Potential impact of CO_2 on subsurface microbial ecosystems and implications for the performance of storage reservoirs

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Abstract

Studies of the potential environmental consequences of carbon capture and storage (CCS) have, to date, focused on the physical and chemical impacts of CO_2 within stable geological formations together with associated monitoring systems to assure that no significant leakage occurs. If leakage did occur after formal closure of the injection site, this is likely to be restricted to discrete point sources, such as abandoned wells, resulting in locally high concentrations of CO_2 in near-surface ecosystems. Consequently, environmental impacts of localised elevated CO_2 on terrestrial and marine ecosystems are areas of active research. However, the CO_2 storage site could also impact on the deep subsurface microbial ecosystem and biogeochemical processes. This paper describes short pilot studies (2136 h/ 89 days) investigating the changes in physical transport properties that are mediated by microbial activity, within samples of sandstone under experimental conditions simulating deep aquifer and reservoir environments in the North Sea. They showed, for the first time, that *P. aeruginosa* and indigenous microbial populations can survive exposure to saline fluids saturated with CO_2. However, little impact on fluid transport under these conditions in these short experiments was observed. It is possible that the microbes require a period of acclimatisation to the extreme environmental conditions generated by the presence of CO_2 before any impacts can be detected. Thus, long-term experiments are needed to clarify the role of microbes on rock transport properties.

Keywords: Microbes: CO_2; transport properties; Sandstone

1. Introduction

It is well recognised that microbes are active in a wide range of subsurface environments, even where they have limited nutrient and energy supplies thus exhibiting very low metabolic rates [1, 2]. Therefore, it is likely that microbes will be found at depths considered for CO_2 storage and, consequently, microbial activity at CO_2 storage sites may be significantly influenced by injected CO_2. Whilst it is extremely unlikely that microbes could survive exposure to super-critical CO_2, many will survive and thrive in contact with the gas or dissolved phases. Additionally, any impurities within the CO_2 stream (e.g H_2S and SO_2) are also likely to stimulate microbial activity [3, 4]. For example, CO_2 can stimulate many microbial communities that can reduce CO_2 to CH_4 in strongly reducing environments. The nature and scale of the geochemical impacts from the redox reactions will be heavily dependent on the characteristics of the geological setting. Nevertheless, the resulting impacts of microbial activity from these reactions could be both physical (e.g. modifying the pore morphology and geometry and thereby altering permeability through the production of biofilms) and chemical (e.g. changing pH, redox conditions, and pore-mineral-surface chemistry) and may result in intracellular or extracellular mineral formation or degradation [3, 5-7]. Formation damage, resulting from the physical impacts of microbial activity immediately within the injection-well wall, is likely to have the most immediate impact on the injection of CO_2 into a reservoir,

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as occurred at Ketzin [4]. However, microbial activity may also directly impact on the physical transport of CO_2 (as a gas or dissolved in fluid), and porewaters, through fractures and porous media further into the reservoir itself.

This paper describes a pilot study which evaluates, for the first time, the interactions between fluids saturated with CO_2/Sherwood Sandstone/microbe (*Pseudomonas aeruginosa*) in transport experiments, using the BGS Biological Flow Apparatus (BFA) under pressurised subsurface conditions.

2. Experimental methodologies

The aim of the study was to evaluate how biofilms, generated by soil bacteria *P. aeruginosa*, influenced the flow of synthetic saline groundwater through intact Sherwood Sandstone. Two experiments, one biotic and the other a control, were carried out using BFA operated at a constant rate of fluid flow 300 µl h^{-1} (~ 7.2 ml day^{-1}) and under pressurised conditions 4000 kPa (40 bar). Changes in biological and chemical parameters were monitored throughout the experiment together with changes in confining pressure and temperature. Pressure transducers, were used to monitor the pressure changes within the cores while the syringe pumps controlled the flow-rate. Fluid samples were collected by syringe at regular intervals for chemical and biological analyses. Schematics of the experimental set-up and the column system are shown in Figures 1 and 2 and further details of the experimental system are given elsewhere [8-9]. The experiments were carried out over approximately 744 h (31 days) and 2136 h (89 days) for the control and biotic experiments respectively and using sandstone samples taken from the Sherwood Sandstone Group from the Cleethorpes borehole at a depth of 1312.26 – 1312.41 mbgl. A saline water (0.25M as NaCl) was prepared, supplemented with sodium acetate (0.25g l^{-1}) to provide a readily available source of organic carbon to promote and sustain bacterial growth in this short pilot experiment, and sterilised by filtration though a Sartorius filter (0.2 µm). For the biotic experiment the water was saturated with carbon dioxide (CO_2).

For the control experiment (i.e. no injection of microorganisms), the apparatus was fully assembled and filled with the saline water on 4th November 2011. The system was monitored until decommissioning on the 5th December 2011 giving a total run time of 744 h (31 days).

The biotic experiment started on 8th December 2011 and filled with saline water, the system was monitored until December 15th 2011, when the pump was re-filled with water saturated with CO_2, 168 h (7 days) after the start of the experiment. This was followed by injection of *P. aeruginosa* on 18th January 2012, 982 h (41 days) after assembly of the experiment. A total of $3.32x10^8$ organisms in 585 ml (SE $1.78x10^7$) of saline fluid saturated with CO_2 were added to the system at this point. Pumping continued until the March 6th 2012. The pump was stopped and the experiment was decommissioned the next day – a total of 2136 h (89 days) from the beginning of the experiment.

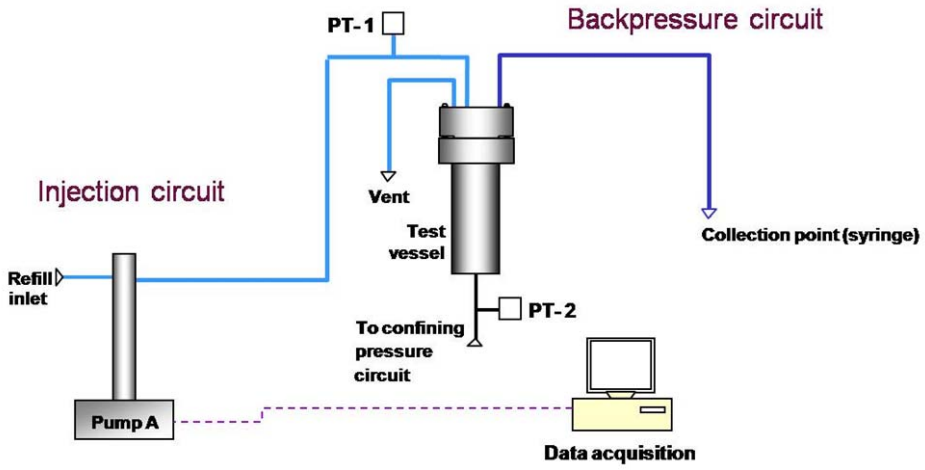

Figure 1 Schematic of the experimental set-up.

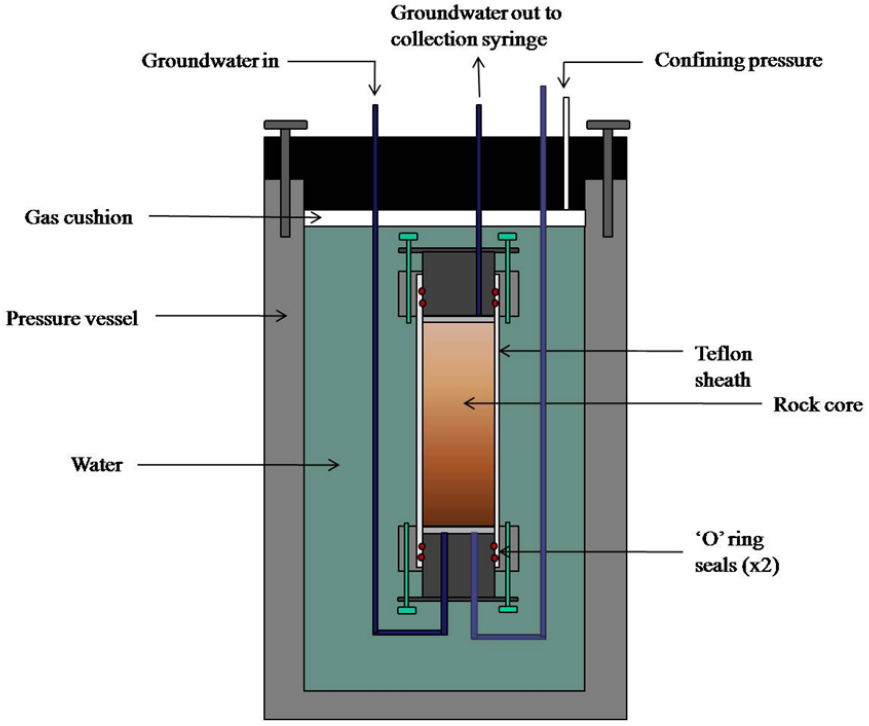

Figure 2 Schematic of pressure vessel with column containing rock core.

3. Results and Discussion

Changes in physical pressure measurement (injection and confining pressure) were continuously monitored with injection pressure presented in Figure 3 together with microbial numbers for both control and biotic experiments. For the biotic core, Figure 3 shows an initial rapid increase in pressure up to circa. 1000 kPa, showing a distinct difference compared to the control core. After the injection of the CO_2 saline solution containing the bacteria, the pressure in the biotic core steadily increases from 120 h (5 days), to circa. 980 h (41days). Beyond this time, the pressure, apart from minor variations, is effectively constant. Figure 3 shows that, for the control experiment, there was no backpressure until 400 h. At this point, an increase in pressure was observed, reaching 400 – 600 kPa between 550 and 700 h. Taken together, the differences in pressure in the biotic and control experiments suggest a difference in flow characteristics and physical properties in the two samples although they were sampled from the same depth in the original core material. After CO_2 injection, microbial numbers in the biotic experiment rapidly drop from ~$1.16x10^7$ ml^{-1} (SE $8.01x10^5$ ml^{-1}) at 354 hours to approximately 10^5 organisms ml^{-1} at the end of the experiment. In the control experiment, numbers in the outflow fluids drop from approximately $2.0x10^6$ (SE 10^4 ml^{-1}) to approximately $2.6x10^4$ ml^{-1} (SE $3x10^4$ ml^{-1}) at the end of the experiment. Thus, an indigenous population naturally exists in the host rock. Other work [8] has shown that such populations can impact on fluid transport in rocks because of the formation of biofilms that then impact on rock transport properties. Such a buildup of pressure does not appear to occur in the biotic experiment where indigenous populations and injected *P. aeruginosa* appear to be impacted by the presence of CO_2. However, a microbial population still exists in the biotic experiments demonstrating that, despite the extreme environmental conditions generated by the presence of CO_2, microorganisms are able to survive. It is possible that the impacts of these microbes on fluid flow will take longer to observe because a period of acclimatisation may be necessary. Consequently, it is important to carry out longer term experiments in order to determine the significance of microbial activity on transport of CO_2 in host rocks relevant to carbon capture and storage.

4. Conclusions

The effect of CO_2 on the activity of any indigenous or introduced microbial populations and resulting impacts on a storage facility, including the movement of the CO_2 plume, is an area of uncertainty, but it is likely that impacts may only apply to storage schemes in specific geological settings. Given these uncertainties, the precautionary principle suggests that the potential impacts should be quantified before projects are initiated. This is the first pilot study to investigate the changes in physical transport properties that are mediated by microbial activity within sandstone samples under experimental conditions simulating CO_2 saturated fluid movement in deep aquifer and reservoir environments in the North Sea. These short experiments utilised *P. aeruginosa* and indigenous microbial populations and showed, for the first time, that these organisms can survive exposure to saline fluids saturated with CO_2. However, the organisms do not seem to impact on fluid transport under these conditions in these short experiments (2136 h/ 89 days). It is possible that the microbes require a period of acclimatisation to the extreme environmental conditions generated by the presence of CO_2 before any impacts can be detected. Additionally, the role of impurities (such as H_2S, SO_X and NO_X) that may be present in the stored CO_2 and could be involved in microbial energy production, [3] also needs to be taken into studied. Thus, long-term experiments are needed to clarify the role of microbes on rock transport properties.

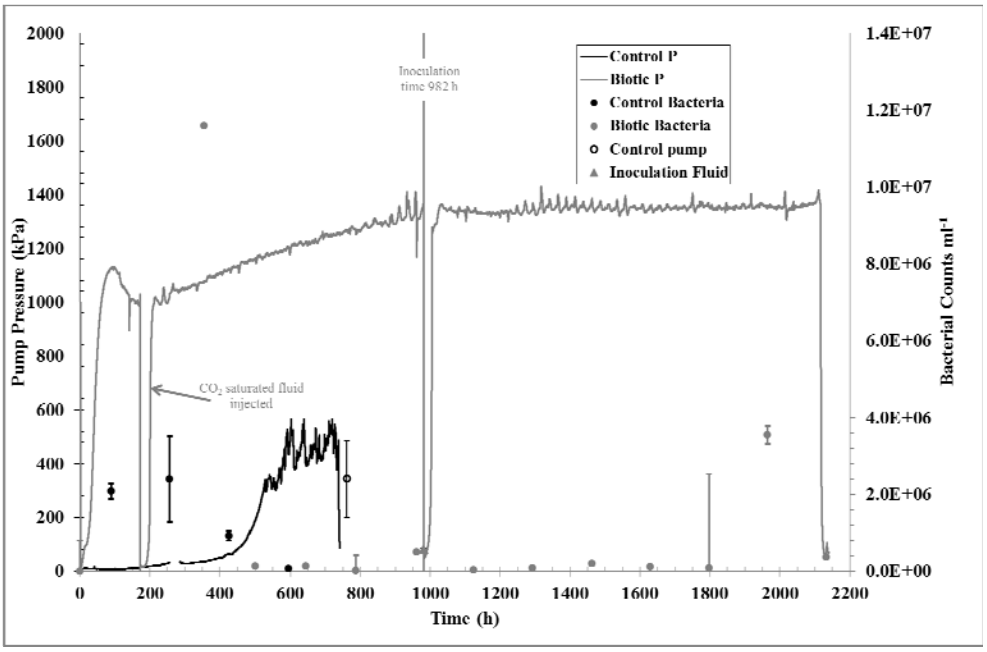

Figure 3. Overlay of recorded pressure and bacterial counts in the outflow fluids from the start of each experiment. The control pressure and bacterial counts are shown by a black line and closed circles respectively with the biotic experiment represented by grey closed circles and line. The number of microbes in the pump at the end of the control experiment are shown by an open black circle. The number of microbes in the biotic inoculant are denoted by a closed grey triangle. The time of inclusion of saturated CO_2 fluid inoculation is marked on plot.

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