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Metal sealing packer technology in deep boreholes

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ABSTRACT

Early hydraulic / hydrofrac tests at the HDR geothermal test sites Bad Urach and Soultz-sous-Forets were characterized by severe technical problems due to conventional (rubber-based) packer technology in hostile downhole environment (high temperature, high gas- and salt content of the borehole fluids). Various metal packer systems have since been developed during the past years to overcome these problems:

- Aluminum packers as part of a wireline hydrofrac straddle packer system to measure in-situ stresses, consisting of soft aluminum sleeves, which were successfully used down to approx. 3.5 km in the **Soultz** boreholes EPS-1 and GPK-1 and in the Urach-3 borehole.
- Copper- and stainless-steel packer elements for permanent and reliable borehole sealing at nuclear waste storage sites.
- Since both laboratory and in-situ tests have demonstrated that the metal packer elements can also support large loads, a new arrangement for casing cementation / anchoring based on copper-nickel alloy packer elements is currently being developed. First prototype tests with the new system show promising results. The metal packers may be used as casing packers during deepening of borehole Soultz GPK-2 to 5 km depth.

KEYWORDS

Metal packer, borehole seal, casing anchoring, HDR

1. Introduction

Although sophisticated packer technology exists (high pressure, high temperature packers), various in-situ applications showed insufficient performance of conventional (rubber-based) packers at great depth due to the high pressure necessary to seal borehole sections, or high temperature and high gas content of the borehole fluids (e g RUMMEL & BAUMGARTNER 1991) This results in failure of the packer elements after short times and may cause severe problems to the borehole Therefore, various metal packer systems for hydraulic / hydrofrac testing at great depth, for the permanent sealing of boreholes (e.g. at nuclear waste storage sites) and for the cementation / anchoring of a casing have been developed during the past few years.

2. Aluminum straddle packer tools for hydraulic / hydrofrac testing

As a first approach, aluminum was selected as packer material on account of its high ductility, good machining properties and low costs. After several tests with 35 mm diameter laboratory models, aluminum straddle packer tools operated by a wireline system were designed for the open-hole sections of boreholes **Soultz** EPS-I (4" diameter), GPK-I (6-¼" diameter) and Uracb-3 (5-7/8" diameter). A schematic diagram of **the** tool **is** shown in figure 1, a photo is presented in figure *2*.

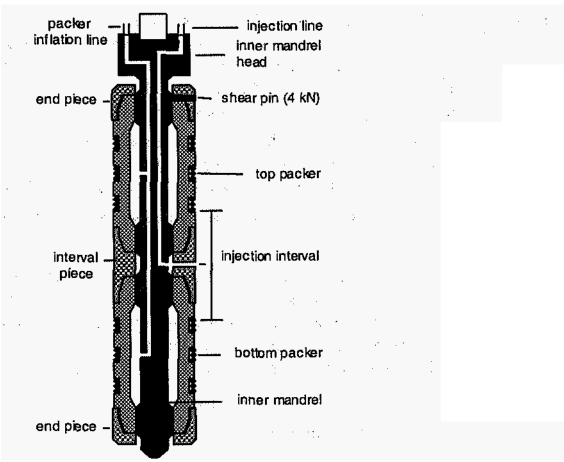

Figure 1 Schematic diagram of the aluminum straddle packer tool

The major characteristics of an alurmnum straddle packer tool are as follows (KLEE & HEGEMANN 1995) The packer elements consist of pure (soft) aluminum (Al 995%) which allows a maximum deformahon of ***25*** % at room temperature The two soft alurmnum packer elements are connected with threads to the interval piece and the two end pieces, both made from high strength aluminum alloy (ERGAL 55) The aluminum assembly is mounted on a stainless steel inner mandrel with deep injection- and packer inflation borings and Viton o-rmg seals The alurmnum parts of the arrangement are fixed on the inner mandrel with a **4** kN shear pin This design enables all steel parts **of** the tool to be recovered after completion of the test, while the aluminum parts remain in the borehole. The aluminum can be drilled out by adequate drilling procedures.

This system was successfully used for several hydraulic and hydrofrac tests in the Soultz and Urach boreholes down to 3.5 km depth at temperatures up to 175 °C (KLEE & RUMMEL 1993).

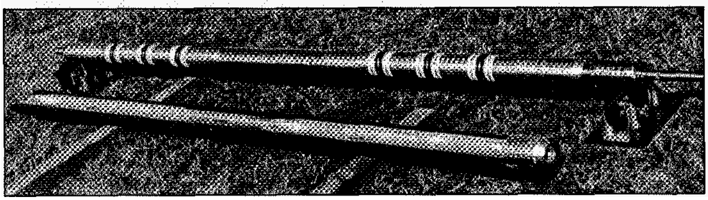

Figure 2: Aluminum straddle packer tool for 4" diameter boreholes before and after prototype testing in a steel testpipe.

3. Copper and stainless steel packers for permanent borehole sealing

The permanent and long-time reliable sealing of boreholes drilled at nuclear waste storage / disposal sites is an important requirement for safe storage. One of the available concepts for permanent borehole closure includes the use of metal packers in combination with other materials before or between the packers (e.g. bentonite or concrete). Based on the experience with aluminum packers, copper and stainless steel were selected as more corrosion resistant materials at crustal environment conditions.

The copper and stainless steel single packer elements consist of a metal pipe with two welded end pieces (figure 3). The upper end piece has a connection for the packer setting- and inflation rods. In the case of a 4" diameter borehole, the packer had an OD of 90 mm and a total length of 1000 mm. Special heat treatment of the packer material after welding was used to guarantee a uniform material structure with high ductility (app. 40 %). To achieve a better clamping at the borehole wall, the outer surface of the packer was profiled with several radial grooves.

Both packer materials were tested in a 4" diameter test-pipe. The tests demonstrated satisfactory packer friction within the test-pipes: after inflation with 40 MPa (copper) and 95 MPa (stainless steel) and subsequent pressure release, the packer elements could not be moved with a maximum pulling force of 80 kN (copper) and 90 kN (stainless steel), respectively. In addition, the copper element showed a better sealing behavior due to the higher ductility of the material and, as demonstrated by various technical applications, a higher chemical resistance against aggressive (salty) fluids.

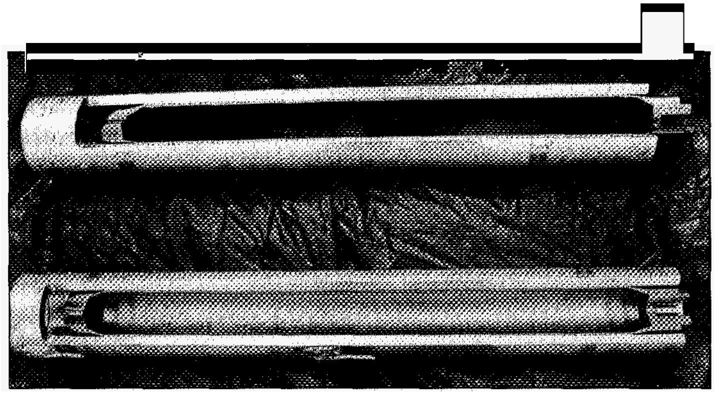

Figure 3: Copper and stainless steel packer prototypes afer testing in a test pipe.

4. Metal packers for casing cementation

A new application of metal packers is the use as cementing packers for the installation of casing strings, in particular in deep and hot (geothermal) wells. In June 1998 MeSy started the development of 7" diameter casing cementation packers to be used during the deepening of the geothermal well Soultz GPK-2. For this operation, the metal casing packers have to fulfil the following requirements:

- Permanent and reliable sealing of the 7" diameter casing in the 8-½" diameter borehole at 5 km depth and temperature of 200 °C.
- Several metal packers have to take the weight of a 7" diameter casing string of 5 km length (app. 150 tons).
- The metal casing packers have to withstand the hostile downhole conditions in a geothermal well for a period of at least 20 years.
- Easy and reliable setting procedure at the end of the casing cementation work.

The first two prototypes were constructed and tested in late 1998. The packer elements were made of copper-nickel alloy which allows a maximum deformation of **30** % at room temperature. Copper-nickel alloy has good resistance against aggressive fluids and therefore is often used in the shipbuilding- and chemical industry.

The wall thickness of the packer sleeve is between 10 mm in the binding area and **4.5** to 6 mm in the inflation section. The inner diameter of the copper-nickel sleeve is adapted to the outer diameter of the 7" diameter casing. The outer diameter of the packer is similar to the OD of the 7" casing collar (200 mm). The packer element has a length of 1000 mm and is mounted on a 1233 mm long 7" diameter casing pipe. The binding area of the metal packer sleeves were steel-ring supported and O-ring sealed.

The first prototype had a non-profiled outer surface and was tested in a 9-5/8" diameter casing (ID 223.5 mm). The packer assembly was completely filled with cement-mud and inflated with an internal pressure of 35.7 MPa. After cement hardening, it was possible to move the element **only** with a force of 180 kN.

The second prototype was tested in a steel-pipe with an ID of 218.5 mm. Again, the packer assembly was filled with cement-mud and inflated with 36 MPa. After cement hardening, it was not possible to move the casing packer in the test pipe until a force of 1640 kN was applied.

This is a encouraging result and it is planned to use an assembly of 5 to *6* copper-nickel casing packers during deepening of the geothermal borehole Soultz GPK-2.

5. Conclusions

A new packer technology based on ductile metals was developed and successfully used for hydraulic / hydrofrac tests at great depth with high temperature and hostile downhole environment.

Prototype tests showed that the technology can contribute to a permanent borehole sealing system at nuclear waste storage projects and a new casing cementation / anchoring system at great depth.

Acknowledgments

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