International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0088

ACOUSTIC PROPERTIES OF HYDRATE-BEARING SEDIMENT WITH HOMOGENEOUS DISTRIBUTION AND HETEROGENEOUS DISTRIBUTION

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ABSTRACT

The distribution models of naturally occurring gas hydrates in sediments are diverse and have significant influence on physical properties of rocks. In this work, acoustic properties of hydrate-bearing sediment with homogeneous distribution or heterogeneous distribution were investigated using an in situ measurement apparatus, in which methane was used as a free gas for forming hydrate. Hydrate-bearing sediments with homogeneous or heterogeneous distribution were synthesized by controlling the system temperature and water migration. The influence of water migration as a result of gravity along with the rising temperature on acoustic properties was examined during the hydrate formation process. The results showed that the memory effect was proved to be exist from macroscopic scale. Hydrate distribution and concentration are all of great significance to the acoustic characteristics for hydrate deposits. And it was found that the P-wave velocity of the hydrate deposits with homogeneous distribution is faster than that with heterogeneous distribution when under a same hydrate saturation.

Keywords: hydrate, P-wave velocity, water migration, homogeneous distribution, heterogeneous distribution

1. INTRODUCTION

Natural gas hydrates (NGHs), regarded as effective energy sources for the future with the gradually increasing energy consumption and the fossil fuels approaching depletion, widely exist in permafrost regions and sea-floor [1, 2]. Understanding the characters (hydrate saturation, lithology, density, permeability etc.) of hydrate deposits is of importance for energy recovery and environmental issues, which contributes to the evaluation of hydrate resources in situ and even the developing technology of natural hydrate-bearing sediments without geo-hazards [3-5]. The acoustic wave velocity is one of the significant geophysical properties, which can provide characteristics of the geological interpretation of seismic for hydrate-bearing sediments [6, 7]. As S-wave has significant attenuation in gas-containing system, measuring the P-wave velocities is usually regarded to be the widest used exploration technology for the detection of hydrate deposits,[8] and it is also widely used to assess the stiffness of stratum during the process of hydrate dissociation[6, 9].

It is known that investigating the properties of natural gas hydrate deposits in situ is difficult and costly, therefore, laboratory methods of synthesizing hydrate have been developed to examine the corresponding properties instead[10, 11]. Compared with the homogeneous distribution of hydrate-bearing sediment, properties of hydrate-bearing sediment with heterogeneous distribution have been relatively less reported under laboratory environment. Li et al. [8] developed a method to form homogeneous distributed hydrate-bearing sediments and added tetrahydrofuran (THF) to accelerate hydrate formation process. After that, they measured the P-wave velocity (V_P) of hydrate-bearing sediments. The results indicated the V_P has a growth trend with the increasing hydrate concentration of the hydrate deposits and eventually reach a stable value; meanwhile, higher THF concentration would increase the ultimate value of V_P to some extent. Zhang et al. [12] prepared a homogeneous distribution sample of hydrate-bearing sediment by keeping low system temperature to avoid water migration. The influences of

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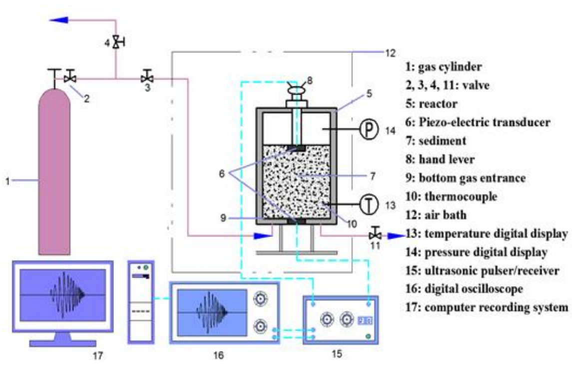
Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

initial brine concentration, hydrate concentration, grain size of sand and water conversion ratio upon V_P of hydrate deposits were studied. It was found that the water conversion ratio is of significance for the distribution of gas hydrates in deposits during hydrate formation process. In Priest et al.'s work, [4] hydrate deposits with homogeneous distribution were synthesized and the properties of the shear wave and compressional wave velocities were tested. The hydrates were found to firstly cement the sandy grains, afterwards, fill in the pore of sandy sediments. Zhang et al.[13] reported behaviors of methane hydrate formation process with the cooling temperature on laboratory. The variations of the resistance and temperature indicate that the methane hydrate heterogeneously distributes in the reactor. However, in their work, the difference of properties of hydrate-bearing sediments between the homogeneous distribution and the heterogeneous one was not explained in detail.

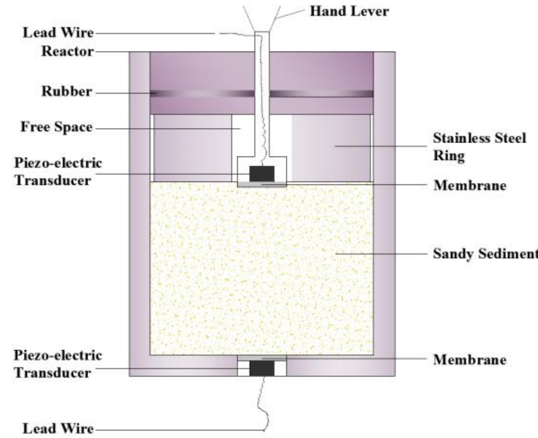
The distribution models of naturally occurring gas hydrates are diverse and can be divided into three models, such as, pore filling, nodules/chunks and lenses/veins [14]. Therefore, it is necessary to study characteristics of hydrate-bearing sediments with heterogeneous distribution for the exploration and exploitation of NGHs. In this work, a measuring device for acoustic properties of hydrate deposits was built for in-situ experiment. Here we studied the phenomenon of water migration and its influence on acoustic properties during hydrate formation. The results supply a method in preparing heterogeneous hydrate-bearing sediments and fundamental understanding in seismic data interpretation.

2. PAPER STRUCTURE

2.1 *Apparatus*



（a）



(b)

Figure 1. (a) Schematic of the experiment device for acoustic properties measurement in situ; (b) The internal structure of the reactor.

Figure 1a shows a schematic of the experiment device used in this work. The internal structure of the reactor is shown in Figure 1b.

2.2 *Material and methods*

2.2.1 Material

Quartz sands with 40-60 meshes were used to form the hydrate-bearing sediment samples. The sodium chloride solution concentration was 3.35 wt% prepared in laboratory.

2.2.2 Methods

Preparation of hydrate deposits was achieved by the method as follows:

(1) Before the experiment, the sediments and NaCl solution were cooled to the temperature about 273.2 K, and the reactor about 275.2 K. Then the sediment mixed homogeneously with NaCl solution was filled into the reactor. Injection of nitrogen gases into the reactor was used to test the leakage of the apparatus. After the leak test, the whole system was vacuumed for 10 min. Methane was then continuously injected into the reactor to produce a pressure about 10.0 MPa. When the temperature and pressure no longer changed, the hydrate was assumed completely formed.

(2) The air bath was turned off to raise the temperature to the room temperature, which led to hydrate dissociation completely. Then the temperature of the air bath was changed to 275.2 K again to examine the properties of hydrate-bearing sediments with heterogeneous distribution. Since the dissociated water will migrate downward because of the gravity, it will form hydrate in situ. The procedure of water migration is

shown as Figure 2.The heterogeneous distribution of hydrate in the porous sediments would be therefore synthesized.

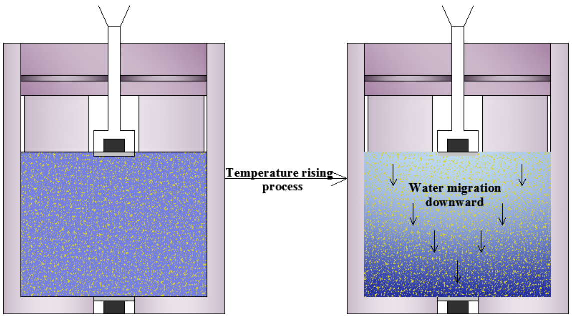


Figure 2 Diagrammatic sketch of water migration in temperature rising process.

In this study, four runs were employed to investigate the effect of homogenous distribution (steps (1)) or heterogeneous distribution (by repeating step (2)) of hydrate upon V_P.

2.3 Results and discussion

A groups of experiments was conducted to examine the variations of acoustic properties in the experimental process and differences between the homogeneous sediment and the heterogeneous one. The experimental conditions and results are listed in Table 1. In Run 1-1, hydrate-bearing sediments were synthesized by keeping at a low system temperature to avoid water migration, and the formed hydrate was distributed homogeneously in the porous sediments; in Runs 1-2 to 1-4, hydrate with heterogeneous distribution was synthesized from the dissociated water which migrated and distributed heterogeneously in the sediments.

Table 1. The Experimental Conditions and Results of Each Run

Group	Run	S_w^a, %	T^b,K	P^c, MPa	S_h^d, %	V_p^e, $m{\cdot}s^{-1}$
1	1-1	30	275.11	7.95	24.7	3507
	1-2		275.23	8.01	23.8	3120
	1-3		275.34	8.01	24.2	3053
	1-4		275.44	8.00	24.1	2720

^{a} S_w: the initial water saturation; ^{b} T: the average temperature during hydrate formation process; ^{c} P: the final experimental pressure; ^{d} S_h: the final hydrate saturation; ^{e} V_p: the final P-wave velocity.

2.3.1. The Evolution of Temperature and Pressure.

Figure 3 indicates the variations in temperature and pressure for Group 1 with 30 vol% initial water saturation. It illustrates a repeated process of keeping-heating-cooling in temperature. Hydrate grew fast after the injection of methane gas into the reactor in the initial pressure about 10MPa. The sudden increases and drops in temperature and pressure at 119 ~ 139 h, 220 ~ 236 h and 310 ~ 330 h is due to that with the air bath being turned off and turned on, hydrate dissociated and re-formed, with aiming to examine the variation in acoustic properties of hydrate deposits along with the water migration. We could also find that as a same deceasing in pressure from 9.71 to 8.02 MPa, it takes about 90.7, 82.5, 70.6 and 58.1h for Runs3-1 to 3-4, respectively. Memory effect is termed as the phenomenon in which hydrate nucleation is faster in hydrate-melt or ice-melt systems than from fresh water systems[15]. The results of the decrease in run time during the same pressure drop for the four runs verify the memory effect during the hydrate formation process. Eventually, it is reaching a stable value in temperature and pressure for the experimental Runs 3-1 to 3-4.

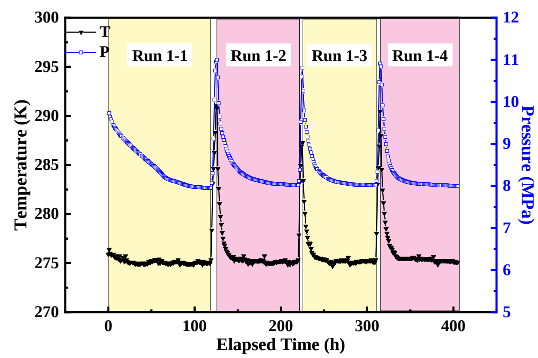


Figure 3. Variations of temperature and pressure with elapsed time during the process of hydrate formation

2.3.2 Variation of P-Wave Velocity with Hydrate Saturation.

Hydrate saturation may be a key parameter on whether the granular medium cement or not[15], which has an important influence on the P-wave velocities[16]. Figure 3 indicates variation of P-wave velocities with the hydrate saturation for Group 1. As shown in Figure 4, V_P increases with CH_4 hydrate saturation for Runs 1-1 to 4-4. However, under the same hydrate saturation, the value of V_P decreases successively from Runs 1-1 to 1-4. In comparison, the value of V_P for Run 3-1 is higher than that of other three runs obviously, while the value of V_P for Runs 3-2 to 3-4 is close when under the same hydrate saturation. The final hydrate saturation for four runs is approximately the same with the value of about 24%, while the final P-wave velocity is different. When hydrate saturation is less than 10%, there is no wave signal due to complete attenuation which is attributable to the free methane gas existing in the unconsolidated sandy sediment.

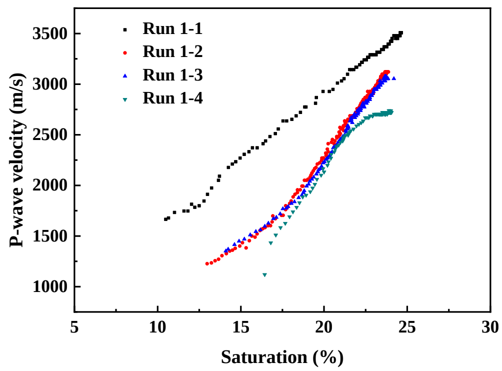


Figure 4 Variation of V_P with saturation in the process of hydrate formation for Group 1

2.4 Conclusions

Since natural gas hydrates in general distribute heterogeneously in permafrost regions or sea-floor, hydrate-bearing sediments with homogeneous distribution and heterogeneous distribution were synthesized respectively by controlling the system temperature and water migration. The P-wave velocities of the homogeneous distribution hydrate deposits are faster than that of the heterogeneous ones when under a same hydrate saturation. It also macroscopically proves the memory effect occurring in the unconsolidated stage which is similar to that occurring in the nucleation stage during the hydrate formation process in the porous sediments.

ACKNOWLEDGEMENT

Financial support received from the National Key Research and Development Program of China (Nos. 2017YFC0307302, 2016YFC0304003, 2017YFC0307306), and the National Natural Science Foundation of China (Nos.21636009,51676207, 51576209) is gratefully acknowledged.

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