Two-Phase Flow Models of Gas Generation and Transport in Geological Formations

O. Silva[1]

[1]Amphos 21 Consulting S.L. - iMaGe Consortium, Barcelona, Spain

Abstract

Gas generation and transport through porous media is a process common to many field applications such as radioactive waste and underground gas storage [1]. 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), as well as the chemical interaction between the fluids and the solid phase (e.g., minerals, concrete, steel). Also, the solubility of gas in the resident fluid at reservoir conditions is a key factor affecting different aspects of the above mentioned operations (efficiency, safety, environmental impact).

In the present work, immiscible and miscible two-phase flow models were developed to simulate the evolution of gases in geological formations. Both models were implemented in COMSOL Multiphysics® software using the coefficient's form of the PDE interface with multiple dependent variables. The state variables are the gas saturation and the liquid pressure in the immiscible approach, and the dissolved gas concentration and the liquid pressure in the miscible formulation.

The immiscible two-phase flow approach was verified with three 1D examples neglecting gravity effects, taken from Amaziane et al. [2] with incompressible wetting phase (water) and the ideal gas law for the non-wetting phase (hydrogen) and a set of van Genuchten's retention and relative permeability functions. In the first simulation, the gas is injected on the left end of the porous medium initially saturated by water (Figure 1). In the second simulation, pure water is injected in a domain filled with 30% of gas (Figure 2). The third simulation considered a constant gas source with intensity of 0.01 kg/day on a 6-m interval of a medium initially saturated by water (Figure 3). The results display good agreement with the Amaziane et al. [2] model.

Meanwhile, the miscible compositional formulation was verified with a 1D problem designed for testing the ability of codes to simulate the gas phase appearance and disappearance including gas solubility [3]. The benchmark considers an isothermal liquid-gas system with two components with properties close to water and hydrogen. Water evaporation is neglected for simplicity. Figure 4 shows the evolution of the total hydrogen mass density, the gas saturation and the liquid pressure, simulated by Amaziane et al. [3] and with COMSOL. It is worth noting that the present model predicts a more realistic evolution of the gas pressure. Figure 4f shows that Amaziane et al. [3] calculated a gas pressure that is always equal or higher than the initial liquid pressure. By contrast, the

present model predicts a zero initial gas pressure at the left boundary, which then starts to increase as the injection proceeds. After stopping gas injection, the present simulation displays a progressive gas pressure decrease at the inlet, which is consistent with the gas disappearance.

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.

Reference

[1] C. K. Ho and S. W. Webb, Gas Transport in Porous Media. Springer, Dordrecht, The Netherlands (2006)
[2] B. Amaziane et al., Modeling and numerical simulations of immiscible compressible two-phase flow in porous media by the concept of global pressure, Transport in Porous Media, Vol. 84, p. 133-152 (2010)
[3] B. Amaziane et al., Modeling compositional compressible two-phase flow in porous media by the concept of the global pressure. Comput. Geosci., Vol. 18, p. 297-309 (2014)

Figures used in the abstract

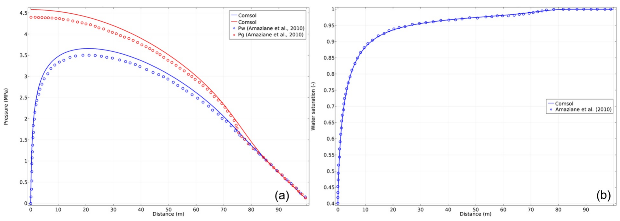

Figure 1: Simulation # 1. Comparison between the immiscible two-phase flow model implemented in Comsol (solid line) and the model of Amaziane et al. [2] (circles): (a) gas (red) and liquid (blue) pressure, and (b) water saturation profiles obtained at 45 days.

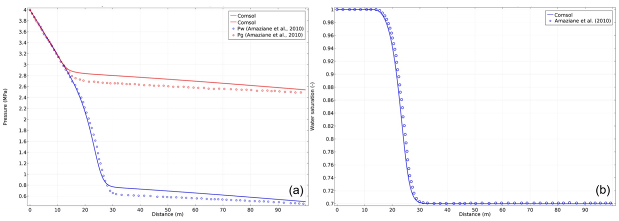

Figure 2: Simulation # 2. Comparison between the immiscible two-phase flow model implemented in Comsol (solid line) and the model of Amaziane et al. [2] (circles): (a) gas (red) and liquid (blue) pressure, and (b) water saturation profiles obtained at 45 days.

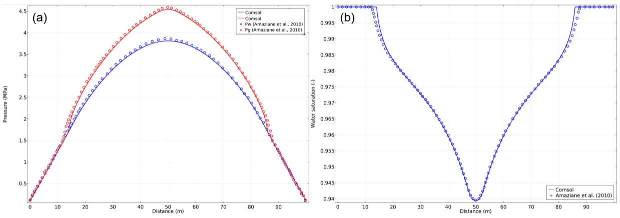

Figure 3: Simulation # 3. Comparison between the immiscible two-phase flow model implemented in Comsol (solid line) and the model of Amaziane et al. [2] (circles): (a) gas (red) and liquid (blue) pressure, and (b) water saturation profiles obtained at 12 days.

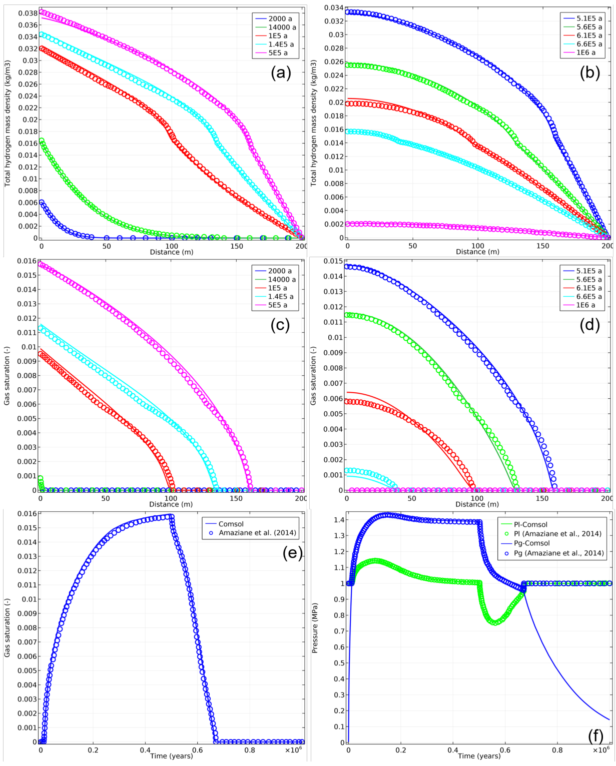

Figure 4: Simulation # 4. Comparison between the compositional formulation of two phase flow implemented in Comsol (solid lines) and the model of Amaziane et al. [3] (circles): evolution of the total hydrogen mass density and gas saturation during (a, c) and after injection (b, d). Evolution of the gas saturation (e) and the pressures (f) at the inlet point (x=0).