ALUMINUM PACKERS FOR HYDROFRAC EXPERIMENTS IN HOSTILE BOREHOLE ENVIRONMENT

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ABSTRACT

Deep hydraulic-fracturing stress measurements at the HDR research test sites Bad Urach and Soultz-sous-Forets were characterized by several technical problems caused by using conventional packer technology in hostile downhole environment (temperatures up to 140 °C, high gas and salt content of the borehole fluids). Therefore a new hydrofrac straddle packer technology based on aluminum packers as a part of a wireline system was developed. The aluminum packer technology was successfully used down to 3.5 km depth (temperatures up to 175 "C) in the Soultz boreholes GPK-1 and EPS-1 and in the Urach-3 borehole.

Laboratory tests of the new aluminum packer technology demonstrated enormous packer capacities which opens the door for future hydrofrac tests at high pressure / high temperature conditions at great depth.

1. INTRODUCTION

Hydraulic-fracturing is the most commonly used technique to carry out stress measurements or stimulation operations at great depth to open flow paths for fluid circulation in the impermeable underground. This is particular important for geothermal energy extraction from Hot-Dry-Rock reservoirs where fractures must be kept open against the acting stress-field.

However, conventional hydrofrac testing at great depth often encounters a number of technical problems such as high fracturing pressure, high temperature and high gas and salt content of the borehole fluids which results in a failure of the packer elements after short-time testing periods (e.g. Baumgartner *et al.*, 1990, Rummel and Baumgiirtner, 1991). Therefore the determination of in-situ stresses at reservoir depth at the HDR test sites Bad Urach and Soultz-sous-Forets required the development of a new technology for zone isolation in deep boreholes based on metal packers as a part of a wireline hydrofrac system.

2. CONCEPTUAL DESIGN OF THE ALUMINUM STRADDLE PACKER TOOLS

As a first approach, aluminum was selected as packer material due to its high ductility, good mechining properties and low costs. After numerous pressure tests with 35 mm diameter laboratory models, aluminum straddle packer tools operated by a wirline system were designed for the open-hole sections of borehole Soultz EPS-1 (96 mm / 4" diameter), GPK-1 (159 mm / 6-1/4") and Urach-3 (149 mm / 5-7/8"), subsequently. A schematic diagram showing the essential details of the tools is shown in Figure 1. The dimensional data for the aluminum straddle packer systems are given in Table 1. The major characteristics are as follows:

The packer elements consist of pure aluminum (Al 99.5%) which allows a maximum deformation of 25% at room temperature. The wall thickness within the packer inflation section is 17 mm for the 96 mm, 24 mm for the 149 mm. and 24.5 mm for the 159 mm diameter borehole system. The outer diameter of the packer elements are adjusted in such a way to accommodate the borehole diameter by approximately 15% of lateral deformation and differential pressures of about 25 MPa. To a certain extent, this enables the aluminum packers to be set in irregular cross-section boreholes. However, inflation in breakouts or washouts will cause packer rupture similar to conventional packers. To guarantee sealing, the outer surface of the aluminum packers are furnished with high temperature Teflon and Viton O-rings. The soft packer elements are threaded into the injection interval part and the end-pieces, both consisting of high strength aluminum alloy (ERGAL 55).

The intelligent inner stainless steel mandrel contains high temperature Viton O-rings as sealing against the aluminum outer-shell and deep borings as hydraulic connections to the packer inflation sections and the injection interval. The mandrel position inside the aluminum shell is fixed with a shear pin with a breaking force of 4 kN. This design enables to recover the steel mandrel after completion of the hydrofrac test while the outer aluminum shell remains in the borehole. The aluminum can be milled-out by adequate drilling procedures.

Table 1: Dimensional data of the aluminum straddle packer tools.

tool element material	packer Al 99.5 %			injection interval ERGAL 55			end piece ERGAL 55		inner mandrel stainless steel	
borehole diameter mm / inch	OD mm	min.wall thickness mm	length mm	OD mm	ID mm	length mm	OD mm	ID mm	max. OD mm	length mm
9614	86	17	860	88	40	900	88	40	40	2680
149/ 5-7/8	138	24	750	140	60	500	140	60	60	2340
159/ 6-1/4	145	24.5	750	148	60	500	148	60	60	2340

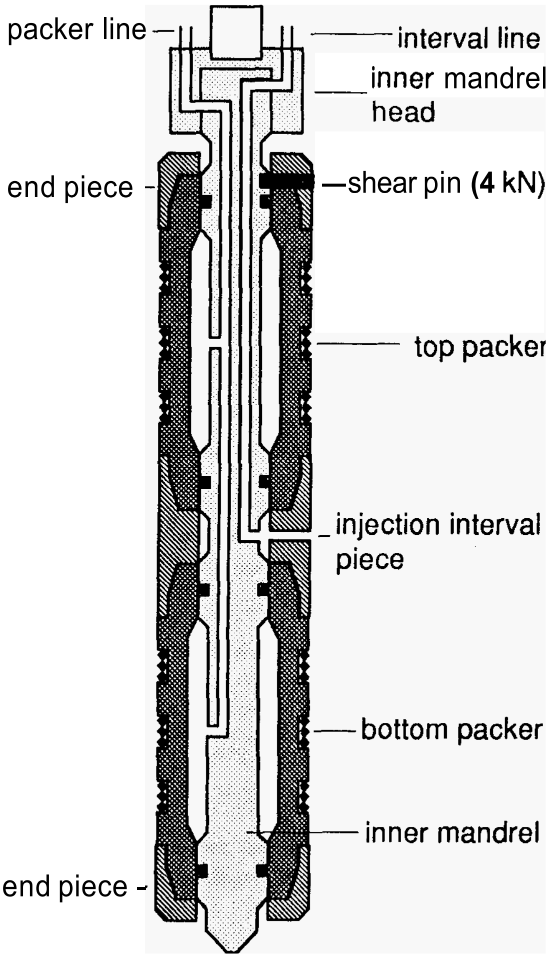

Figure 1: Schematic diagram of the aluminum packer tool.

3. TEST RESULTS

3.1 PROTOTYPE LABORATORY TESTING

Prior to in-situ hydrofracturing two prototype aluminum packer assemblies for 96 mm diameter boreholes were tested in a borehole simulator autoclave (Hegemann, submitted).

The first test at room temperature showed that the tools can be operated up to 91 MPa packer pressure and 81 MPa interval pressure (Figure 2). Packer burst occurred at a pressure of 98 MPa.

In a high temperature (175 "C) / high pressure (30 MPa) test, failure occurred at 57 MPa interval pressure during packer pressurization from 66 MPa to 77 MPa. This unexpected low packer capacity was caused by failure of one of the inner mandrel O-ring seals. By some minor modifications the tool has considerably been improved and the present versions should allow hydrofrac tests at pressures up to 100 MPa under severe in-situ conditions.

After recovery from the autoclave, the test-pipes were cut in half. The soft aluminum packer elements showed perfect contact with the test-tubes.

3.2 IN-SITU HYDROFHAC TESTING

Several hydrofrac experiments were conducted by using the new aluminum packer arrangements in the Soultz and Urach HDR research boreholes.

The first two tests were carried out in borehole Soultz EPS-1 at 2205 m and 2195 m depth (temperature 150 "C), one technology test was conducted in borehole Urach-3 at 3355 m depth (temperature 140 "C), two additional tests were carried out in borehole Soultz GPK-1 at 3506 m and 3315 m depth (temperatures up to 175 "C). The test zones were selected on the basis of FMI and Caliper as well as on BHTV-logs. The logs demonstrated rather smooth open-hole boreholes with several sections well fitted for testing. The results of the hydrofrac tests are presented by Klee and Rummel (1993). The operational results of these experiments can be summarized as follows:

The aluminum packer technology for hydrofracturing in a hot, gassy and geochemically aggressive downhole environment was a full success. Setting of the aluminum packers occurred at differential pressures of 20 MPa to 25 MPa, exactly as expected from the design of the new tool. Packer sealing at differential pressures up to 33 MPa was excellent as predicted from preceding laboratory autoclave tests. At the end of the tests the shear-off of the shear pin occurred as expected from laboratory testing and the inner mandrel could easily be recovered. During the tests the downhole data recording system was in the hot environment for 5 to 6 hours.

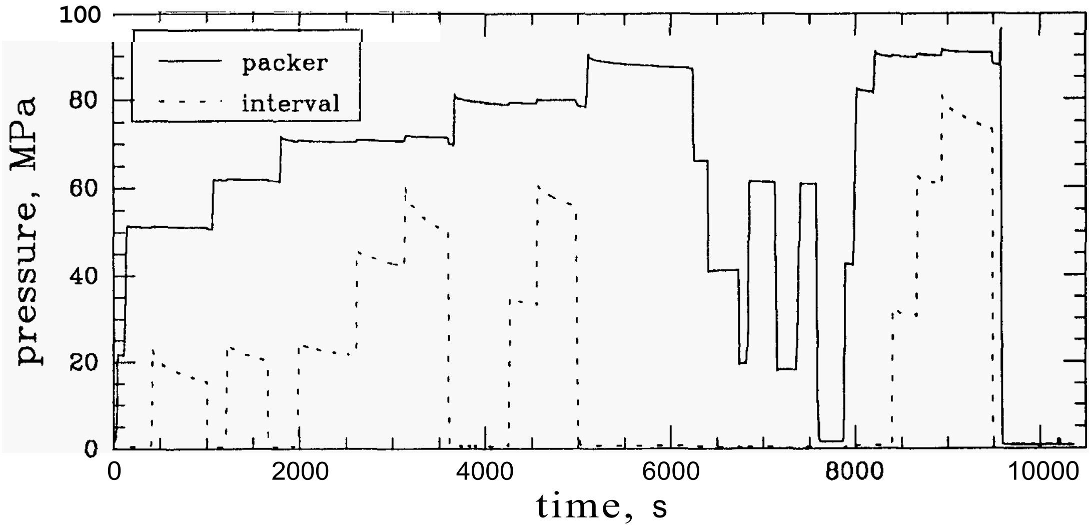

Figure 2: Packer and interval pressure record of the prototype aluminum packer test at room temperature.

During this time, the dewar with the heat sink showed excellent performance. Finally, it should be noted that the milling of the downhole remaining aluminum shells in borehole Urach-3 and GPK-1 was successful. The operation also demonstrated that the deflated aluminum shells can support large loads which opens the door for a full range of new applications (side-tracking, bridge plugs. casing packers etc.) for hostile downhole conditions.

4. CONCLUSIONS

A new packer technology for hydraulic-testing and hydro-fracturing at great depth with high temperature and hostile downhole conditions was developed and successfully used down to 3.5 km depth.

The results of laboratory autoclave and in-situ tests opens the door for a wide range of future applications (e.g. side-tracking, bridge-blugs, casing packers) of the metal packer technology. However, future work will concentrate on improvement of the technology regarding the withdrawal of the packer shells.

5. ACKNOWLEDGEMENT

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