Proceedings of the 4th World Congress on Momentum, Heat and Mass Transfer (MHMT'19)
Rome, Italy – April, 2019
Paper No. ENFHT 141
DOI: 10.11159/enfht19.141

Coupled Fluid Flow Modeling in the Wellbore and Reservoir for CO_2 Injection at the CaMI Field Research Station

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Extended Abstract

Field Research Station (FRS) is built by the CMC Research Institutes, Inc. and the University of Calgary to develop and calibrate monitoring technologies required for verifying secure storage of CO_2. The focus of this research station is on CO_2 detection thresholds at shallow depths. An injection well was drilled to introduce a small volume of CO_2 into a sandstone formation at a depth of 300 m to simulate an escape of CO_2 from a storage site at greater depth. Two observation wells were drilled around the injection well for monitoring the lateral extent of the CO_2 plume. Two bottom-hole pressure and temperature gauges and a DTS fiber cable are installed in the injection well for downhole measurements.

One of the most important aspect of this project is the evaluation of caprock integrity for the storage complex. Therefore, our first step was to develop an isothermal coupled flow and geomechanical model for the injection zone and surrounding formations to determine a safe operating pressure range for the injection well. A maximum operating pressure of 5000 kPa was determined and used for injection tests in the reservoir.

CO_2 is being injected in gas phase with a temperature at the well head of approximately 30ºC and an average rate of ~400 kg/d. The general pattern of reservoir response during and following injection cycles is consistently repeatable. As expected, wellhead and downhole pressure increase during injection. The maximum measured pressure difference between the two downhole gauges reached 30 kPa. This indicated the formation of a fluid denser than the injected gas phase and confirmed a phase change of CO_2 from gas to liquid in the well bore. In addition, injection test cycles consistently showed a downhole temperature drop in the well after the bottom-hole pressure reached a value of about 4700 kPa. The main objective of this paper is to find causes of the sudden decrease in the downhole temperature.

Measured bottom-hole injection pressure and temperature data, as well as DTS data, were analyzed to investigate the observed temperature variation. The change noted was a sudden temperature drop with slightly increasing or constant injection pressure. The repeatable temperature drop was also recorded by the DTS fiber on the injection tubing. This behavior was observed during cycles with higher downhole injection pressure (>4700 kPa).

We simulated the CO_2 flow in the well by building another coupled model for fluid flow in the wellbore and reservoir to investigate the causes of the temperature drop. Mass, heat, and momentum transfer equations were solved for the reservoir and wellbore in a coupled fashion to get the pressure and temperature profile in the well. Phase equilibrium flash calculations were completed for every simulation time step using a pressure and temperature dependent K-value function for CO_2 to model the phase change. We concluded that the temperature drop is caused by Joule-Thompson cooling during a CO_2 phase transition from liquid to gas in the wellbore. The JT cooling is resulted from a decrease in the level of liquid CO_2 column in the well and expansion of the gas phase. The drop is speculated to be caused by an induced small fracture in the formation and the consequent increased injectivity.

Our analysis shows that the limited reservoir injectivity, heat transfer between the injected fluid and the surrounding formation rocks, and the phase change of injected CO_2 in the wellbore could result in the sand face injection pressure beyond the designed safe operation limit. This is extremely important with respect to safe operation of CO_2 storage projects.