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# Evaluation of Sorbents at Elevated Temperatures for Downhole Application

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The drilling of geothermal wellbores provides a basis for an efficient exploitation of geothermal energy. It is usually more demanding than conventional high-temperature applications for the oil and gas industry. The temperatures are generally higher, and all components of the downhole system will be exposed to temperatures between 200 °C and 250 °C and to harsh environmental conditions like strong vibrations, shocks, and high pressures. The high wellbore temperatures may prevent the utilization of electronic components and can negatively influence accuracy and precision of sensors.
Due to the drilling depth of deep geothermal wellbores a failure of a downhole system seriously impacts the cost and economical efficiency of the geothermal project. Therefore, reliable technical solutions are paramount for the success of geothermal projects.
To date, there is no existing commercial technology capable of providing instrumentation that meets the requirements for the operation of downhole instrumentation in deep and hot geothermal wellbores. One solution under investigation is to use an active cooling system to cool existing sensors and electronics. Techniques that lower the temperature inside the cooling systems below the downhole temperature are considered as active cooling methods, in contrast to passive heat dissipation.
Active cooling systems based on phase change from solid to liquid as well as from liquid to gas provide a good compromise between cooling power, temperature drop, and operation time. While phase change from solid to liquid was used in the past, it provides significantly lower enthalpy compared to a phase change from liquid to gas. Therefore, the liquid-to-gas concept is appealing. Unfortunately, the large gas volume is not easy to manage downhole. The sorption of gas in a desiccant is one potential solution and will be further investigated in this paper.
Important for the considered cooling system are selection of an optimal phase change material and the design and application of a suitable sorption process. We designed two special experimental setups to investigate the sorption process, and to characterize the sorption rate and capacity of different desiccants at elevated temperatures and pressures. We show results of a characterization of two potential desiccants for downhole application.

## 1. Cooling Technologies

Several concepts for actively cooling downhole electronics were investigated in the past (Bennett 1986; Flores, 1996), always in combination with thermal insulation. Thermal insulation is critical because it minimizes the amount of cooling energy, phase change material, and desiccant.
Thermoelectric cooling may be used for hot-spot cooling of certain electronic components or sensors, but this technique adds heat to the thermally insulated electronics. Furthermore, thermoelectric cooling is dependent on an external energy supply. This external energy is commonly provided by a turbine

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near the downhole instrumentation and driven by the drilling mud flow. If this external energy supply stops because of a trip out or because the flow of the drilling mud is interrupted due to a technical problem in the pump system, the thermoelectric cooling fails. Furthermore, if the flow of the drilling mud is interrupted, the wellbore is not longer cooled, and most active cooling methods that are based on an external energy supply would also fail. The electronics would have to survive the subsequent raise in temperature because of the heat flow from the wellbore into the downhole instrumentation and the heat dissipation of the electronics. Energy storage, such as batteries, cannot be used because of the high temperatures.
In this situation, cooling by a phase change material that can keep the temperature below a certain threshold during the operation time is preferable. Phase change can be from solid to liquid as well as from liquid to gas. In the later case the significant difference in volume between the phases provides additional challenges for the design of such cooling systems. Therefore, solid-to-liquid phase change cooling was applied primarily in the past. Phase change materials (PCMs), in combination with thermal insulation, are in common use in wireline applications (Bennett, 1998).
There are two major disadvantages of using phase change from solid to liquid. First, the enthalpy of fusion is lower than the enthalpy of evaporation. Second, after the cooling by a phase change from solid to liquid starts, the process cannot be controlled, whether cooling is still necessary or not. Therefore, to ensure an independent and reliable cooling of the electronics and sensors of the bottomhole assembly, a system based on liquid-to-gas phase change is promising, provided one can find a way to deal with the gas volume.
Due to wellbore pressures as high as 2000 bar, a release of the gaseous refrigerant into the environment is not possible. Another possibility would be a compression and reuse of the evaporated refrigerant. Such a cooling system would be complicated and dependant on an external energy supply which is, as mentioned above, not desirable.
Therefore, one solution for a reliable and controllable downhole cooling system is the use of a sorption process. In a sorption cooler a refrigerant evaporates, cools the electronic components and sensors, and is then stored in a desiccant. This cooling system would be independent of the external energy supply and the cooling process could be started and stopped to control the temperatures when required. The component for starting and stopping the cooling process could be a pressure or temperature controlled evaporation valve.
Every downhole active cooling systems comprises a cooling unit in combination with thermal insulation. An excellent thermal insulation, in combination with an electronics design optimized with regards to power consumption and size, helps to keep the necessary amount of cooling energy low and reduces the amount of phase change material and desiccant to a minimum.

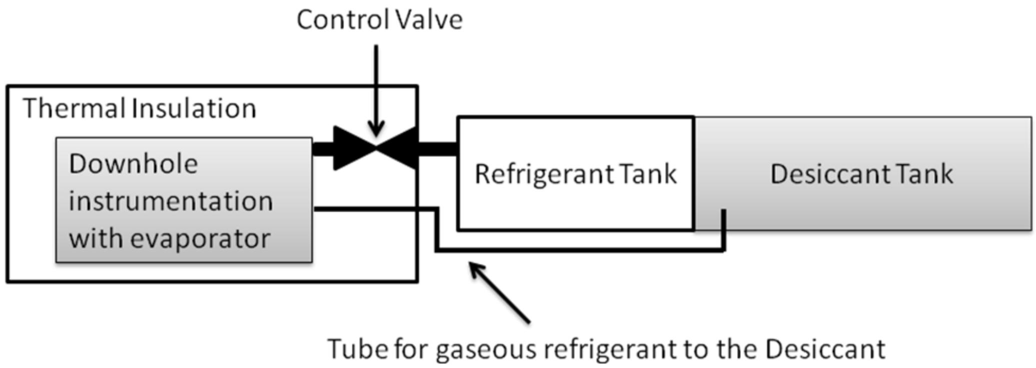


*Figure 1: Schematic design of a downhole sorption cooler, thermal insulation, required components and electronics.*

Figure 1 shows a schematic of a liquid-to-gas phase change cooler. The concept could be integrated in a measurement while drilling (MWD) or wireline tool. This concept comprises the following components: refrigerant tank, where the phase change material is stored, desiccant tank, where the gas is finally stored, control valve, evaporator and thermal insulation.

## 2. Sorption Cooling

One important aspect of a downhole cooler is the performance of the phase change material and the desiccant. For a downhole sorption cooler we have, as mentioned above, special requirements for the desiccant and refrigerant, compared to conventional applications. The desiccant and the refrigerant must be investigated in combination with each other. Some critical specifications for a downhole application of the refrigerant are:
- High phase change enthalpy per volume.
- The refrigerant should preferably be non-hazardous, and non-toxic.
- The vapor pressure of the refrigerant should be in the order of 1 mbar to around 50 bar.

Water is a good candidate for a refrigerant because it meets all these requirements. Some critical specifications for a downhole application of the desiccant are:
- The volumetric storage capacity of the desiccant with respect to water has to be high.
- The speed of sorption for the vaporous water under high temperature must be considered when determining sufficient cooling power.
- As with all other components used in the drilling system, the desiccant must possess stability against shock and vibration.
- The desiccant has preferably to be to be non-hazardous and non-toxic.
- The desiccant should not appreciably increase the price for a downhole tool, as we will require this material in kilograms-per-tool quantities.

Previous investigations of the sorption rate and capacity have shown that the presence of air in a desiccant tank can negatively influence the sorption process. The creation and maintenance of a vacuum in a downhole tool during wellbore operations could be relatively challenging. Therefore, it is preferable to use desiccant in a system that is not evacuated. Because of this, we investigated the sorption rate and capacity of different desiccants in combination with water in an evacuated and non-evacuated experimental system.

To select an optimal combination of water and desiccant experimental investigations are necessary. Here we show a characterization of two potential desiccants for downhole applications, named desiccant A and desiccant B.

An experimental setup to investigate a desiccant and the gaseous refrigerant at temperatures of 250°C and elevated pressures is challenging due to the materials for containing the substances and sealing the containers. We designed two special experimental setups to investigate the sorption process to determine the velocity and capacity of water and different desiccants at higher temperatures and pressures. The two most-promising choices will be explained below.

### 2.1 First setup: investigation of storage capacity at downhole conditions

In a downhole sorption cooler we have one water tank in contact with another tank filled with a desiccant. This is schematically displayed in Figure 1. We used an experimental setup based on this later system. This setup enabled us to characterize the storage capacity of different desiccants at downhole temperatures and different pressures of the vaporous refrigerant. Other components like the evaporator, valve and downhole instrumentation were neglected in these first investigations.

Figure 2 displays the weight percent of a test run with water as the refrigerant at a pressure of 9 bar, stored in desiccant A and desiccant B with a temperature of $T_{Desiccant}$ = 230 °C.

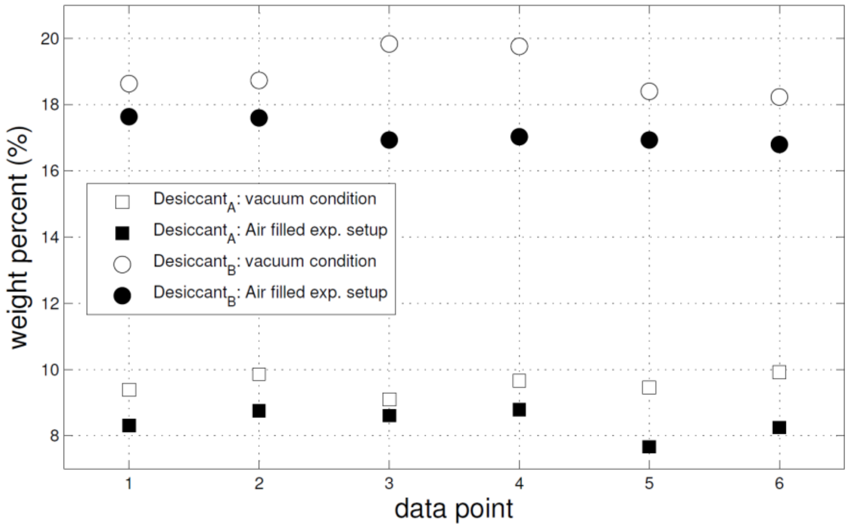


*Figure 2: Comparison of the storage capacity in weight percent of desiccant A and desiccant B at 230 °C and with a generated vacuum or air filled in the experimental setup*

The mean weight percent of stored refrigerant in the two desiccants in a vacuum condition and with an air-filled experimental setup is given in Table 1:

*Table 1: Comparison of two special desiccants for downhole application*

| | Weight percent (Air in exp. setup) | Weight percent (vacuum condition) | Difference of storage cap. (because of vacuum) |
|---|---|---|---|
| Desiccant A | 8.39 % | 9.56 % | 1.17 % |
| Desiccant B | 17.15 % | 18.93 % | 1.78 % |

We conclude that, at elevated temperatures of 230 °C, desiccant B has around two times the storage capacity of desiccant A in combination with water. Furthermore, the creation of a vacuum in a potential downhole phase change cooler is desirable. The air in the desiccant tank might prevent a certain volume of the desiccant from being saturated/reached by the vaporous water. Another possibility might be that without creating a vacuum in the experimental system, air remains in the pores of the desiccant, preventing to be filled by vaporous water.

**2.2 Second setup: speed of sorption**

By using a setup of two tanks in contact as described above it is not possible to monitor the speed of sorption of a desiccant. The loading velocity of a desiccant in a downhole application may be a decisive aspect. If the desiccant is not able to store the vaporous water at a rate which is evaporated to cool the downhole instrumentation, the cooling process will break down.

Therefore, we designed a special experimental setup to investigate the sorption process to determine the sorption rate and capacity of different desiccants in combination with water at higher temperatures and pressures.

The principal test setup is shown in Figure 3. With this test we were able to investigate the sorption process in real time.

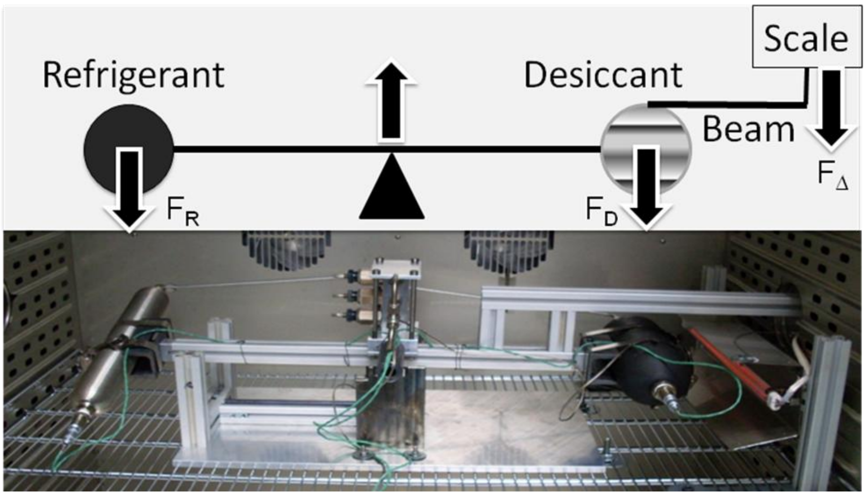


*Figure 3: Picture and schematics of the test setup to investigate the sorption velocity and capacity for different material combinations.*

This setup uses the principle of a beam balance. A tank filled with a desiccant is mounted on one arm of the beam and a refrigerant tank on the other. Both tanks are in contact via a tube and a valve. The beam-balance is supported on a thin metal blade to enable the setup to rotate with extremely low friction. An arm is mounted on the beam balance and transfers the force out of the oven to a scale. At first, a calibration measurement is performed to transform the measured weight at the scale into the amount of adsorbed refrigerant in the desiccant.

The setup was designed to control the temperature of both tanks independently. By using an IR-heater temperatures differences of up to 125 °C are possible. Results of one example of the test runs of desiccant B are displayed in Figure 4.

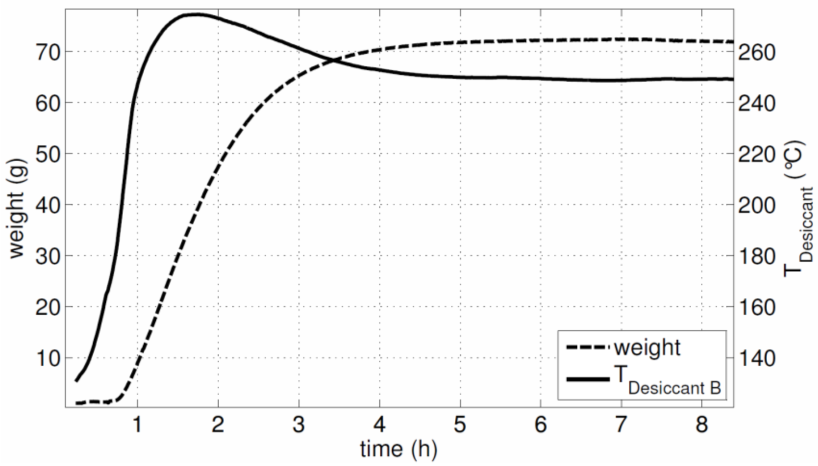


*Figure 4: Weight of stored refrigerant and temperature of desiccant B with vacuum condition in the experimental system.*

The weight percent stored in desiccant B at vacuum conditions and with air in the experimental system is displayed in Figure 5. Here the exponential time constant is calculated via Eq. 1:

$$f = X_1 + X_2 \cdot e^{-t/\tau} \qquad (1)$$

Here X1 and X2 are fit-parameter and tau is the time constant, given as well in Figure 5.

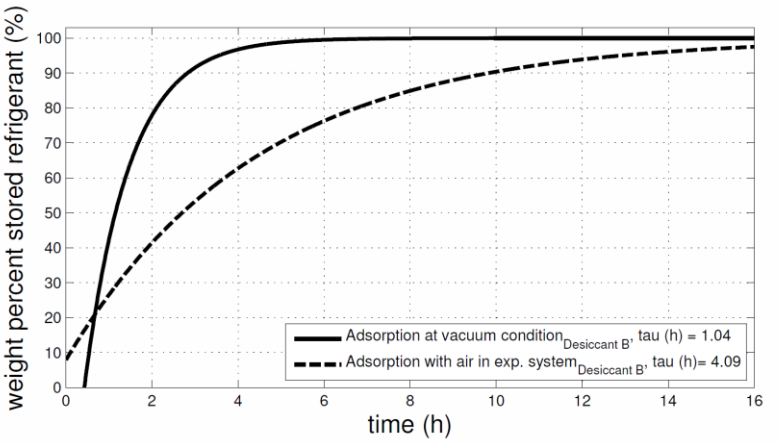


*Figure 5: Weight percent of stored refrigerant and temperature of desiccant B. Comparison of the sorption speed at vacuum condition and with air in the system*

At vacuum condition the sorption rate is around four times faster than compared to an air-filled experimental system.

## 3. Conclusion

Active cooling in combination with thermal insulation is a paramount for the exploration and drilling of hot geothermal wellbores and can increase the operational temperature and the reliability of the electronic components of downhole instrumentation. We considered different active cooling methods. One interesting cooling method might be sorption cooling because this method is independent of an external energy supply and can be used at downhole conditions. Water as the refrigerant is a good option. The storage capacity and loading speed of two promising desiccants were investigated and results are shown. We found one desiccant that could be used in a downhole environment at 250 °C. The influence of the presence of air in a desiccant tank was investigated. Although the creation of a vacuum within a downhole cooling system is technically challenging, the sorption rate and capacity of a non-evacuated desiccant tank is inferior with respect to desiccant at vacuum conditions.

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