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Research paper

Analysis on geologic conditions affecting the performance of gas production from hydrate deposits

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ABSTRACT

Potential of gas production from hydrate deposits depends on occurrence features of the hydrate deposits and production methods, and fundamentally it is determined by geologic conditions of the hydrate reservoir. The geologic conditions mainly include reservoir porosity (Φ), hydrate saturation (S_H), formation permeability (K), thickness of hydrate-bearing layer (HBL) (H), initial pressure (P_0) and temperature (T_0) of the HBL. Profound differences of the conditions have been revealed by the global marine drilling programs. Orthogonal design, as a statistic method, is employed in this work to systematically investigate the relative importance of these diverse geologic conditions on hydrate decomposition as well as production performance of gas and water from the Class 2 offshore hydrate accumulations. The analysis results show that the order of the significance levels of the geologic conditions on cumulative gas production is $K > \Phi > S_H > T_0 > P_0 > H$; while the order of that on the *water-to-gas* ratio is $P_0 > K > \Phi > S_H > H > T_0$. The results suggest that it is favorable for production from the hydrate deposits characterized by the conditions of the high permeability, moderate porosity (40%), moderate-to-high hydrate saturation (38%–67%) and the low initial pressure (10.79–13.38 MPa). This research gives a forward sight for production prediction and provides a reference in selection of production target.

1. Introduction

Gas hydrate is a kind of clathrate, ice-like compounds composed of water and gas (Sloan and Koh, 2008). It is considered as the most promising renewable energy resources in the 21st as the large amount of gases may burst from destabilized hydrates. In theory, 1 m^3 of gas hydrate expands 164 m^3 of gas in gaseous at the standard conditions (Kvenvolden, 1998). In nature, the gas hydrate only occurs in sediments of slopes at the continental margins and the arctic permafrost (Kvenvolden, 1998). The combination of pressure-temperature stability condition, gas resource, availability of water, gas migration, suitable host sediment and the timing constitutes a "gas hydrate petroleum system" developed from the concept of normal petroleum system (Collett et al., 2009). Compared to permafrost areas, a large amount of biogenetic methane in marine environment renders that the oceanic hydrate deposits is more attractive in the energy resource (Boswell and Collett, 2011; Lashof and Ahuja, 1990).

The hydrate occurrences under seafloors have been confirmed by the worldwide field drilling programs. The locations of the notable expeditions are marked in Fig. 1. However, the drilling programs indicated that the hydrates in nature occur in a variety of geologic conditions. For instance, the gas hydrate occurs in the coarse-grained turbidite sands in the eastern Nankai Trough and in the fine-grained clay-silts in Shenhu area of the South China Sea (Tsuji et al., 2009; Zhang et al., 2007). The hydrate concentration is 14% at the Blake Ridge and over 40% with the average of 67% at the Gulf of Mexico (Paull and Matsumoto, 2000; Boswell et al., 2012; Frye et al., 2012). The thickness of the hydrate-bearing layer is about 10 m at the Site 3 and 25 m at the Site 7, although the sites are within a small area of Shenhu drilling area (GMGS1, 2007). These different geologic conditions mentioned above constitute the specific characteristics of the marine hydrate deposits, and have significant implications for potential of gas production from the

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Nomenclature

Δr	radial increment (m)
Δz	discretization along the z-axis (m)
H	thickness of hydrate-bearing layer (m)
K	intrinsic permeability (m^2)
k_{Θ}	composite thermal conductivity (W/m/K)
k_{dry}	“dry” thermal conductivity (W/m/K)
k_{wet}	“wet” thermal conductivity (W/m/K)
M_w	cumulative mass of water produced from the well (kg)
P	pressure (Pa)
Q_R	volumetric rate of CH_4 released from dissociation (ST m^3/s)
Q_P	volumetric rate of CH_4 release from the well (ST m^3/s)
R_{WGC}	water-to-gas ratio (m^3 water per ST m^3 of gas)
r, z	cylindrical coordinates (m)
r_{max}	maximum radius of the simulation domain (m)
r_w	well radius (m)
S	phase saturation
t	time (days)
T	temperature (°C)
V_R	cumulative volume of CH_4 released from dissociation (ST m^3)
V_P	cumulative volume of CH_4 produced from the well (ST m^3)

Greek symbols

λ	van Genuchten exponent
Φ	porosity

Subscripts and superscripts

0	denotes initial state
G	gas phase
irA	irreducible aqueous phase
irG	irreducible gas
n	permeability reduction exponent
n_G	gas permeability reduction exponent

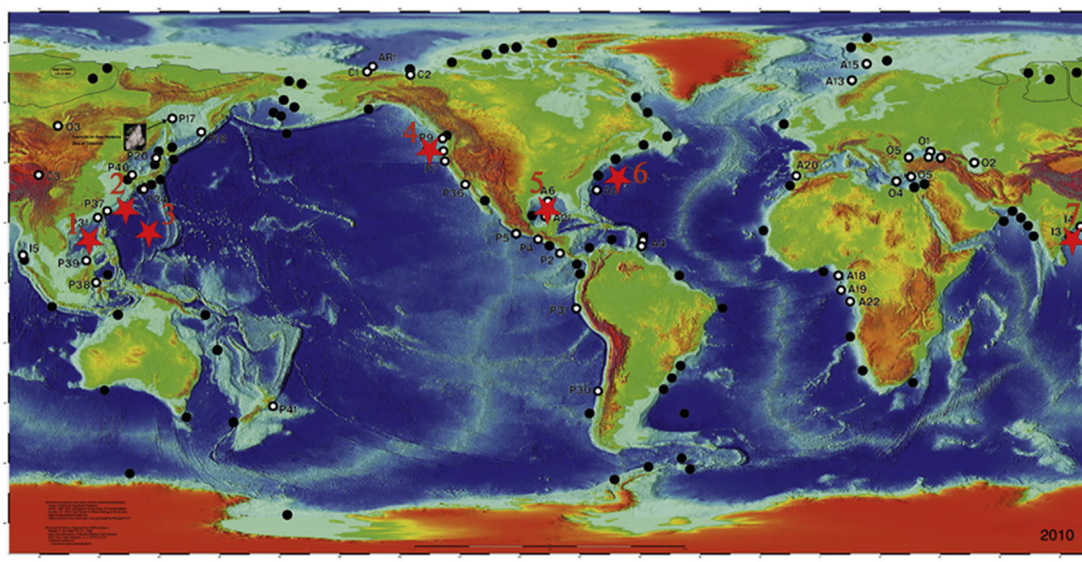

Fig. 1. Locations of the notable drilling programs at the offshore marine hydrate deposits around the world (modified from (Collett et al., 2009)). 1. Chinese GMGS-1&2; 2. Korean UBGH 1&2; 3. Japanese MH21; 4. ODP 204 and IODP 311 in Hydrate Ridge; 5. JIP Legs 1&2 in Gulf of Mexico; 6. ODP 164 in Blake Ridge; 7. Indian NGHP-01.

deposits (Boswell and Collett, 2011).

As a matter of fact, the possible effects of the geologic conditions on gas production potential have been investigated through a series of experiments and numerical studies. Gas hydrate concentration and sediment porosity commonly used to quantify the quality of hydrate deposits are confirmed to affect the gas and water production in the depressurization production (Zhang et al., 2015; Reagan et al., 2009). The flow ability permeability, as revealed by Tang et al (Tang et al., 2007). and Konoo et al. (Konno et al., 2010), controls the production process in the field hydrate accumulations. Konno et al (Konno et al., 2010). also reported that the initial temperature of hydrate formation could greatly affect the gas productivity. Recently, a study of the priority of gas production from the sandstone hydrate reservoirs has already been obtained, which supports that lithology is a significant influential factor in hydrate production (Huang et al., 2015). These works are indispensable and also initial efforts in the commercial exploitation of the hydrate reservoirs. Nevertheless, the relative impact of diverse geologic conditions on the gas production potential that is of significant importance for the selection of production target is still unknown. Although until now, most studies have assessed the effects of some geologic parameters on gas production in the specific areas (Moridis et al., 2009; Su et al., 2012; Myshakin et al., 2012; Vedachalm et al., 2015).

In this paper, a scientific statistic method of orthogonal design is employed to select the most representative combinations of the main geologic conditions of marine hydrate reservoirs including formation porosity (Φ), hydrate saturation (S_H), reservoir permeability (K), thickness of HBL (H) and initial pressure (P_0) and temperature (T_0). All the values of the parameters are originated from the notable offshore hydrate accumulations detected in the marine field drilling programs. The gas production potentials of the