Laboratory study of the acoustic properties of sand samples containing ice

G A Dugarov, A A Duchkov and M I Fokin
Trofimuk Institute of Petroleum Geology and Geophysics, Novosibirsk, Russia

E-mail: dugarovga@ipgg.sbras.ru

Abstract. The paper considers a series of experiments with sand samples containing ice. The acoustic measurements were performed in specialized laboratory setup which allows also to form synthetic hydrate-bearing samples in order to find differences between ice and methane hydrate. We find that the velocities of compressional and shear waves depend on the rate of temperature drop below 0°C. During the long-time maintaining of the constant negative temperature the decreasing of the velocities was observed. These dependences can possibly be explained by that in a case of quick freezing formed ice is not energetically favourable, after formation ice particles reconstruct into the pore space with less mechanical stress.

1. Introduction
Natural gas hydrates are considered as a promising new source of natural gas [1, 2]. Also, the presence of gas hydrates in the area of deposit development could cause complications such as accidents due to gas dynamic phenomena during hydrate decomposition and hydrate formation in the bottomhole zone [3]. For stability of gas hydrates high pressure and low temperature are needed [4]. These conditions exists in deep-water sediments and in permafrost. But in the permafrost regions it is hard to distinguish gas hydrate from ice.

The physical properties of samples containing hydrate and ice depending on many factors, such as material of rock matrix, type of pore fluid, saturation by hydrate or ice, etc. Specialized laboratory setups are used for study of the properties of synthetic hydrate-bearing samples [5-7]. In previous works we used our laboratory setup [8] for investigation of acoustic properties of sand samples containing methane hydrate and ice [9]. In this work the results of additional experiments with samples containing ice are presented.

2. Method
For forming sand samples, we place the mixture of quartz sand with a grain size of 0.2-0.25 mm and distilled water in special caprolone cells with ends closed by grids. The internal diameter of the cells is 26 mm; the height varies in the range from 35 mm to 45 mm for compensation of axial compression. We place the cells in the high pressure chamber with temperature maintaining system. The external axial and lateral pressure is about 300 atm.

The acoustic measurements were done by piezoceramic elements mounted in the upper and lower punches. Two discs with a diameter of 18 mm and thickness of 2 mm are mounted in each punch. One disk is used for generating or receiving compressional (P) wave, the second one for generating or receiving shear (S) wave. The signal frequency range is 300-700 kHz. Acoustic measurements were
performed every 5 min during the whole experiment. The height of the samples was also measured during the whole experiment for correct velocity estimation and accounting samples compaction.

The saturation of the samples is controlled by the amount of initial added water. The water saturation of the samples is about 0.3 (except one dry sample), the porosity of the samples is about 0.45.

For forming methane hydrate in sand samples in previous works we applied temperature cycles within methane hydrate stability region or maintain a constant temperature low enough for forming hydrate. Therefore, in this work we form the samples containing ice by maintaining of a constant negative temperature or reformed it many times with temperature cycles.

3. Results

The variations in velocities of P- and S-waves at temperature cycles are presented on figure 1. The temperature varies from 5°C to -15°C. The duration of temperature cycles increases from 1 hour to 24 hours. We can see fast velocity increase when the temperature drops below 0°C due to cementation of the sand by formed ice. But we see that a slower decrease of the temperature leads to a lower increase of the velocities.

For checking that this dependence is determined by the rate of temperature drop and not by the number of temperature cycles we did an experiment with reverse sequence of temperature cycles (figure 2). We can see that a faster decrease of the temperature leads to a stronger increase of the velocities, which means that the rate of temperature decrease is the determining factor.

On figure 3 we show the values of P- and S-waves at -10°C for temperature decreasing at different rate for both experiments: with increasing cycle duration (experiment from figure 1) and decreasing cycle duration (experiment from figure 2). The differences between velocity values for shorter and longer temperature cycles are about 0.21 km/s (6.1%) for P-wave and 0.12 km/s (5.6%) for S-wave.

![Figure 1](image_url)

**Figure 1.** Variations in compressional (P) and shear (S) wave velocities in sand sample containing ice/water at temperature cycles with increasing duration.
We see that the velocity dependences from the rate of temperature drop can be approximated by linear functions. The slopes of the approximation functions for both experiments are the same (figure 3), but they are different for different type of waves. For P-wave the slope (0.009) is almost twice larger than for S-wave (0.005). The vertical shift of the approximation functions can be explained by the small differences in the initial water saturation of the samples.
On figures 1 and 2 we can see also the decrease of the velocities during the time for long-time cycles. For checking this we made an experiment with long maintaining of the constant temperature (figure 4). We can see permanent decrease of both velocities during 120 hours. After 120 hours P-wave velocity decreased by 0.51 km/s (14.6%) and S-wave velocity decreased by 0.3 km/s (13.3%). The values of the velocity drop of every 10 hours presented on figure 5. After 90 hours the decreasing of the velocity drops is so small that it is almost constant, 0.15 km/s every 10 hours for P-wave and 0.1 km/s every 10 hours for S-wave. Similar experiment was made with dry sample (figure 6). After 80 hours of maintaining of the constant negative temperature we see no drops in P- and S-wave velocities.

![Figure 4](image4.png)

**Figure 4.** Decreasing of velocities with time at the constant negative temperature.

![Figure 5](image5.png)

**Figure 5.** The velocity drops values for every 10 hours.
Figure 6. Variation in velocities with time at the constant negative temperature for dry sample.

4. Conclusions
The results of the first two experiments show that the values of velocities after temperature drops below 0°C depend on the rate of the temperature decreasing. A slower decrease of the temperature leads to a lower increase of the velocities. These dependencies could be approximated by linear functions. The slopes of the approximation functions for both experiments are the same but they are different for different type of waves. For P-wave the slope is almost twice larger than for S-wave.

The decreasing of the velocities is also observed during long-time maintaining of the constant negative temperature. The decrease of the velocities for the sample containing ice can be explained by reduction of cementation degree. Both dependences can possibly be explained by that in a case of quick freezing formed ice is not energetically favorable, ice takes over a part of the load on the host matrix. When the water-saturated sample is quickly frozen and the negative temperature is maintained the crystal of ice can slowly pass into an equilibrium state, ice particles possibly reconstruct into the pore space with less mechanical stress.

Acknowledgements
This research has been carried out according to the Complex Program of Basic Research of the Siberian Branch of the Russian Academy of Sciences. The work was supported by Russian Foundation of Basic Research and “National Intellectual Development” foundation [17-35-80023].

References
[1] Chong Z R, Yang S H B, Babu P, Linga P and Li X S 2016 Applied Energy 162 1633-52
[2] Makogon Y F and Omelchenko R Y 2013 Journal of Natural Gas Science and Engineering 11 1-6
[3] Istomin V A, Moiseykin P A, Abrashov V N, Fedulov D M, Chernykh V V, Medvedev S G and Sopnev T V 2013 Vesti Gazovoy Nauki 99-104
[4] Manakov A Yu and Duchkov A D 2017 Russian Geology and Geophysics 58 240-52
[5] Winters W J, Dillon W P, Pecher I A and Mason D H 2000 Natural Gas Hydrate in Oceanic and Permafrost Environments ed M D Max (Springer) Chapter 24 311–22
[6] Kulenkampff J and Spangenberg E 2005 *Scientific Results from the Mallik 2002 Gas Hydrate Production Research Well Program, Mackenzie Delta, Northwest Territories, Canada* ed S R Dallimore, T S Collett (Canada: Natural Resources Canada) p 16

[7] Priegnitz M, Thaler J, Spangenberg E, Rücker C and Schicks J M 2013 *Review of Scientific Instruments* **84** 104502

[8] Duchkov A D, Golikov N A, Duchkov A A, Manakov A Yu, Permyakov M E and Drobchik A N 2016 *Seismic Instruments* **52** 70–8

[9] Duchkov A D, Duchkov A A, Dugarov G A and Drobchik A N 2018 *Doklady Earth Sciences* **478** 74–8