

Thermodynamics in geothermal fluid flow

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Abstract

A geothermal reservoir is an anisotropic porous medium trapping a multicomponent fluid (essentially H₂O, CO₂ and NaCl) at high temperature and pressure. In order to describe the evolution of the basin, we need to couple a fluid dynamic model for the transport/diffusion processes with a thermodynamic model describing the phase behaviour of the mixture.

In this work we shall focus on thermodynamics and in particular on the solution of the thermodynamic equilibrium (TE): given the fluid composition, pressure and temperature of the system evaluate if the mixture is a single phase gas, a single phase liquid or a two phase fluid (and in this case evaluate the mole fraction of each phase).

Objectives

In what follows we are attempting to solve the thermodynamic equilibrium of a multicomponent two-phase geothermal fluid. Our aim is to find a rigorous and general approach to phase-split calculation based on the work of Michelsen [4] and [5].

Given a mixture $\{x_i^0\}$, $i=1,2,\dots,m$ we want to find the mole fraction of gas (x_i^G) and liquid (x_i^L) phase for given values of pressure and temperature.

Instead of minimizing the Gibbs Free Energy of the system we look for an equilibrium of the system satisfying the equality of chemical potentials.

Methodology

We start an iterative procedure which is stopped whenever the following relation is met within some fixed tolerance:

$$\ln K_i + \beta (\mu_i^G - \mu_i^L) = 0, i=1,2,\dots,m$$

At any step we solve the so-called Rachford-Rice equation

$$R(\phi^G) = \sum \frac{x_i^0 (K_i - 1)}{\phi^G (K_i - 1) + 1} = 0$$

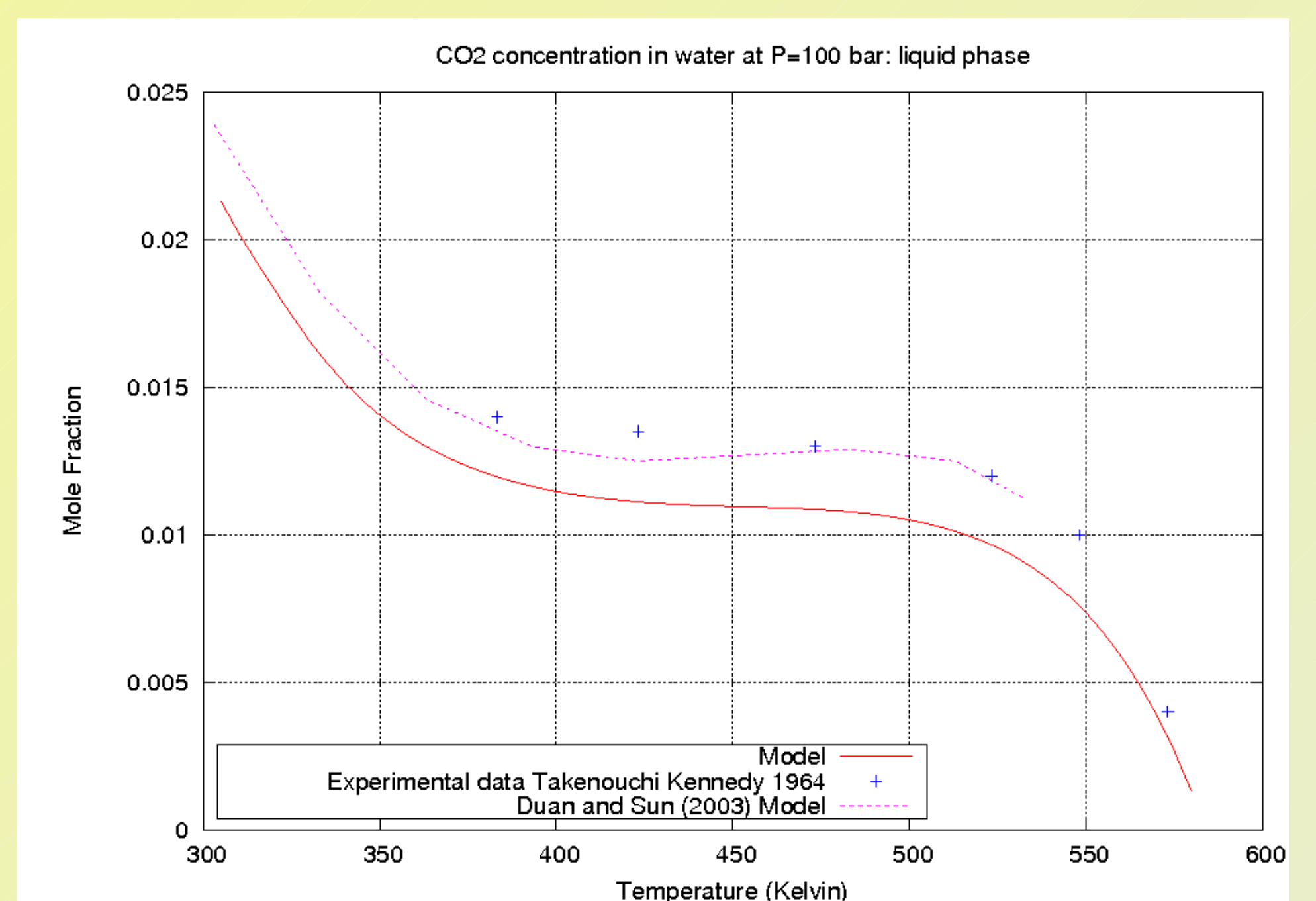
And find a value of ϕ^G (the volume fraction of gas phase with respect to the total volume of the mixture).

To evaluate the chemical potentials we used the Peng-Robinson equation of state defined as in [2]:

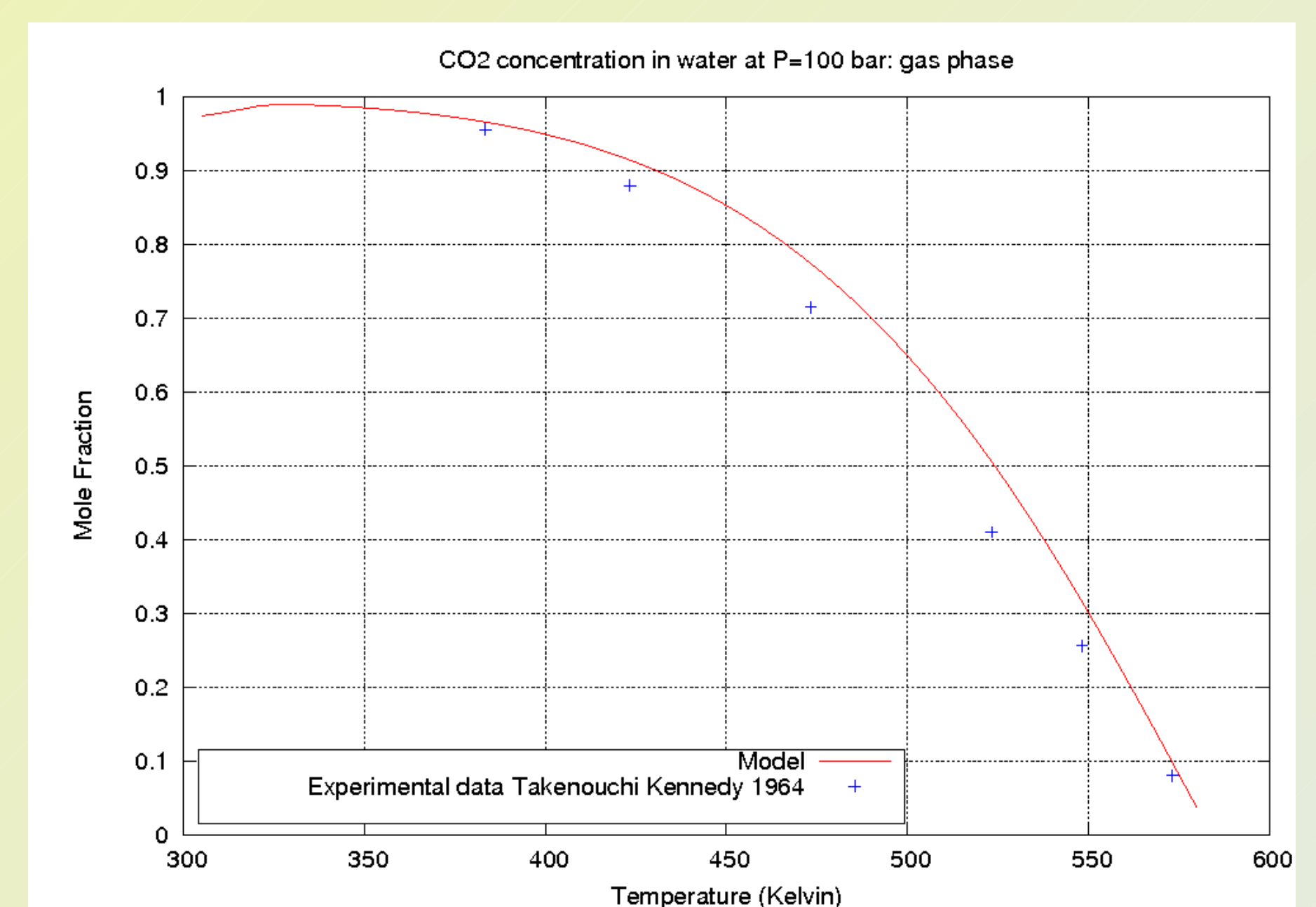
$$\beta P = \frac{1}{v - B} - \frac{D}{v^2 + 2vB - B^2}$$

Results

We consider in our simulations a mixture of 10% CO₂ and 90% water.



CO₂ liquid phase: comparison of our procedure (red line) with experimental data in [1] (points) and a model of Duan and Sun [1]



CO₂ gas phase: comparison with experimental results.

References

- [1] Duan Z. and Sun R. An Improved Model Calculating CO₂ solubility in pure water and NaCl solutions from 273 to 533 K and from 0 to 2000 bar, *Chemical Geology*, 193,257-271, 2003.
- [2] Peng D.Y. and Robinson D.B. A New Two-Constant Equation Of State. *Ind Eng Chem Fundam*, 15(1):59, 1976.
- [3] Takenouchi S. and Kennedy G.C. The binary system H₂O-CO₂ at high temperature and pressure. *Am. J. Sci.*262, 1055-1074, 1964.
- [4] Michelsen M. L. The Isothermal Flash Problem. Part I Stability, *Fluid Phase Equilibria*, 9 (1982), 1-19.
- [5] Michelsen M. L. The Isothermal Flash Problem. Part II. Phase-Split Calculation, *Fluid Phase Equilibria*, 9 (1982), 21-40.