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DEVELOPMENT OF A HIGH TEMPERATURE BOREHOLE FLUID SAMPLER AND ITS FIELD EXPERIMENTS IN THE LARDERELLO GEOTHERMAL FIELD, ITALY

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ABSTRACT

The objective of the high temperature fluid sampler development programme is to produce a downhole system capable of capturing a very high quality, representative sample of the borehole fluid and to deliver it to the surface for subsequent analysis. The maximum operating temperature of the system will be 400°C. Minimal sample alteration and zero contamination are required.

The development of the high temperature fluid sampler for the New Energy and Industrial Technology Development Organization (NEDO), for the deep seated geothermal resources research programme began in 1993, with the first prototype tool rated at 300°C (Halladay, 1997). Following these tests reported here the second prototype rated for 400°C will be designed, built and tested.

The development programme has included extensive high temperature seal performance tests, material corrosion trials and subsystem design studies. Several types of sampler have been identified and the controlled displacement type (CDS), chosen as the one which offers the best potential for the highest quality sample and further development for use at high temperature. A high temperature CDS sampling tool has been designed, constructed and has been tested downhole at 200°C.

This paper presents the field experiments with the first prototype tool at the Larderello site of ENEL in Castiglioni-1 borehole. Over the 6 days period of the test the sampler was deployed 9 times. Initially, some difficulty was experienced with the non-return inlet valve seal leaking, and several deployments returned a small volume of non-pressurised sample. This was rectified by a modification to the seal assembly. The final 5 deployments returned complete pressurised borehole fluid samples to the surface from a depth of 1125 metres. The samples were analysed later and the results are presented in Table 1 below.

1. INTRODUCTION

Two methods of sampler tool operation have been generally applied for obtaining borehole fluid samples at 300°C or above, these are the "flow through" type of sampler and the "vacuum" type.

The flow through type can be visualised as a tube which has both ends open allowing fluid to pass through the device when lowered down the borehole. When the selected depth in the borehole is reached, the ends of the tube are closed thus trapping a sample of the fluid inside the sampler. This sample is then recovered at the surface for analysis. However fluid inside the sampler may be a mixture of the fluid the sampler has encountered on its passage down the borehole with the fluid at the target collection depth. Thus the chemistry of the fluid sample may be confused.

The vacuum type of sampler consists of an empty sample tube which is opened at the desired depth in the borehole allowing fluid to enter the sample chamber. The valve is then closed and the sampler is recovered to the surface as before. It is described as a vacuum type because the internal pressure of the sample tube is either atmospheric or a partial vacuum before the inlet valve is opened to take the sample. Therefore when the inlet valve is opened the high temperature and pressure sample will boil as it enters the chamber and the geochemistry will subsequently alter. Both types of tool have been used for sampling fluids up to 300°C.

The type of sampler developed for the NEDO research programme is based on the Controlled Displacement Sampler (CDS) which was conventionally used for sampling lower temperature fluids. The programme acknowledges some of the benefits of the existing CDS type samplers and develops the system for use at high temperature.

2. THE CONTROLLED DISPLACEMENT SAMPLER

In the prototype CDS sampler described below there are two coaxial chambers inside a heat insulated pressure body (see Figure 1). The inner chamber is divided into two sections by a movable piston. Before deployment, during the set-up procedure this piston is positioned at the fluid sample entry end of the chamber. The small quantity of air left between the sample inlet valve and the face of the movable piston is purged and replaced with pure water. The cavity on the other side of the piston is also filled with water before deployment and this is referred to as the working fluid. The working fluid cannot contaminate the sample fluid as it is separated from it by the movable piston. The outer coaxial chamber is connected to the working fluid chamber by an adjustable throttling valve and check valve. When a sample is collected the working fluid is transferred to the outer chamber under the control of the throttling valve.

A sample is collected by perforating a thin rupture disk with a timer controlled piercing needle. The time delay before piercing is pre-set at the surface so no communication with the tool is required. This obviates the use of non standard, specialist, very high temperature logging cables. The needle mechanism is controlled by a battery powered motor and ball screw. The in-line ball latches and magnetic coupling first employed in the prototype have been replaced by the current spring assisted, pressure balanced mechanism to improve reliability.

When the rupture disk is pierced the high pressure fluid enters the sampler causing the non return valve to open. The sample fluid applies pressure to the face of the movable piston and so the working fluid, is forced to transfer to the outer chamber at a controlled rate via the throttling valve. This reduces the flow of the incoming sample therefore preventing the sample from boiling. The transfer of the working fluid into the outer coaxial chamber also acts as a cooling medium for the sample. The seals on the moving piston are passing over metal which has not been exposed to the hot borehole fluid and is being cooled by the displaced working fluid. When the sample chamber is full and the pressure has equalized, the sampler can be brought to the surface; the increasing differential pressure closes the inlet valve.

3. FIELD EXPERIMENTS IN LARDERELLO, ITALY

Before the trials in the ENEL Castiglioni-1 borehole, the sampler had extensive low temperature testing in the ABB-Rosemanowes 2.5 km deep test boreholes in Cornwall, UK.

The wells at ABB Rosemanowes test site have a maximum bottom hole temperature of 80°C. Therefore it was necessary to move off-site to continue the developmental testing of the sampler. In October 1998 the sampler was taken to the ENEL Larderello-Valle Secolo geothermal site in Tuscany Italy, (Figure 2). There were two objectives in this series of field trials. The first was to test the modifications to the operating mechanism of the sampler including the redesigned rupture disk piercing system, and to prove the operation of the inlet and check valve within the tool. The second objective was to achieve a number of complete functional tests of the sampler, including collecting the fluid samples for later chemical analysis. Both objectives were achieved.

The borehole used for this series of tests was Castiglioni-1 which is located at the margin of the geothermal steam field. The sampler was deployed to a vertical depth of 1125 metres and the borehole fluid level was 500 metres below the surface. A pressure and temperature tool was fitted between the top of the sampler and the wireline. This allowed a full log of the borehole during the first sampler test deployment. The temperature and pressure plots are shown in Figure 3. Castiligoni-1 borehole was originally 1766 metres deep and cased to 754 metres. Deployment below 1200 metres is not advisable as the borehole is too obstructed by debris for safety. Samples were therefore taken at 1125 metres depth at which the temperature measured 199.52°C at a pressure of 58.1 Bar (5.81 MPa).

The sample inlet rupture disk piercing mechanism worked faultlessly for the entire field test. The operation of the inlet valve required some modification during the initial testing period. The inlet valve used a spring energised PTFE (teflon) lip seal with a split PTFE back-up ring. In the initial tests the split back-up ring became displaced by the flow of the sample entering the tool. This prevented the inlet valve from fully closing; thus a pressurised sample was not contained within the tool when it was returned to the surface. Figure 4 shows the back-up ring damage. A second test using new components presented the same failure mode. Several modifications to the inlet valve seals were proposed and tested by deployment in the borehole. The final changes to the operation of the system were to (a) introduce a 1 mm diameter flow restrictor to slow the inrush of borehole fluid, (b) the split PTFE back-up was replaced with a continuous ring manufactured from Nickel alloy 625 and (c) the internal sample pathways between the rupture disk, inlet valve and recovery port were fully purged of air by pumping water through the system.

4. RESULTS

The initial results after the first deployment were disappointing, with deployments 2 and 3 failing to return a pressurised sample. The inlet valve modification produced a pressurised sample from deployment 4, however this was using a viton "O" ring as the seal on the inlet valve. Before each sample was extracted from the tool the pressure of the sample within the sample chamber was recorded by a gauge fitted to the extraction equipment. The pressure recorded from deployment 4 was 34.3 bar. This was a higher pressure than deployment 1 and also higher than a previous trial in this borehole in 1997. Although a different type of seal was used for deployment 4 the pressure difference could not be attributed to it. The sample from deployment 4 measured 1100 cc's which is the capacity of the sample chamber, after it was measured the sample was sealed for later laboratory analysis at CSMA Minerals. Before deployment 5 the inlet valve sealing components were changed to a PTFE lip seal and a modified back-up ring, also the flow restrictor was fitted. When the sampler was returned to the surface the pressure was measured at 20 bar using a replacement calibrated gauge. The gauge used in deployment 4 was tested on return to the UK and found to require re-calibration. The sampler returned a 1100 cc sample from deployment 5 and this was again sealed for later analysis. All subsequent deployments returned 1100 cc's of sample at the expected chamber pressure and the sampler worked well and reliably

The sample pressure indicated on the extraction equipment gauge is not the hydrostratic pressure at the sample collection depth, but is the pressure of the sample within the tool sample chamber after the tool has been returned to the surface.

Table 1 shows the good consistency of the sample analysis from deployments 5 to 9, however there are some small differences between the results and these are also shown. Deploying and recovering the sampler many times would be expected to create an uneven chemical distribution in an inactive and stagnant borehole. As this method of stirring is not ideal, it would be difficult to get a uniform chemical distribution within the borehole. If the borehole was flowing, for example if fluid was entering the borehole at discrete flowing joints, a greater consistency could be expected.

5. CONCLUSION

A high temperature downhole controlled displacement fluid sampler has been developed and bench tested to 300°C, and has now had a successful field trial in Castiglioni-1 borehole at 200°C. The changes to the rupture disk piercing mechanism proved very reliable and the modifications to the inlet valve sealing components were successful. Five pressurized samples were collected for later analysis. Generally the tool performed well, but further understanding of the dynamics of the inlet valve is desirable. It is also recommended that further trials of the sampler are conducted in a borehole with a temperature closer to the bench test temperature of 300ºC.

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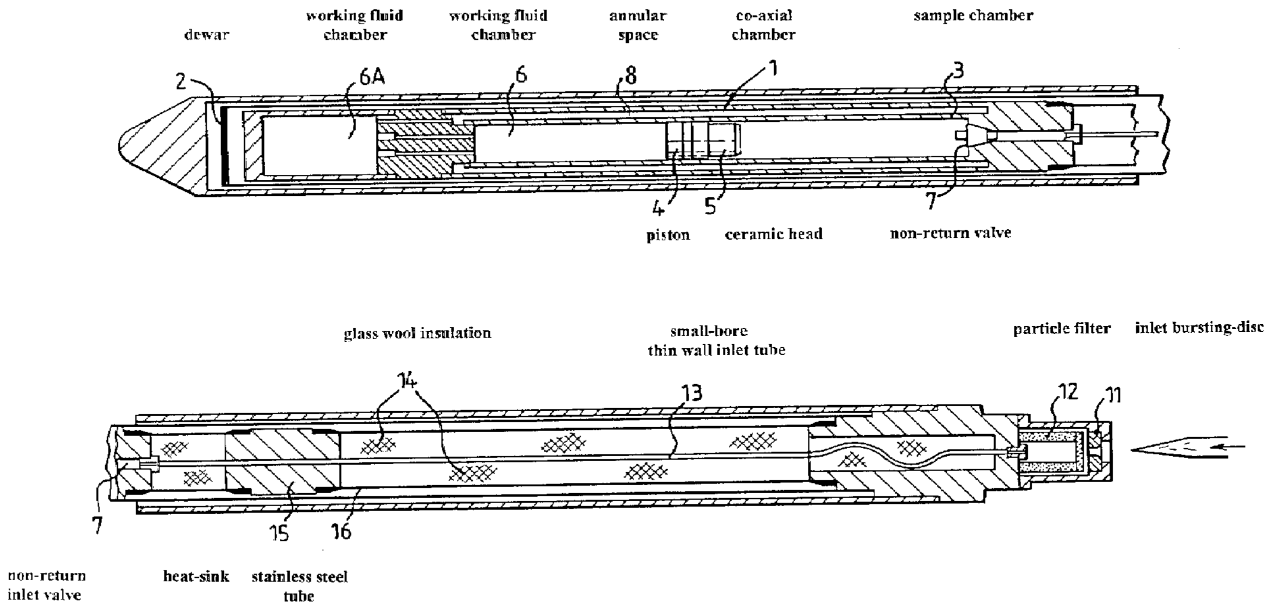

Figure 1 Schematic of Sampler

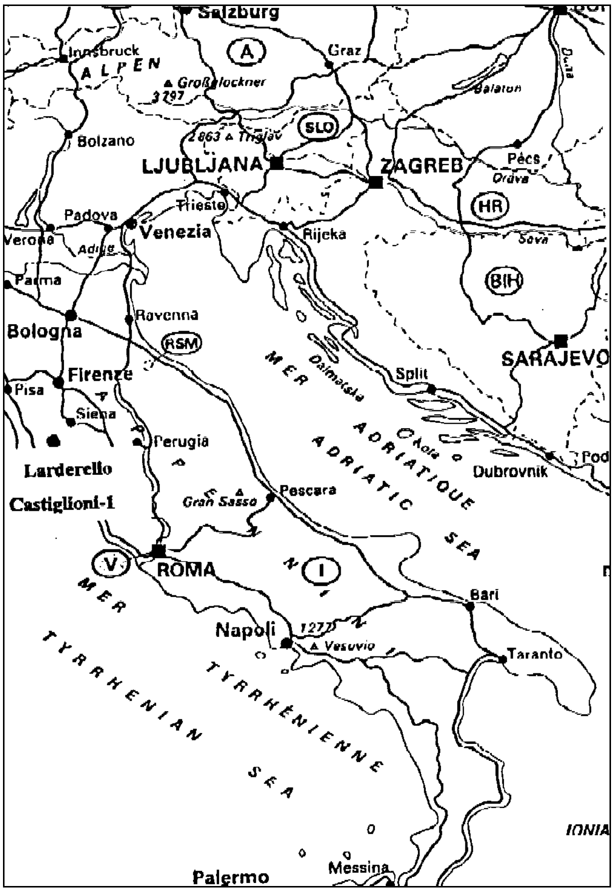

Figure 2 Larderello-Valle Secolo Geothermal Site, Tuscany, Italy

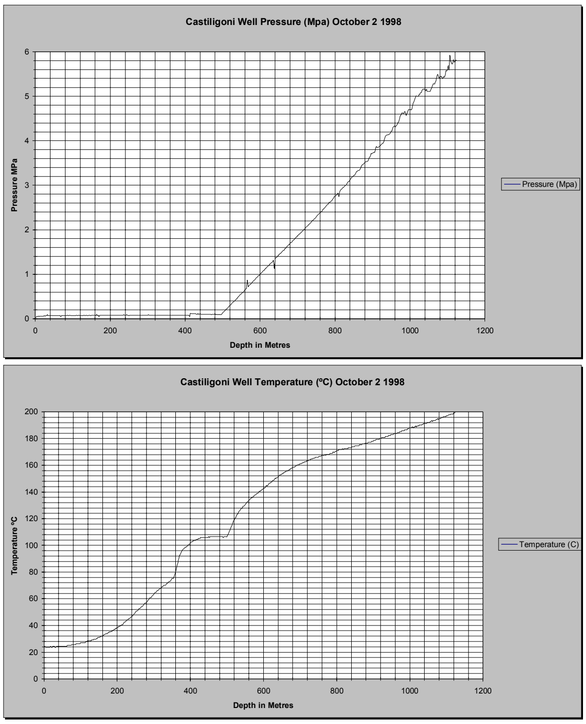

Figure 3 Castiligoni well pressure and temperature charts

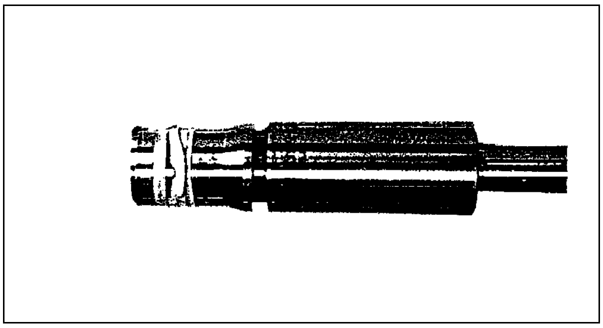

Figure 4 Back-up ring damage

Table 1 Sample volume and chemical analysis

No	sample press. (bar)	volume (CC)	valve	pH	conduct (mS)	Fe	Mn	Cu	Zn	Pb	Cd	Ni	Al	NO,R	SO,S	Cl
1	20.5	1000	EVS+SS	8	5.68	0.173	0.009	0.039	0.221	0.009	<0.001	0.077	0.009	<0.01	260	1550
2	-	450	EVS+SS	7	5.98	0.128	0.004	0.039	0.142	0.004	0.003	0.838	0.028	<0.01	310	1655
3	-	450	EVS+SS	6.8	6.06	0.262	0.005	0.011	0.035	0.003	<0.001	0.116	0.047	<0.01	300	1625
4	34.3	1100	O-ring	6.12	5.54	0.166	0.002	0.045	0.105	0.009	<0.001	0.192	0.027	<0.01	270	1460
5	20	1100	EVS+SC	6.38	5.61	0.123	<0.00	0.035	0.137	0.003	0.001	0.095	0.022	<0.01	290	1445
6	21	1100	EVS+SC	6.18	5.45	0.352	0.002	0.121	0.149	0.008	0.001	0.321	0.034	<0.01	270	1445
7	20.2	1100	EVS+SC	6.19	5.56	0.22	0.008	0.028	0.041	0.003	<0.001	0.098	0.024	<0.01	280	1445
8	20.4	1100	EVS+SC	6.24	5.57	0.19	0.002	0.046	0.219	0.003	0.001	0.195	0.032	<0.01	280	1460
9	20.3	1100	EVS+SC	6.19	6.2	0.199	0.003	0.045	0.067	0.005	<0.001	0.116	0.033	<0.01	300	1565