Testing of an adsorption chiller prototype for data center cooling

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Abstract

The main objective of this study is to present a novel adsorption chiller prototype (designed and realized by the company Sorption Technologies GmbH) that is suitable for cooling of data center servers. This prototype has been designed to fit into commercially-available data center racks. This adsorption prototype has been designed to cool down the rack servers by means of liquid cooling. Furthermore, an air-cooler heat exchanger is also integrated into the adsorption machine to cool down the rest of the rack components (i.e., patch panels, HDD). This way, the adsorption system is able to cool down all rack components. Phase-change chambers are integrated into the adsorption modules for direct evaporation/condensation, removing the need of large vacuum valves and allowing to have a more simpler and compact vacuum system. This also means that the refrigerant distribution is completely done in liquid phase. The prototype is installed at the Department of Energy at the Politecnico di Milano and testing will be carried out using cooling water temperatures in the range 25 – 30 °C and hot water temperatures in the range 55 – 65 °C.

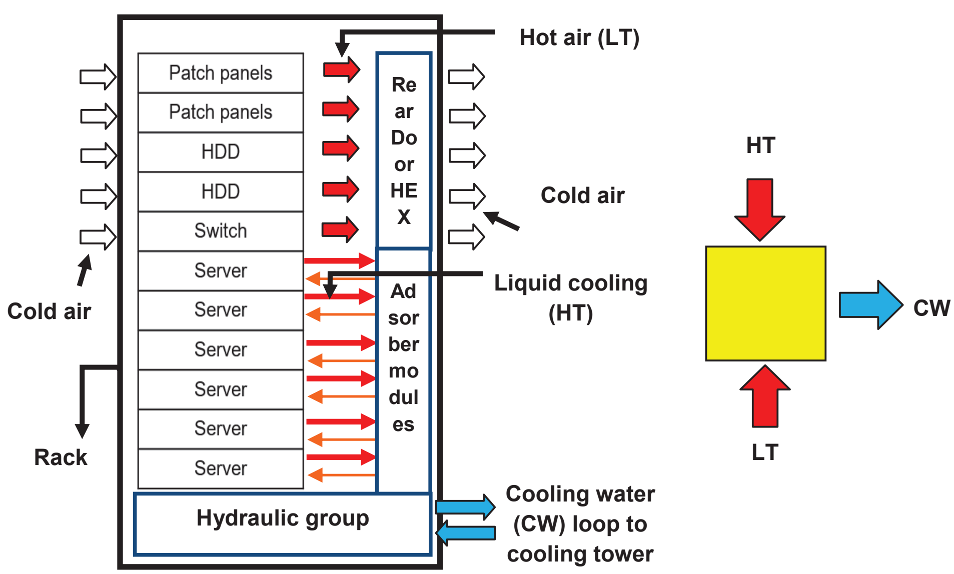
Keywords: adsorption, cooling, data center, energy efficiency.

Introduction

Adsorption cycles are refrigeration systems that can produce a cooling effect using low-temperature heat sources (lower than 90 °C), such as waste heat [1] and hot water from solar collectors [2]. The core system of an adsorption unit is generally composed by an evaporator, a condenser and two adsorption beds; these sorption beds are devices that carry out the thermo-chemical compression of the refrigerant. The working principle of an adsorption cycle contemplates simultaneous adsorption/evaporation and desorption/condensation processes. Since the evaporator's performance can represent a bottleneck situation for the overall performance of the machine, different configurations have been studied in literature, such as pool boiling [3] and falling-film evaporators [4].

Considering that different applications may produce waste heat at a temperature high enough to drive the adsorption machine, their range of application can always be increased, and one of these applications can be using waste heat from data centers to produce the required cooling for the server racks. Data centers energy consumption has become an important topic to discuss and analyze [5]. Their biggest energy consumption is related to IT equipment power (e.g., computer hardware and severs) and cooling, with the latter being responsible for 40 % of the total energy consumption of a data center [6]. For an air-cooled data center, the cooling plant is composed by the installed mechanical equipment and the heat rejection system. Direct expansion systems using a computer room air conditioner can be used for data center cooling, with air-cooled condensers as the heat rejection system [6]. Chilled water systems can also be used for high IT power densities, but the introduction of fans and chillers results in extra energy costs [7]. Cooling systems that employ air also present some

disadvantages related to air management, such as cold-air bypass and generation of hot spots. Liquid cooling possesses several advantages that can help to reduce the cooling system energy consumption. The most important advantage of a liquid cooling system is a higher heat transfer capacity per unit, which means a reduction in required equipment, facility cost and a higher reliability of the cooling system [7]. Adsorption chillers for data center cooling were first proposed by the company Fahrenheit GmbH (SorTech) with the Leibniz Supercomputer Center (LRZ), where direct liquid cooling for the SuperMUC-NG supercomputer is done by means of a centralized adsorption system [8]. This installation proves the feasibility of the concept along with energy savings, with the only disadvantage for broad applications being the centralized system piping design and complexity.
The aim of this work is to present the concept of an adsorption chiller prototype that could be used for cooling individual racks from a data center. The prototype, designed and realized by the company Sorption Technologies GmbH, is located at the Department of Energy at the Politecnico di Milano. This adsorption chiller design has been patented by Sorption Technologies GmbH and its inventor Walter Mittelbach under publication number WO 2021/089818 (European Pattent Office EP4055330) [9]. The core system of the adsorption chiller includes two adsorption modules each integrated with a phase-change chamber for direct evaporation/condensation. The use of direct evaporation/condensation means that refrigerant distribution within the cycle is done completely in liquid phase, with no refrigerant transport in vapor phase nor large vacuum valves; furthermore, this also means a more simpler and compact design. The analysis of the energy balance of this new machine is shown in Figure 1. As can be seen from said figure, this prototype provides the idea of a rack-integrated adsorption chiller, where the heat removed from the servers by means of liquid cooling is used as driving heat source in the adsorption modules (this driving heat from the servers is referred to as high-temperature energy source in Figure 1, HT). Heat from other components from the rack (i.e., patch panels, HDD) can also be removed by means of an air-cooler installed at the top of the modules (referred to as low-temperature energy source in Figure 1, LT). This way, the adsorption machine is able to remove all heat from all the components of the rack. Another important highlight of this prototype is that heat rejection can be done through a cooling water loop that can be directly connected to a cooling tower without any components in between.



(a) (b)

Figure 1. Rack-integrated adsorption chiller: (a) scheme, (b) energy balance

Discussion and Results

The experimental set-up of this study contemplates the adsorption chiller prototype as well as the external water circuits connected to it, as shown in the scheme from Figure 2. A picture of the assembled adsorption prototype and its components is shown in Figure 3.

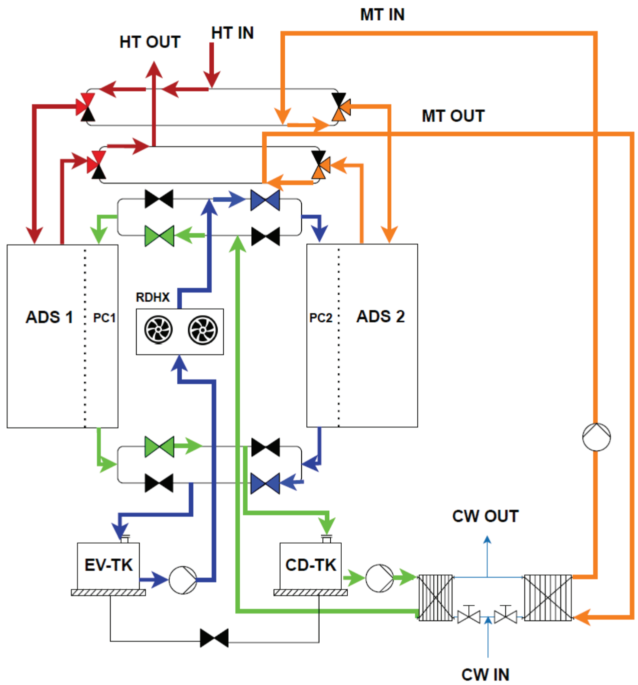
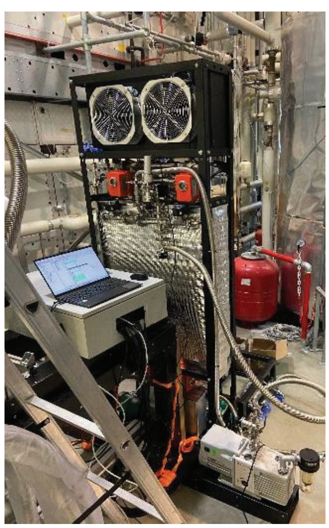
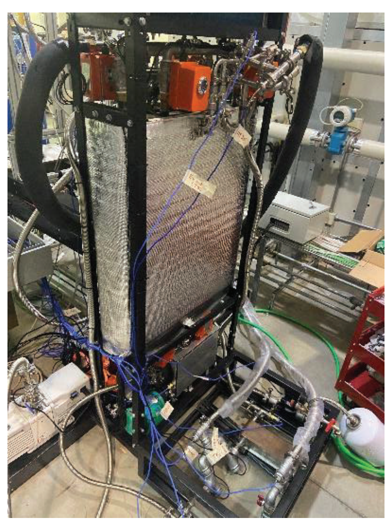


Figure 2. Experimental set-up scheme



(a)



(b)

Figure 3. Adsorption chiller protype: (a) back (b) front

As detailed in Figure 2, the adsorption chiller prototype is composed by two adsorption modules (employing silica gel pellets as adsorbent media) with two internal phase-change chambers ("PC1", "PC2"), an air-cooler heat exchanger ("RDHX"), two small refrigerant tanks (one for the condenser, "CD-TK", and one for the evaporator, "EV-TK"), circulating pumps for the condenser and evaporator loops, and two plate heat exchangers. Both the refrigerant and water flowrates are redirected accordingly using three-way and two-way valves. The two tanks "CD-TK" and "EV-TK" are also connected between them for refrigerant mass transfer. Furthermore, the external water circuits are identified as hot water (HT) and cooling water (CW) temperature circuits, while an internal medium-temperature (MT) water circuit is used to cool down the adsorbers during adsorption/evaporation. Water temperatures are measured on different points of the system using PT-100 and PT-1000 temperature sensors, while pressure from one module can be measured through a vacuum pressure transmitter (range: 0 – 20 kPa, accuracy 0.5 % FS). The water from the CW circuit is prepared at a given setpoint temperature using two flowrates from a 4000 L hot water tank (heated up with a 15 kW electric resistance) and a 3000 L cold water tank. The HT water is prepared using a separate water circuit with a 200 L tank and a 9 kW electric resistance. The working principle of this new adsorption chiller contemplates cyclic adsorption/desorption processes, as well as heat recovery stages, which are all organized into four phases. These four phases are illustrated in Figure 4, while the description of each phase is detailed as follows:

1) **Desorption in module 1 and adsorption in module 2:** during the first phase, shown in Figure 4.a, the hot water directly enters module 1 for desorption/condensation. Once the refrigerant is desorbed, it condenses on the bottom of the "PC1" chamber and falls to the "CD-TK" tank; it is then pumped to the "PHE2" heat exchanger and rejects heat to the CW circuit, before going back to the "PC1" chamber to carry more condensed refrigerant. Simultaneously, adsorption/evaporation happens inside module 2. A fraction of the liquid refrigerant entering the "PC2" chamber evaporates and is adsorbed, while the rest falls to the "EV-TK" tank. The refrigerant is then pumped and circulates through the "RDHX" heat exchanger before entering again into the "PC2" chamber for further evaporation/adsorption. The water circulating inside module 2 is heated up by the adsorption process and rejects heat to the CW circuit through the MT loop.
2) **Mass transfer and heat recovery (cooling of module 1):** when phase 1 is over, the pressure inside the modules needs to be readjusted to switch their operation from adsorption to desorption, and vice versa. As can be noticed from Figure 4.b, hot water begins to circulate in module 2, to increase its pressure. The cooled down water from module 2 flows (through the MT loop) to module 1 to decrease its pressure. During this phase, the refrigerant circulation is interrupted (i.e., pumps are turned off). Furthermore, the remaining refrigerant to in the phase-change chambers exit to either "EV-TK" or "CD-TK".
3) **Desorption in module 2 and adsorption in module 1:** this phase analysis is similar to that of phase 1, with the only difference being the internal operation of the modules. Hot water now circulates inside module 2 for desorption/condensation, while water from the MT loop is redirected to module 1 for adsorption/evaporation. Considering the refrigerant loop, circulating pumps are turned on again and the refrigerant circulates through the "RDHX" and "PC1" for adsorption, and also through "PC2" for desorption. This phase is visually presented in Figure 4.c.
4) **Mass transfer and heat recovery (cooling of module 2):** the final phase, shown in Figure 4.d, follows the same principle of phase 2, in which there is heat recovery to adjust the pressure within the modules. The HT loop is redirected to module 1, and the

resulting cooled down water enters module 2. Circulating pumps are turned off, and the remaining refrigerant exits to the “EV-TK” and “CD-TK” tanks.

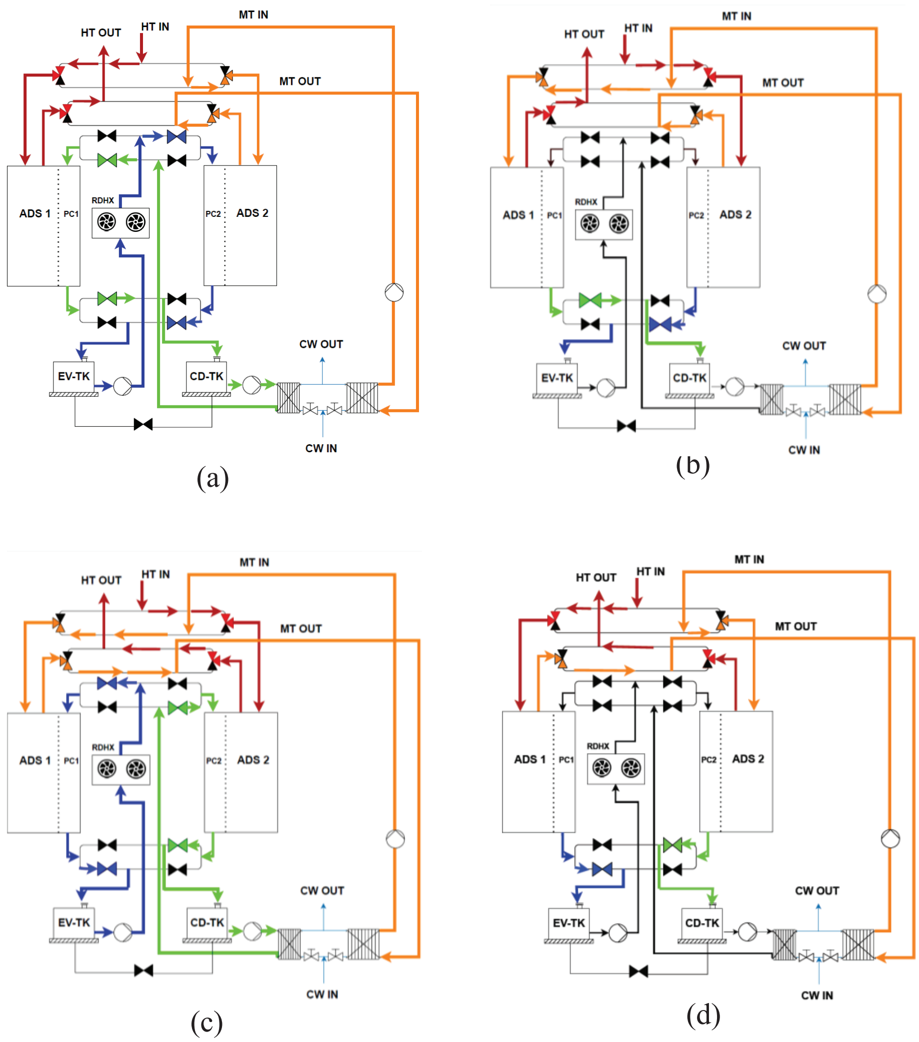


Figure 4. Working phases: (a) Phase 1, (b) Phase 2, (c) Phase 3, (d) Phase 4

Experimental tests are scheduled to be performed considering an inlet HT temperature of 65 °C and inlet CW temperature of 25. Furthermore, HT flowrate is set to 2.3 m^3/h while the CW flowrate is set to 2.1 m^3/h.

Conclusions

In this article, a novel adsorption chiller configuration for rack-based server cooling is presented, with the first prorotype installed at the Department of Energy of the Politecnico di Milano. This new system contains adsorption modules that have their own phase-change chambers integrated into their architecture. In these chambers, direct evaporation/condensation is carried out, allowing to have the refrigerant distribution completely done in liquid phase. Furthermore, by having the refrigerant distribution completely in liquid phase, the adsorption system can have a more simpler and compact design.

This rack-integrated adsorption chiller is designed to remove the heat from all the components of the rack and use it as heat input to carry out adsorption/evaporation and desorption/condensation. Rack servers can be liquid cooled, while the rest of the rack components (i.e., patch panels and HDD) that cannot be liquid cooled, can be air-cooled with the rear-door heat exchanger (RDHX). The high-temperature (HT) heat source from liquid cooling is used as driving energy source for desorption, while the low-temperature (LT) heat input from the air-cooler (RDHX) is used in the evaporator loop. This way, by means of an air-cooler and liquid cooling all components of the rack can be cooled down.

References:

[1] Pan, Q., Peng, J., Wang, R., "Experimental study of an adsorption chiller for extra low temperature waste heat utilization", Applied Thermal Engineering, 2019.
[2] Roumpedakis, T.C., Vasta, S., Sapienza, A., Kallis, G., Karellas, S., Wittstadt, U., Tanne, M., Harborth, N., Sonnenfeld, U., "Performance results of a solar adsorption cooling and heating unit", Energies, 2020.
[3] Thimmaiah, P.C., Sharafian, A., Rouhani, M., Huttema, W., Bahrami, M., "Evaluation of low-pressure flooded evaporator performance for adsorption chillers", Energy, 2017.
[4] Aprile, M., Di Cicco, A.J., Toppi, T., Freni, A., Motta, M., "Modelling of a falling-film evaporator for adsorption chillers", International Journal of Refrigeration, 2023.
[5] R., Hintemann. Boom führt zu deutlich steigendem Energiebedarf der Rechenzentren in Deutschland im Jahr 2017, Borderstep Institut, (2017).
[6] Capozzoli, A., Primiceri, G., "Cooling systems in data centers: state of art and emerging technologies", Energy Procedia, 2015.
[7] Chi, Y.Q., Summers, J., Hopton, P., Deakin, K., Real, A., Kapur, N., Thompson, H., "Case study of a data centre using enclosed, immersed, direct liquid-cooled servers", Proceedings of the 30th Annual Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2014.
[8] Fahrenheit GmbH. (2021, May 21). Self-Cooling Supercomputer [Press release]. https://fahrenheit.cool/en/self-cooling-supercomputer/
[9] Mittelbach, W. (2021). Adsorption refrigeration machine or heat pump with a liquid-phase refrigerant distribution function, and method for operating the adsorption refrigeration machine or heat pump. (European Patent No. 2021089818). European Pattent Office.