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ScienceDirect

Energy Procedia 125 (2017) 467–476

Energy Procedia

www.elsevier.com/locate/procedia

European Geosciences Union General Assembly 2017, EGU
Division Energy, Resources & Environment, ERE

Numerical simulation of gas hydrate exploitation from subsea reservoirs in the Black Sea

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Abstract

The potential of producing natural gas from subsea gas hydrate deposits located in the Black Sea is numerically studied within the German research project »SUGAR«. A case study reveals that the production by simple depressurization is possible but at quite low rates. It can be shown that the hydrate decomposition and thus the gas production strongly depend on the geophysical properties of the reservoir, the mass and heat transport within the reservoir, and the model settings. In particular, permeability and available heat required to decompose the hydrate, play an important role.

Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).

Keywords: natural gas; subsea gas hydrates; methane hydrates; hydrate exploitation; numerical simulation; HyReS; SUGAR; Black Sea

1. Introduction

Natural gas has gained in importance compared to other fossil energy carriers, because it is considered a relatively »clean« fuel for power generation, heating systems and as transport fuel. It enabled the development of modern power plants like gas and steam cogeneration plants and peak load power plants, and serves as hydrogen source for fuel cells and chemical processes. When coal is replaced by natural gas in power production, the emission of carbon dioxide can be reduced by ~50 %. Besides the production of biogas, the extraction of methane from hydrates is considered to be a promising way to overcome future shortages. To increase their potential for energy applications new technological approaches are being discussed and developed worldwide. In recent years, intense research has

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Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).
10.1016/j.egypro.2017.08.157

been focused on the simulation of natural gas exploitation from gas hydrate reservoirs. Besides the technical and economical efforts for drilling in submarine sediments, the challenges concern the reaction kinetics and transport phenomena within the sediments in which gas hydrates are embedded in natural reservoirs. Thus, to find the optimal strategy for the gas exploitation with or without CO_2 storage, a large variety of parameters describing the properties of particular target layers as well as time and position dependent thermodynamic conditions of hydrate/gas/water systems have to be considered. The potential of producing methane by different approaches is numerically studied in the frame of the research project »SUGAR - Submarine Gas Hydrate Reservoirs«. In order to describe the methane production from subsea hydrate deposits and the replacement of methane by CO_2, a scientific simulation model based on a two-phase Darcy flow in a sediment/hydrate matrix called HyReS was developed and implemented in COMSOL Multiphysics [1]. This tool turned out to be especially suited for the flexible implementation of non-standard correlations concerning heat transfer, fluid flow, hydrate kinetics, and other relevant model data.

In the following, the results of the calculations based on particular reservoir parameters from a site in the Black Sea and simple depressurization of a methane hydrate bearing reservoir at varied layer disposals are discussed.

Nomenclature

a	volumetric interface area, m^2/m^3	φ	composition derivation coefficient, 1
c	molar concentration, mol/m^3	ψ	mass transfer coefficient, m/s
c_p	specific heat capacity, J/(kg·K)	η	dynamic viscosity, Pa·s
g	gravitational acceleration, m/s^2	Λ	hydraulic conductivity, 1/(Pa·s)
Δh	latent heat, J/mol	λ	heat conductivity, W/(m·K)
k	dissociation constant, mol/(m^2 Pa s)	ν	hydrate number
k_{rel}	relative permeability, 1	ρ	specific density, kg/m^3
K_f	intrinsic permeability, m^2	$\tilde{\rho}$	molar density, mol/m^3
$\tilde{M}$	molar mass, kg/mol	*Indices*	
P	pressure, Pa	*	in phase equilibrium
q	heat source, W/m^3	abs	absorption
R	composition rate, mol/(m^3s)	C	CO_2 / capillary pressure
S	saturation, m^3/m^3	CH	CO_2 hydrate
s	mass source, kg/m^3	G	gas phase
$\tilde{s}$	molar source, mol/m^3	H	hydrate phase
T	Temperature, K	i	component i
u	Darcy velocity, m/s	j	phase j
y	molar fraction, mol/mol	L	liquid phase
β	volumetric expansivity, 1/K	M	methane
χ	isothermal compressibility, 1/Pa	MH	methane hydrate
δ	diffusion coefficient, m^2/s	n	inert gas component n
ε	artificial diffusion coefficient, m^2/s	rel	relative
ϕ	porosity, m^3/m^3	S	sediment phase

1.1. Characteristics of gas hydrates

Gas hydrates are non-stoichiometric, ice-like compounds of water and gas molecules. At gas specific conditions of low temperature and elevated pressure they form in an exothermal reaction. A lattice of water molecules encloses the gas molecules. Generally, gas hydrates can contain different gases in different cage structures, depending on their size and given thermodynamic conditions. Besides methane – the main component of natural gas and the predominant component in natural gas hydrates – other small hydrocarbons, CO_2 and nitrogen are involved. Additives can be used either to promote or to inhibit their formation. [2]

Regarding the worldwide distribution of natural gas hydrate deposits several factors must coexist for hydrate occurrence. This is to say water, organic matter for the gas formation in sediments, and the right pressure and