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WaSam, a Modularly Designed Fluid Downhole Sampler for Deep Geothermal Applications

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ABSTRACT

The fluid sampler WaSam is being developed for downhole sampling in deep geothermal boreholes. A new sampling and storage concept is developed and realized in a functional demonstrator (sampling volume 480 cm³). Via the wireline, the demonstrator sampling system is remotely controlled using real time data. Temperature, pressure in different locations of the probe, and electronic components are permanently monitored and recorded. The in situ storage of the monophasic sample is being realized by an adaptive hydraulic and heating control. Furthermore, the functional demonstrator fulfills the requirements of the design standard for downhole logging tools (T = 200°C, p = 60 MPa, harsh and corrosive fluids). For this, a highly loadable demonstrator housing made of Inconel® 718 is reused from standard parts of the design construction kit.

1. Introduction

In this paper, a new concept of a downhole fluid probe sampler, and the final design of a functional demonstrator built with a construction kit called ZWERG are presented. Mainly the mechanical components, such as the hydraulic system, the pressure vessel, and the sample procedure are described.

In conventional downhole sampling, a cylinder tube is lowered downhole on a wire line. A fluid sample is taken and held under in situ conditions in a pressure chamber. In situ means “in place”, hence the local pressure and temperature in the sample chamber must remain constant (Wolff-Boenisch, Evans, 2014). At the surface, the mechanism transfers the sample in a transport bottle, e.g., in the One Phase™ Sampling Cylinder provided by Leutert.

The positive displacement sampler (PDS) is a state-of-the art device. It consists of a floating piston, a sample pressure chamber that is filled with a displacement fluid, an air chamber, a trigger mechanism, and a clock housing. All components are encased in a housing and are connected to a cable head to attach a wireline to the surface. The displacement fluid is under pressure in the sample chamber. The trigger mechanism, a preset timer, activates a valve and initiates sampling through a pressure difference. A closing mechanism shuts off the inlet and keeps the sample in the chamber during uplift (Kampman et al., 2013).

The Armada® Slickline Single-Phase Sampler provided by Haliburton has a maximum operating temperature of 177°C and a sampling pressure of 1379 bar; it can take two 400 cm^3 fluid samples (Haliburton, 2020). The One Phase™ Sampler OPS supplied by Leutert is designed for a maximum operating temperature of 180°C and an operating pressure of 1035 bar, and retrieves a fluid sample of 600 cm^3 (Friedrich Leutert GmbH & Co. KG, 2020).

“During uplift, the fluid is inevitably cooled and experiences thermal contraction, i.e. volume shrinkage, which reduces the hydraulic pressure of the compressed fluid on the cylinder wall” (Wolff-Boenisch, Evans, 2014: 71). In order to avoid changes in the sample composition during retrieval of the sample, many manufactures, such as Schlumberger and Leutert, include a pressurization system in the sample chamber. A pressure cylinder filled with nitrogen compresses the fluid sample with a piston. The pressure on the sample is kept above reservoir pressure (Friedrich Leutert GmbH & Co. KG, 2020).

However, the new fluid sampler Water Sampler (WaSam) introduced in the present paper increases the quality of a representative reservoir fluid sample with remote control of the sample system, storage, and retrieval, plus continuous monitoring of pressure, temperature, and electronic components. With actively steerable hydraulics and adaptive control of pressure and temperature, the fluid sample can be stored permanently under in situ conditions without the need for primer fluid and pressurized nitrogen.

The mission of the downhole fluid sampler WaSam is to take a sample larger than 400 cm^3 from the borehole at a desired depth and retrieve a single-phase sample to the surface. The sample must be kept monophasic to avoid flashing and phase separation, which would alter it irreversibly. Furthermore, WaSam is specially designed to meet the requirements of geothermal boreholes in central Europe. The main requirements are an operating temperature of 200°C, a maximum thermal water pressure of 60 MPa, and resistance against very corrosive and harsh environments (Spatafora et al., 2019).

These requirements are consolidated in the so-called ZWERG requirements: At the Karlsruhe Institute of Technology, within the workgroup Geothermal Energy at the Institute for Applied Computer Science and Automation, an open-source platform for geothermal borehole tools and devices to enhance the information quality of deep geothermal applications has been developed. The platform is referred to as ZWERG (Holbein et al., 2018). ZWERG links the requirements of deep boreholes, electronic hard- and software, a design construction kit, and standardized testing for variable applications such as the GeoKam system (Spatafora et al., 2017), the permanent cooling system (Holbein, 2019) and a new downhole sampling system (Isele et al., 2015).

2. Concept and Performance of Fluid Sampler WaSam

The outer structure of WaSam is similar to that of a conventional PDS. The bottom of the housing is closed with a tip (bull nose) and the top is joined with a cable head and connected via wireline to the surface. The fluid sampler WaSam concept, in principle, consists of an insulated and heated pressure vessel connected to a hydraulic system. The system is equipped with an electric control circuit and measuring sensors. These components are encased in a thermo-mechanical highly loadable Inconel® 718 housing. The sampling process and pressurization are simplified by a pressure vessel with an inlet hole, mechanical stops, and a sample piston and valve piston. The pressure vessel is insulated and heated (Figure 1). The sampling procedure consists of four steps. With increasing downhole depth, the thermal water pressure on the sample piston increases. A counterforce F keeps the pressure vessel closed. The valve piston is pressed against the right stop by the thermal water pressure p (Figure 1-I). During sampling, the thermal water flows into the container at a velocity v, the valve piston does not move (Figure 1-II). The water sample is trapped in the pressure vessel by closing the inlet with the valve piston, which moves the sample piston to the left stop (Figure 1-III). The valve piston presses on the water sample with force F, while the sample temperature is kept constant by heat Q (Figure 1-IV).

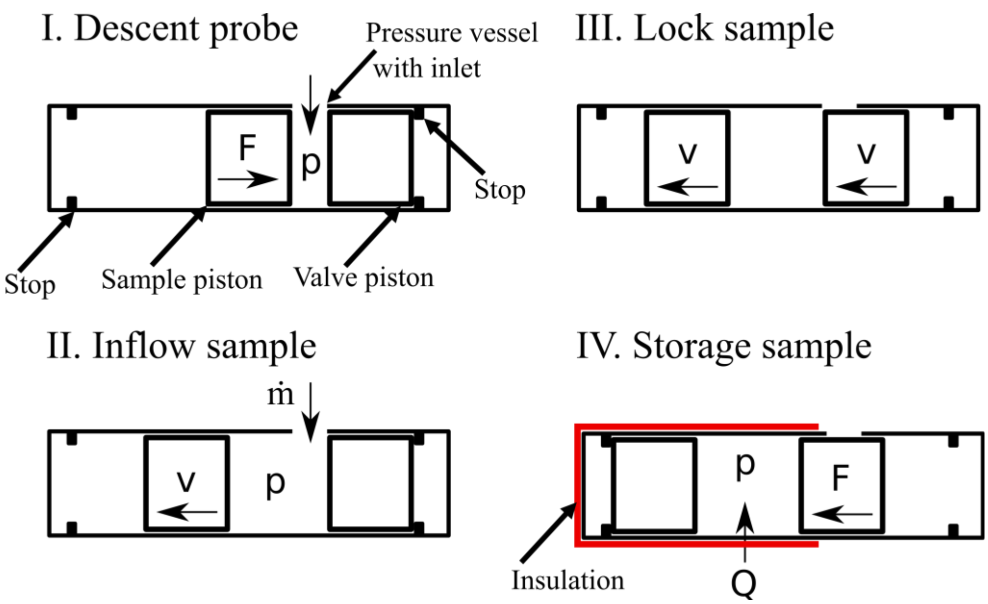

Figure 1: Schematic design of sample system with states I to IV.

Figure 2 shows the entire construction of the functional demonstrator and the important sections. The hydraulic system is on the right side of the socket (Holbein et al., 2017). The logical structure is shown in Figure 3. To the left of the socket, two hydraulic pistons are connected in series via a short piston rod. The lower hydraulic piston is rigidly mounted to the long piston rod. This arrangement allows greater forces to be transmitted to the long piston rod. The direction of movement of the pistons is controlled by a 4/3 directional control valve. The hydraulic pump controls the volume flow and hydraulic pressure, which is additionally measured in the hydraulic cylinder (Figure 3). The pressure vessel is rigidly connected to the hydraulic cylinder via a connecting element. The pressure vessel has an inlet hole with a tight connection to the house drilling, which is described in detail in Section 3. To the left of the inlet hole, the pressure vessel is sheathed with an electrical heater and insulation. A dewar from the modular platform is used for insulation. The pressure vessel is closed by a solid screw lid and the valve piston.

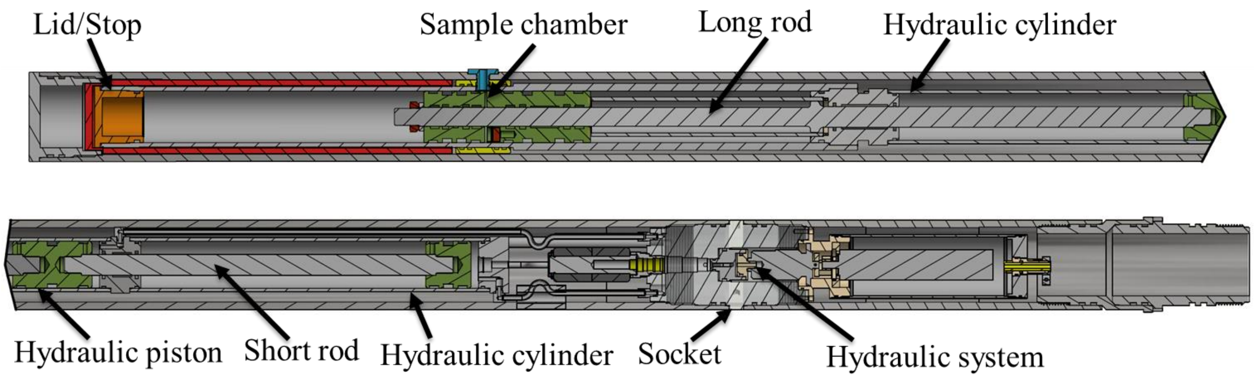

Figure 2: Construction of fluid sampler functional demonstrator (cut in half-section).

The sample piston and valve piston are mounted axially movable on the long piston rod. The sample piston and valve piston are equipped with piston seals with back-up rings, rod seals, and guiding tape. The sealing material is fluorocarbon rubber (FKM, Shore 80) which is very resistant to high temperatures, hydraulic fluids, and chemicals. The back-up rings are made of PTFE and guiding tapes are composed of PTFE and bronze.

Figure 4 shows the fluid sampler in state I, prepared for deployment in the well. In the borehole, the thermal water pushes the valve piston against the housing stop and the sample piston against an adjustable groove nut which is screwed onto the long piston rod (Figure 4). The hydraulic system actively secures the sample piston in the hydraulic unit by overpressure control in relation to the ambient water pressure. In state II, sample inflow is initiated by a controlled reduction of the hydraulic pressure below ambient pressure. The sample piston is moved down by the thermal water pressure and the water sample is drawn. The speed of the sample piston is controlled by the hydraulic counter pressure control and a throttle valve. The inflowing thermal water pushes the sample piston with the long piston rod into the pressure vessel until the rod collar touches the valve piston. Sample piston and valve piston are pushed outwards against the stops. The system is stable. A force greater than the friction force in the hydraulic system moves the long piston rod to the left, putting the WaSam in state III, locking the sample in the vessel. The transition from underpressure to overpressure must increase accordingly and without any pressure drops. The rod collar pushes the valve piston, the fluid sample, and the sample piston to the left into the pressure vessel until the sample piston touches the cover (stop). With hydraulic force via the

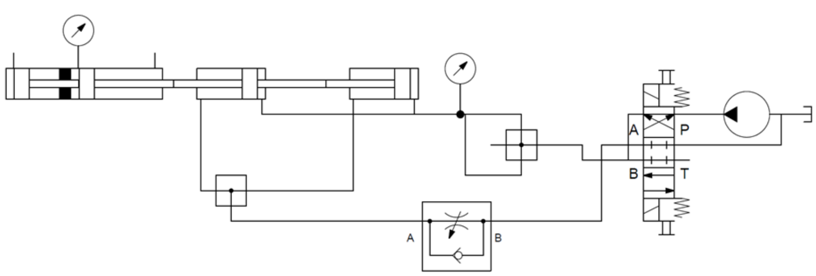

Figure 3: Schematic fluid sampler: Hydraulic system and pressure vessel with valve piston and sample piston.

valve piston, the fluid sample pressure can be adaptively controlled, state IV storage sample. A pressure sensor is mounted in the valve piston. With a feedback control of the electric heating and the hydraulic piston force, the fluid temperature and pressure are kept constant. Taking into account the ZWERG platform standard, the housing outer diameter must not exceed 95 mm and a total length of 3500 mm (Spatafora et al., 2016). Hence, the unaltered sample volume is 480 cm^3. As a functional demonstrator, the probe volume can easily be increased. Consequently, the cylinder housing of other ZWERG tools can be used as a housing. The housing is manufactured from Inconel® 718, which is highly resistant to corrosion, even at high temperatures. To reduce production costs, the inner parts are made of chromium nickel martensitic stainless steel with molybdenum addition, which is widely used in the oil and gas industry (Deutsche Edelstahlwerke GmbH, 2020).

3. Design-related Challenges

Two design challenges had to be solved, i.e., the installation space of the probe and the tube connection from the housing hole to the pressure vessel.

The installation space of the pressure vessel is limited by the inner diameter of the housing cylinder and the dewar dimensions (both components are standardized through the ZWERG platform rules), the heating system and the maximum volume in the pressure vessel. The inner diameter of the housing cylinder is 79 mm and the outer and inner diameters of the dewar are 78 mm and 66 mm (see Figure 4). The inner diameter of the dewar of 66 mm and the 0.5 mm gap between the dewar and the pressure vessel for resistance heating results in a maximum outer diameter of 64 mm for the pressure vessel. Considering the dimensions (Table 1), the maximum outer diameter of the pressure vessel, the material and the operating conditions such as internal pressure and maximum temperature, a minimum wall thickness for cylindrical tubes with internal load is $4.06\,mm$ (Equation 1; AD 2000, 2018). In order to be able to use standard components such as seals, pistons, cylinders, and instruments (according to the ZWERG principle) for construction of the pressure vessel, the calculated minimum wall thickness is increased to $4.5\,mm$, resulting in an inner diameter of the pressure vessel of 55 mm.

$$s_{min} = \frac{D_{out}\,p}{20\frac{K}{s}v + p} + c1 + c2 \tag{1}$$

Table 1: Calculation of the minimum thickness of the pressure vessel (Isele, Holbein, 2013).

Formula Symbol	Legend	Value
s_{min}	wall thickness in mm	4.06
D_{out}	outer diameter in mm	64
p	pressure in bar	600
K	yield strength at calculated temperature in N/mm²	$1.4313\ QT\ 900$ $R_{p0.2} = 665(200°C)$
S	safety factor (1.5 for rolled steel)	1.5
v	factor for considering joint (0.8 to 1)	1
C_1	addition for dimensional tolerances of the tube in mm	0
C_2	erosion addition in mm	0

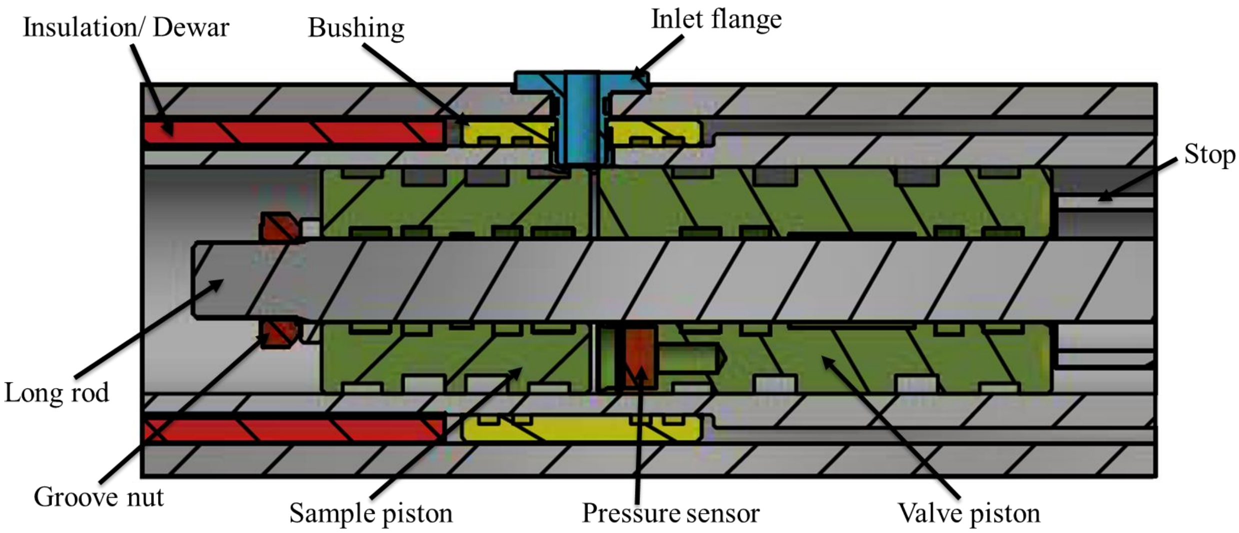

Figure 4: Construction state-I – probe ready for descent.

During uplift to the surface, the housing is flushed with cold fluids, while the fluid sample is kept at extraction temperature by the heater in the pressure vessel and at extraction pressure by the valve piston force. For sampling, a tight connecting tube between the housing bore and the pressure vessel (Figure 4) is required. Temperature differences and a varying mechanical load between housing and pressure cylinder lead to different material expansions, which would lead to the failure of a rigid connecting tube. This problem is solved by a design arrangement that allows small radial and axial movements of the crucial components. This is realized with a bushing which is axially movable on the pressure vessel and is connected to the inlet flange so as to move radially (Figure 4). Additionally, the assembly of the housing and inner workings is simplified, since the radial bore of the sleeve is centered by the fixed inlet flange. Since this involves small movements, sealing is done with O-rings.

4. Conclusion

The concept of downhole sampling fluids and the engineering of a functional demonstrator to given requirements have been accomplished. The demonstrator structure was mainly designed from modular components of the ZWERG system. This had a strong impact on the development and manufacturing costs. For other parts, the design know-how of the modular kit could be used to design static pressure sealing, fine threads, and handling of high-performance materials. The functional demonstrator is a concept with an adaptive pressure and temperature control of the fluid sample. In situ sampling can be applied at multiple depths and can even be used with a sequence of samplers. Hence, it has the potential to gain samples of higher quality for a better understanding of deep geothermal boreholes.

Meanwhile, all parts are manufactured and will be assembled and tested shortly. A functional electronic control system is under development.

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