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Detecting CO_2 leakage around the wellbore by monitoring temperature profiles: A scoping analysis

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A B S T R A C T

Leakage through abandoned wells represents one of the greatest risks to secure storage of CO_2 in geologic formations. In this work, we evaluate the feasibility of using temperature as an indicator for detecting leakage in and around wellbores. Numerical simulation tools are used to simulate temperature propagation both along and around the wellbore when leakage occurs. Typical overall heat transfer coefficient of formation rock is applied to quantify heat dissipation from the fluids leaked in well. We have tested the cases of CO_2 phase only and the mixture of CO_2 and brine. Thermodynamic phase change of CO_2 throughout the wellbore depth is accounted by an equation-of-state. Both vertical and slant (offshore) wells are examined. Our results indicate that strong temperature variation is observed within 100 m from borehole and then virtual hot layers circulating the fluid column within 3 m radius are formed. However, differences from the ambient temperatures are not significant. The hot CO_2 column loses heat in 70 m of well depth from reservoir compared to 50 m height in the case of CO_2/brine mixture.

1. Introduction

CO_2 released to the atmosphere is the principal cause of the greenhouse effect. Carbon capture and sequestration (CCS) is being pursued globally as a complementary approach to the current CO_2 mitigation efforts of improved energy efficiency and increased use of alternative energy sources. The overall energy demand has increased as population increases and standard of living progresses. CCS enables the continued use of fossil fuels which supply over 80% of the primary power demand by mankind [1]. A significant reduction of CO_2 emissions is necessary to keep atmospheric greenhouse gas concentrations at around 450 ppm CO_2 equivalent [2]. Reduction targets suggest a 30% reduction of 1990-level by 2020 and even up to 80% by 2050 [39]. Among all sedimentary basins, the deep (>800 m) saline aquifers and depleted oil/gas reservoirs are viable candidates for geologic CO_2 sequestration and are widely available throughout the world [3–8]. Their estimated global storage capacity (1000-11,000 Gt) is much greater than the estimated total annual global CO_2 emission of 24 Gt [9–11].

The purpose of CO_2 storage can be compromised when defective wells and geologic faults form leakage pathways, allowing unintended migration of CO_2 out of the storage formations. It is anticipated that CO_2 can be safely stored in the reservoirs for at least a few hundred years through proper management. However, the level of well and reservoir seal integrity is still a major risk factor concerning potential leakage [6,12–17]. During the site screening or monitoring survey if the flow paths (e.g., fractures, faults, boreholes, etc.) within or near reservoirs are overlooked, CO_2 could migrate and eventually release to the atmosphere upon reaching the surface. As discrete pathways through geologic formations, boreholes and wells are critical to the success of geologic sequestration because of the access they provide to storage reservoirs for site characterization, CO_2 injection, monitoring, and fluid withdrawal [18]. However, abandoned wells from oil or gas exploration and production activities are potential leakage pathways for injected CO_2 and displaced brine.

There are various monitoring techniques available to assure storage quality and to detect and characterize leakage pathways. Leaked CO_2, brine, or their mixture can induce physical and chemical anomalies (e.g., pressure, temperature, and geochemistry) in the storage and surrounding formations. Monitoring of the pressure signal to detect leakage pathways are investigated in a number of researches [19–24]. Authors in Refs. [25,26] studied the techniques on the basis of temperature signal. Hovorka et al. [27]

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found a traceable temperature signal upon CO_2 arrival at an observation well in the injection zone. Hurter et al. [28] discussed the dynamic temperature signal associated with CO_2 leakage and plume movement in the porous rock. They suggested that CO_2 leakage can produce significant cooling that may be easily detectable. Bielnski et al. [29] surveyed the possibility of using temperature-measurement devices for CO_2 monitoring in the injection zone. They showed that a detectable temperature effect at the observation well could be obtained, from which CO_2 plume information could be captured. Singh et al. [30] showed cooling intensity in the injection zone for CO_2 injected in a gas field. Han et al. [31] modeled spatiotemporal thermal response to CO_2 injection in saline formations. Ruan et al. [32] studied flow and thermal modeling of CO_2 injection well during geological sequestration. Temperature can be monitored using point measurements, wireline-deployed instruments that produce logs of temperature versus depth, or fiber-optic distributed temperature sensing (DTS) cables. The DTS technology has the advantage of providing continuous temperature measurements both in time and in space along the cable. Nunez-Lopez et al. [26] showed the applications of this technology.

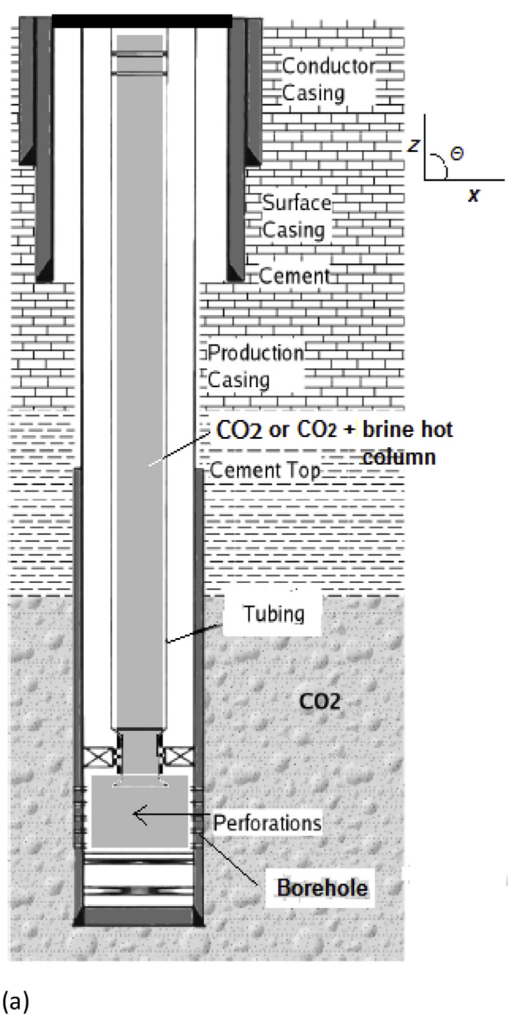
Most of the aforementioned studies considered leakage to release from host reservoirs into the overlying zones through simplified leakage pathways, such as high permeable medium or faults. It is also equally important to determine whether leakage occurs inside the wellbores. Anomalous temperature signals in wellbore may be an indication of CO_2 leakage and thus can alarm to take necessary measures for avoiding further deterioration.

After leaking through borehole, the CO_2 or CO_2/brine fluids will act as a hot column (i.e., heat source) from which heat will dissipate to the surrounding formations. In this work, the objectives are to predict magnitudes of the resulting temperature signals and how far from the wellbore they can propagate. Leakages from both on- and off-shore wells are studied.

2. Governing equations and conceptual model

Fig. 1 shows a typical wellbore model of which the top head in the surface is completely blocked like in the case of an abandoned well. The fluid (CO_2 or CO_2/brine) is leaked through perforations in borehole. Because the wellhead is filled in a short period the still fluid column filled in tubing is expected to reach thermal equilibrium where heat will dissipate continuously to the surrounding formations. Heat is transferred in x and z directions. The model domain is infinitely wide in x direction and the tubing height in z direction is spread from borehole to the surface.

Based on the pressure drop, heat conduction, and compressibility (phase) alteration of the fluid column the governing



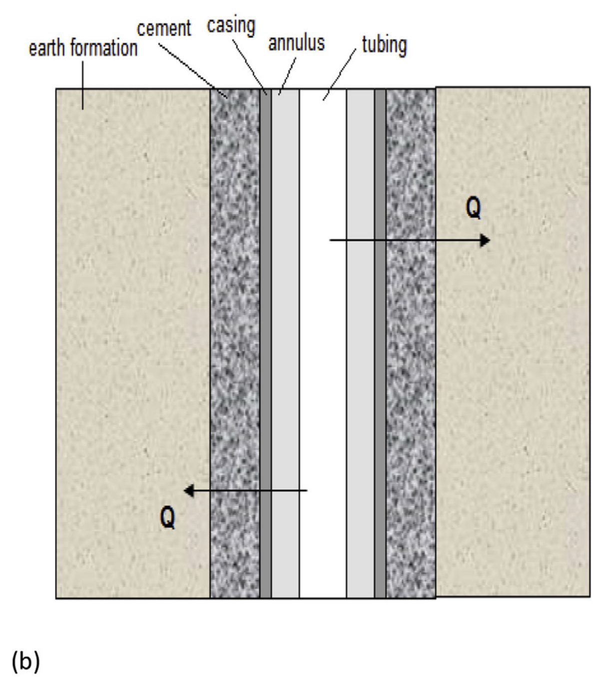


Fig. 1. (a) A vertical concealed wellbore model. Leaked hot fluid column is shown inside the tubing (after Carey [33] with modifications). (b) Side view of wellbore parts.