Nonisothermal Effects During CO_2 Leakage from a Geologic Disposal Reservoir

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RESEARCH OBJECTIVES

There is general consensus in the scientific community that geologic disposal of CO_2 into saline aquifers would be made at supercritical pressures, P > Pcrit = 73.82 bars. However, CO_2 escaping from a storage reservoir may migrate upwards towards regions with lower temperatures and pressures, where CO_2 would be in subcritical conditions. An assessment of the fate of leaking CO_2 requires the capability to model not only supercritical but also subcritical CO_2, as well as phase changes between liquid and gaseous CO_2 in subcritical conditions.

APPROACH

A new fluid property module was written for the general-purpose TOUGH2 simulator to represent mixtures of brine and CO_2 in all possible phase states, including gaseous, liquid, and supercritical CO_2, as well as an aqueous phase and solid precipitate. This was applied to a study of leakage behavior in a simplified hypothetical model system.

ACCOMPLISHMENTS

Starting from a typical geothermal gradient of 30°C/km in continental crust and hydrostatic pressures, the response to leaking CO_2 entering a vertical channel with elevated permeability at 1,000 m depth was simulated in 2-D cylindrical geometry. A first simulation case was run with an average land surface temperature of 5°C. In this case, the initial T,P-profile intersected the CO_2 saturation line, suggesting that liquid CO_2 will boil as it rises.

The system behavior observed in the simulation can be summarized as follows. Some of the CO_2 dissolved in water, but most of it formed a separate liquid phase. The liquid rose and started vaporizing at about a 630 m depth. Vaporization was partial and gave rise to evolution of a three-phase zone: aqueous—liquid CO_2—gaseous CO_2. Latent heat transfer during phase change caused considerable cooling of the rock, which allowed the liquid front to advance upward (see Figure 1). Over time, the three-phase zone became several hundred meters thick. Upflow across the three-phase zone was impeded by interference between the phases. As a consequence, CO_2 discharge at the land surface was more dispersed than it otherwise would have been.

The simulation stopped after 391.2 years as freezing conditions were approached. This stoppage occurred because the fluid-property treatment adopted here has no provisions to deal with phase change from liquid water to ice or solid hydrate phases.

Another simulation was run for a larger land-surface temperature of 15°C, in which the initial T,P-profile did not intersect the CO_2 saturation line. Although the rising CO_2 was not subject to phase change, there were nevertheless strong cooling effects because specific enthalpy of CO_2 increases upon depressurization. Over time, temperatures declined and a three-phase zone evolved, similar to what was observed for lower land-surface temperature.

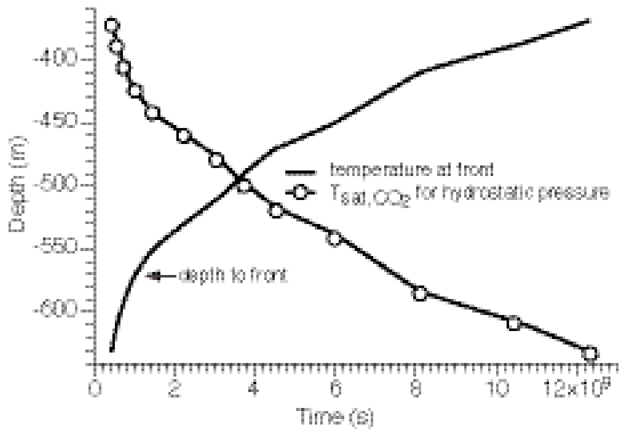

Figure 1. Advancement of liquid front, and frontal temperature, as a function of time

SIGNIFICANCE OF FINDINGS

Upward migration of CO_2 from a geologic disposal reservoir is accompanied by strong heat-transfer effects and gives rise to the evolution of a thick and broad three-phase zone.

RELATED PUBLICATION

Pruess, K., Numerical simulation of CO_2 leakage from a geologic disposal reservoir, including transitions from super- to subcritical conditions, and boiling of liquid CO_2. SPE Journal, 2003 (submitted). Berkeley Lab Report LBNL-52423.

ACKNOWLEDGMENTS

This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.