



Non-equilibrium simulation of CH₄ production through the depressurization method from gas hydrate reservoirs

Khadijeh Qorbani and Bjørn Kvamme

Institute of Physics and Technology, University of Bergen, Norway

Natural gas hydrates (NGHs) in nature are formed from various hydrate formers (i.e. aqueous, gas, and adsorbed phases). As a result, due to Gibbs phase rule and the combined first and second laws of thermodynamics CH₄-hydrate cannot reach thermodynamic equilibrium in real reservoir conditions. CH₄ is the dominant component in NGH reservoirs. It is formed as a result of biogenic degradation of biological material in the upper few hundred meters of subsurface. It has been estimated that the amount of fuel-gas reserve in NGHs exceed the total amount of fossil fuel explored until today. Thus, these reservoirs have the potential to satisfy the energy requirements of the future. However, released CH₄ from dissociated NGHs could find its way to the atmosphere and it is a far more aggressive greenhouse gas than CO₂, even though its life-time is shorter.

Lack of reliable field data makes it difficult to predict the production potential, as well as safety of CH₄ production from NGHs. Computer simulations can be used as a tool to investigate CH₄ production through different scenarios. Most hydrate simulators within academia and industry treat hydrate phase transitions as an equilibrium process and those which employ the kinetic approach utilize simple laboratory data in their models. Furthermore, it is typical to utilize a limited thermodynamic description where only temperature and pressure projections are considered. Another widely used simplification is to assume only a single route for the hydrate phase transitions.

The non-equilibrium nature of hydrate indicates a need for proper kinetic models to describe hydrate dissociation and reformation in the reservoir with respect to thermodynamics variables, CH₄ mole-fraction, pressure and temperature. The RetrasoCodeBright (RCB) hydrate simulator has previously been extended to model CH₄-hydrate dissociation towards CH₄ gas and water. CH₄-hydrate is added to the RCB data-base as a pseudo mineral. Phase transitions are treated as non-equilibrium processes under local constraint of mass and heat fluxes. In this work, we have extended RCB by adding another route for dissociation or reformation of CH₄-hydrate towards CH₄ into the aqueous phase and water. CH₄-hydrate formation and dissociation is resolved by looking at supersaturation and undersaturation with respect to thermodynamics variables. Hydrate instability due to undersaturation of CH₄ in the contacting water phase is also considered. A complete non-equilibrium thermodynamic package, developed in-house, was combined with RCB to account for competing phase transitions by considering the minimization of Gibb's free energy. The energy differences were calculated from variations in chemical potentials of hydrate and hydrate formers. Mass transport, heat transport and non-equilibrium thermodynamic effects were implemented through classical nucleation theory to model the kinetic rate of hydrate phase transitions. To illustrate our implementations we ran simulations covering time-spans in the order of hundred years. CH₄ production was modelled using the depressurization method, where we employed the Messoyakha field data. We discuss our implementations, as well as results obtained from simulations utilizing our modifications.