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An approach for methane hydrates reservoir dissociation in a marine setting, Krishna Godhavari Basin, east coast India

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ABSTRACT

Gas hydrates are considered to be potential sources of clean energy. Various methods of gas hydrates extraction such as thermal stimulation, depressurization and inhibitor injection have been proposed, but each of them has some advantages and disadvantages depending upon reservoir conditions. This study deals with a production method applicable to the fine-grained clay-rich reservoir conditions in the Krishna–Godhavari (KG) Basin of India, by means of introducing an electrode into a gas hydrate reservoir to confine the energy delivery for dissociation and continue with depressurization for sustained production. The simulation of electrical heating using MATLAB and hydrate dissociation quantification using TOUGH + HYDRATE modeling programs, supported by laboratory studies, indicate that the reservoir temperature can be raised to 21.5 °C in one hour at a distance of 1 m from the electrode. Results indicate that 20.1 m^3 of hydrate-bearing reservoir section with 90% hydrate saturation can be dissociated in 72 h at a given power of 90 kW. The energy balance calculations show that the energy supplied to produce is at the ratio of 1:3.5. To enhance the energy efficiency after 15 h of heating either the input power is increased in incremental stages or thermal stimulation is stopped and extraction is continued with the depressurization technique by pumping out dissociated freshwater from the zone of dissociation within the reservoir at a rate of 144 m^3/h with a perforated borehole area of 2 m^2 in the reservoir.

1. Introduction

The global consumption of fossil fuel is increasing at an alarming rate. About 34% of today's energy requirements are met from oil and 21% from natural gas (Hughes and Rudolph, 2010). Between 1960 and 1970, 120 oil and gas fields were discovered with recoverable reserves of 400 Giga barrels, whereas during the period from 2000 to 2006 only 20 fields were discovered whose recoverable reserves amounted only to 30 Giga barrels (Hook et al., 2009). Further, production from many offshore fields of Oil Producing and Exporting Countries have plateaued (Hughes and Rudolph, 2010). In addition, Norwegian offshore oil production, which contributed 10% of global production, has declined by 15% over the period from 1990 to 2005 (Spencer et al., 2008). To keep pace with the economic growth, engineers and scientists are exploring for an alternative form of energy. Under the list of non conventional energy resources, laboratory research and field investigations are in progress on coal bed methane, shale gas, and gas hydrates as potential alternative sources of energy.

Gas hydrates are crystalline substances composed of water and hydrocarbon gas molecules (methane), in which solid lattices of water molecules trap gas molecules in a cage-like structure known as a clathrate and are considered to be one of the promising future sources of energy (Gabitto and Tsouris, 2010). Based on the pressure and temperature stability condition observations for the occurrence of gas hydrate, it is a well established fact that gas hydrate can exists at subsurface depths ranging from about 130 to 2000 m in permafrost regions, while in offshore continental margins, hydrates can occur below the sea floor at a water depth of about 800–3000 m (Milkov et al., 2000). Bathymetry, seafloor temperature, total organic carbon content, sediment thickness, rate of sedimentation and geothermal gradient are the controlling factors for the occurrence of gas hydrate (Milkov et al., 2000; Sloan and Koh, 2008).

The amount of methane sequestered in gas hydrates is enormous. Estimates of the amount of gas in hydrate accumulations in the United States range from 3200 to 19,000 trillion m^3 (Moridis et al., 2011), while ~1900 trillion cubic meters of methane gas, stored in the form of gas-hydrates have been predicted to occur within the Indian Exclusive Economic Zone (Sain et al., 2012). The Indian National Gas Hydrate Program (NGHP) established the

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presence of gas hydrates in the Krishna–Godavari (KG), Mahanadi and Andaman basins (Collett et al., 2008). The estimated available volume of gas in the form of gas hydrate is more than 1500 times of India's present conventional natural gas reserves, and it is estimated that only 10% of this huge cache of energy can meet India's energy requirement for about a century (National Energy Map for India, 2013). Even though geophysical and scientific drilling have allowed for the identification and characterization of the occurrence of gas hydrate in the offshore of India (Collett et al., 2008), understanding the reservoir conditions and developing suitable technologies for extraction is challenging (Todd et al., 2006). Engineering innovations are required to develop the technologies needed to produce gas from gas hydrate.

Based on the hydrate formation mechanism, it is an understood fact that the change in pressure and temperature conditions of the gas hydrates reservoir will result in gas hydrate dissociation and the release of encapsulated gas (Dou et al., 2010). Different combinations of such methods are in the conceptual and field testing stage for exploiting gas hydrate; methods being considered include thermal stimulation, depressurization, inhibitor injection, cyclic steam stimulation (Kurihara and Narita, 2011) and the CH_4–CO_2 exchange method (Collett et al., 2009; 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 realised (Moridis et al., 2011).

Gas hydrate production computer simulators have been developed to quantify the volume of gas that can be recovered from various types of gas hydrate accumulations (Tsimpanogiannis and Lichtner, 2011; Jang and Santamarina, 2011). Hydrate saturation with 60–90% are established for resource grade natural sandy gas hydrate reservoirs (Waite and Spangenberg, 2013; Collett et al., 2009). Economic considerations for production include the mapping of economically extractable gas hydrate locations, production costs, proximity to large energy markets and pipeline networks. Analyses of the economics of gas hydrate production, using thermal, depressurisation and conventional gas production techniques, were studied extensively, to understand the energy economics of the hydrate system (Collett et al., 2009). This forms the basis of the economic modeling of gas production for this study.

In the global scenario, experimental wells were drilled and gas production was demonstrated in permafrost regions, including areas in northern Canada and Alaska areas (Collett et al., 2009, 2011; Hancock et al., 2005) and in the West Siberian Basin (Collett and Ginsburg, 1998). Production from continental marine margins has been successfully demonstrated in Japan (JOGMEC, 2013), where a cumulative gas production of 12×10^4 m^3 in a 6 day period was reported in 2013 and it is high when compared to 13×10^3 m^3 production in a 5.5 day period in the second onshore production test in Mallik well site in Canada in 2008 (MH21, 2010). The results of these limited field production test are encouraging, but more work is needed to understand the sustainability of production from a gas hydrate reservoir, and to further characterize the range of geo-mechanical and environmental hazards associated with the production of gas hydrate. This paper deals with an in-situ electric heating method supported by depressurization. Results from numerical simulation and laboratory experiments have been used to develop and describe a conceptual extraction methodology.

2. Background information of the KG Basin and electro thermal heating techniques

The electrical properties of the gas hydrate bearing sedimentary section and overlying layers were logged using downhole logging-while-drilling technology in Hole NGHP-01-10D in the KG Basin (Collett et al., 2008; Shankar and Sain, 2012a,b). The electrical resistivity values are 100 Ω-m, 10 Ω-m and 0.2 Ω-m in the gas hydrate bearing zone, overlying non-hydrate bearing formation and sea water respectively (Fig. 1) (Shankar and Sain, 2012a,b). Higher electrical resistivity of the gas hydrate zone in the study area when compared to the non-hydrate bearing overburden and sea water is advantageous, and it encourages the examination of the efficiency of in-situ electro-thermal heating technique for gas hydrate dissociation.

The concept of using alternating electric current to heat oil-bearing reservoirs have been studied by Harvey and Arnold (1980), and it is established that the method is effective for heating the formation in the immediate vicinity of an electrode. The in-situ thermal recovery method using electrical current was demonstrated to increase hydrocarbon recovery from oil sand deposits, by raising the temperature of the host formation (Mcgee, 2008). It was shown that transferring the electromagnetic energy to the formation proved to be the most effective means of supplying heat to the formation. In the electro-thermal stimulation process, electromagnetic energy is converted to in-situ heat, using a system of electrodes from which electric current flows through the formation. It was experimentally demonstrated that with the proper choice of the voltage, electrode location and spacing, that the temperature-profile across the oil-bearing reservoir could be modified and afflictively controlled. Du Frane et al. (2011) carried out electrical impedance measurements on laboratory synthesized gas hydrates over a wide range of frequencies, and their findings are shown in Table 1.

As shown, the electrical impedance offered by the gas hydrate decreases with frequency. Therefore, at lower frequencies, the Joule heating (I^2R losses) shall be more effective and it has been inferred that DC power could be a better choice for Joule heating (Du Frane et al., 2011). By considering the advantage of localized heating, electro-thermal stimulation using DC power for Joule heating was studied in detail for gas hydrate dissociation.

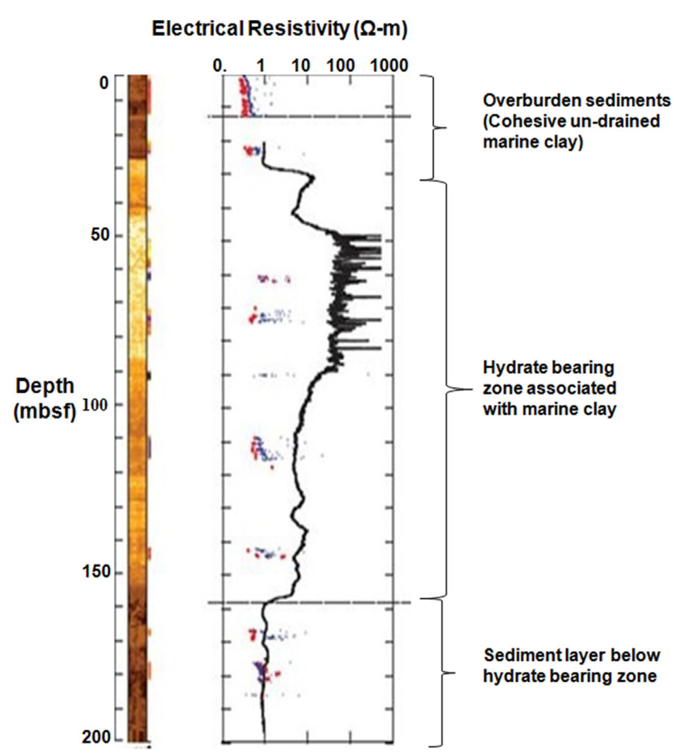

Figure 1. Electrical resistivity well log data from Hole NGHP-01-10D in the KG Basin.