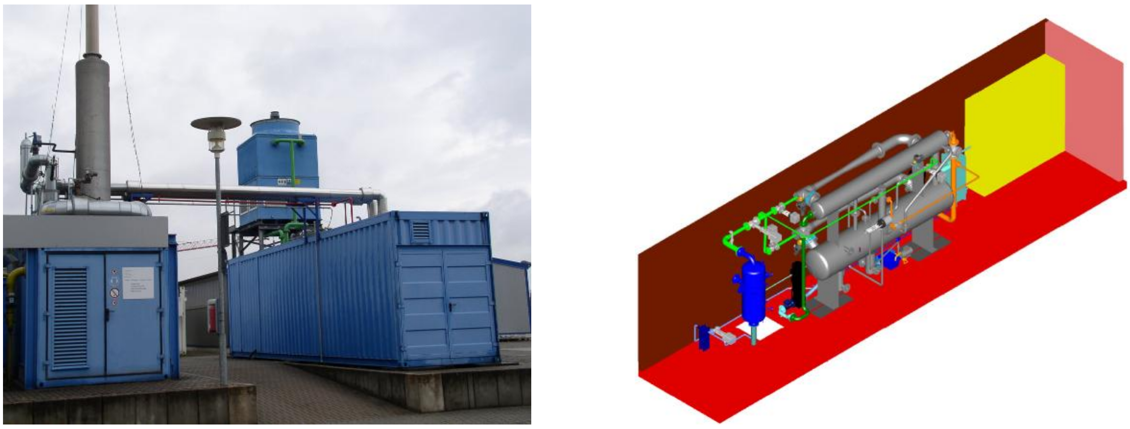

Figure 4: SJE chiller (cooling capacity of 80 – 200 kW) at Fraunhofer UMSICHT in standard container, driven by waste heat from a CHP unit

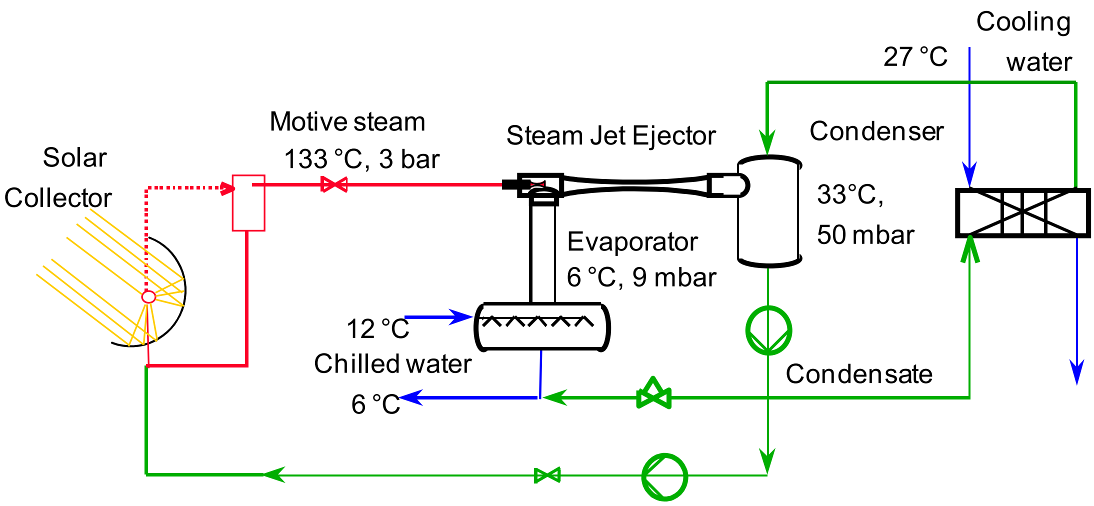

Figure 5: Process scheme of solar driven steam jet ejector chiller

In order to establish solar cooling of buildings as an energy-efficient and electricity saving technology in the Indian market, Fraunhofer UMSICHT and its cooperation partner »VSM Energy« founded the spin-off company VSM Solar PLC in 2011.

For demonstration purposes a solar driven cooling system of 60 kW will be installed at the companies building in Bangalore, supplying the AC with chilled water (Figure 6).

Figure 6: Design concept of company building with solar cooling – with roof mounted collector field (Fraunhofer JV VSM Solar, Bangalore, India)

In the frame of the German-Egyptian Joint Research Fund activities (GERF, supported by the Bundesministerium für Bildung und Forschung) a cooperation project was performed by the University of Assiut and UMSICHT. It aimed at the realization of an AC system powered by solar-thermal energy from a 40 m² vacuum tube collector field. The system with a 7.5 kW adsorption chiller as the key component was successfully put into operation in summer 2012, followed by long-term monitoring and performance measurements.

Figure 7: Solar cooling system at Assiut University (GERF demonstration project)

In continuing the R&D activities in thermal driven cooling processes a test bench for sorption heat pumps and chillers was set up in the department lab. For the time being it is used for experimental work with water/lithium bromide absorption cycles and their components, especially for the development of a membrane absorption process (as described below).

Figure 8: Test bench for sorption heat pumps and chillers at Fraunhofer UMSICHT lab

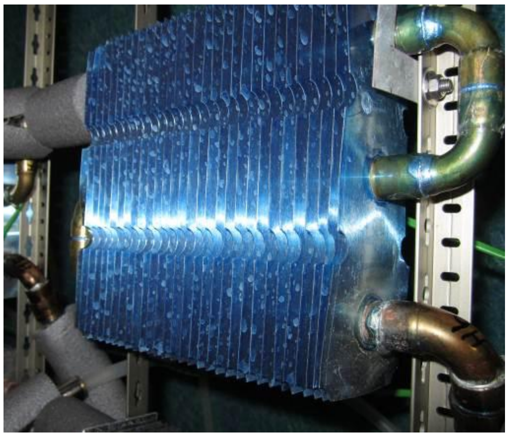

Figure 9: Long-term spray and performance tests on hybrid cooling towers for improved heat rejection of thermally driven chillers

To improve thermal transport and storage capacity of water based cold supply systems, intensive research work is being performed in the field of Phase Change Materials (PCM) respective slurries. Two demonstration plants are already realized based on ice-slurries for cold storage. Several actual projects are concentrating on Paraffin/water-dispersions for cold and heat storage, in various capacities, and with concern to e.g. thermal management of power batteries, mobile cooling, capillary tubes for wall/ceiling cooling, cold and heat storages with a small temperature shift (Kappels et. al. 2011).

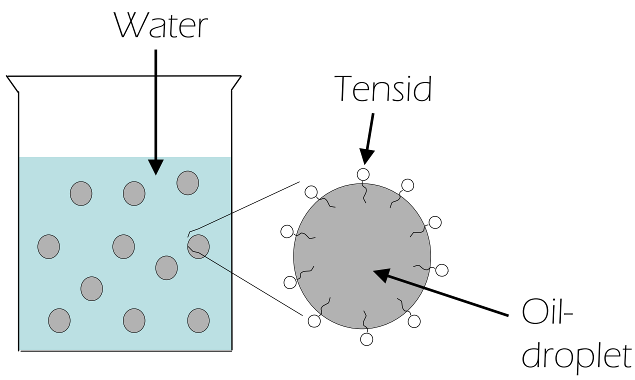

Figure 10: Paraffin/water-dispersion as phase change slurry for latent heat storage and transport

3 DEVELOPMENT OF A MEMBRANE ABSORPTION CHILLER

Since some years and mainly in Europe there is a strong scope on the development and market entry of small thermally driven heat pumps (i.e. cooling capacity 5-15 kW or more) which can be used for residential heating and cooling purposes.

Especially the water/lithium bromide (LiBr) absorption cycle, which is environmentally friendly and traditionally well established in large scale applications, still offers great promise as a high-efficient cooling process for small capacities as well. This technology could be used for non-electric driven residential cooling, driven by widely available low temperature heat. As a precondition, these units should be easy to install and to operate, which requires a significant reduction in size and weight, because space in private houses is strictly limited. Furthermore, reducing the initial costs is necessary to enable small absorption chillers entering the residential building market.

Fraunhofer UMSICHT is working on a new absorption process technology, aiming at replacing the traditional falling film shell and tube heat exchangers by a compact, stack-like design, using a pervaporation process with microporous membranes. A significant reduction of the unit size is expected by using flat plate modules. In this arrangement the refrigerant vapor (water) is passing through flat semipermeable membrane sheets to be absorbed in very thin LiBr-solution films, thus achieving large contact surfaces per volume for improved heat and mass transfer. To enable constant absorption, the heat of absorption is simultaneously transferred to the cooling water plate, forming the backside of the solution film. To achieve a certain absorption capacity several modules are integrated to one stack.

3.1 Membrane selection

Today a large variety of membranes is available for medical purposes or technical processes, such as filtration, desalination or sewage treatment plants. Also in the field of HVAC membrane technologies become more present, i.e. in so called enthalpy heat exchangers, recovering both heat and humidity in building ventilation systems or for cooling and air dehumidification in chilled ceilings.

In the beginning the focus was on selection of membranes which also meet the special requirements for use in a membrane absorber, as they especially must be compatible with the LiBr solution, reliably hydrophobic, mechanically stable and have a high refrigerant vapor transport capacity (flux). Like in conventional falling film absorbers also in a membrane sorption process the partial pressure difference is the driving force for the refrigerant mass transfer into (absorption) or from the solution (desorption). In pervaporation the driving force additionally has to cover the pressure drop caused by the membrane pores, which was evaluated in previous simulations of membrane absorption (Ali and Schwerdt 2009). A large variety of membranes from several manufacturers were investigated and characterized in a test cell to select the most suitable types.

Based on these results a modular stack design for membrane sorption was developed by adapting basic principles of plate heat exchangers and membrane filtration (Figure 11). The active membrane area was set to 180 x 250 mm (8 x 10“), corresponding to a common sheet format. From the results of previous screenings with various hydrophobic membranes a PTFE membrane with 0.45 µm pore size and 80% porosity was selected, which had had shown the best vapor flux, sufficient hydrophobicity and good mechanical stability. Design and assembling of the module components had to meet challenging requirements like being vacuum tight on the process side, leakproof and stable against the cooling water pressure.

After function testing of basic single-membrane-units a membrane sorption module with two active membranes, one cooling module and several variable features was built and tested.

3.2 Module design and experimental results

The performance of the membrane sorption process was experimentally investigated under realistic conditions of the external temperatures: T cold water : 9-17°C, T cooling water 28-32°C, T driving hot water 50-60°C. The external temperatures were supplied by two laboratory thermostats (Figure 12.). To cover both absorption and desorption conditions the operation parameters were varied in a wide range: starting from favorable absorption conditions the partial pressure difference was stepwise reduced and then inverted by increasing the solution and reducing the refrigerant temperature. This resulted in changing the absorption process smoothly to desorption, without interrupting the operation (Figure 13). The concentration of the supplied LiBr solution was in a range of 53-55 %.

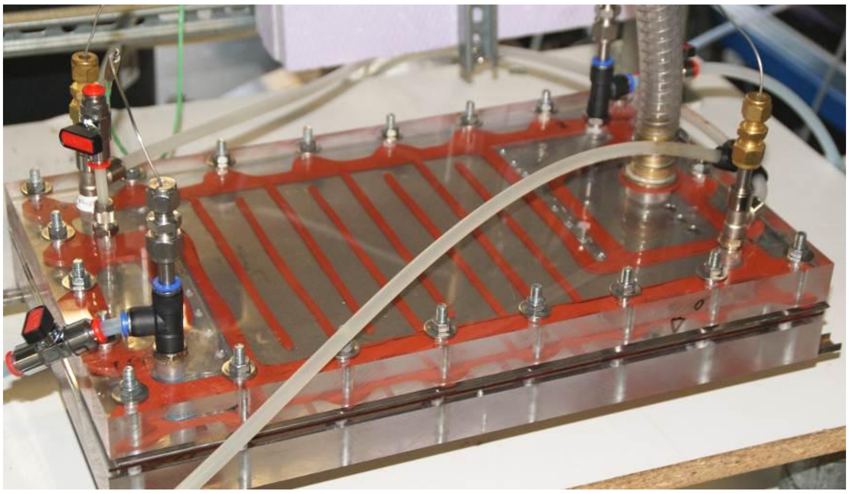

Figure 11: Membrane module for sorption performance testing in LiBr/H_2O-system

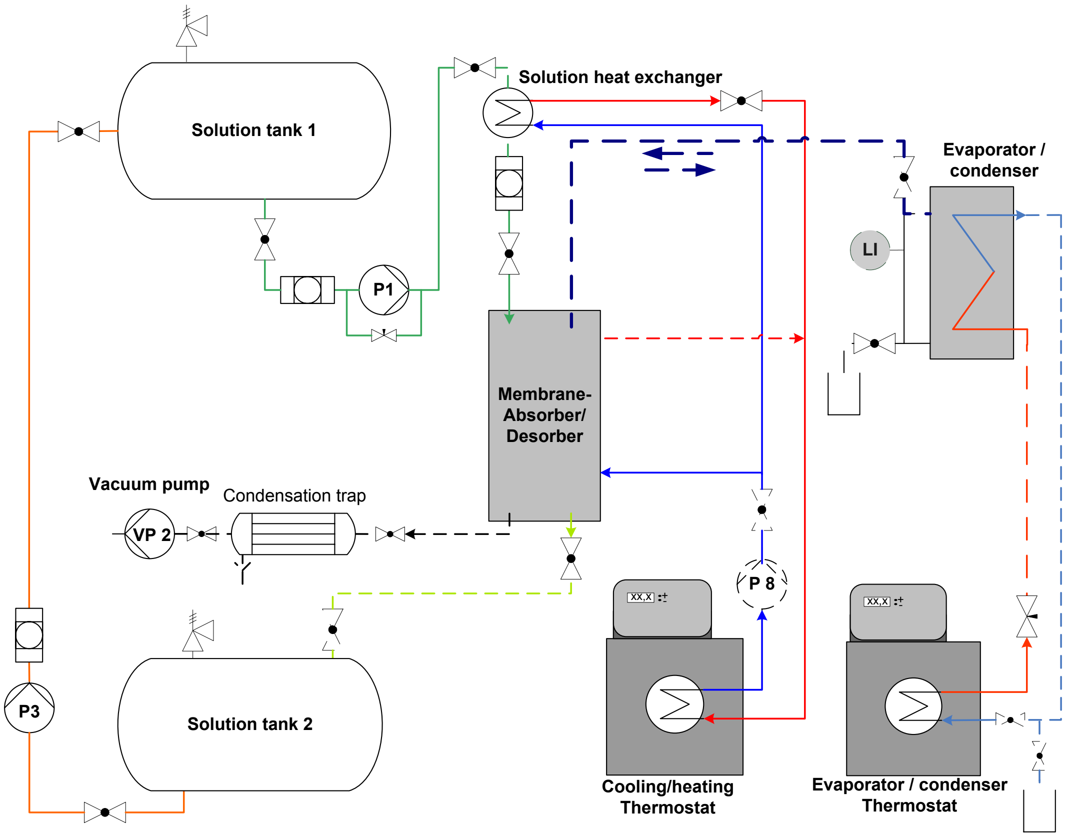

Figure 12: Experimental set up for membrane module investigation

The partial pressure difference as the driving force is calculated from the actual refrigerant vapor pressure p_v and the partial pressure of vapor in the solution p_s according to

$$\Delta p_{part.} = p_V - p_S \quad (1)$$

The solution partial pressure is determined from the solution concentration and temperature. The vapor flux was measured to 2.25 kg/m²/h at driving pressure Δp_{part} of just 0.9 kPa for absorption and 1.5 kg/m²/h for desorption conditions and Δp_{part} of 1.6 kPa.

It is obvious that these relatively low flux values are in line with the low partial pressure difference as the driving force.

The measurements of the trans-membrane vapor flux (represented by the exchanged heat) were performed with several parameters varied, e.g. the solution flow, the solution concentration, the film thickness and the spacers used in the vapor and solution channels.

The membrane process allows both absorption and desorption, with a slightly better performance of absorption, as displayed in Figure 13. Although different types of membranes were used, their results almost show similar trends. From these first results the total absorber membrane area of the scheduled LiBr-Water sorption chiller of 5 kW cooling power could be estimated to about 3.3 m² at Δp_{part} of 7 mbar. The desorber would need about 4.2 m² at 11 mbar Δp_{part}.

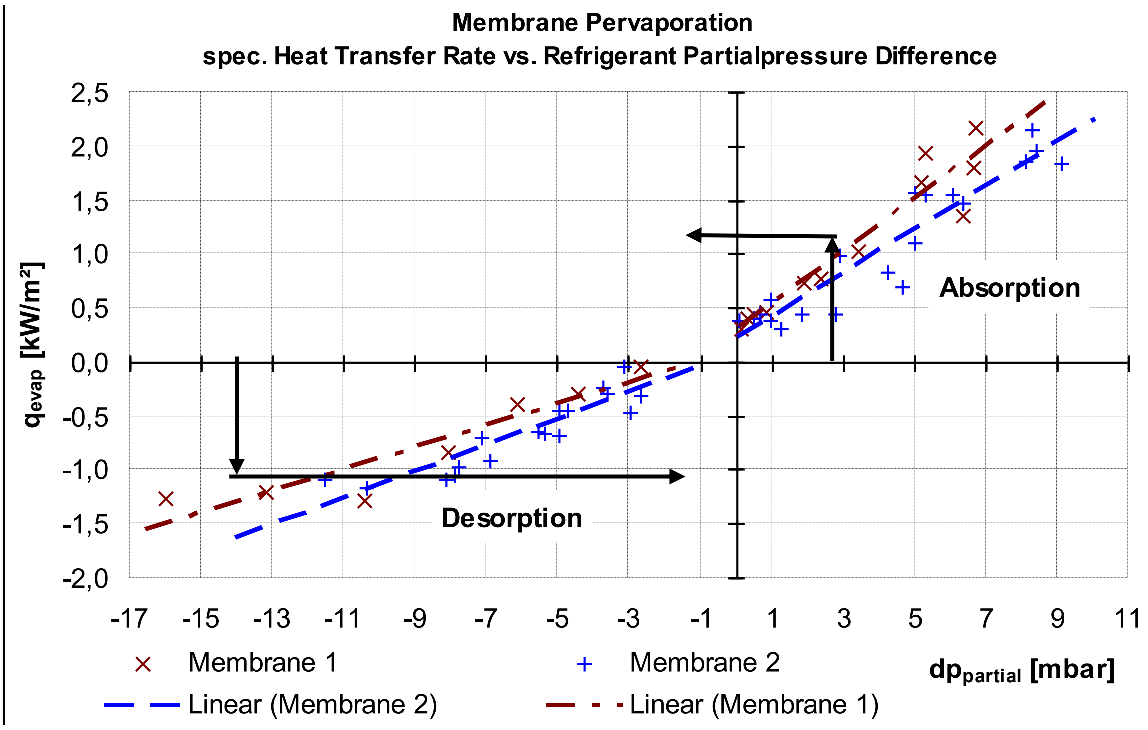

Figure 13: Performance of heat transfer rate vs. refrigerant partial pressure difference

3.3 Design concept for membrane-absorber and -desorber

For the layout-concept of a membrane sorption unit, like it is shown in Figure 14, some basic edge conditions were considered:

- absorption capacity of about 5.5 kW, desorption heat load of 5.9 kW
- flat plate stack with just a few different components made of stainless steel and non-metal materials
- all media connections (solution in/out, cooling/heating water in/out, refrigerant vapor) on the end plates
- cooling water module as a stable, pressure tight sandwich plate
- possible use of different types of membranes
- easy access of all media channels and spacers inside

With the required membrane area of about 3.3 m² and the actual component layout the membrane stack would consist of 76 membranes (absorber). To reduce this large number several modifications will be included to improve the module performance, like e.g. reducing the pressure drop of the vapor channel spacer. By a modified design the module thickness will be reduced additionally, so that the absorber stack will just have 56 membranes and a volume of 26 liters. The desorber would need 90 modules and 41 liters respectively. This could be drastically reduced by allowing an increased heating water temperature, which is available from solar thermal plants or other heat sources.

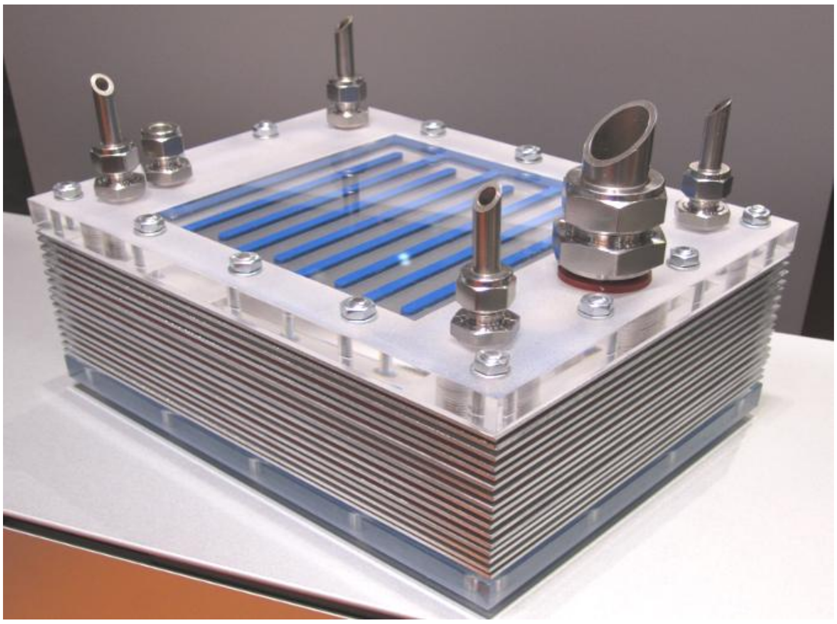

Figure 14: Design study of a multiple cell membrane stack for both absorption and desorption

3.4 Outlook

The membrane pervaporation process, realized in compact stack design with flat sheet membranes could replace the conventional falling film absorption and desorption apparatus in small scale chillers. The actual experiments with very low partial process driving pressures resulted in a vapour flux of 2.2 kg/m²/h heat flux, representing about 1.6 to 2.1 kW/m². The drafted module design seems promising as a basis for multiplication to achieve a nominal cooling capacity of 5 kW, producing chilled water of 17°C. Nevertheless the membrane module is subject to further modification concerning the membranes and the solution channel spacers. Emphasis will be put on increasing the vapour flux to reduce the number of required modules of the absorber and desorber stack.

4 SUMMARY

The worldwide growing demand for air conditioning requires the use of thermally driven cooling processes in order to save primary energy and to avoid overloads of the electrical grids. As an alternative to electrically driven compression cycles thermally actuated chillers could supply buildings and processes, powered by solar thermal energy, district heating or waste heat. Several technologies have been investigated and realized by Fraunhofer UMSICHT. In 1998 a steam jet ejector chiller (SJEC) with a cooling capacity of about 600 kW was erected in Gera (Germany). The system is driven by steam of a municipal power station and is serving a district cooling network. A similar process with about 1 MW was realized in a paper mill for cooling purposes. Small scale solar driven SJEC were built and tested at Fraunhofer UMSICHT and within an IEA cooperation project.

The institute´s solar cooling demonstration plant with a 35 kW Yasaki absorption chiller is operating since 2002. The system driven by solar energy from 100m² of vacuum tubes collectors and supplies cold water to the institute´s labs or feeds hot water into the heating system.

Recently Fraunhofer UMSICHT has started a joint venture with an Indian partner to promote solar/thermal cooling technology for the Indian Market. Actual research is focusing on PCM and PCS for heat or cold storage, thermo active building systems, thermal battery management etc.

A novel absorption process with water/lithium bromide is being developed for low capacity residential cooling, based on membrane pervaporation in compact, stack-type heat and mass exchangers.

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