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Evaluation of the depressurization based technique for methane hydrates reservoir dissociation in a marine setting, in the Krishna Godavari Basin, east coast of India

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ABSTRACT

This paper analyses the effectiveness of the depressurization technique for methane gas production from an unconfined gas hydrate setting in the Krishna Godavari Basin of India. TOUGH + HYDRATE reservoir modeling and production simulation software is used for identifying the depressurization range for sustained dissociation. For the identified depressurization range, a borehole based pumping technique is modeled using MATLAB software, to identify the effectiveness of the technique in dissociating the reservoir with post-dissociation permeability (PDP) ranging between 1 and 500 mD, the likely scenario for the KG basin. The results indicate that the depressurization technique shall be effective for reservoirs with higher PDP, while the reach of the bore well depends on the capacity of the pump and hydrate zone well perforation area. The simulation results indicate that a bore well with 50 m^2 of hydrate zone surface area could be effective in dissociating the reservoir up to a distance of 1000 m, with a pump of 128 kW electric capacities in formations with PDP of 500 mD. The results could serve as a basis for the economic planning of production wells in gas hydrate reservoirs.

1. Introduction

The global fossil fuel consumption is increasing at an alarming rate, and is expected to reach about 21,000 Mtoe in 2040 (IEO, 2013). The increasing concerns on nuclear energy safety after the Fukushima accident (Gallardo and Matsuzaki, 2014), challenges in the disposal of spent nuclear fuel, (Grambow and Bretesche, 2014) and the stringent emission standards in coal based power production (Rubbelke and Vogele, 2014), increase the demand for natural gas in energy intense economies. Based on the global energy analysis, conventional fossil fuels are expected to continue the supply of around 80% of the world's primary energy till 2040 (IEO, 2013; Vedachalam et al., 2015). As the global demand for conventional oil and gas is on the upswing, new oil and gas field discoveries are on the decline (Hook et al., 2009; Hook and Tang, 2013). To meet the energy demand-supply gap, global efforts are under progress for exploring alternative energy resources. Gas hydrates are crystalline substances composed of water and hydrocarbon gas molecules, Methane hydrate represented in equation (1), CO_2 hydrate (Li et al., 2010a), or other refrigerant hydrates (Li et al., 2010b) are considered to be one of the promising future sources of clean energy (Gabitto and Tsouris, 2010).

$$CH_4 + nH_2O \leftrightarrow CH_4{\cdot}nH_2O \quad (1)$$

Based on the pressure and temperature conditions, gas hydrates exist at subsurface depths ranging between 130 and 2000 m in permafrost regions, while in offshore continental margins, hydrates occur below the sea floor at water depths ranging between 800 and 3000 m (Sun et al., 2014). Bathymetry, sea floor temperature, total organic carbon content, sediment thickness and geothermal gradient are the controlling factors for the occurrence of gas hydrates (Milkov et al., 2000; Sloan and Koh, 2008). Gas hydrate accumulations are classified based on the geologic formations, with Class 1 deposits comprising of the Hydrate Bearing Layers (HBL) and an underlying two phase fluid zone containing free mobile gas and water; Class 2 deposits with HBL and overlying zone of mobile water; Class 3 deposits comprising of only the HBL zone without

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Nomenclature

ΔP	Pressure difference
A	Influx area in m^2
A	Area of the cross section
CH_4	Methane
D	Diameter
f	Friction coefficient
FPSO	Floating Production Storage and Offloading
g	Acceleration due to gravity
H	Static head in m
H_2O	Water
k	Permeability of the formation in m^2
KG	Krishna Godavari
L	Length of the flow path in m
NGHP	National Gas Hydrate Programme (NGHP)
PDP	Post Dissociation Permeability
Q	Flow rate in m^3/hr
Re	Reynolds number
T + H	Tough + Hydrate
V	Velocity

Greek symbols

μ	Dynamic viscosity in pa-s
ρ	Density in kg/m^3
€	Relative roughness
γ	Kinematic viscosity in m^2/sec

Units

kW	kilo Watt
mD	milli Darcy
m	meter
m^3/hr	cubic meter per hour
°C	Degree Centigrade
m^2	square meter

mobile water; and Class 4 deposits pertaining to oceanic accumulations.

Till date, over 230 natural gas hydrate deposits have been identified globally (Lu, 2015) with over 97% of the accumulations in marine settings (Makogon and Omelchenko, 2013). The amounts of methane gas sequestered in gas hydrate bearing sediments are enormous, with global speculative estimates ranging from 3114 to 7,634,000 trillion m^3, which is more than the energy available in the conventional fossil fuels (Milkov, 2004). Huge investments and efforts are being made by countries including the US, Japan, China, India and Korea with the aim of realizing gas hydrates as the future source of energy (Lu, 2015; Koh et al., 2012). Even though geophysical and scientific drilling have allowed for the identification and characterization of the occurrence of gas hydrates offshore (Collett et al., 2008; Su et al., 2012; Matsumoto et al., 2011; Reagan et al., 2014), understanding the reservoir conditions and developing suitable technologies for extraction are challenging tasks. Based on the hydrate formation mechanism, changes in the pressure, and temperature conditions of the gas hydrate reservoir, will result in gas hydrate dissociation resulting in the release of methane gas (Myshakin et al., 2012; Zatsepina et al., 2011). Different combinations of methods are in the conceptual and field testing stage for exploiting gas hydrates; the methods being considered include thermal stimulation (Ramesh et al., 2014; Kurihara and Narita, 2011) depressurization (Zhao et al., 2013; Kanno et al., 2014), inhibitor injection and molecular substitution (Seo et al., 2013; Duyen et al., 2012). However, owing to the challenges in the controlled and sustained release of methane by considering the environmental challenges and economic factors, a suitable technology for extraction on a commercial scale is yet to be realized (Moridis et al., 2011). Economic considerations for production include the mapping of economically extractable gas hydrate locations, production costs, proximity to large energy markets and pipeline networks. The analysis of the economics of gas hydrate production using thermal, depressurization, and conventional oil and gas production techniques, was studied extensively to understand the energy economics of extraction from hydrate systems (Sun et al., 2014), which forms the basis of the economic modeling of gas production.

In the global scenario, most of the published literature is about the simulation and field test results based on the depressurization technique for gas hydrate dissociation pertaining to permafrost and sandy reservoir marine settings. Experimental wells were drilled and gas production demonstrated in permafrost regions, using the depressurization technique. Based on the inputs from depressurization, experiments carried out in a Class 3 permafrost deposit in the Mallik field in the Mackenzie delta during April 2008, where the gas hydrates are overlain about 600 m of permafrost (with a formation pressure of about 91 bar), numerical production modeling is done for a single horizontal well in the reservoir having a permeability of 1200 mD, and it is identified that the depressurization could be effective up to a distance of 800 m from the well bore. The simulation results indicated that a constant ΔP of 27 bar (a pressure slightly above the quadruple point) resulted in hydrate dissociation up to a horizontal distance of up to 280 m from the well bore (Rutqvist et al., 2009; Saeki, 2014). Likewise, the modeling done for a single vertical well in hydrate deposits at 380 m depth overlain in the Qilian mountain permafrost in the Qinghai–Tibet plateau of China indicated a well reach of up to 20 m (Zhao et al., 2013).

Production from continental marine settings (Class 4 reservoirs) using the depressurization technique and modeled using CMG STAR reservoir modeling software, for a site 313 in the Walker Ridge in the Gulf of Mexico with a formation permeability of 1000 mD, indicated hydrate dissociation of up to 450 m from the well bore (Myshakin et al., 2012). The Offshore field has been successfully demonstrated in the Nankai Trough in Japan, where a cumulative gas production of 1.2×10^5 m^3 in a 6 day period was reported in 2013 (Fujii et al., 2013). Based on the inputs obtained from the field production tests, the collected soil parameters and the site geometry, gas production trial based on the depressurization technique is numerically modeled, using the matured fully coupled reservoir simulator CMHGS. The simulation done for a 50 day trial at a ΔP ranging between 30 and 70 bar in the formation with a permeability of 500 mD indicated effective dissociation of up to 380 m from the well bore (Saeki, 2014; Zhou et al., 2014). Laboratory based studies for depressurization supported by numerical modeling are also undertaken, to estimate the effectiveness of the depressurization technique applicable to hydrate reservoirs (Sakamoto et al., 2009; Zhao et al., 2015; Wang et al., 2015).

Very few marine reservoirs in the world, such as the Ulleung Basin, Gulf of Mexico and Krishna Godavari (KG) Basin, are characterized by fine grained clay type marine settings (Boswell et al., 2011). Fine grained clayey hydrate marine reservoir settings have not been studied extensively, when compared to coarse grained settings, due to constraints in the resource economics and due to the limited data availability on understanding factors such as the formation mechanism, and mechanical stability (Moridis et al.,