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Thermodynamical effects during carbon dioxide release

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Pruess [1] investigated the risk of carbon dioxide leakage from shallow storage sites by modeling scenarios. Such a fluid release is associated with mechanical work performed by formation fluid against expansion without taking heat from ambient environment. Understanding of heat related to mechanical work is essential to predict the temperature at the leak. According to the first law of thermodynamics, internal energy of working fluid decreases with an amount which is equivalent to this work hence, working fluid lost its own heat. Such kind of heat loss depends strongly on whether the expansion process is adiabatic or isothermal. Isothermal expansion allows the working fluid to interact thermally with the solid matrix. Adiabatic expansion is an isenthalpic process that takes heat from the working fluid and the ambient environment remains unchanged. This work is part of the CLEAN research project [6].

In this study, thermodynamic effects of mechanical work during eventual carbon dioxide leakage are investigated numerically. In particular, we are interested to detect the temperature at leakage scenarios and its deviation with different thermodynamic processes. Finite element simulation is conducted with a two-dimensional rectangular geometry representing a shallow storage site which bottom was located at -300m below the land surface. A fully saturated porous medium is assumed where the pore space is filled completely with carbon dioxide. Carbon dioxide accumulated in the secondary trap at 30 Bar and 24 °C is allowed to leak from top right point of rectangle with atmospheric pressure. With (i) adiabatic and (ii) isothermal compressibility factors, temperature around leakage area has been calculated which show a significant difference. With some simplification, this study detects leak temperature which is very close with [1]. Temporal evaluation at the leaky area shows that the working fluid temperature can be reduced to -20 °C when the leakage scenario is performed under isothermal expansion. Under adiabatic expansion, further reduction in the working fluid temperature can be expected.

The governing equations from mass and energy balance laws of porous media mechanics are used for problem description. Pressure and fluid phase temperature are chosen as the primary variables. Extended ideal gas law is used with super compressibility factor (SCF) to predict real gas density for large range of pressure and temperature [2]. Cubic equation based on Peng-Robinson equation of state was solved analytically for SCF [3]. Real fluid properties, such as dynamic viscosity, thermal conductivity and specific heat capacity used in this study are density and temperature dependent. Analytical expression for the derivatives of SCF with respect to temperature and pressure are used. Subsequently, these derivatives are utilized to define isothermal compressibility, adiabatic compressibility and thermal expansion coefficient for the real gas. These parameters can influence heat loss due to thermodynamic effects significantly. The governing equations are discretized spatially within the Galerkin approach, whereas for the temporal discretization, we adopt generalized single step method [5]. The coupled system of governing equations is solved in a monolithic way with variable time stepping. The numerical module has been implemented within the open source object-oriented finite element code OpenGeoSys [4].

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