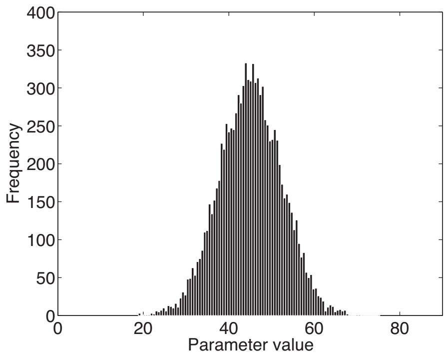
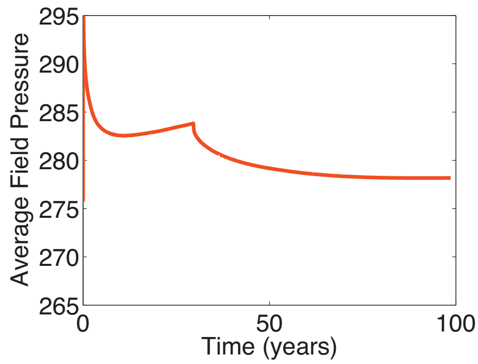
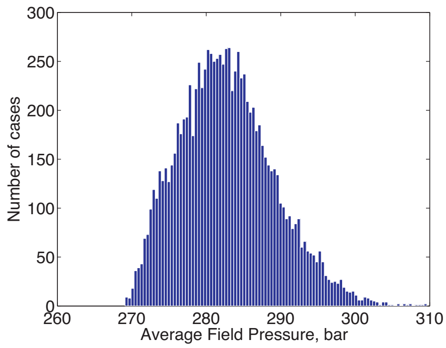


(a) Histogram of aggradation angle filtered out for extreme values.



(b) Expected average CO_2 pressure.



(c) Histogram of average CO_2 pressures.

Fig. 15. Extreme aggradation angle values can result in impractical injection operations. Filtering out the extreme aggradation cases (e.g., by geophysical screening) leads to more favorable conditions. (a) More narrow distribution of aggradation. (b) New expected value for CO_2 field-average pressure under more narrow aggradation range. (c) New distribution of CO_2 field-average pressure at end of injection. The initial pressure peak in (b) reached 341 bar, and is truncated here.

methods that interpolate or extrapolate simulation results in the parameter space, because their setup is not based on the mass conservation equation. In this specific case, the mass conservation issue is caused by approximating the response surface via polynomials, with vanishing residuals only at the collocation points. The polynomials are evaluated at many randomly chosen parameter sets drawn from the histograms shown in Fig. 7, which do not coincide with the collocation points.

Finally, we report how the corresponding probabilities change over time in Fig. 13a–c. High pressure buildup is considerable during the early injection time, and it is negligible after injection during plume migration (Fig. 13a). An over-pressurized injection can induce fracturing in the medium, extending to the sealing layers. Any fractures caused in the structural traps can expose the mobile CO_2 to leakage paths. Therefore, higher pressure values can be interpreted as high risk in early time.

The presented framework for risk assessment indicates that the pressure in the reservoir is unacceptably large (see Section 5.1 and Fig. 11c) and can be too high. In the following, we use our method to investigate this critical issue. Fig. 14a and b shows the predicted time evolution of field-average CO_2 pressure for a collocation point with adverse and well-suitable values of the aggradation angle, respectively. It becomes apparent, that the unacceptable pressure values arise only under extreme values of the aggradation angle. Reacting to this insight, we see and discuss two possible options in the following.

The first option is to lower the injection rate, so that we keep the pressure values in a safe region, even under the probability that the reservoir might have an adverse aggradation angle. Fig. 14e shows the injection rate for a safe scenario: the injection rate ramps up over a year from zero to one fifth of the level used before. The corresponding pressure behavior for the adverse and the well-suitable cases is shown in Fig. 14c and d. Please note that the case with the less extreme aggradation angle shows the typical rise in CO_2 pressure up to the end of injection (Fig. 14b and d), following just after the initial pressure peak due to first entry.

The second option is to improve our understanding about the properties of the analyzed storage site. In particular, some additional exploration actions could help to reduce the uncertainty in the aggradation angle. In the previous analysis we considered that all values of aggradation angle between zero and ninety degrees are equiprobable, which is a very conservative assumption on the initial state of knowledge. As a scenario variation, we will now assume that further exploration decreased the probability of the extreme aggradation values. Fig. 15a shows the modified assumption on the aggradation distribution, where the extreme values have low probability values in comparison to the initial assumption. The present aPC framework allows estimating the influence of such an uncertainty reduction onto the model output without expensive computational costs. Technically, the Monte-Carlo process can be performed on the response surface under the new assumption on uncertainty. Fig. 15b and c shows the new expected field-average CO_2 pressure and the histogram of average CO_2 pressure at the end of injection, respectively. The new pressure statistics indicate a feasible reservoir operation, even with the original (large) injection rate.

6. Conclusion

In this paper, we used the arbitrary polynomial chaos expansion (aPC) method in a sensitivity analysis and risk assessment process.

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