Development of a cooling system for geothermal borehole probes

Benedict Holbein

Why the system is needed
• applications
• challenge
• benefit

How the system works
• concept
• process
• components
• experiments

What the system misses
• problems
• next steps
• cooperation

Structure of presentation
Why the system is needed

- applications
- challenge
- benefit

Interesting requests

- long operation times
- many operations at frequent intervals
- little amount of maintenance between operations

Application example

- long operation times with different modules
- hot environments

Protection for electronics required
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challenges and benefits

- no time limitations for operations
- operations also in very hot boreholes
- standard electronics usable
- heat protected measurement advices

Why the system is needed
- applications
- challenge
- benefit

application range

environment / operation

<table>
<thead>
<tr>
<th>depth</th>
<th>&gt; 5 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>borehole pressure</td>
<td>&gt; 600 bar</td>
</tr>
<tr>
<td>borehole temperature</td>
<td>&gt; 200 °C</td>
</tr>
<tr>
<td>borehole media</td>
<td>corrosive thermal water</td>
</tr>
<tr>
<td>borehole diameter</td>
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</tr>
<tr>
<td>cool – room temperature</td>
<td>&lt; 70°C</td>
</tr>
</tbody>
</table>
The Components (I)

<table>
<thead>
<tr>
<th>Environment / Operation</th>
<th>Cooling System</th>
</tr>
</thead>
<tbody>
<tr>
<td>depth &gt; 5 km</td>
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<th>Cooling Process</th>
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<tr>
<td>Refrigerant</td>
</tr>
<tr>
<td>Acetone</td>
</tr>
<tr>
<td>Evaporation temperature</td>
</tr>
<tr>
<td>Max. working temperature</td>
</tr>
<tr>
<td>Surrounding media</td>
</tr>
<tr>
<td>Condensing pressure</td>
</tr>
<tr>
<td>Max. diameter inside</td>
</tr>
<tr>
<td>Max. diameter outside</td>
</tr>
</tbody>
</table>

Boundary Conditions
- Environmental
- Operational
- Cycle process

Concept of the Cooling System

- Cycle process
  - Refrigerant
  - Aligned process conduct
  - Heat conduction

- Insulation
  - Vacuum
  - MLJ

- Components
  - Robust materials
  - Custom-built engineering
  - Modular design
The cycle process

- refrigerant
- aligned process conduct
- heat conduction

- insulation
  - vacuum
  - MLI

- components
  - robust materials
  - custom-built engineering
  - modular design

The cycle process

- sub-processes: acetone
  - evaporation ($4 \rightarrow 1$)
    - $\approx 56.5 ^\circ C$
    - $\approx 1$ bar
  - compression ($1^* \rightarrow 2$)
    - $\approx 230 ^\circ C$
    - $\approx 40$ bar
  - condensation ($2^* \rightarrow 3^*$)
    - $\approx 215 ^\circ C$
    - $\approx 40$ bar
  - expansion ($3 \rightarrow 4$)
    - $\approx -39$ bar
    - $\approx 140 ^\circ C$

refrigerating capacity: after C. Clapeyron

- $\frac{dT}{dx} \equiv \frac{m}{T_1 + (T_1 - s_2) / (h_1 - h_4)}$
The insulation

- heat input from outside
- heat radiation
- heat conduction
- heat convection

- Multi Layer Insulation (MLI)
- Teflon (PTFE)
- vacuum Insulation

- radial
  - Multi Layer Insulation
  - vacuum

- axial
  - solid insulation
    - PTFE
    - ceramic wool

* d/l: 110/900 mm
* max. refrigerating capacity: 110 W

The Components (I)

- actual evaporator:
  - pressure-resistant: 1 bar (l) / 1 bar (o)
  - max. diameter: 110 mm
  - mounting surface for electronic
  - maximal heat conduction surface
  - high heat transfer coefficient

  * wound up tube heat exchanger
  * copper
  * d/l: 110/1400 mm
  * max. refrigerating capacity: 110 W

- new evaporator:
  - grooved plate heat exchanger
  - copper
  - d/l: 110/800 mm
  - max. refrigerating capacity: 190 W

- main components
  - evaporator
  - condenser
  - compressor
  - expansion valve

- inside
  - refrigerant
    - acetone
  - max. inside pressure
    - ~1 bar
  - max. inside temperature
    - ~60 °C

- surrounding media
  - air
  - max. outer pressure
    - ~1 bar
  - max. outer temperature
    - ~70 °C
  - max. diameter
    - 110 mm
## The Components (II)

### condenser:
- pressure-resistant: 40 bar (i) // 600 bar (o)
- max. diameter: **170 mm**
- corrosion-resistant
- maximal heat conduction surface
- high heat transfer coefficient

*straight tube heat exchanger*

*material: Inconel 600; Nicofer 721 ...*

*d:l: 170/2000 mm*

### compressor:
- pressure-resistant: 40 bar (i) // 600 bar (o)
- compression ratio: 1/40
- max. diameter: **170 mm**
- corrosion-resistant
- acetone gas-resistant
- low power input

*piston compressor*

*gaskets: PTFE; PCTFE; PVDF ...*

*d:l: 170/1200 mm*

### experiments (I)

**temperature profiles**

**vacuum influence**

### experiments
- Insulation
- Heat transfer
- Sub-processes
- Cycle process

**test set-up**
- Thermocouples inside cool room
- Heating jacket outside
- Insulation installed

- **heating up from outside**: > 200°C
- **vacuum inside barrier**: < 5 E-4 mbar

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Institute of Applied Computer Science IAI

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cooling system

experiments (IVa)

- simulation of heat transfer improvement with CPU-fan installed on the load board
- significant improvement caused by acceleration of air

13.12.2013

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Institute of Applied Computer Science (IAI)

cooling system

experiments (IVb)

- heating up from outside: > 200°C
- vacuum inside barrier: < 0.5 E-4 mbar
- liquid acetone in evaporator: ~ 700 ml
- internal heat input: 20 Watt

- slight improvement but load temperatures still too high

13.12.2013

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open questions

materials
- gaskets + joints for compressor
- delivery times and batch
- grindability vs. shape

thermodynamics
- process control
- refrigerants

What the system misses

- problems
- next steps
- cooperation

resources
- cooperation

open tasks

components
- optimized evaporator
- optimized condenser

What the system misses

- problems
- next steps
- cooperation

missing components
- new evaporator
- condenser
- lab compressor
- expansion valve

missing resources
- laboratory equipment

future experiments
- evaporation v.2
- condensation
- compression
- heat exchange v.2
- expansion
- complete cycle process
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### 2-stage system

**What the system misses**

- problems
- next steps
- cooperation

#### 2 stages concept

- condenser of stage 1 inside cool room of stage 2
- condenser of first stage = evaporator of 2nd stage
- 2nd refrigerant for other boundary conditions required
- 2nd complete cycle process at higher temperature level

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**open tasks**

An active cooling system for borehole probes would be a great advance

The concept for cooling system works

There’s still a lot of work to do
The insulation (I)

- Multi Layer Insulation (MLI)
- Vacuum

- Solid insulation
  - PTFE
  - Ceramic
  - Wool
**The insulation (II)**

- **Vacuum Insulation**
  - Temperature profiles influenced by vacuum

- **Heat Convection**

**Vacuum experiment:**
- Heating jacket around housing: 200°C
- Vacuum inside barrier: < 9.5 E-4 mbar

**Radial**
- Multi Layer Insulation
- Vacuum

**Axial**
- *Solid insulation*
  - PTFE
  - Ceramic
  - Wool

**Open Tasks**

- Prototype
- Borehole probe cooling system

**What the system misses**
- Problems
- Next steps
- Cooperation

**Preparation**
- Construction of components
- Testing
- Optimization

**Ready for operation prototype**
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### Contact Information

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summarized information to take away

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**Time Table**

<table>
<thead>
<tr>
<th>Year</th>
<th>Tasks</th>
</tr>
</thead>
</table>
| 2013 | - sub-process experiments  
- construction of missing components  
- realisation of cycle process in laboratory |
| 2014 | - completion of test  
- construction of prototype  
- first field test ??? |

**What the system misses**

- next steps
- problems
- cooperation

KIT – University of the State of Baden-Wuerttemberg and National Laboratory of the Helmholtz Association