

Cooling Systems for Borehole Tools

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Abstract: Since 2012 the work on a cooling system for borehole probes is going on at the IAI. It is supposed to allow the usage of standard electronics, as a first approach in borehole environments at 5 km depth, with 200 °C and 600 bar. Within ZWERG, the cooling system serves as base to realize different measurement operations without time limitations. Therefore it contains an insulation to reduce outer heat input, an active cooling system to cool down components which are sensitive to heat inside, like electronics, as well as a cooled room where the electronic can be installed. The first approach based on the example borehole in Soultz-sous-fôret, France (5 km, 200 °C) shall initiate further project in this field, with the perspective to conduct measurement operations in even hotter boreholes. Alternative methods of heat management in borehole probes investigated and developed at IAI, are high temperature electronics and PCM-systems.

Key words: Cooling, deep geothermal energy, borehole tools, down-hole monitoring.

1. Introduction

The deep geothermal energy has the potential to play an important role for the energy supply of the future although it stays behind his possibilities so far. This is caused by several problems the technology has to fight with. There is a high investment risk which is linked to the difficulties of aiming exactly at the aquifer. Additionally it is impossible to optimize running plant processes without real-time data of the open¹ hole. Risks caused by seismic activities cannot be predicted either and the public acceptance is suffering. All this problems are mainly influenced by a lack of information of geothermal wells during the whole life cycle, starting with the drilling until the energy production [1].

Because of the extreme conditions in geothermal boreholes, namely the high temperatures and pressures paired with highly corrosive thermal waters, like in Iceland, the use of measurement devices is difficult [2]. Many standard electronics do not stand temperatures above 70 °C, high-temperature components are rare

and very expensive [3]. These circumstances make a cooling system necessary. For short operations of a few hours, a PCM (phase change material) concept, where the PCM i.e. ice takes away the harmful heat while changing its phase that can do the job. The cooling effect in this case is limited by the mass of PCM material carried inside the probe. An increased mass of carried PCM for longer cooling also increases the length of the probes. This brings difficulties for their handling with it and provokes higher heat-input from outside [4]. Another method, the cooling by Peltier-elements only enables low cooling capacities, which will not be sufficient for most applications [5]. Therefore, it would be helpful for widespread borehole investigations to have a functional unlimited-cooling-system as basic module of a system platform for various measurement operations called ZWERG, with which is help it be possible to quickly construct different tools for different application, serving “blueprints” for repeating components [6]. To realize operation-times of several weeks, we are developing an active cooling system at the Institute of Applied Computer Science. This system is based on the principle of a cooling-machine and make it

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possible to perform measurement and monitoring operations over the complete life-cycle of geothermal wells, starting with the drilling phase and ending with the running plant. Doing so, it makes an important contribute to overcome the lack of borehole-data and the problems of geothermal energy in general.

2. Applications

The cooling system will be usable within the complete lifecycle of boreholes (Fig. 1). Thereby it allows generating widespread information in all phases of geothermal energy production.

The cooling system could for example cool a SPWD (seismic prediction while drilling) unit to realize the investigation already during the drilling phase. This would help targeting exactly the aquifer [7]. Afterwards it could be used for widespread pre-investigations of water chemic to specifically adjust plant parameter and components. While energy

production, by a cooled probe generated real-time data would allow risk predictions and enable intervention and process optimization in time.

3. Conditions and Concept

The expected operation conditions for the cooling system corresponding to the operation depth of 5 km are: surrounding temperatures up to 200 °C and surrounding pressure up to 600 bar.

To realize the cooling function during time periods of several weeks, the system conducts a thermodynamic cycle process with a refrigerant. The refrigerant evaporates at a temperature below 70 °C inside the cooled room and gets compressed by a compressor at a pressure higher than the vapor pressure (of refrigerant) at 200 °C. Like this the refrigerant can condense at a temperature above the surrounding temperature (200 °C) while it transfers heat to the borehole.

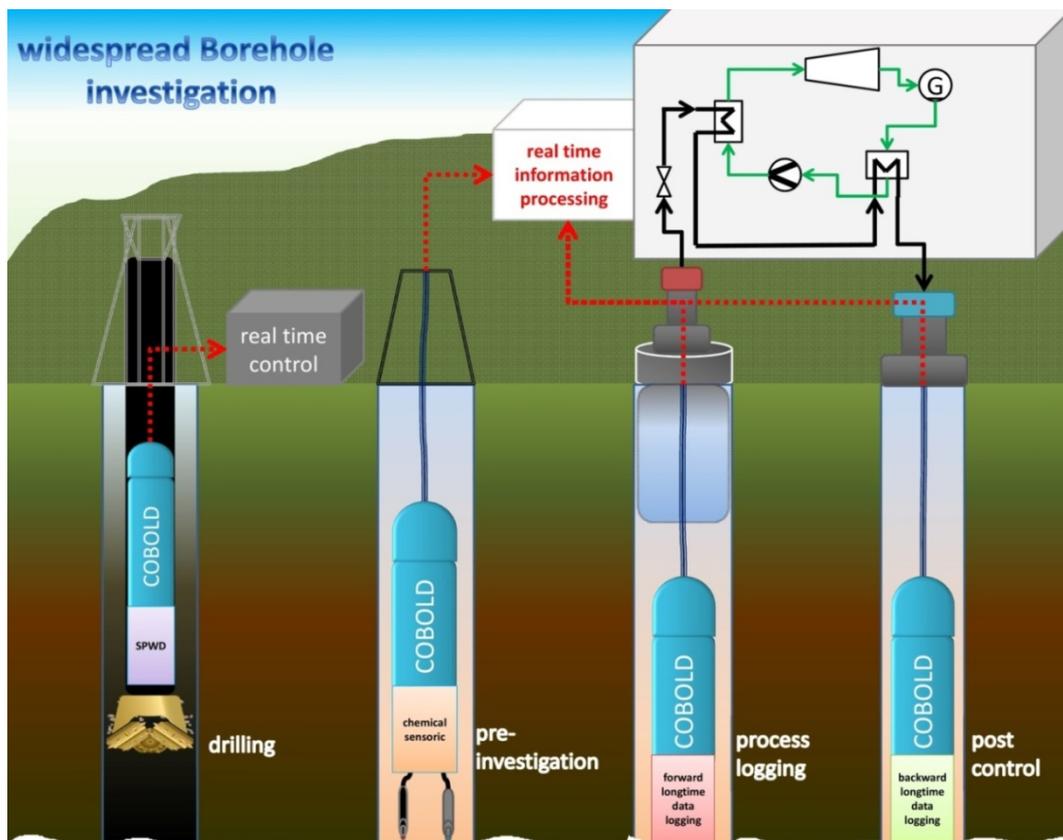


Fig. 1 Overview over different application options for the cooling system.

To close the process, the condensed substance passes an expansion to start-pressure and start-temperature.

4. The Cooling Machine

4.1 Cycle Process

As refrigerant, acetone is regarded at the moment. The evaporation temperature at atmospheric pressure is about 56.5 °C, which is far enough below 70 °C. This means that electronics temperatures can be kept below 70 °C as well. The condensing temperature when compressed at 40 bar is 220 °C, thus the temperature gradient to the borehole temperature is sufficient to transfer the heat to the surrounding. Fig. 2 shows the complete cycle in a log p-h (pressure enthalpy) plot.

The compression process is assumed as polytropic compression. With Eq. (1) the required compression effort can be calculated. The achievable cooling capacity can be estimated with the enthalpy balances of the plot (Fig. 2) or calculated using Eq. (2).

$$P_{com.} = dm/dt \times R \times T \times \frac{n}{n-1} \times \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] \quad (1)$$

where, dm/dt is mass flow, R is gas constant, T is

temperature and p is pressure.

$$\dot{Q}_{cool.} = dm/dt \times \left[\frac{dp}{dT} \times T_1 \times x \times (v'' - v') \right] \quad (2)$$

where, in the equation after Clausius Clapeyron, dp/dT is the temperature dependent pressure gradient; T_1 is the evaporation temperature, x the liquid ratio, v'' the specific superheated and v' the specific saturated steam volume [9].

Table 1 shows the most important process parameters, calculated with different approaches. The polytropic compression approach seems to generate the most realistic results compared with first experimental results. According to that, a cooling capacity of 100 W could be achieved with nearly similar effort for the compression.

Experiments for the validation of the insulation of the cooling housing showed that outer heat inputs of around 20 W have to be expected. Thus approximately 80 W heat could be transferred from the probe in the described constellation. For many of the electronic systems this would be sufficient. In case of higher heat input, this system is flexible, thus cooling capacity can be increased according to an increased mass-flow by increasing the compressor frequency.

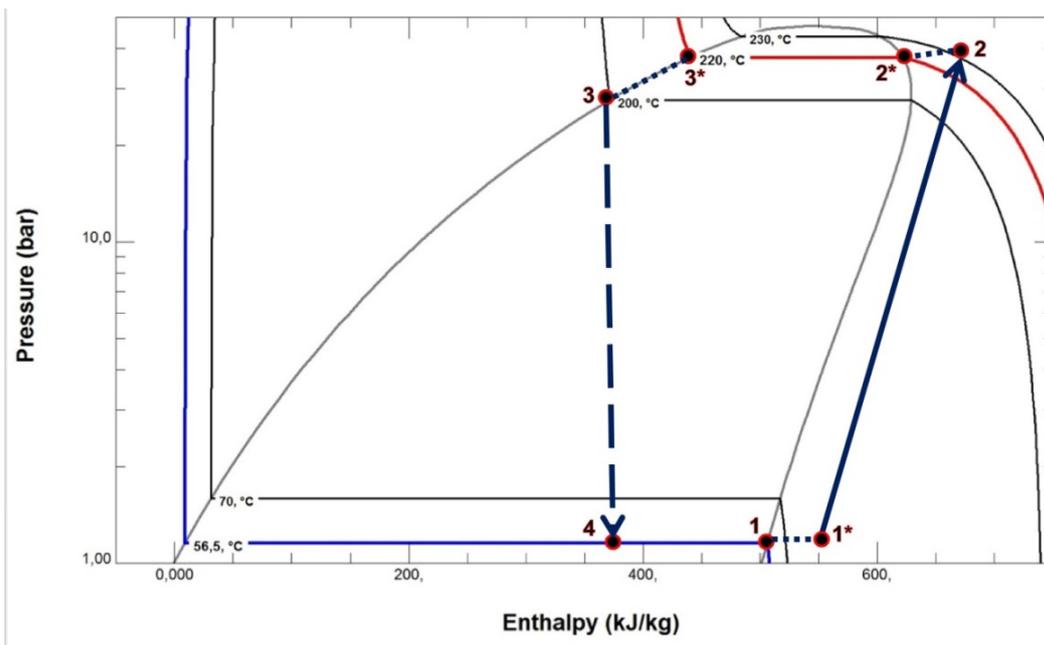


Fig. 2 Log p-h plot of the cooling cycle [8].

Table 1 Calculated process parameter.

Used input parameters						
Adjusted mass-flow dm/dt (kg/h)	Evaporation temperature T_1 (K)	Starting pressure p_1 (bar)	Final pressure p_2 (bar)	Gas constant R [J/(kg-K)]	Pressure gradient dp/dT (bar/ K)	Measurement mass-flow dm/dt (kg/h)
2	324.15	1.19	40.93	143.15	0.05	~ 1.97
Calculated process parameters						
Calculation approach	Cooling capacity (W)	Compression effort (W)	Heat output (W)	Liquid ratio x	Polytropic exponent n	
Idealistic approach	353.7	77.28	431	-	-	
Polytropic compression approach	114.49	112.35	118.14	0.4	1.13	
Measurement projection approach	94.3	96	190.37	0.38	-	

4.2 Materials

The material question is an important one as four every down-hole tool. It is a great field and will not be discussed in detail in this paper. So far, nickel-based alloys i.e. Inconel 718 are preferred for outer elements such as the housings and the condenser. Because of their high mechanical strength combined with high corrosion and temperature resistance, they are a good choice.

Their disadvantages are the high costs and low machinability, thus a lot of effort is put in the development of manufacture techniques and geometrical simple design. For the seal problematic perfluorinated rubber seals, which stand high temperatures and aggressive refrigerant substances are tested.

4.3 Probe Engineering

To realize the described process, the central components evaporator, compressor, condenser and expansion valve are required. Furthermore, a cool-room-housing with sufficient insulation and installation surface for the components, which has to be cooled down. The insulation consists of a vacuum, located in the double wall of the housing and MLI (Multi Layer Insulation) at the inner wall. Experiments showed that this structure can reduce the outer heat input significantly [10].

Fig. 3 shows a possible assembly of the components.

From the right you can see a sensor unit as exemplary application which is connected to the cool-room-housing. Inside the evaporator with installed electronic is located. The compressor housing which also contains the expansion valve is connected to the evaporator. An electrical driven version (fitted) for the use with wire line, as well as a hydraulic driven variant for drill string operations is showed. At the upper end the condenser as outer heat exchanger is mounted. The whole system is closed as cycle.

5. Results and Current Works

So far, the experiment results show good properties for the heat transfer and support the impression of the suitability of acetone as refrigerant. Other refrigerants are tested parallel.

Fig. 4 shows the possible cooling process with R113. At the moment, we are realizing an experimental assembly to display the complete cooling process with realistic surrounding conditions. Therefore, an experimental compressor with pneumatic engine which reaches the required final pressure has been engineered and manufactured (Fig. 5). An evaporator prototype as well as a condenser



Fig. 3 Computer aided design illustration of the cooling system.

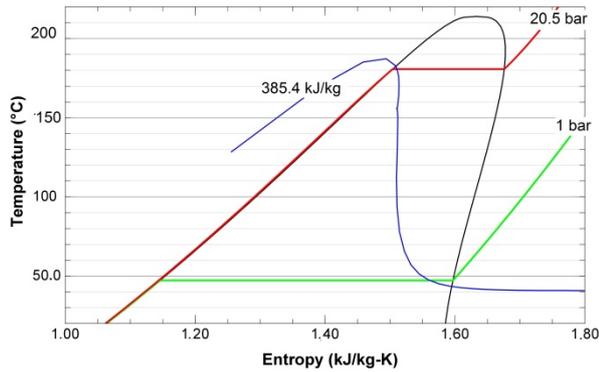


Fig. 4 Cooling process with R113 in T - s (temperature-entropy) plot at 170°C .



Fig. 5 Laboratory compressor.

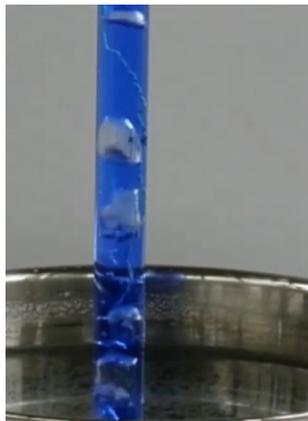


Fig. 6 Evaporation of colored acetone at 57°C .

prototype get currently manufactured and will be ready soon. Further experiments are planned.

Based on previous experiments concerning the evaporation behavior of acetone (Fig. 6), fluid flow models are developed. The models are used for the

simulation of heat transfers. These simulations will help adjusting optimal process parameters and designing optimized components.

6. Conclusions

The previous results allow an optimistic view in the future. The active cooling concept seems to be promising, thus its realization will be continued with great effort.

Additionally, the work on the process validation, component design optimization and ways of integrating the demands of geothermal technology in the processes will be intensified in the following years.

A project-application in cooperation with different scientific and industrial partners has been submitted to the BMU (Federal Ministry of Environment, Germany). The approval is very likely to be granted in summer 2014 and will support the further development a lot.

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