Optimization of injection rates for geological CO2 storage in brine formations using EASiTool

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Optimization of injection rates for geological CO_2 storage in brine formations using EASiTool

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1- Summary

To meet the need of massive CO_2 sequestration into geological formations multi-well injection scenarios are expected to be employed in the field. As part of our ongoing work to develop an enhanced analytical simulation tool (**EASiTool**) for capacity estimation, based on the analytical solution we compute the distribution of injection rates so all the injection wells will have the same bottom hole pressure at the end of injection period. Our models consider for two-phase flow with partial miscibility, evaporation and salt precipitation coupled with principle of superposition in both closed and open boundary conditions. Computation results show that assigning optimized injection rates, in which injection rate is smallest for wells close to the center of reservoir and larger away from the center, yields higher total injection rate than assigning identical injection rate for all injection wells for a given pressure limit. This computation model will be useful in determining the optimum number of injection wells as well as optimized allocation of injection rates to maximize the storage capacity based on net present value analysis. We will demonstrate the results for both open and close boundary conditions.

2- Analytical Models

Semi-analytical formulations for a multi-well scenario has been developed based on Mathias et al. (2011), Hosseini et al. (2012), and Azizi and Cinar (2013; a, b). Superposition technique is used to find a distribution of pressure build-up for a multi-well scenario. For an infinite-boundary condition with a number of wells N_w, normalized bottom-hole pressure of a reference well P_{wD} is:

$$P_{wD} = \frac{1}{2}\left(\ln(t_D) + 0.80908\right) + S_a - \frac{1}{2}\sum_{i=1}^{N_w-1} q_{Di}\frac{\overline{\lambda_g}}{\overline{\lambda_w}} E_i\left(-\frac{r_{Di}^2}{4\eta_{D3}t_D}\right)$$

where t_D is normalized time, S_a is apparent skin associated with the two-phase flow, q_{Di} is relative injection rate with respect to the reference well, λ_g is gas mobility in gas zone, λ_w is endpoint brine mobility, r_{Di} is normalized radius, and E_i is Exponential integral function. Above equation can be rearranged into a matrix computation A.X=B to solve for unknown flow rates.

$$\begin{bmatrix} \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D1-2}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D1-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D2-1}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D2-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D3-1}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D3-2}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a \end{bmatrix} \begin{Bmatrix} q^1 \\ q^2 \\ q^3 \end{Bmatrix} = \begin{Bmatrix} \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P \end{Bmatrix}$$

These models was embedded into EASiTool using Goldsim framework (**Figure 1**). The developed analytical formulation considers mutual solubility between CO_2 and water, and salt precipitation in the dry zone (near the injection well) for calculating CO_2 saturation. Gravity and capillary forces are not considered.

3- EASiTool Interface

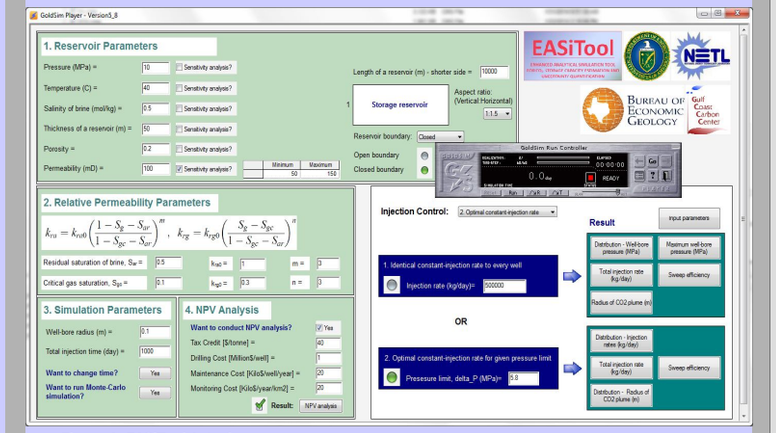

Figure 1. EASiTool Interface

Download EASiTool for free from:
http://www.beg.utexas.edu/gccc/EASiTool/index.php

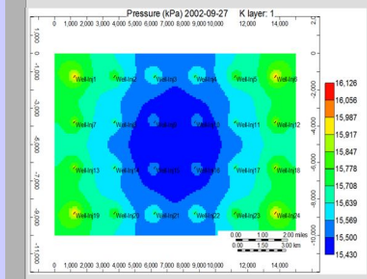

Figure 2. Pressure distribution in brine aquifer with 24 injection wells equally spaced in 150 km2 closed boundary reservoir. Pressure increase is 5.4-6.1 MPa versus designed value of 5.8 MPa.

Boundary	Infinite	Closed		Infinite	Closed
Well Number	Q [kg/day]	Q [kg/day]	Well Number	Q [kg/day]	Q [kg/day]
1	1152200	394650	13	874040	302790
2	831000	288000	14	528180	187240
3	734160	255070	15	431650	154050
4	734160	255070	16	431650	154050
5	831000	288000	17	528180	187240
6	1152200	394650	18	874040	302790
7	874040	302790	19	1152200	394650
8	528180	187240	20	831000	288000
9	431650	154050	21	734160	255070
10	431650	154050	22	734160	255070
11	528180	187240	23	831000	288000
12	874040	302790	24	1152200	394650

Table 1. Injection rate of individual wells designed to increase the bottom hole pressure of all well by 5.8 MPA in 1000 days. Notice the symmetry in the results.

4- Verification and Results

As part of the study we verify the analytical models with numerical simulations of CMG-GEM. In one scenario we used 24 equally spaced injection wells (**Figure 2**) to inject CO_2 into an aquifer of size of 10 km by 15 km for 1000 days in both open (**Figure 3**) and closed (**Figure 4**). boundary conditions. The output of the models is the injection rates of each individual well such that bottom hole pressure at all wells will be around 15.8 MPa i.e. maximum allowable injection pressure (initial reservoir pressure is 10MPa). (**Table 1**)

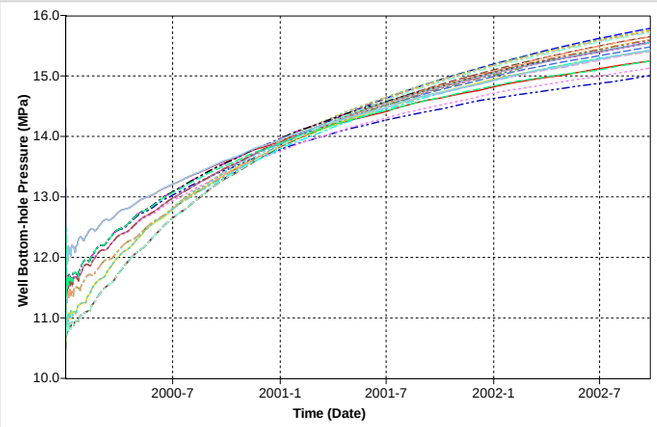

Figure 3. Bottom hole pressure of 24 wells in open boundary condition scenario. All the well have 5 to 5.8 MPa increase in their BHP in 1000 days.

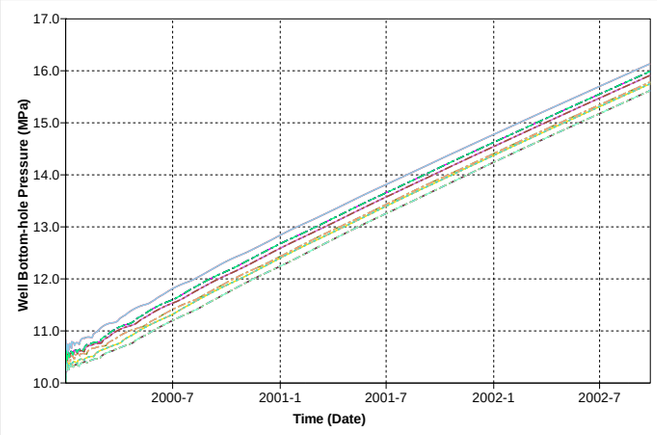

Figure 4. Bottom hole pressure of 24 wells in closed boundary condition scenario. All the well have 5.4 to 6.1 MPa increase in their BHP in 1000 days.

5- Summary

1. We developed an analytical based simulation tool to estimate the CO_2 storage capacity.
2. It models multi-well injection scenario s for both closed and open boundary conditions.
3. EASiTool can provide the optimized number of wells to maximize NPV.
4. Software is capable to run sensitivity analysis on model inputs.

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