Transient flow modelling of CO_2 injection into deep geological formations

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1. Objectives and problem statement

This study is focussed on modelling the transient flow behaviour of carbon dioxide (CO_2) during geological sequestration. Our objectives are:

- **Develop and validate a transient flow model for the injection of pure CO_2.**
- **Demonstrate the usefulness of the model developed by applying data from a real CO_2 injection system as a test case.**
- **Employ the findings to predict optimum CO_2 injection strategies.**

Injecting a highly-pressurised CO_2 into a formation with lower pressure will induce a rapid quasi-adiabatic Joule-Thomson expansion effect. As such, the resulting effect on the formation may be:

- ✓ **Blockage due hydrate and ice formation with interstitial water around the wellbore and**
- ✓ **Thermal shocking of the wellbore casing steel, leading to its fracture and ultimately escape of CO_2.**

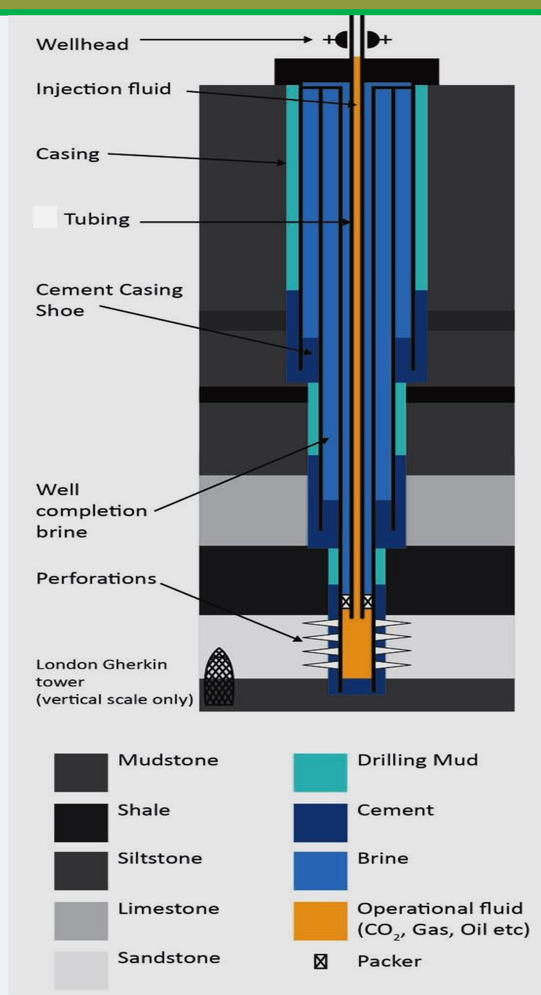


Fig 1: CO_2 injection well (UKCCS, 2016)

Geological sequestration of CO_2 has been recognised as an important strategy for reducing the CO_2 concentration in the atmosphere .

From the head of the injection well to the reservoir the CO_2 is affected by several physical effects that contribute to the pressure and temperature profile along the well. Heat will be exchanged with the surrounding rocks along the well. This will not only affect the fluid properties of the CO_2 in the well but also the rock will be cooled or heated by the fluid flow.

Thus, this research is focused on developing economically viable techniques for geological sequestration of CO_2.

2. Model development

The development of a transient flow model for CO_2 geological sequestration comprises of three major steps:

i. **Formulating the basic governing equations of the flow**
ii. **Selecting and implementing an efficient and accurate method that resolves or simplifies the model equations**
iii. **Validating the model against available field or experimental data.**

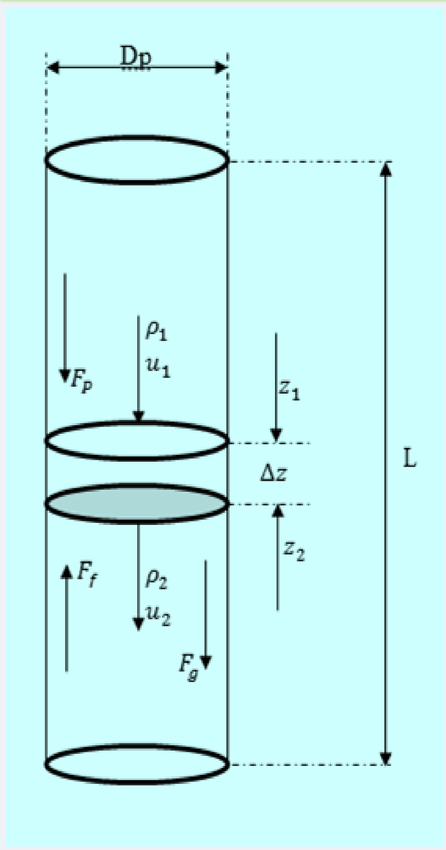


Fig 2: Schematic CO_2 injection process diagram

The system of four partial differential equations for the CO_2 liquid/gas mixture, to be solved in the well tubing, can be written in conservative form as follows:

$$\frac{\partial}{\partial t}U + \frac{\partial}{\partial z}F(U) = S_1 + S_2$$

where

$$U = \begin{pmatrix} \rho A \\ \rho u A \\ \rho E A \\ A \end{pmatrix}, \qquad F(U) = \begin{pmatrix} \rho u A \\ \rho u^2 A + A P \\ \rho u H A \\ 0 \end{pmatrix},$$

$$S_1 = \begin{pmatrix} 0 \\ P\frac{\partial A}{\partial z} \\ 0 \\ 0 \end{pmatrix}, \qquad S_2 = \begin{pmatrix} 0 \\ A(F + \rho\beta g) \\ A(Fu + \rho u\beta g + Q) \\ 0 \end{pmatrix}$$

A is the cross-sectional area, u and ρ are the mixture velocity and density, P is the mixture pressure, while E and H represent the specific total energy and total enthalpy of the mixture, respectively. z denotes the space coordinate, t the time, F the viscous friction force, Q the heat flux, and g the gravitational acceleration.

3. Initial and boundary conditions

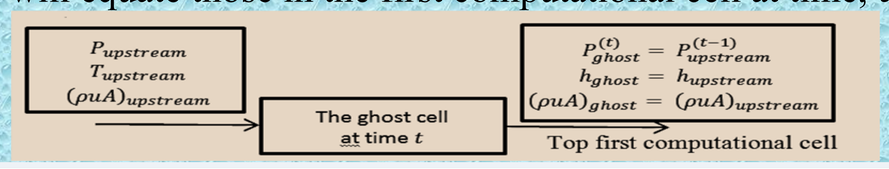
The model was validated using Ketzin pilot site Brandenburg, Germany CO_2 injection well initial and boundary conditions (Moller et al, 2014).

- ➢ Inlet pressure 57 bar, inlet temperatures are 10 °C and 20 °C, and injection mass flow rate 0.41 kg/s.
- ➢ Initial wellhead pressure 48 bar and temperature 10 °C,
- ➢ Total well depth 550m; 0.0889m internal diameter
- ➢ Initial bottom-hole pressure 68 bar and temperature 33 °C,

At the bottom of the well an empirical pressure-flow relationship derived from reservoir properties is employed:

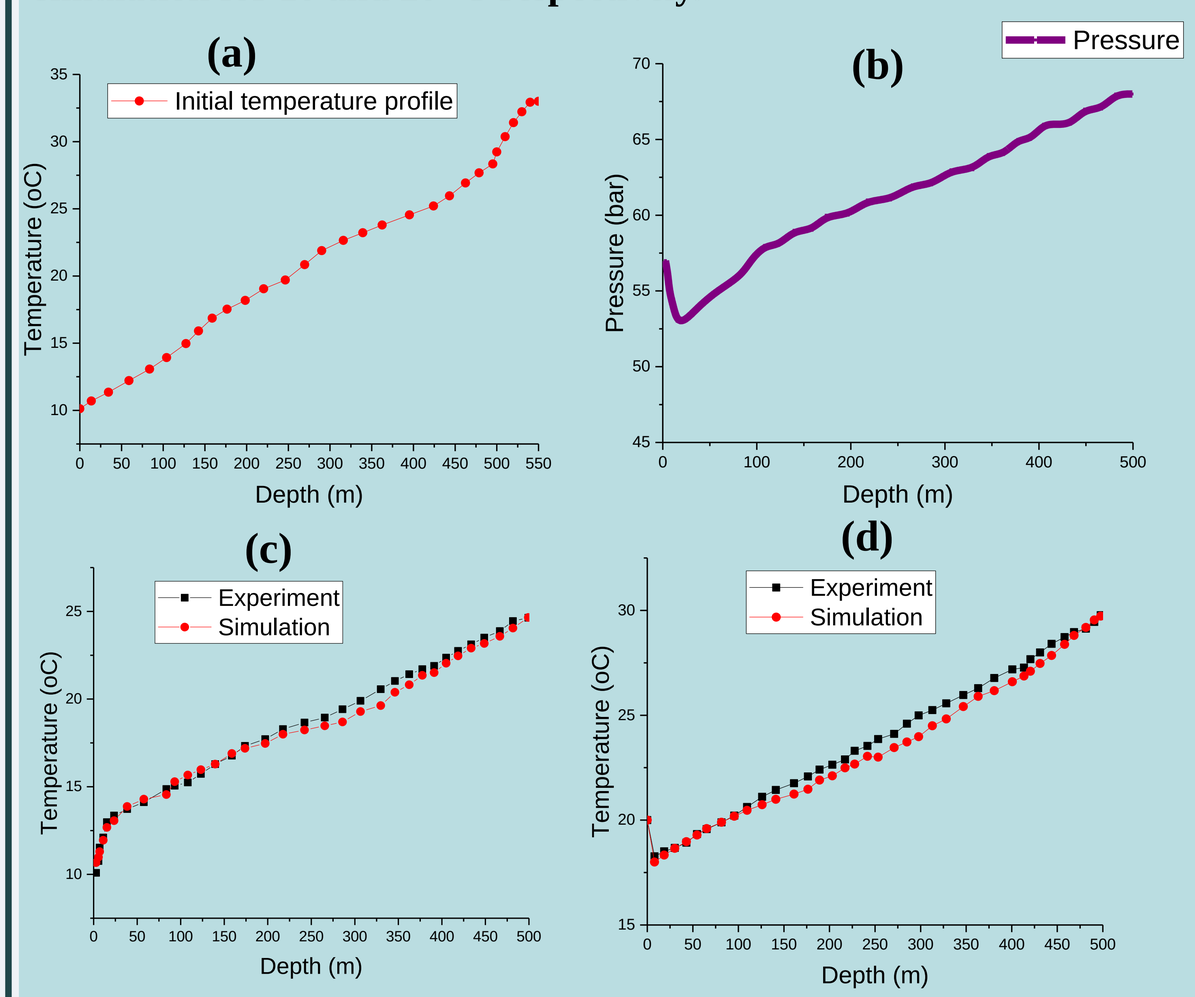
$$\tilde{A} + \tilde{B} \times M + \tilde{C} \times M^2 = P_{BHF}^2 - P_{res}^2$$

At the top of the well, the pressure, enthalpy and mass flowrate in the ghost cell will equate those in the first computational cell at time, $t - \Delta t$.



4. Results and conclusion

The flow and thermal behaviour of CO_2 in injection well is investigated using the above model and the corresponding results are plotted against experimental data. Fig 3 (a) shows the initial well temperature profile while Fig 3 (b) shows the pressure profile after injection. Fig 3 (c) and (d) show results of experiment versus simulation for 10 and 20 °C respectively.



- ➢ **Injecting at an initial temperature of 10°C and 20°C our simulation results show perfect agreement with the experimental data.**

References

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