Submarine Gas Hydrate Reservoir Simulations: A Gas/Liquid Fluid Flow Model for Gas Hydrate Containing Sediments

S. Schlüter[1], T. Hennig[1], G. Janicki[1], G. Deerberg[1]

[1]Fraunhofer UMSICHT, Oberhausen, Germany

Abstract

Introduction: In the medium term, gas hydrate reservoirs in the subsea sediment are intended as deposits for carbon dioxide (CO_2) from fossil fuel consumption [1-3]. This idea is supported by the thermodynamics of CO_2 and methane (CH_4) hydrates and the fact that CO_2 hydrates are more stable than CH_4 hydrates in a certain P-T range. The potential of producing CH_4 by depressurization and/or by injecting CO_2 is numerically studied in the frame of the SUGAR project (SUbmarine GAs Hydrate Reservoirs project) funded by the German government.

Modeling and simulation: Within the SUGAR project the reservoir simulator HYRES was developed. Based on ideas of Diaz-Vera et al. [4] and Bundschuh et al. [5] for oil-water flows in sediments, a model for gas-liquid flow in sediments containing CH_4 and CO_2 gas hydrates under time dependent P-T conditions was developed and implemented with the PDE/ODE interface of COMSOL Multiphysics® as a set of user defined field equations. The physics of the process leads to strong non-linear couplings between hydraulic fluid flow, hydrate dissociation and formation, hydraulic properties of the sediment, partial pressures and seawater solution of components and the thermal budget of the system described by the heat equation [6]. The time dependent solution of this set of equations is achieved in COMSOL Multiphysics® with BDF time stepping and the fully coupled solution approach with a direct linear solver. Since 2012 simulations were performed with this code in a broad area of problems: depressurization of methane hydrate bearing sediments, CO_2 injection in depressurized CH_4 hydrate reservoirs, simultaneous CH_4 production and CO_2 injection in CH_4 hydrate reservoirs, calculations for different safety relevant problems.

Results and conclusions: 15-years depressurization of a reservoir with five CH_4 hydrate layers (4 m in deep) interrupted by clay is shown in Fig. 1. Clearly the so-called fingering in hydrate saturation can be seen and the increased hydrate dissociation in the outer layers. Both are thermal effects due to heat conduction inside the subsea sediment. In Fig. 2 the methane production rate is shown compared to a single 20 m layer of the same hydrate content. The large rate increase compared to a single layer is the result of these thermal effects. Another important case is the simultaneous CO_2 injection and CH_4 production in the same reservoir with two wells. Fig. 3 shows the CH_4 hydrate distribution for such a study. CH_4 hydrate is replaced by CO_2 hydrate in the area of injection at the top right corner (CH_4 production at lower left corner). After 13 years

CO2 gas is produced at the producer and the injection has to be stopped (see Fig. 4).

Reference

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Figures used in the abstract

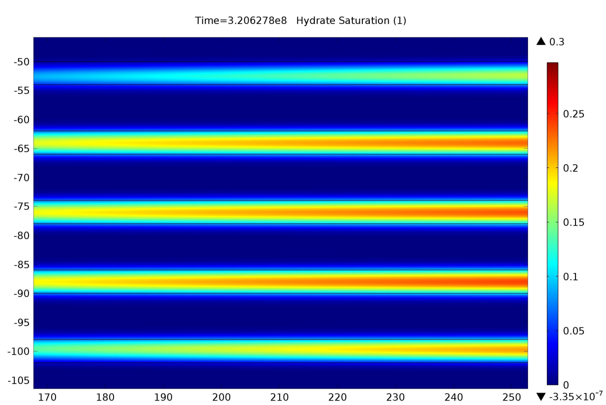

Figure 1: Hydrate saturation distribution within a 5-layer hydrate system after 10 years of depressurization, single layer deep 4 m, 2d simulation of a 1000 m in diameter reservoir

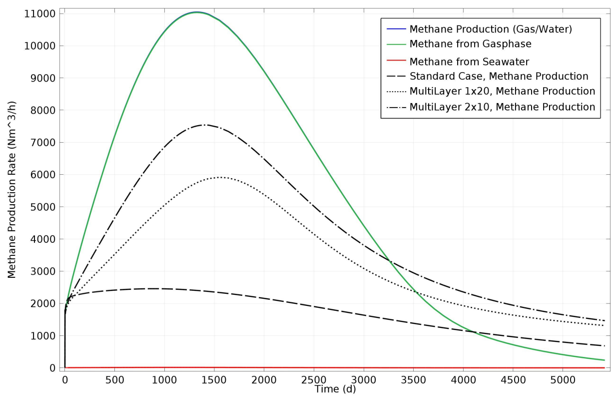

Figure 2: Methane production rate at the producer well, conditions as for Fig. 1, dotted/dashed curves for 1- and 2-layer systems and the reference single layer without burden

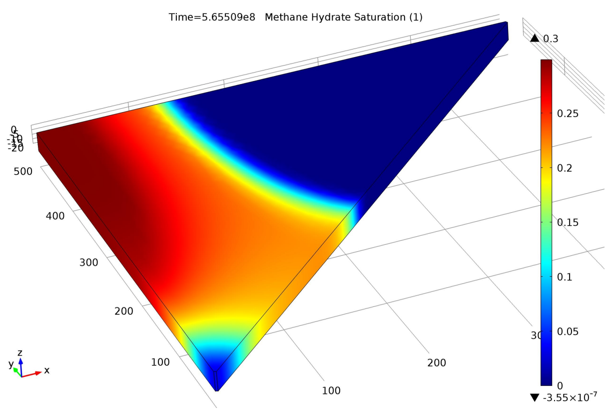

Figure 3: Methane hydrate saturation after 15 years for a simultaneous 2-well production/injection study with injection of carbon dioxide, 3d simulation for a larger reservoir with 700 m well distance, depressurization/production at lower left corner, CO2 injection at upper right corner

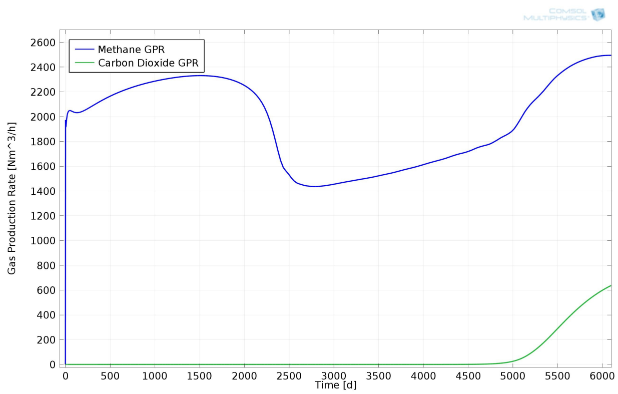

Figure 4: Methane and carbon dioxide production rates at the producer well, conditions as for Fig. 3, carbon dioxide break through after 5000 days