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Review Paper

Review of available fluid sampling tools and sample recovery techniques for groundwater and unconventional geothermal research as well as carbon storage in deep sedimentary aquifers

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SUMMARY

Sampling fluids from deep wells and subsequent sample treatment prior to gas and liquid analysis requires special equipment and sampling techniques to account for the relatively high temperatures, pressures, and potential gas content present at depth. This paper reviews five major sampling methodologies, ranging from different in situ wireline samplers to producing pumps and the U-tube and discusses their advantages and drawbacks in the light of three principal applications, deep groundwater research, unconventional geothermal exploration, and carbon storage. Geochemical modelling is used to investigate the probability of decarbonation and concomitant carbonate scaling during sampling in geothermal and carbon sequestration applications. The two principal sample recovery techniques associated with the fluid samplers are also presented.

Contents

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1. Introduction

To curb carbon dioxide emissions, renewables are expected to play an ever increasing part in the society's energy consumption mix (McGowan, 1991). The need to find and harness alternative energy sources to fossil fuels has motivated widespread investigation and development of renewable energy sources, including unconventional geothermal systems. Since volcanic activity is absent in unconventional geothermal systems, the viability of thermal and electrical energy production depends on the type of heat source and permeability of the host rock. Hot sedimentary aquifers (HSA) can combine sufficient hot fluid volume with relatively high permeabilities to permit heat extraction on an economic scale, principally for direct heat applications. Furthermore, HSA are more widespread than magma-related sources and technologically less challenging than engineered geothermal systems like hot dry rocks. Given that HSA are common worldwide, exploitation of geothermal energy from these sources has become a focus of attention in recent years (Lund et al., 2011).

Besides increased use of renewables, carbon capture and storage are considered important mechanisms for reduction of the carbon footprint that originates from the burning of fossil fuels (Herzog, 2001). Both unconventional geothermal research and exploration (uGT) into HSA and carbon storage (CS) initiatives rely on similar host rock properties for success, viz. porous, thick sedimentary formations with appreciable storage capacity and permeability, overlain by a caprock that works as thermal insulation and seal, respectively. UGT focuses on extracting huge quantities of hot water, in the range of tens of litres per second from a sufficiently hot aquifer while CS concentrates on injecting vast quantities of supercritical CO_2, on the order of Mt/y, into a sufficiently pressurised aquifer. Given the similar scale of extracted versus injected volume over time, it is not surprising that recent studies are looking into how to exploit this intimate link and maximise the benefit of both strategies (Pruess, 2010; Randolph and Saar, 2011; Ueda et al., 2005). Such projects, whether combined or separate, require accurate geochemical analyses of formation water and gas samples for chemical characterisation and monitoring purposes. Given the increasing number of CS and uGT geoengineering projects, the need for accurate in situ fluid sampling will steadily increase over the coming years and motivates this review of available downhole sampling and sample recovery techniques.

The petroleum industry has ample experience in deep well fluid sampling and has developed an impressive assortment of wireline formation tester and sampling tools, such as the modular formation dynamics tester (MDT), cased hole dynamics tester (CHDT), production logging tool (PLT), life fluid analyser (LFA), or single phase reservoir sampler (SRS), to name but a few (Aghar et al., 2007). These are all proprietary brands from the well service company Schlumberger Limited, and can only be rented at prices that are likely beyond pilot projects and smaller scale commercial and academic research projects designed as proof of concept type studies. However, an array of commercial samplers is also available and the aim of this review is to focus on samplers suitable for 'deep' sedimentary aquifer applications, like ground and formation water research, uGT, and CS.

In this context, the adjective 'deep' is used qualitatively in the text as the sampling depth depends on the application. For CS, pressure is the key factor to keep CO_2 supercritical (or dissolved in the aquifer) and thus injection starts at a minimum of ca. 800 m – but can go down to several km. For uGT from non-magmatic sources, temperature is the crucial parameter and the sampling depth depends on the geothermal gradient which can vary widely. Assumption of a reasonable average geothermal gradient for a sedimentary basin of 30 °C/km (Bachu and Burwash, 1991) yields a potential production and thus sampling depth of around 3 km to reach 100 °C hot water. At these depths, regular groundwater sampling equipment is unsuitable because of relatively high temperature (T), pressure (P), or X conditions (where X refers to the molar fraction of dissolved gas). It is these conditions and applications that require special downhole sampling gear whose peculiarities and limitations will be presented and discussed in the following text. The goal is to provide the reader with the necessary data to make an informed decision on which tool to develop or procure for his/her deep well application.

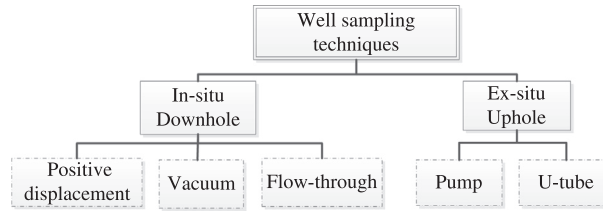

Fig. 1. The five major deep well sampling techniques.

2. Overview of deep reservoir sampling techniques

This section assumes that the injection/production/monitoring well has been suitably completed, i.e., cased and perforated when dealing with a closed well, and further developed in case of an open well, meaning that packers, liners, screens, gravel packs or other similar options are in place to allow unhindered sampling of the target formation. A packer is a sealing device that isolates the horizon targeted for sampling within the wellbore and enables formation fluid sampling from different depth levels. Packers are inflatable or swellable and provide a seal of the annulus, which is the space between the outside of the sampler and either the inside of the perforated casing (in case of a perforated production casing) or of the slotted/screened liner (in case of an open hole). It is further assumed that researchers are interested in the dissolved gas component of samples; such gases contribute to undesirable consequences of heat extraction such as mineral scaling, gas evolution and hydrogen embrittlement (Aksoy, 2007; Kelessidis et al., 2007; Song and Curtin, 2013). Thus, acquisition of a single phase sample, or at the very least, a sample from which the properties of the single phase sample can be deduced, is highly desirable.

There are basically two ways of sampling fluids from a deep developed well, either directly at the depth of interest, denominated 'in situ' or 'downhole' sampling, or by conveying the fluid to the surface, which is termed 'ex situ' or 'uphole' sampling (Fig. 1). In situ sampling requires lowering a pipe-shaped sampler connected to a wire or slickline down the wellbore to the target depth. Positive displacement, vacuum, and flow-through samplers are designed similarly and utilise comparable valve tripping mechanisms but the former two rely on a pressure differential between formation and sampler for sample acquisition while flow-through samplers do not. The importance of this distinction will become evident when comparing the respective sampling techniques. Ex situ (or uphole) sampling, on the other hand, refrains from introducing any wireline tool into the casing/liner and involves transfer of the fluid to the wellhead, usually via a production pump or by blowing out reservoir fluid from a U-shaped pipe (U-tube) using an inert carrier gas. The latter technique is not to be confused with the so-called 'gas lift' where a compressed gas is introduced through the casing-pipe annulus to reduce the fluid density and stimulate self-lift against the hydrostatic pressure of the fluid column (American_Petroleum_Institute, 1994). Gas lift will not be treated as a means to acquire a subsurface sample in this study