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CO2-Leaking Well - Analytical Modeling

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The long-term integrity of CO2 storage in geological system relies highly on local trapping mechanisms but also on the absence/control of any kind of outlets. Indeed numerous pathways (faults, wells, rock heterogeneities…) exist that can lead stored gas back to the surface. Thus, such leakage risks must be assessed and quantified if possible. In France, BRGM is inquired for evaluating safety criteria and developing a methodology for qualifying potential geological storage sites. This implies in particular to study the leakage scenario, here through a water-filled well as a worth scenario case. In order to determine the kinds of impacts leaking CO2 can have; knowing the velocity and flow rate of uprising CO2 is a necessity.

That is why a better knowledge of CO2 in storage conditions and its behaviour with the environment is required. The following study aims at characterising the CO2 flowing into the well and then rising up in a water column over the vertical dimension. An analytical model was built that describes:
- In a first step, the CO2 flow between the reservoir and the inside of the well, depending on quality and thickness of different seals, which determines the flow rate through the well.
- In a second step, the CO2 uprising through an open and water filled well, however in steady state, which excludes a priori the characterisation of periodic or chaotic behaviours such as geyser formation.
The objective is to give numerous orders of magnitude concerning CO2 thermodynamic properties while rising up: specific enthalpy, density, viscosity, velocity, flow, gas volume fraction and expansion, pressure and temperature gradient. Dissolution is partially taken into account, however without kinetic.

The strength of this model is to compute analytically – easily and instantaneously – the 1-dimensional rising velocity of CO2 in a water column as a function of the CO2 density, interfacial tension and initial volume fraction. Characteristic speeds – the ones given by the literature – are combined with a prior study of CO2 thermodynamic properties over pressure and temperature conditions at typical geological depths. Different kinds of assumptions can be used in this model:
- CO2 rises along a hydrostatic profile of pressure and temperature if we consider that energy exchanges are small and fast enough at every depth.
- CO2 rises along an isenthalpic profile of pressure and temperature if on the contrary we consider that the CO2 does not exchange energy (any more) with surrounding water.
- CO2 stays in a bubble flow or not, with transition or not.

Besides intrinsic results such as flow rate, speed and state of the CO2 along the water column – that could be a badly cemented well, a water-filled fault, or any other extent where water is free – it can be used as a tool for other more developed scenarios (vertical transfer between 2 aquifers, etc.). Preliminary interesting results concern the transition phase of the fluid that arises at about 800m. Indeed, at such critical depth and according to the gas specific enthalpy, CO2 bubbles may expand a lot and accelerate, or on the contrary condensate into liquid phase and slow down.