Coupling Between Fluid Flow and Heat Transfer - A Mechanism for Quasi-Periodic Variations in CO2 Discharges from Deep Underground Sources

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Leakage of CO2 from underground sources is of interest in connection with volcanic hazards assessment, and with the integrity and safety of geologic disposal reservoirs for CO2 that have been proposed as a means for mitigating global warming from atmospheric emissions. Underground accumulations of CO2, whether naturally occurring or man-made, store vast amounts of compressional energy. At subsurface temperature and pressure conditions, CO2 is always buoyant relative to aqueous fluids, and its upward migration may conceivably give rise to a self-enhancing runaway release due to decompression and the much lower viscosity as compared to water. Natural occurrences of CO2 have been implicated in hydrothermal eruptions, and may be capable of causing "pneumatic" eruptions that are not powered by thermal energy.

We have performed numerical simulations of CO2 release through fracture zones and faults in order to determine under what conditions, if any, a self-enhancing, eruptive release may be possible. Our simulations include coupling between multiphase fluid flow and associated heat transfer effects, and accurately represent the thermophysical properties of CO2 in sub-critical (liquid or gaseous) and supercritical conditions, as well as transitions between different phase compositions, and phase partitioning between CO2-rich and aqueous phases.

The behavior of rising CO2 plumes is found to be strongly affected by heat transfer effects. As supercritical CO2 migrates upward it cools due to expansion. Much stronger cooling may arise from boiling of liquid CO2 that may occur after temperatures and pressures drop below critical values (Tcrit = 31.04 deg-C, Pcrit = 73.82 bar). Our simulations of CO2 migration up a fault zone produce quasi-periodic cycling of thermodynamic conditions and substantial variations of CO2 fluxes discharged at the land surface on a time scale of order 1 year. This behavior is explained in terms of an interplay between multiphase flow in the fault zone and conductive heat exchange with surrounding country rock of low permeability. CO2 upflow rates are reduced by heat transfer limitations, which give rise to substantial increase in fluid density as temperatures decline. A better understanding of natural hydrothermal and pneumatic eruptions is necessary in order that the effectiveness and safety of geologic disposal systems for CO2 may be evaluated.

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