ANNEX 34 –THERMALLY DRIVEN HEAT PUMPS FOR HEATING AND COOLING – AIMS AND STATE OF THE ART

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Abstract: Most heat pumps as well as chillers, providing the building sector with heat or cold respectively, are driven by electricity. However, the substitution of the electrically driven compressor by the use of a thermally driven might lead to significant primary energy savings, especially if the heat is provided via solar or waste heat. To quantify this, a project by the International Energy Agency (IEA), named Annex 34 – Thermally Driven Heat Pumps for Heating and Cooling, has been bring into being. In this article the general aim of Annex 34 is pointed out followed by a detailed Task structure with each corresponding goal. In addition, the technology is introduced containing the physical process of thermal cooling and an example of adsorber development as further an example of system integration. The article concludes with the state-of-the-art in Task development and future prospects.

Key Words: thermally driven heat pumps, absorption, adsorption, solarheat, waste heat

1 INTRODUCTION

The aim of Annex 34 is to reduce the environmental impact of heating and cooling by the use of thermally driven heat pumps with scope on domestic and small commercial buildings. Beside conventional heating systems the use of electrically driven heat pumps and chillers, providing the building sector with heat or cold, significantly increased within the last years. With regard to concerns over ozone-depletion and global warming effects of working fluids used in vapour compression devices and increasing grid loads thermally driven heat pumps and chillers provide an alternative. In addition, substitution of the electrically driven compressor by a thermally driven one could lead to significant primary energy savings, especially if the primary driving energy form (heat) is provided from solar systems or in combination with processes where heat is produced and cannot be further used (waste heat). It is based on the results of Annex 24, “Absorption Machines for Heating and Cooling in Future Energy Systems”, and cooperates with Task 38, “Solar Air-Conditioning and Refrigeration” of the IEA “Solar Heating and Cooling” (SHC) Implementing Agreement. Annex 34 is concerned with the development of performance evaluation standards and with further development of thermally driven heat pumps with higher efficiencies.

One of the main objectives of Annex 34 is to quantify the economic, environmental and energy performance of integrated thermally driven heat pumps in cooling and heating systems under various climatic conditions , different countries and applications. From this, those areas and applications with the greatest environmental benefit, the best economics and the greatest market potential will be identified.

2 STRUCTURE OF THE ANNEX 34 AND TASK DESCRIPTION

The work in this Annex 34 is organised in five Tasks that in turn consist of several work packages as documented in Figure 1. A more detailed Task description is given below.

Task A: Market overview/state of the art

WP 1 – state of the art/ country reports
WP 2 – Outlook
WP 3 – politics/ labeling

Task B: Performance evaluation

WP 1 – existing standards
WP 2 – Performance definition
WP 3 – Test procedures
WP 4 – Comparisions
WP 5 – Labeling

Task C: Apparatus technology	Task D: System technology
WP 1 – Methodology Characterization WP 2 – Database WP 3 – Stability WP 4 – developement of components	WP 1 – System design WP 2 – Integration WP 3 – Simulation WP 4 - Demonstration

Task E: Implemetation/ marked transfer activities

WP 1 – Best case examples
WP 2 – Guidelines
WP 3 – Dissemination

Figure 1: Tasks and work package structure of the Annex 34

Task A Market overview and state-of-the-art

Task A gives a survey on the state of the art of thermally driven heat pumps and their actual situation and future perspectives in the market of cooling and heating systems including the regulatory framework.

Task B Performance evaluation

Thermally driven heat pumps offer the possibility of primary energy savings compared to electrical compression systems. To evaluate the primary energy saving potential a comparison of both types of systems is carried out. Therefore a methodology of ‘how to determine the COP’ (use and spread EN standard) and a test procedure has been developed and proposed. Furthermore, the COP has been extended to an annual basis in order to allow a uniform and transparent comparison of a) heat consumption, b) required temperature level of the heat and c) work consumption.

Task C Apparatus technology

Task C deals with the apparatus technology of thermally driven heat pumps and brings together the broad field of ongoing developments of both materials and apparatuses. Even for differing technologies like absorption and adsorption some parts of the apparatus are exposed to the same problems (e.g. vacuum, corrosion, evaporator/ condenser efficiency etc.). The aim of this Task is to identify the overlap between different technologies and to make synergies possible. As a basis for research on the apparatus, properties of materials and working pairs is collected and brought together in a database. In addition a common measurement procedure for evaluation of materials for heat pumping application has been proposed and is discussed with the international experts.

Task D System technology

Task D deals with the system technology and gives a survey on the different ways of integrating the apparatus in the system of heat sources and sinks (integration of heat rejection, air/ground- heat sources, efficient burners) and different control strategies. Several ways to visualize a more generic system layout and best case examples are collected.

Task E Implementation

Task E concludes the results of Task A, B, C, and D and will transfer them to the target audiences in terms of a handbook and several workshops. Target audiences are manufacturers of components, suppliers of systems, planers and installers.

3 PARTICIPANTS AND TIME SCHEDULE

Currently 19 organisations from 9 different countries participate at Annex 34 while the work is observed from UK (which actually just joined in again the heat pump program), Japan, Sweden, Spain and Rumania. (list of participants on web-page: http://www.annex34.org)

Operating agent is Fraunhofer Institute for Solar Energy Systems (ISE) from Germany and the Task leadership is subdivided as described in the following:

Task A **First: Energy research Centre of the Netherlands (ECN), Netherlands**
Now: Fraunhofer Institute for Solar Energy Systems (ISE), Germany

Task B **Austrian Institute of Technology (AIT), Austria**

Task C **Institute of Advanced Energy Technologies (CNR-ITAE), Italy**

Task D **European Academy of Bozen/Bolzano (EURAC), Italy**

Task E **Technical University of Berlin (TU-Berlin), Germany**

The work on Annex started in October 2007 and will end in December 2011.

4 TECHNOLOGY - INTRODUCTION

4.1 The physical process of thermal cooling and adsorber development example

Today the ‘grid-driven’ vapour compressor is most frequently used to produce heat or cold (e.g. vapour compression chillers for air-conditioning, fridges that are installed in almost every household, the heat pump or the air conditioning system in a car). The basic components of a compression chiller or heat pump respectively are evaporator, compressor, condenser and expansion valve. During the process heat is removed from the environment at the evaporator at low temperature level, compressed and accordingly heated (compressor) before it is rejected to the environment via condenser at high temperature level. To run this kind of ‘heat pump’ process, electricity is required in order to compress the refrigerant.

In contrast to this, a thermally driven compressor is applied in sorption machines. The following briefly explains the underlying physical process, illustrated by an experiment [2].

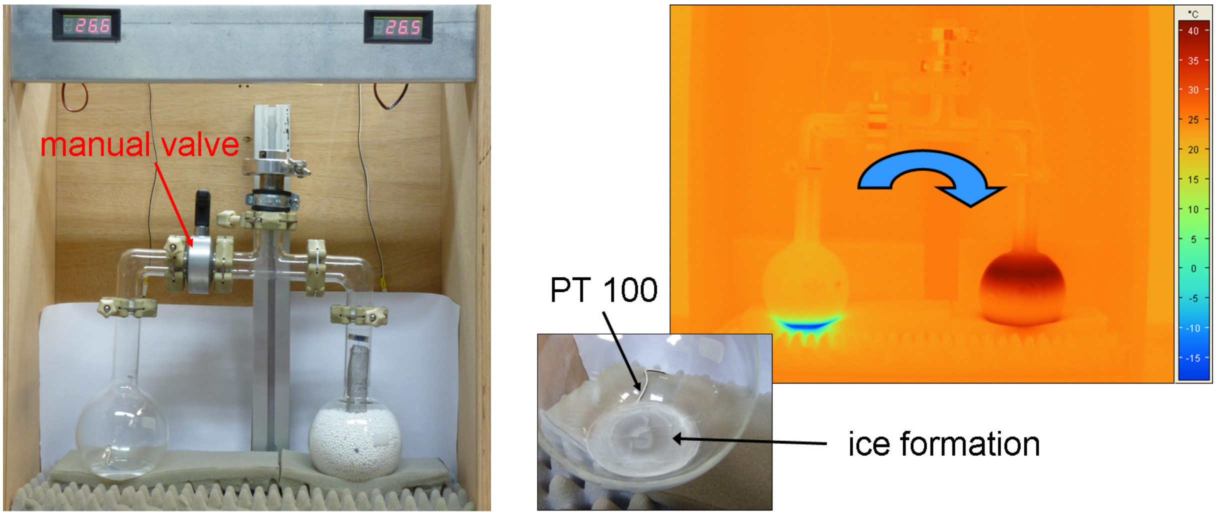

Figure 2: Experimental set-up to demonstrate sorptive heat pumping in a thermally driven adsorption chiller (left). The thermal image (right) shows the temperature distribution in the equipment after opening the valve between the flask containing water and the flask containing the zeolite (white spheres). The inset picture shows ice formation in the water from which water vapour is being evaporated [2].

The left hand photograph in Figure 2 shows the experimental set-up at starting conditions (steady state), i.e. ambient temperature ($\vartheta_{amb} \approx 26{,}5°C$, as can be seen on the temperature display at the top). The set-up consists of two vacuum-tight round-bottom flasks containing water (left) and dried zeolite (right). These two flasks are connected via an isolating valve, which is initially closed.

By opening the valve, the previously dried zeolite, which is highly hydrophilic, a mass transfer of water vapour (cf. blue arrow) occurs). The adsorption process is exothermic (i.e. heat is released), which causes the temperature increase if the the zeolite to approximately 50°C. The water vapour pressure in the whole system is reduced, as water molecules are adsorbed at the zeolite's surface. Therefore, the zeolite acts as a water vapour sink, continuously taking water vapour from the water reservoir. This, in turn, causes continuous evaporation of water in the left-hand flask. The overall effect is that heat (thermal energy) is pumped from the left-hand flask to the right-hand flask, so that the temperature on the left decreases while the temperature on the right increases. Heat and mass transport are shown in the right-hand picture by the blue arrow against the thermal image, with the temperature scale showing the temperatures of the various parts. As can be seen in the inset picture, the latent heat necessary for evaporation is very much larger than the sensible heat content of the water volume, with the result that the water reservoir freezes.

The adsorption process continues till no more water vapour is available or, in practice, the zeolite is saturated, i.e. unable to adsorb any more water. Unlike compression systems or absorption systems the adsorption heat pump has a cyclic behaviour. With regard to the actual implementation, at least two heat exchangers are used to supply heat for the vaporation (i.e. cooling of the heat exchanger's fluid circuit) and to remove the heat from the zeolite (e.g. heat rejection to a cooling tower, or useful heat). For quasi-continuous operation the adsorption material must be regenerated. This requires heat in order to remove the water molecules from the surface of the zeolite (desorption process). Suitable sources of heat can be solar energy, waste heat or in case of a heat pump heat generated by a conventional burner.

The driving force behind thermally driven absorption machines is similar (adsorption versus absorption affinity). However, in the absorption case, solid material is replaced by a liquid mixture, which requires significant considerations in constructing machines (e.g. a solvent pump is required) and in system management.

The work within Task C focuses on material development, i.e. solid sorption materials, but also entire component development in order to develop highly efficient machines.
With regard to some limitations of current available adsorption systems in terms of heat and mass transfer the research on the component level focuses mainly on evaporator and absorber and adsorber development. As example the evolution of such a adsorber unit starting with state of the art up to highly efficient adsorbers is presented here [3].

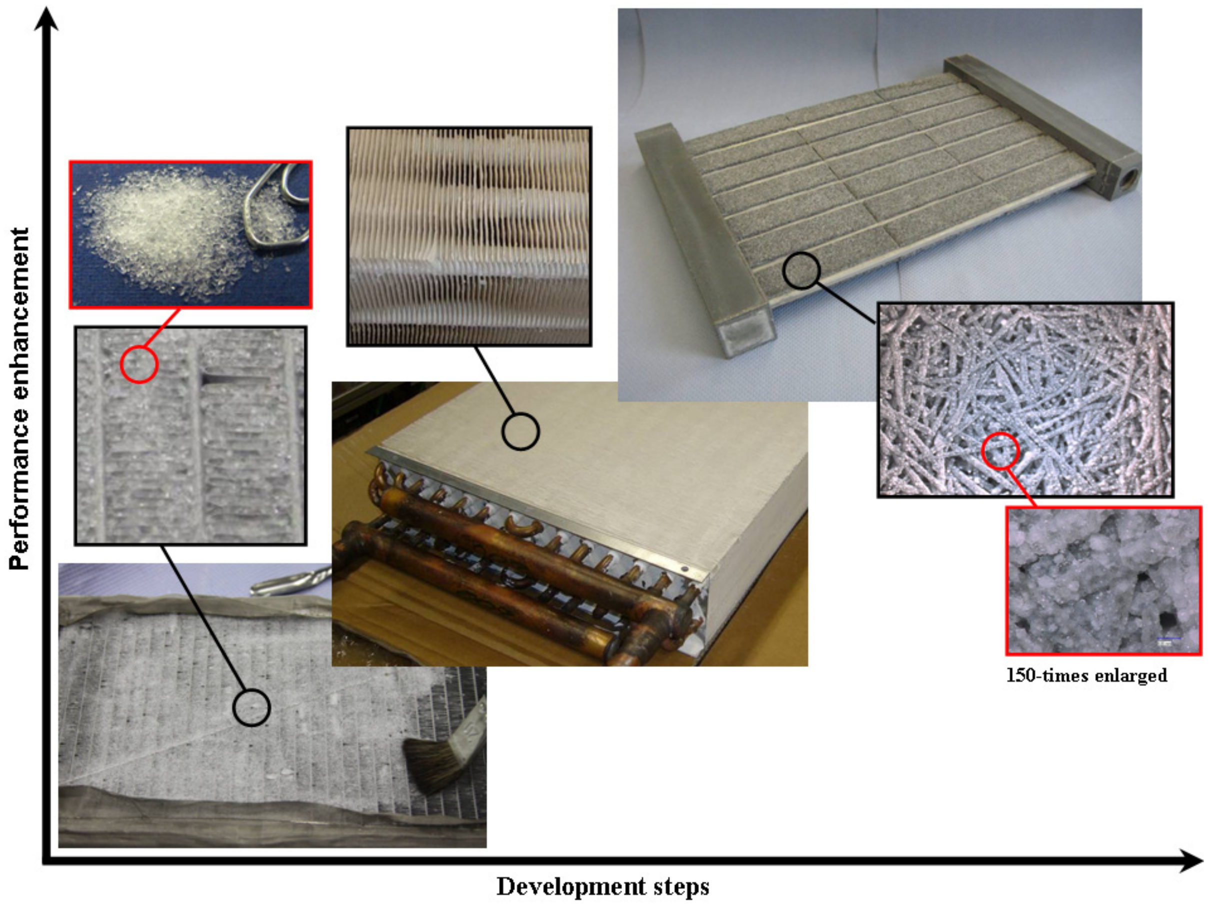

Figure 3: Different evolution steps of the performance enhancement in adsorber development: Packed-bed heat exchanger (left), binder based dip-coated lamella heat exchanger (middle) and direct crystallisation connection of the sorbent (right) on 3D-metal structure heat exchanger [3].

Figure 3 illustrates the performance enhancement of the adsorber heat exchanger in several development steps. The left-hand photo shows an automotive cooling unit used to create a packed bed adsorber where the sorbent is prevented from falling out at the bottom by a wire mesh, and a brush helps to fill in the sorbent very closely. Although the volume specific density (sorbent per volume) is very high in this case, the thermal connection between the sorbent and the heat exchanger fin is fairly poor. Due to the fact, that in best case there are more or less two point contacts between the spherical granule and the heat exchanger fin, the heat transfer arising form the adsorption process from the granules to the heat transfer fluid is limited. To overcome this, for example a binder based dip coating of the lamella heat exchanger can be applied as next step (middle). Here, a uniform connection is realised all over the heat exchanger and only small air gaps (if any) exist between sorbent and fin. However, with increasing thermal conductivity, the heat transfer may be again the limiting factor. Therefore, finally, a direct crystallisation connection, as can be seen in the right hand photograph (150 times enlarged), can be done on top of a metallic short fibre structure (sinter-fused structure), giving an enormous increase of surface area (3-D). This combination provides both good thermal conductivity in the metal and an excellent sorption-material-to-metal-mass ratio.

Annex 34 participants use the web page www.annex34.org to share latest material information and to create an overall material data base.

4.2 System integration

The sorption technology can be integrated in several ways. One example to use solar radiation for cooling in summer (cf. cooling mode) is presented via a scheme in Figure 4 [1]. Here, 'heat' is removed from the chilled water circuit (cold creation) and rejected to the environment due to the cooling tower (cf. heat rejection).

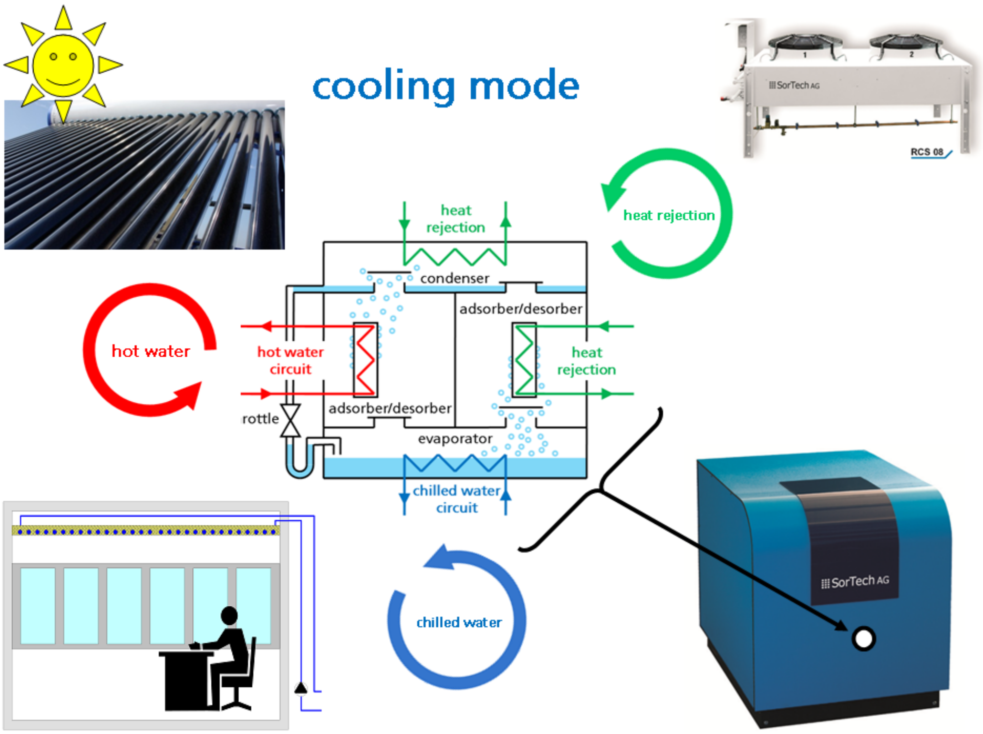

Figure 4: Scheme of a thermally driven adsorption machine in cooling mode using solar energy as driving force. Internal action in the machine (bubbles indicate the motion of the water vapour) and hydraulic connections are shown [1].

In winter mode, the hydraulic connection is adapted and the machine operates as one typically understands the work of a heat pump. Thus, the evaporator is linked to a ground heat source and the heat rejection circuit to floor heating for example.

Work in Task D focuses on turning out how to integrate the apparatus into the system in order to save primary energy as best as possible.

5 TASK DEVELOPMENT – STATE OF THE ART

According to the Task description in '2 TASK OVERVIEW AND GOALS' the state of the art is described here:

Task A Market overview and state-of-the-art – Several Country Reports were collected and first results are published in a contribution of to the 10th IEA Heat Pump Conference 2011 [4]. Much work has been carried out to rebuild the web page fundamentally (www.annex34.org) in order to simplify the teamwork of the contributing participants and to scan the market for currently available products. Unfortunately, an application for EU funding, aiming to ensure the cooperation of the participants beyond the project duration failed, but a second has already been resubmitted. The deliverables, i.e. up to date information on market overview with possible applications and examples of demonstration projects or cases – published at the Annex 34 internet web page at the same time – as well as a technical report of state of the art, will be completed at the end of April 2011. An existing nice overview on problems and solutions of adsorption heat pumps can be found in [5].

Task B Performance evaluation – The database of existing standards was updated with new and revised documents currently under revision or development (e.g. EN14825, EN12309) and is almost completed. On European level the Kemna model is now obsolete and the commission currently sends out a proposal for a labelling based on EN 14825. The revision of EN12309 is nearly completed and the new version will include auxiliary energy and further specific test conditions in order to calculate seasonal performance indexes. Discussions to split this standard into two parts are still open as well as the question of how to include water fired/ indirect fired machines. Results will be accessible on the internal webpages. The German directive (VDI-Richtlinie) has already been published. A final proposal for the definition of performance figures was presented agreed upon and will be finalised soon. Work on test procedures still consumes lot of effort. The outcome - i.e. a proposal for a description of a standard to determine COP values and other energy performance figures of TDHPs and of systems using TDHPs - has been divided into four technical reports.

Task C Apparatus technology – The sorption material database has been expanded on the internal web pages with further material data according to the proposed measurement procedures. This includes mainly new promising commercially available silica gels and zeolites.

A technical report on the different technologies, their potentials and limits will be provided soon. A first description of possible standards to determine sorption material properties and a comparison on two reference materials have been presented at the ISHPC in Padova [6].
In addition work on stability investigations of sorption materials has been carried out [7, 8].

Work on continuous extension of the database, material sources and experimental expertise is also being carried out.

Task D System technology – A template to summarise data from existing plants has been developed. First results (13 templates) were already gained, providing information on system understanding, i.e. how does the TDHP work (proper functioning), how it is integrated (system components) and how does it operate within the whole system (control strategies). This included calculation of the system performance by analysing the monitoring data. According to Task 38 the nomenclature to describe the system has been changed. In addition, available tools for the design of TDHP systems and for calculating their energy and economic performances were summarised. Both simulations and calculations will be completed till the end of May as well as case studies will be available.

Task E Implementation – A number of useful demonstration projects have been collected. Authors as well as responsible authors for most chapters of the planned handbook have already been decided upon. It is planned to finish the first chapters, i.e. an overview of standards as the outcome of Task B, at the beginning of 2011. Several workshops have been carried out to promote the idea of thermally driven heat pumps.

6 CONCLUSION

Annex 34 aims to promote efficient heating and cooling by the use of thermally driven heat pumps. To do so it collects the international state of the art, proposes standards for performance evaluation of these kind of heat pumps and procedures of material- and performance measurements as well as best case examples and system integration. It is spreading its results in several international papers and workshops as well as through its web-site http://www.annex34.org and aims to provide a state of the art handbook at the end of the annex in 2012.

7 REFERENCES

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