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DOI
10.3997/2214-4609.202210625

Publication date
2022

Document Version
Final published version

Published in
83rd EAGE Conference and Exhibition 2022

Citation (APA)
Li, Y., Lu, H., Wang, L., Eltayieb, M., & Slob, E. (2022). The feasibility of csem monitoring in gas hydrate production of the range of porosity and saturation. In S. Flowers (Ed.), *83rd EAGE Conference and Exhibition 2022* (pp. 2349-2353). EAGE. https://doi.org/10.3997/2214-4609.202210625

THE FEASIBILITY OF CSEM MONITORING IN GAS HYDRATE PRODUCTION OF THE RANGE OF POROSITY AND SATURATION

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Summary

Natural gas hydrates production tests over the last two decades has sown that production is not without risks. Indirect effects in the sedimentary rocks of phase changes are changes in porosity, permeability, and saturation. From a field production test site, porosity changes in the range of 15% to 19% and saturation from 5% to 60% were reported. Monitoring is in principle possible using an electromagnetic survey with a downhole vertical electric source and a horizontal electric field receiver on the seafloor. Computed model responses over a wide frequency range and for many depth locations of an electric current source show that both changes can be detected. Best detectability occurs when the current source is below the reservoir layer in case of changes differences can be detected above, inside and below the reservoir layer at frequencyies below 10 Hz. At a source operating frequency of 0.1 Hz maximum response difference between the two values in saturation occur when the source is 20 m above the top of the reservoir layer unil 100 m below the bottom. Only below the top of the reservoir there is almost no difference in the electric field amplitude between the two saturation levels below 10 Hz.

The feasibility of CSEM monitoring in gas hydrate production of the range in porosity and saturation

Introduction

Nature gas hydrate (NGH) is a potential energy source. Several trial productions have been implemented during the last two decades in several places. From 2002, the gas hydrate production test in permafrost has been adopted in Mackenzie Delta, Canada (Yamamoto and Dallimore 2008). Ten years later, researchers of the USA and Japan have also tried gas hydrate production with a combined method of CO2 replacement and depressurization, in Mount Elbert Gas Hydrate Stratigraphic Test Well on the Alaskan northern slope (Collett et al. 2011). After the test on permafrost on land, the world's first offshore production test has been promoted at the eastern Nankai Troughor in 2014 (Konno et al. 2017). Another round of trial production was implemented in Nankai Trough in 2017 (Yamamoto et al. 2019). Two deep sea production tests have been performed, first in the South China Sea in 2017 (Li et al. 2018) and the second from October 2019 to April 2020 (Ye et al. 2020). Aiming for the commercial exploitation of NGH, exploration and production targets have been arranged by some countries(Chen et al. 2021).

Quite different from conventional hydrocarbon production, during the production of NGH, the natural gas hydrate may experience phase changes in solid, liquid and gas depending on pressure and temperature conditions (Shi et al. 2019). For this reason, researchers need more accurate information on parameter variables during production to monitoring the changes between the different phase states of NGH (Suzuki et al. 2015). While they are still in a stable condition before production, the NGH transform for production may also alter the unconsolidated NGH reservoir properties. For this reason, measurements of the geological conditions are nessarary at the production test area (Chen, Lu, Gu, Shang, Zhang, Huang and Zhang 2021). To improve production safety, better control of the gas production rate is required. The NGH phase state directly affects the production of free gas and water. If they change into a solid in the borehole, well drilling accidents, pipeline incidents and spills or leaks may occur (Rana 2008). By increasing the amount and quality of the information about the physical properties of the methane hydrate reservoir and its sediments we have during production we can reduce the risks.

For these reasons, researchers have measured different parameters during gas production (Shi, Liang, Yang, Yuan, Wu and Kong 2019). The important gas hydrate layer parameters are saturation, porosity and hydraulic permeability. However, unlike in a laboratory experiment, these parameters cannot be measured directly in the field (Radke and Gillis 1990). Geophysical properties like electric resistivity, P- and S-wave velocities and density are indiretly influenced by these parameters. For this reason geophysical surveys can be indicative of gas hydrate phase state and its changes over time. During well logging it has ben shown that electromagnetic fields are sensitive to the variation of NGH, however, the degree or the accuracy were not known until recent (Collett and Lee 2012). For safe production, the monitoring of the NGH production is necessary to have more accurate parameter estimates or estimates of changes in the process of gas hydrate production. These will give better ability to detect structural changes in the NGH reservoir layer. For this reason we computed several changes in porosity and fluid saturation to determine the extent of range of parameter changes that can be detected by electromagnetic methods with transmitters in a borehole and one receiver on the seafloor.

Method

We take a 1D charicature of a real production field for our modelling exercise. The reservoir layer can be divided into three layers. These are an NHG layer, a mixing layer and a free gas layer. This separation is based on inversion results (Ye et al., 2020). Here we focus on the parameter changes in the NGH layer, and we only take the NGH layer into account to investigate the ability to detect any changes in this layer. The three most important parameters for production are porosity, saturation, and permeability, which provide valuable information to monitor the production process. The intitial model is the untouched reservoir in natural state with solid NGH in the pore space of the sediments. This is our background model. When production starts the NGH is change phase form solid to gas. Gas flows up through the produciton well and the pores can be filled with formation brines or free gas. This will generate interaction with the NGH that is still solid phase and may lead to changes in porosity, but also in saturation changes. This may inturn lead to changes in the hydraulic permeability.

In our study, we focus on porosity and saturation for the actual range that was encountered in an actual field trial. We assign the range of gas hydrate saturation with a minimum of 5 % and a maximum of 60% (Qin et al. 2020) and the porosity rage is from 5% to 30% (Qin et al., 2020). In order to find the minimum range difference that can be detected during parameter changes that are generated by the gas production, we model the electromagnet field for two scnarios. One scenario is the background model and the other is model after some production time has passed. We then look at the normalized amplitude of the difference in the electric field due to the changes.

According to the formulation of Archie’s law(Archie 1942) the saturation and the porosity changes can be reflect into the changes in resistivity. And according to the real area condition,

$$R_t = aR_w\phi^{-m}S_w^{-n} \tag{1}$$

where the constant a is called the tortuosity factor, which associated to the permeability, m represents the cementation exponent, and n represent the saturation exponent. We set the values for a, m, and n according to the results obtained in the field (Qin et al., 2020). When the porosity ϕ and the saturation S_w changes, the resistivity can be calculated with equation (1) and the effect of such changes on the electric field can be computed by modelling an experiment before and after the changes have occurred.

Based on this, we performed 1D modelling to check if a CSEM method could be used to detect the variable changes in the parameters. The model has five different layers, air, sea, overburden, the target layer (NGH layer) and the lower half space. The survey begins with the transmitter on the seafloor and is then lowered down hole in the monitoring well. The configuration is shown in the Figure 1. The electric field response of the model is computed for 22 frequency values in the range 0.1~100 Hz evenly spaced on a logarithmic scale. We use 41 transmitters with 10 m interval in the vertical well. The receiver is a horizontal electric field receiver with a horizontal offset of 50 m. We used the open source code DIPOLE1D from Scripps Institute of Oceanography to compute the electric field responses (Key, 2009). Reciprocal measurements with a vertical electric field receiver in a borehole and a horizontal electric current source on the ocean floor is possibly easier to achieve andw ill give the ssame results due to source-receiver reciprocity.

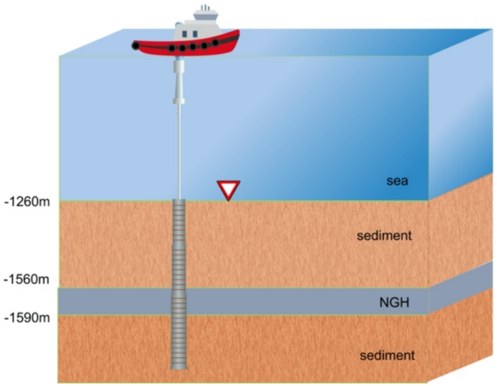

Figure 1 *This is the 1D modelling structure. This is the conceptual model of an actual NGH field. The sea depth is 1260 m and we set the sources in the well with one receive at the seafloor to receive the electric field. The grey coloured layer is the target layer containing NGH and its top lies 300m below the seafloor and the layer is 30 m thick. The lower half space has the same parameters as the overburden.*

Result

The amplitude of the x-component of the electic field is computed for two different saturation values, which are 5% and 60%, which values are taken from field observations. We also compute the electric field responses for two porosity values, which we take as 15% and 19% and are also taken form field observations. We compute the amplitude of the normalized the difference using,

$$D(percentage) = \left|\frac{E_{changes} - E_{background}}{E_{background}}\right| * 100 \qquad (2)$$

Figure 2 shows the values computed from equation (2) as a function of depth versus logarithmic frequency for the porosity change (2A, left graph) and saturation change (2B, right graph). The location of the reservoir layer is indicated by the whilte solid lines in the colour plots. The colour scale is limited between 0% and 35% difference. Figure 2A shows that when the transmitter is below the target layer, the porosity change can be detectable with changes of 15% or higher for frequencies below 1 Hz. Figure 2B shows that the saturation range can be detected will for a wide depth range of transmitters and for almost all frequencies used in the study. For frequencies higher than 10 Hz the changes in saturation lead to differences well above 15% starting 10 m above the top of the reservoir layer and down to all modelled depths. However, the electric field strength has values there that will be too small to measured without too much influence by noise. For frequencies below 3 Hz, the changes are also very well detectable with differences above 15% in the depth range from 10 m above top of reservoir to all modelled larger depth values. There is a small zone around the top of resevoir where no change is observed for thse lower frequencies. When the frequency is 0.1 Hz, the maximum normalized difference is well above 35% between 10 m and 20 m above the top of the target layer. Also inside the reservori layer the differences are above 35% at 0.1 Hz.

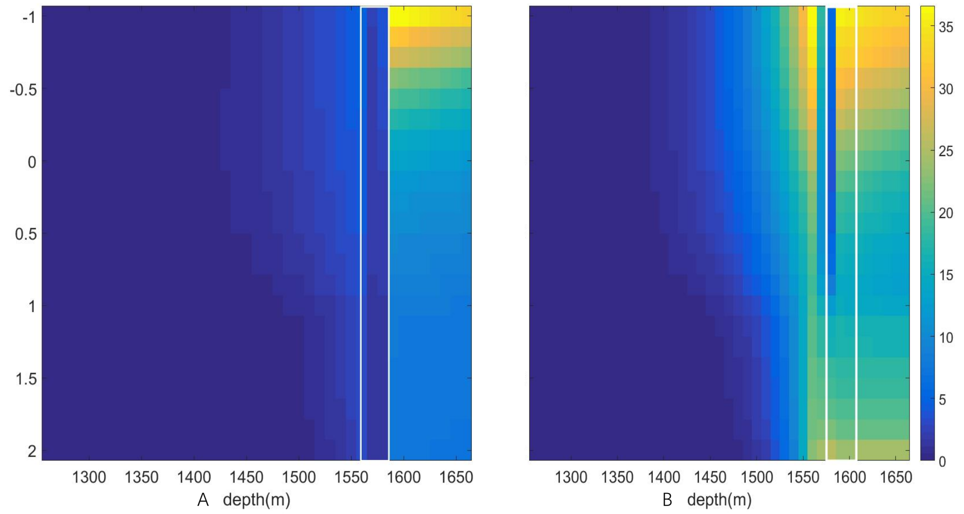

Figure 2 *The formula result of the porosity from 15%~19% in A and the result of saturation variation from 5%~60% in B. The white rectangle highlights the target layer. The values are computed according to equation (2).*

Conclusions

The differences between changes of the properties of NGH layers seem to be detectable by usng a vertical electric current transmitter in a borehole and a horizontal electric field receiver on the oceanfloor or the reciprocal setup. The frequency range that can be used for monitoring in the 1D model that we used is quite large and spans approximately two orders of magnitude from 10 Hz to 0.1 Hz. The depth range where the changes in the reservoir layer can be detected starts 20 m above top of reservoir and continues to 100 m below bottom of the reservoir layer. For these frequency values and depth ranges we expect the electric field strength to be large enough to be measureable in the presence of noise. For frequencies above 10 Hz, detactability is also quite good but signal strength is most likely too small to be detectable. The detected difference indicate that further studies involving more realistic 3D models can be worthwhile.

Acknowledgements

The authors would like to acknowledge the financial support provided by CSC and the financial support provided by the project (DD20190234) of China Geological Survey and the project (Grant No. P20040-4) of Sinopec Ministry of Science and Technology and the financial support of Beijing Information and Science Technology University.

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