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Two-phase flow models of gas generation and transport in geological formations

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Introduction

Gas generation and transport through porous media is a process common to many field applications such as radioactive waste and underground gas storage (Ho and Webb, 2006). In these operations, the gas phase evolution depends on the thermodynamic conditions at depth, the properties of the fluids (density, viscosity, surface tension) and the geological formation (permeability, porosity, retention curve), and the chemical interaction between the fluids and the solid phase (e.g., minerals, concrete, steel). Altogether, these properties affect the efficiency, safety, environmental impact of the above mentioned operations.

Objective

To develop immiscible and miscible two-phase flow models to simulate the evolution of gases in geological formations.

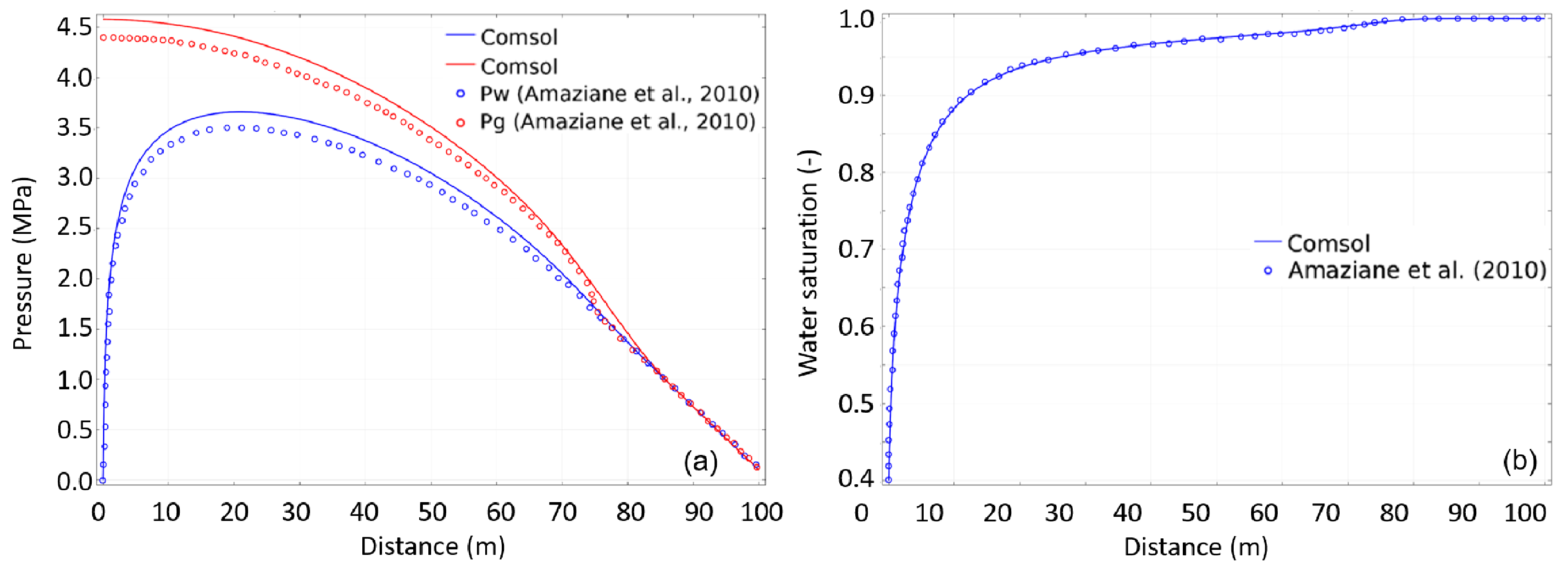

Figure 1. Immiscible two-phase flow model implemented in Comsol (solid line) versus the model of Amaziane et al. (2010) (circles): (a) gas (red) and liquid (blue) pressure, and (b) water saturation profiles obtained at 45 days.

Modeling approach

- ☐ Governing equations:

Immiscible two-phase flow

$$\phi\rho_g\frac{\partial S_g}{\partial t}+\nabla\cdot\left(-\mathbf{k}\lambda_g\rho_g\nabla P_l-\mathbf{k}\lambda_g\rho_g\frac{\partial P_c}{\partial S_g}\nabla S_g-\mathbf{k}\lambda_g\rho_g^2 g\mathbf{z}\right)+\frac{\partial(\phi\rho_g)}{\partial t}S_g=\sum_{k=1}^{N_c}Q_g^k$$

$$\phi(\rho_g-\rho_l)\frac{\partial S_g}{\partial t}+\nabla\cdot\left(-\mathbf{k}(\lambda_g\rho_g+\lambda_l\rho_l)\nabla P_l-\mathbf{k}\lambda_g\rho_g\frac{\partial P_c}{\partial S_g}\nabla S_g-\mathbf{k}(\lambda_g\rho_g^2+\lambda_l\rho_l^2)g\mathbf{z}\right)$$

$$+\frac{\partial(\phi(\rho_g-\rho_l))}{\partial t}S_g=-\frac{\partial(\phi\rho_l)}{\partial t}+\sum_{k=1}^{N_c}\left(Q_l^k+Q_g^k\right)$$

Miscible compositional approach

$$\frac{\partial C_T^k}{\partial t}=-\nabla\cdot\left(\mathbf{J}_l^k+\mathbf{J}_g^k+\mathbf{q}^k C_l^k\right)+Q_l^k+Q_g^k$$

$$C_T^k=\phi S_l C_l^k+\phi S_g C_g^k+(1-\phi)C_s^k$$

$$\mathbf{q}_i=-\frac{\mathbf{k}k_{ri}}{\mu_i}\left(\nabla P_i+\rho_i g\mathbf{z}\right)$$

$$\mathbf{q}^k=\mathbf{q}_l+\mathbf{q}_g H_{gl}^k$$

$$\mathbf{J}_i^k=-\phi S_i\mathbf{D}_i^k\nabla C_i^k$$

- ☐ COMSOL implementation: using the Coefficient's Form of the PDE module with multiple dependent variables.
- ☐ State variables: liquid pressure and (i) gas saturation in the immiscible approach; (ii) dissolved gas concentration in the miscible formulation.

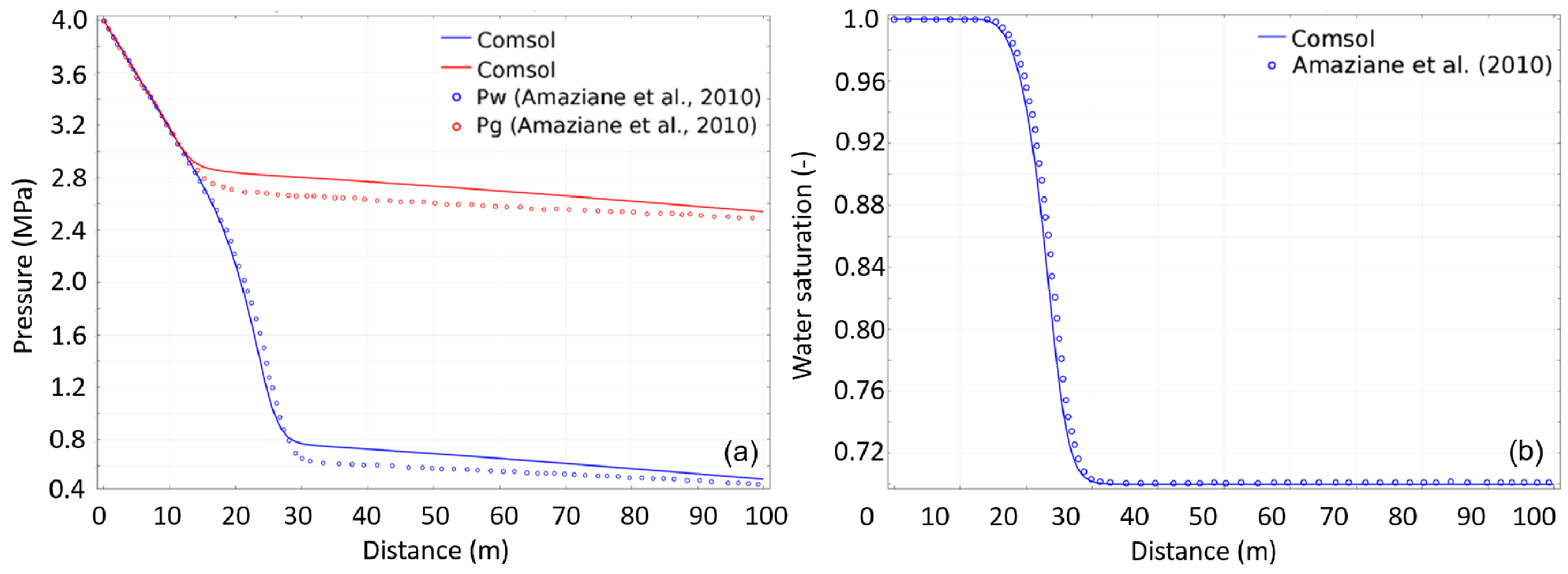

Figure 2. Immiscible two-phase flow model implemented in Comsol (solid line) versus the model of Amaziane et al. (2010) (circles): (a) gas (red) and liquid (blue) pressure, and (b) water saturation profiles obtained at 45 days.

- ☐ Verification: the immiscible approach was verified with three 1D examples neglecting gravity effects (Amaziane et al., 2010). The miscible formulation was verified with a 1D problem for testing the ability of codes to simulate the gas phase appearance and disappearance including gas solubility (Amaziane et al., 2014).

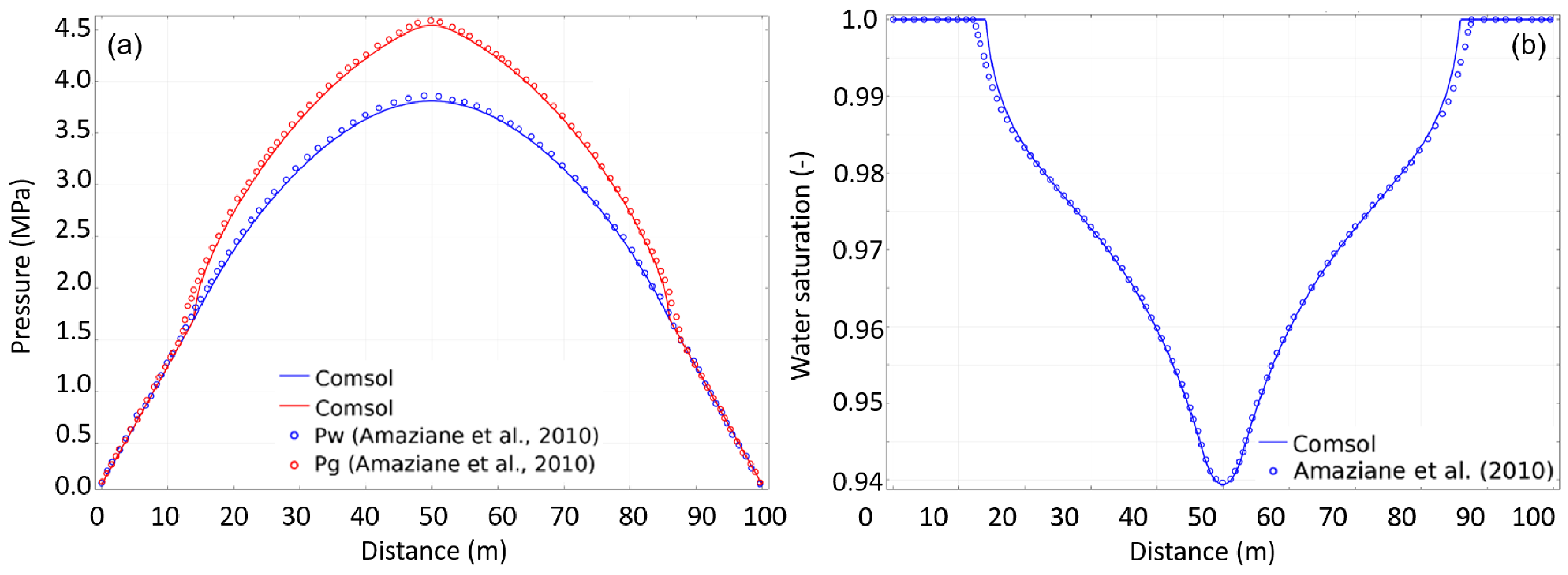

Figure 3. Immiscible two-phase flow model implemented in Comsol (solid line) versus the model of Amaziane et al. (2010) (circles): (a) gas (red) and liquid (blue) pressure, and (b) water saturation profiles obtained at 12 days.

Results

The benchmarks consider an isothermal liquid-gas system with two components with properties close to water and hydrogen. The results display good agreement with the Amaziane et al. (2010, 2014) models, as shown in Figure 1, 2, 3 and 4.

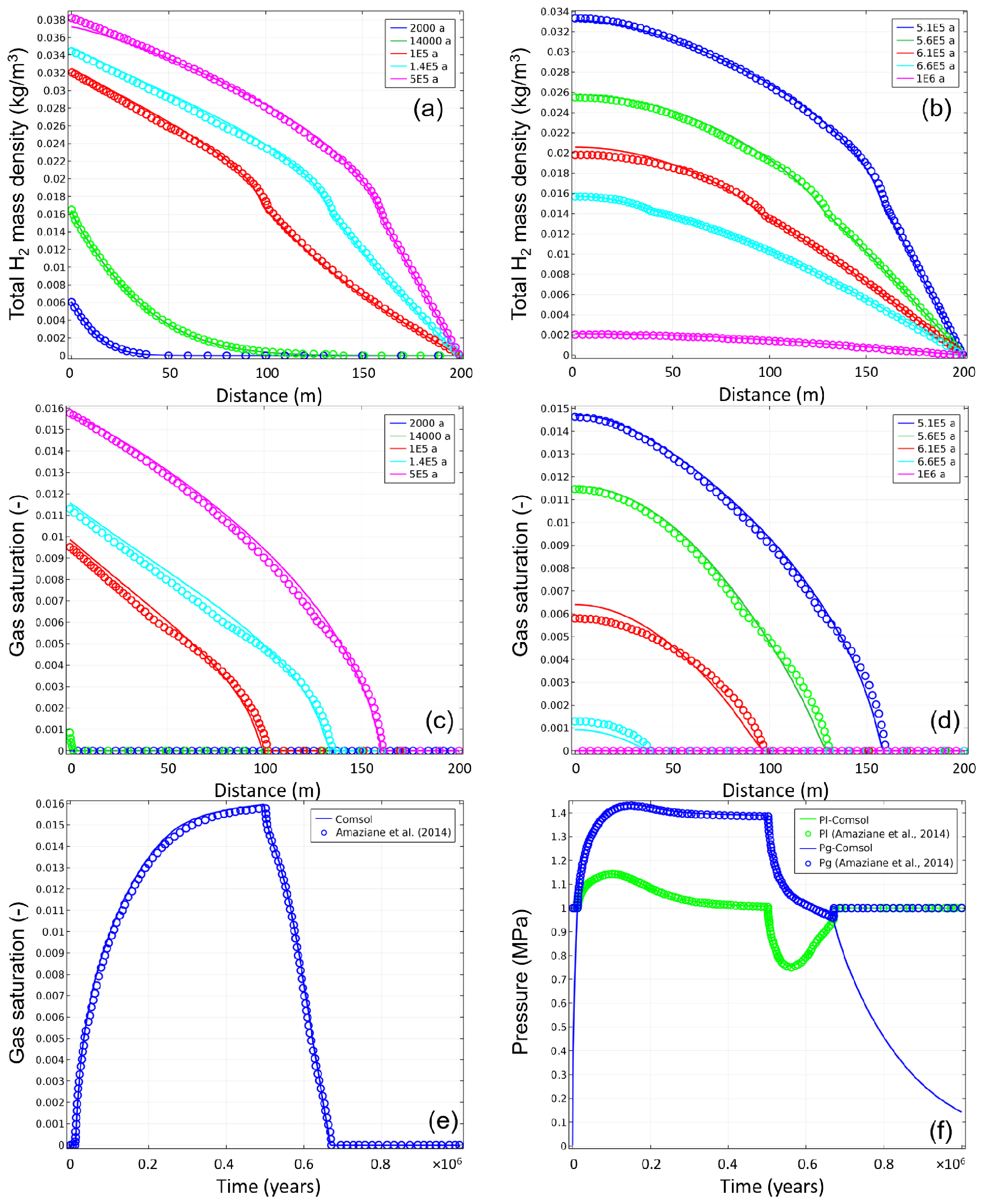

Figure 4. Compositional formulation of two-phase flow implemented in Comsol (solid lines) versus the model of Amaziane et al. (2014) (circles): evolution of the total H_2 mass density and gas saturation during (a, c) and after injection (b, d). Evolution of the gas saturation (e) and the pressures (f) at the inlet point (x=0).

Conclusions

It is concluded that the present two-phase flow approaches are able to describe gas generation and transport under miscible and immiscible conditions. Which approach is more practical or advantageous depends on the specific application.

References

Amaziane, B., Jurak, M., Žgaljić-Keko, A., 2010. Modeling and numerical simulations of immiscible compressible two-phase flow in porous media by the concept of global pressure, *Transport in Porous Media* 84, 133-152.

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