

Modelling Wellhead-to-Reservoir Thermal Effects during CO₂ Injection into Depleted Gas Reservoirs

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Abstract

Storing CO₂ in depleted gas reservoirs is a practical solution for reducing greenhouse-gas emissions and can contribute to meeting the global warming mitigation targets of the Paris Agreement. In particular, CO₂ sequestration can support the decarbonization of hard-to-abate industries, such as refineries, chemical plants, and cement production facilities, where direct emission reduction may be technically difficult or economically prohibitive. Depleted gas fields – often with recovery factor up to 95% and abandonment pressure as low as 5-10 bar – are attractive candidates because containment integrity has been proven along geological time scales, they are better characterized than saline aquifers and existing infrastructures can be repurposed. Although the storage concept relies on reusing pore volume previously occupied by high-pressure gas, CO₂ injection is governed by a broader and more strongly coupled set of physical processes than gas production. A key component of this complexity is the development of thermal transients triggered as a relatively cold CO₂ stream flows from the wellhead into a warmer, low-pressure gas reservoir, where compression and expansion effects, including Joule–Thomson cooling in the near-wellbore region, may generate thermal fronts that evolve differently from the advancing CO₂ plume; this may affect injectivity, cap rock integrity and modify pressure plume. It is then necessary to move beyond conventional isothermal reservoir simulations and adopt thermal formulations capable of capturing the coupled flow, heat-transfer, and thermodynamic processes governing CO₂ storage in depleted gas reservoirs. In this work we first highlight some key thermal formulations available to model CO₂ injection in gas reservoir, addressing computational issues related to phase behaviour along the critical point for narrow-boiling point mixtures. Subsequently, we explore the wellbore/reservoir interaction, showing how an explicit coupling between an open source, multiphase thermal well model and an industrial grade reservoir simulator can be used to model the process including thermal effects along well tubing and in the near wellbore region as the process approaches the original reservoir pressure. The methodologies will be illustrated using public datasets and synthetic models, with the aim of clarifying the modelling assumptions and highlighting the key mechanisms controlling the thermal response of the system.