Response Statement to Community's Comments (CC2)

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The authors thank the reviewer for the valuable comments. The manuscript has been revised by carefully considering all the comments. The changes are highlighted in the marked copy, and detailed responses to the reviewer's comments are provided below.

Comment #CC2:

Right now, near-saturated risks sounding like a convenience assumption rather than a controlled approximation. You explore Sr 0.80–1.0, but (as written) saturation appears prescribed rather than evolving, which is a big modeling decision for landfill liners and many barrier systems. Please add a short model scope paragraph early (end of Introduction or start of Methods) stating explicitly: (1) saturation is constant in time (if that's the case), (2) when this is reasonable (e.g., quasi-saturated low gas mobility, slow infiltration variability relative to consolidation time, etc.), (3) when it is not (drying fronts, strong unsaturated flow, gas phase transport). Consider adding a brief comparison to Richards/unsaturated THMC literature (even if you don't implement it). And be explicit whether near-saturated here means "two-phase but simplified compressibility" vs "single-phase with effective compressibility."

Response:

We thank the reviewer for this important comment. A dedicated model-scope paragraph has been added at the assumptions to clarify that the degree of saturation is prescribed as a constant and that the formulation corresponds to a single-phase liquid flow framework under near-saturated conditions, with residual gas treated as immobile. The paragraph also specifies the physical regimes in which this approximation is appropriate (e.g. quasi-saturated, low-permeability geomaterials with slow saturation variations) and those in which it becomes invalid (e.g. drying fronts, strong transient infiltration or connected gas pathways). A brief comparison with unsaturated multi-field coupling frameworks is additionally provided to delineate the scope of the present study.

[Deleted content:] ~~The porous medium is assumed to remain nearly saturated. The liquid phase forms a~~

~~continuous network that governs flow, while the gas phase is treated as isolated, immobile bubbles that do not participate in advection. The degree of saturation is therefore prescribed as a constant rather than solved as a dynamic variable, representing conditions where the liquid phase dominates and no significant air invasion occurs. Under this assumption, capillary effects, gas-phase flow, and the transport of dissolved or volatile elements through the gas phase are excluded from the model. The constant saturation also implies that its potential influence on the reaction surface area or transport coefficients is neglected. This simplification is appropriate for wet, deformable porous media in which the liquid phase remains continuous and the gas phase persists only as immobile bubbles; it becomes invalid when continuous gas pathways develop or when gas dissolution, exsolution, or volatilisation exerts a notable influence~~

[Added new content:] *The porous medium is assumed to remain nearly saturated. The liquid phase forms a continuous network and controls flow, while the gas phase is idealised as isolated, immobile bubbles that do not participate in advection. Hence, the degree of saturation S_r is prescribed as a constant rather than solved as a state variable, leading to a single-phase liquid formulation in which residual gas influences the system only through the effective compressibility of the pore fluid–solid skeleton. This treatment is consistent with mass conservation under drained conditions, whereby the decrease in pore volume during consolidation is accommodated by outward Darcy drainage, so that the volumetric water content $\theta = nS_r$ evolves implicitly through the liquid-phase mass balance while S_r is treated as approximately constant. This approximation is suitable for wet, low-permeability geomaterials where S_r typically exceeds 0.8–0.9 and varies slowly relative to the consolidation timescale, such that deformation-driven transport dominates over transient unsaturated flow, as in compacted clay barriers and landfill liners under quasi-steady infiltration.*

The formulation becomes invalid when drying fronts develop, when strong transient infiltration induces significant saturation changes, or when connected gas pathways form such that gas-phase transport is no longer negligible. Under these circumstances, prescribing S_r is inappropriate and the single-phase assumption may fail (Zeng et al., 2011). Accordingly, the present modelling philosophy is to focus on deformation-driven transport under quasi-saturated conditions, rather than adopting thermodynamics-based unsaturated multi-field frameworks in which saturation, multiphase pore pressures and chemical potentials are fully coupled (Liu et al., 2025). This simplification is appropriate for a wide range of low-permeability geomaterials under near-saturated conditions, in which saturation evolves slowly relative to the consolidation timescale and gas connectivity remains limited, so that deformation-driven transport dominates over transient unsaturated flow processes.

[Line 131–145]

References

Liu, J.H., Ma, T.S., Fu, J.H., Gao, J.J., Martyushev, D.A., Ranjith, P.G., 2025. Thermodynamics-based unsaturated hydro-mechanical-chemical coupling model for wellbore stability analysis in chemically active gas formations. Journal of Rock Mechanics and Geotechnical Engineering 17, 3644–3661. doi:https://doi.org/10.1016/j.jrmge.2024.09.024.

Zeng, Y.J., Su, Z.B., Wan, L., Wen, J., 2011. Numerical analysis of air-water-heat flow in unsaturated soil: Is it necessary to consider airflow in land surface models? Journal of Geophysical Research: Atmospheres 116. doi:https://doi.org/10.1029/2011JD015835.