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Mathematical modelling and development of a computer tool for laboratory methane gas production from hydrates by depressurization method

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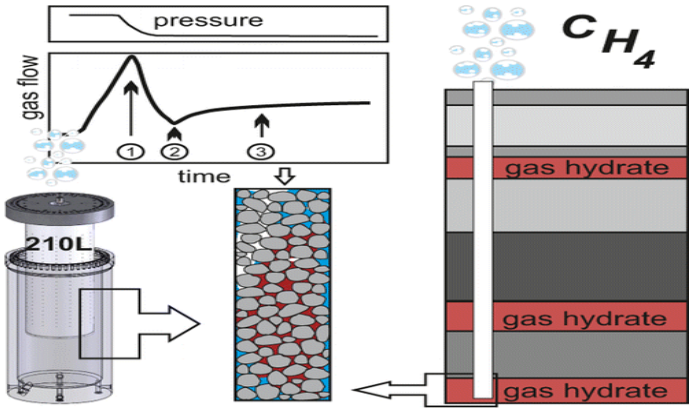
Abstract

A mathematical model developed for laboratory methane gas production from hydrates by depressurization method is presented. This model, solved through numerical analysis and programmed in programming language, becomes in a software tool whose results are compared to previously published laboratory tests. The proposed mathematical model is based on mass balance equations where liquid and gas are considered as mobile phases and the hydrate as an immobile phase. It is also assumed that there are not dramatic changes in temperature, so energy balance is overlooked. The proposed equations were discretized in cells by the method of finite differences and solved through Newton-Rhapson numerical method. Constitutive equations were also used to gas/water flow or production, gas hydrate dissociation and permeability changes due to the above-mentioned phenomenon.

Numerical solution was programmed in m language from MATLAB, and a graphical user interface was designed to generate a software. Simulation results were compared with two previously published laboratory tests to validate the mathematical model proposed. The data analyzed was the cumulative production of gas against time, obtaining differences under the 7% between the calculated and the reported results in the two cases. In addition, the developed software also gives dissociated gas/water volumes, saturation changes and permeability changes in the rock.

The novelty of this research is in the report of the changes in the saturations of the three phases due to hydrate dissociation in the rock, which can be supportive to a better gas reserves calculation of these structures non-produced commercially yet. Recently methane hydrates have attracted attention due to their large quantity on the earth and their potential as a new resource of energy. This paper describes a one-dimensional mathematical model and numerical simulation of methane hydrate dissociation in hydrate reserves by both depressurization and thermal stimulation using a one-dimensional radial flow system (axisymmetric reservoir). A moving front that separates the hydrate reserve into two zones is included in this model. A numerical coordinate transformation method was used to solve the moving boundary problem. The partial differential equations were discretized into ordinary differential equations using the method of lines. Our simulations showed that the moving front location and the gas flow rate production are strong functions of the well pressure and reservoir temperature. The impermeable boundary condition at the reservoir results in very low temperature at the moving front and the formation of ice. The formation of ice, which plugs the pore volume for the gas to flow, should be avoided. Compared with a stationary water phase model, our simulations showed that the assumption of a stationary water phase overpredicts the location of the moving front and the dissociation temperature at the moving front and underpredicts the gas flow rate. The thermal stimulation using constant temperature at the well method using a single well was found to have a limited effect on gas production compared to gas production due to depressurization.



Gas hydrate production is still in the test phase. It is only now that numerical models are being developed to describe data and production scenarios. Laboratory experiments are carried out to test the rationale of the conceptual models and deliver input data. Major experimental challenges include (I) the simulation of a natural three-phase system of sand–hydrate–liquid with known and high hydrate saturations and (II) the simulation of transport behavior as deduced from field data. The large-scale reservoir simulator (LARS; 210 L sample) at the GFZ has met these challenges and allowed for the first simulation of the gas production test from permafrost hydrates at the Mallik drill site (Canada) via multistage depressurization. At the starting position, hydrate saturation was as high as 90%, formed from dissolved methane only. Whereas gas hydrate dissociation determined the flow patterns in the early pressure stages, the importance of different transport behaviors increased at lower pressure stages and increasing water content. Gas flow patterns as observed in Mallik were recorded.

While the conceptual model for the experimental data does agree with the model proposed for Mallik at moderate and low gas production, it is different at high gas production rates.

In the medium term, gas hydrate reservoirs in the subsea sediment are intended as deposits for carbon dioxide (CO2) from fossil fuel consumption. This idea is supported by the thermodynamics of CO2 and methane (CH4) hydrates and the fact that CO2 hydrates are more stable than CH4 hydrates in a certain P-T range. The potential of producing methane by depressurization and/or by injecting CO2 is numerically studied in the frame of the SUGAR project. Simulations are performed with the commercial code STARS from CMG and the newly developed code HyReS (hydrate reservoir simulator) especially designed for hydrate processing in the subsea sediment. HyReS is a nonisothermal multiphase Darcy flow model combined with thermodynamics and rate kinetics suitable for gas hydrate calculations. Two scenarios are considered: the depressurization of an area 1,000 m in diameter and a one/two-well scenario with CO2 injection. Realistic rates for injection and production are estimated, and limitations of these processes are discussed.

Gas hydrates are ice-like solid compounds of water and gas molecules (clathrates) which are stable at low temperature and elevated pressure. The water molecules build out cages by hydrogen bonds in which gas molecules are embedded. Generally, gas hydrates can contain different guest molecules in different cages, depending on their sizes and the availability of guest molecules under given thermodynamic conditions, but methane is the prevalent gas in natural gas hydrates. The exploitation of natural gas hydrate deposits that are known in various permafrost regions and submarine sediments all over the world is in the focus of several research groups because the amount of methane to be recovered could overcome future energy shortages. The greenhouse gas CO2 is able to build hydrates too, and these hydrates are thermodynamically more stable than methane hydrates. The possibility to destabilize methane hydrate by injecting CO2 as pressurized gas or in liquid form was verified in several small-scale experiments carried out by different research groups. Thus, the combination of both processes offers the opportunity to open up new energy resources as well as to combat climate change by reducing CO2 emissions. However, the technical realization of this combination of processes has to face various challenges. Besides the technical and economic efforts for drilling in submarine sediments or in deep layers in permafrost regions, these challenges concern the reaction kinetics and transport resistances within the sediments in which methane hydrates are embedded in natural deposits.

Thus, to find the best strategy for methane recovery from a specific deposit with or without CO2 sequestration, a large variety of parameters describing the properties of the particular layer as well as the time- and location-dependent thermodynamic conditions have to be considered. Within the framework of the German SUGAR (SUbmarine GAs Hydrate Reservoirs) project, strategies to produce natural gas from marine methane hydrates and simultaneously store CO2 as hydrates are explored. Before undertaking drilling tests, numerical simulations of the local processes are necessary and helpful. For this purpose, a new scientific simulation model called UMSICHT HyReS was developed to describe the methane production from submarine hydrate layers and the exchange of methane by carbon dioxide. In addition, the commercially available simulation tool STARS (CMG Ltd., Canada) was used. In the following, the new simulation tool is described, and the results of the calculations based on particular reservoir parameters, reaction kinetics, and extraction techniques are outlined.