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# System Platform Approach For The Effective Development Of Borehole Tools Solving General Problems

Benedict Holbein, Chris Bauer, Stefan Dietze, Joerg Isele, Luigi Spatafora

Herrmann-von-Helmholtz Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

Benedict.holbein@kit.edu

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**ABSTRACT**

It is undeniable, that Geothermal Energy faces a huge disparity between claim, based on its potential and reality. Equally obvious is the big deficiency of reliable data about the conditions in and around geothermal wells, which are of great importance for the technical and economic efficiency of the related energy production. Another point is the missing resources for interactions inside geothermal boreholes, evident for interventions in case of acute problems. Mainly responsible for this is the unavailability of adequate geothermal tools, due to the high development costs and missing standardization.

The ZWERG project was started in 2009 at the Institute of Applied Computer Science IAI, Karlsruhe Institute of Technology KIT. The aim of ZWERG is to create a system platform for the development of various borehole devices in a time- and money saving way, by providing blueprints and repeating modules for general problems. Basic problems like the material choice and organization, methods and devices for cooling heat-sensitive components, adequate housing and fitting designs for high surrounding pressures and typical borehole dimensions and robust jointing methods for operations in hot and corrosive environments, once solved can further be managed universally. Additionally the “geothermiewiki” an open-access website is supposed to simplify the exchange and research of important information.

## 1. INTRODUCTION

Geothermal Energy is facing some basic problems, preventing that it´s taking a central role on the energy production sector. The economic risks for investors are too high for a widespread usage of this technology, due to technical risks and missing political support. The negative examples, especially in Europe play their part, too and the acceptance in the population is low. At the same time, the potential of geothermal energy sources in Europe is huge, regarding both, electricity and heat production [ABFT2003]. Taking into account, that Geothermal Energy is the only renewable energy which can serve as base load supplier and is nearly everywhere available, this discrepancy appears even bigger, e.g. [Holbein06-2014]. Besides the problems linked to political and market situations there are also scientific reasons responsible for this [IPGT2012].

For most of the problems occurring only interpretations instead of clear diagnoses exist, which makes an expedient intervention impossible. Apart from that the tools for interactions aren´t available neither. Generally the lack of borehole data leads to difficulties over the whole life cycle of boreholes, starting with the exploration until possible pre-interventional failure detections.

The number of tools for the investigation and interaction in geothermal boreholes is small. Affordable tools for scientists and operators are barely available. The service i.e. for a borehole video inspection is provided only by a few companies and very costly. The extreme conditions in boreholes, corrosion, high temperatures and pressures, overall in the interesting areas in great depths make the development of tools technically challenging and expensive which effects the usage costs as well [Kleinberg2001][Polsky 2008].

ZWERG shall help to improve this situation by inducing the needed standardization and knowledge exchange to allow the fast development of borehole tools for individual purposes and purchases. Therefore it paves the way for widespread investigations and in the end for a more efficient use of Geothermal Energy.

An example for borehole probes based on the ZWERG platform is the GeoKam, a video inspection tool for deep boreholes. A module for the safe visit of the open hole and a borehole refrigerator for the unlimited cooling of standard electronics in hot boreholes are further research projects in process.

## 2. ZWERG

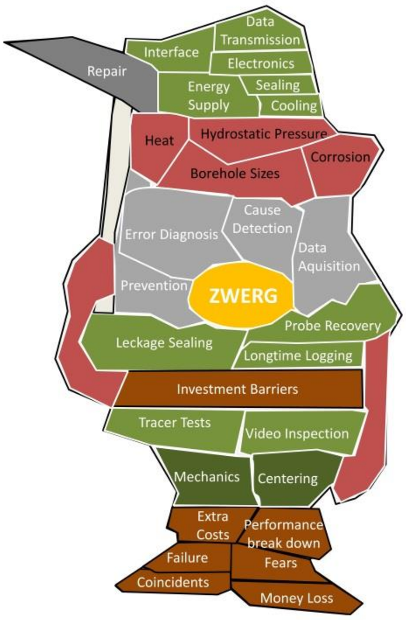


**Figure 1: Sketched overview of ZWERG related research issues**

ZWERG follows a diverse approach, containing the work on solution concepts for different general and specific problems. On the one hand this is done by fundamentally collecting information about related problem fields like i.e. the material questions, which materials are fitting the constraints of geothermal borehole use, where and under which conditions can these materials be purchased, which alternatives exist, what manufacture and jointing restrictions have to be followed, to name just a few examples. On the other hand actual solutions for tasks and related problems are generated within ZWERG, including electronic systems for the connection between tool and wireline with energy supply and data transmission, cooling devices for electronics in hot environments and blueprints for probe parts like housings, connectors and fittings with borehole adequate dimensions for high surrounding pressures (see Figure 2), e.g. [Isele et al 2014].

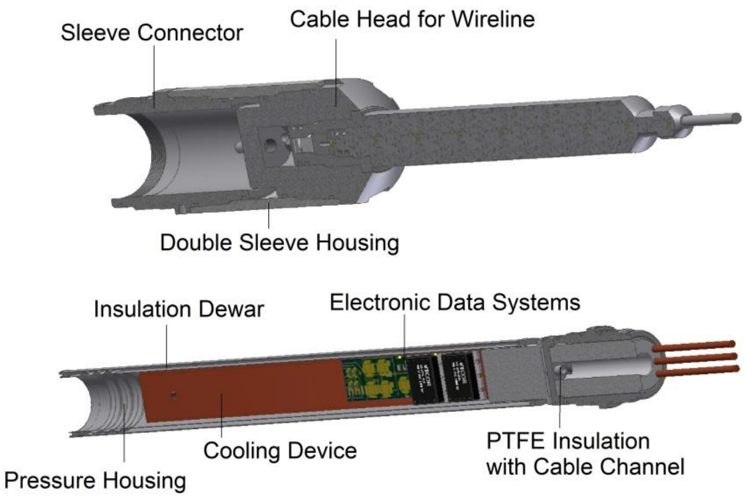


**Figure 2: Standard borehole tool components**

Additionally ZWERG aims at the exchange of important information between scientific groups developing borehole devices or applications. An open –access website called geothermiewiki is being created for this purpose, where all the generated data, such as important links and contacts until calculations, experimental results and design drawings can be accessed, edited and complemented.

## 3. HEAT MANAGEMENT

A central difficulty being worked on within ZWERG is the heat management, since the tools shall be usable in deep boreholes with high environmental temperatures. The first element of the heat management is the insulation against external heat input. Besides solid insulation materials like PTFE, which are used in axial direction as well as for the affixing of internal components, an efficient radial insulation is needed. Therefore vacuum insulation, realized through internal Dewar flask is used. But after all there is still an amount of external heat input and as well the heat, produced inside the tools i.e. by the electronic components. This is why even for relatively short operations of a few hours, some kind of cooling is necessary. Depending on the actual operational surrounding temperature and the operation period, different cooling solutions are appropriate.

The technically simpler method is a PCM (Phase Change Material) – Heatpipe system, which is used i.e. in the GeoKam where operation times of maximal 6-8 hours are foreseen. Heatpipes contain a nominal amount of refrigerant. Through evacuation interfering particles inside the pipes are minimized and the evaporation temperature can be adjusted. By alternating evaporation and condensation of the substance inside the pipe, a huge heat transfer between their two tails, many times higher than by normal heat conduction is realized when they are contacted to a heat sink and source respectively. As heat sink a PCM is used, which consumes a big amount of heat while changing its´ phase. Of course this way of cooling is strictly limited by the amount of PCM stored in the tool. An example: For a surrounding temperature of 165 °C, the internal of a tool with outer diameter 95 mm (outer heat input ~12 $W/m_{length}$) and internal heat input of 150 W can be cooled below 70°C for approximately 6 ½ hours with ~9 kg of ice. For carrying this mass of ice the PCM container needs a length of 3 m. To reach 11 hours cooling time, this container had to be 6 m long, e.g. [Holbein02-2014]. This shows clearly that long operations can´t be realized with a PCM-Heatpipe system, neither can operations in hotter environments, where the external heat input is noticeably higher.

For longer operations and higher environmental temperatures an active cooling system is being developed within ZWERG. It is based on the principle of a cooling machine used in common refrigerators, where a thermodynamic cycle allows continues cooling of internal components. Of course this principle has to be adjusted for the use in geothermal boreholes with totally different surrounding conditions, which have a great impact on the dimensions of the components, the choice of housing materials and the cooling cycle itself including the used refrigerant. Figure 3 shows the cooling cycle with acetone as refrigerant in a logarithmic p (pressure)-h (enthalpy) diagram.

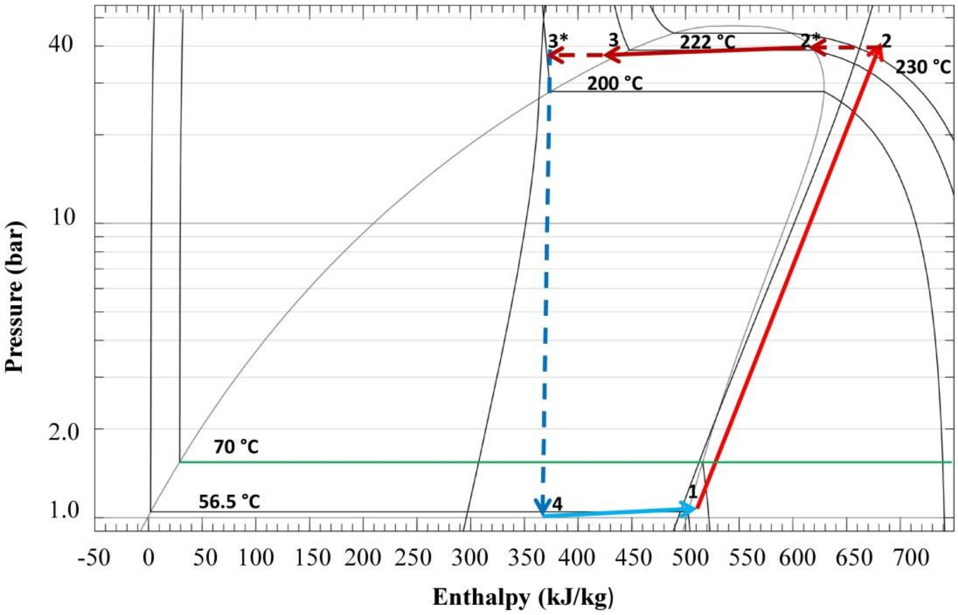


**Figure 3: Log. p-h diagram of borehole cooling cycle with acetone**

The process showed is running at environmental temperature of 200 °C. The main sub-processes are marked between the numbered process points.

| | |
|---|---|
| 4 - 1 | Isothermal evaporation |
| 1 - 2 | Polytropic compression |
| 2* - 3 | Isothermal condensation |
| 3* - 4 | Isenthalpic expansion |

When it evaporates, the refrigerant consumes latent heat which it absorbs from the cooled components inside the tool. After being compressed to a pressure at which the condensation temperature is higher than the environment temperature, it condenses and transfers latent heat to the surrounding. By stronger compressing the evaporated refrigerant, the condensation temperature can be increased for cooling at hotter environments. Like this, the system is adjustable to different environments. Because of the cycle process there is no limitation of time for cooling with the borehole refrigerator. The disadvantage of this refrigerator is the energy demand for driving the compressor. For further investigations of the cooling process and testing prototypes of borehole refrigerator components a test-bed has been constructed at the IAI, e.g. [Holbein04-2014].

## 4. TOOL ELECTRONICS

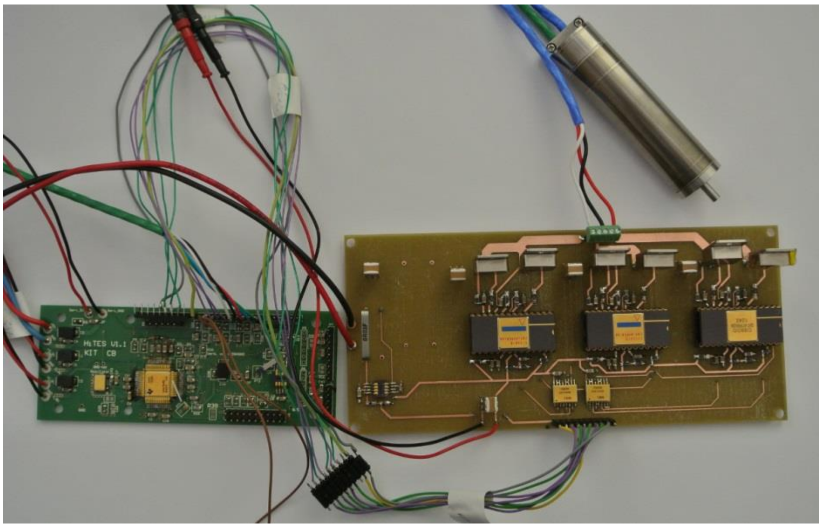

**Figure 4: High temperature BLDC Servo Controller**

Tools performing various tasks inside boreholes need electronic systems in most cases. The functions range from converting the electrical supply i.e. of the wireline to the demand of the electrical consumer to the transmission of data in bidirectional way. In case of complicated applications like the GeoKam there are many motors, illumination and so one to be controlled from the surface. Because of the often very particular task and the small amount of space inside the tools, the components and electronic systems have to be especially manufactured and adapted. Another point is that at some conditions it might be necessary to have high temperature electronics, when cooling is not practical or the relevant electronics can´t be installed in the cooled area (i.e. a motor controller for the refrigerant compressor or an actor for probes). For this reason high temperature electronic systems are developed. One example is a high temperature brushless dc motor controller for ambient temperatures of 200 °C consisting of a High Temperature Embedded System called TI HiTES in combination with a PCB (Printed Circuit Board) with needed power electronic. The TI HiTES is a multi-purpose system usable for further jobs e.g. logging the temperature, pressure or other necessary parameters. These electronic circuits are developed as part of the ZWERG platform, where commonly needed electronic jobs for downhole tools are implemented, e.g. [Bauer2011].

## 5. GEOKAM

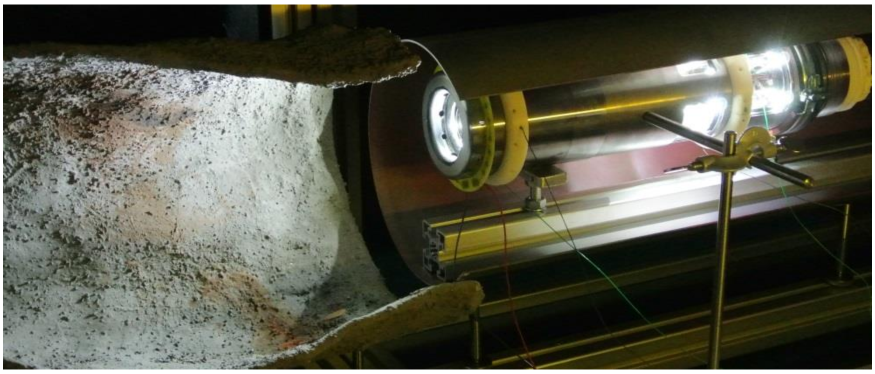

**Figure 5: GeoKam prototype inside borehole model**

The first probe-project based on ZWERG is the actually running GeoKam Project, founded by the Federal Ministry for Economic Affairs and Energy (BMWI, Nr: 0325580). GeoKam is a video inspection probe for taking and transmitting life videos from boreholes to the surface. It is usable in depth up to 4000 m with ambient temperatures of 165 °C. It contains a cooling system allowing operation times of up to 8 hours in the named environment. A high performance illumination system and controllable apertures and focuses allow clear and detailed insights. Cameras in radial direction allow a 360° angle to observe the borehole casing; the front camera can be adjusted for close looks at the wall or distant views. The housing including corrosion resistant steel, transparent windows and seals is designed for pressures up to 600 bar, e.g. [Spatafora et al 2014].

In 2015 the GeoKam will be tested in situ in a well near Munich.

## OUTLOOK

Besides the already running GeoKam project additional projects and an extension of the geothermiewiki will be worked on in the following years. With the perspective of a universal supply of widespread investigation and reparation tools for boreholes, several projects have been planned as logical approach for the final ZWERG target. In this context the concepts for the safe visit of the open hole (SOHLE), for the development of robust ceramic-steel jointing (GIMLI) and a borehole usage adjusted refrigerator for continues cooling of electronic components (GARM) have to be named. For enhanced testing of complete systems and tool components test stands for testing various elements, like the cooling processes and systems for borehole tools, the thermo-mechanical stability of components, illumination adjustments for an optimal in hole visibility and others are currently being realized in the laboratories of the IAI. At the same time the effort to intensify the actual cooperation with scientific and industrial partners and the acquisition of new partners is reinforced.

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