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RESERVOIR FORMATION DAMAGE DURING HYDRATE DISSOCIATION IN SAND-CLAY SEDIMENT

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ABSTRACT

Permeability is known as a key factor affecting the gas production effectiveness from the natural hydrate reservoir. The formation and dissociation processes of gas hydrate in the sediments also have an influence on the permeability. In this study, samples from hydrate reservoir in Qilian Mountain permafrost were taken for the measurement of permeability changes before hydrate formation, with hydrate and also after hydrate dissociation. An unexpected permeability decrease was observed after the dissociation of methane hydrate, which was explained as the "reservoir formation damage". Permeability variation is also related to hydrate saturation in the sediments.

Keywords: Gas Hydrate; Reservoir Formation Damage; Hydrate Dissociation; Gas Production

1. INTRODUCTION

Gas hydrates are ice-like crystalline solids formed from gas and water molecules at low temperatures and elevated pressures [1]. They have therefore been found in the sediments along the continental margins as well as in permafrost regions and in locations with similar conditions. Even though only a small proportion of natural gas from natural gas hydrate reservoirs is recoverable, it is still considered as a promising clean energy resource for the future and worth exploiting. Natural hydrate deposits can be classified in 3 classes in terms of geological characteristics and reservoir conditions [2,3].

Thermal stimulation, depressurization, inhibitor injection and CH4-CO2 exchange are the four most commonly proposed and used techniques in gas hydrate exploiting for both field trials and lab experiments [2,4–8]. In field trials, it is also widely agreed that a combination of these techniques may enhance the effectiveness of gas production. The field test at Mallik site in 2002 has been conducted applying thermal stimulation [9]. Other field tests such as the Mount Elbert well in Alaska North Slope in 2007 [10], as well as Mallik sites in 2007-2008 [11,12] were done by applying depressurization. In 2011, field trials in Qilian Mountain permafrost were implemented using depressurization combining with hot air and hot steam stimulation [13]. The above mentioned tests are all onshore field tests since they were carried out in the permafrost areas. In 2013, the first marine gas hydrate field production test was conducted in Nankai Trough in Margin of the Daini Atsumi Knoll by depressurization [14]. In 2017, China also conducted the first production tests of offshore natural gas hydrate by applying the formation fluid extraction method for 60 days [15]. It is noted from the above production trials that production values increased progressively over the tests.

Despite the fact that sand production and sediments deformation are the key factors to prevent long term gas production from hydrate bearing sediments and became an important issue during production in the field trials, , experimental data are lacking or insufficient [16].

Nevertheless, for an efficient production a high permeability is of primary importance. Permeability controls fluid migration through sedimentary systems and plays also an important role in heat and chemical transfer occurring via fluid migration [17]. In hydrate-bearing sediments, permeability determines the accumulation and distribution of dissolved gas, free gas and hydrates [18]. It also affects the ability and efficiency to produce methane gas from hydrate reservoirs [19–

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21]. Gas and water production at longer time scales may be hindered by the formation damages caused by the low permeability of the hydrate reservoir. At a longer time-scale of production from a hydrate-bearing reservoir formation damage may become an important issue. Among all the factors leading to different types of formation damage, the migration of fine particles is often considered as a major cause. Fine particles may physically break away during hydrodynamic flows and may accumulate in pores and thus reduce the permeability [22–24].

In this study, we investigate the changes of permeability during hydrate formation and dissociation processes in sand-silt core samples.

2. EXPERIMENTS

2.1 Experimental Setup

As shown in Fig. 1, a system for experimental petrophysics was applied for sediment permeability measurements and hydrate formation/decomposition. SEPP consists of an autoclave with a heating/cooling jacked containing the sample setup. The inner diameter is 70 mm, and the usable length of the vessel is 250 mm. It is designed for a maximum pressure of 80 MPa. The sample setup is mounted at the top closure of the autoclave containing the feedthroughs for confining pressure oil, pore fluid inlet and pore fluid outlet, and the signal lines. The sample is separated from the confining pressure oil by means of a Viton jacket and the Hastelloy end caps. To control the sample temperature, a Pt100 temperature sensor is attached to the Viton jacket. The fluid feedthroughs in the end caps allow for pumping the pore fluid through the sample, to apply a certain pore pressure or to exchange the pore fluid. To simulate in situ pressure and temperature conditions, the autoclave is connected to a syringe pump (ISCO 100DM) to build-up the confining pressure and to a thermostat (Huber K6 s-CC-NR) to temper the sample. A detailed description of SEPP is provided elsewhere [25].

2.2 Experimental Procedures

The temperature at the sample surface was monitored using the Pt100 RTD. The heat generated by hydrate or ice formation dissipates over the sample surface, and the ambient temperature was controlled by the thermostat to be constant at 274 K.

The permeability was estimated using Darcy's law. For the initial experiments without hydrate, the degassed 5 % KCl solution, used to saturate the sample was pumped through the setup with rates of 0.5 ml/min, 1 ml/min, 2 ml/min, 3 ml/min, 4 ml/min, 3 ml/min, 2 ml/min, 1 ml/min, and 0.5 ml/min. For each injection rate, the injection duration was about 5 minutes. The outlet was connected to fluid sampling container open to air. The pressure on the inlet and the solution injection rate were recorded in real time.

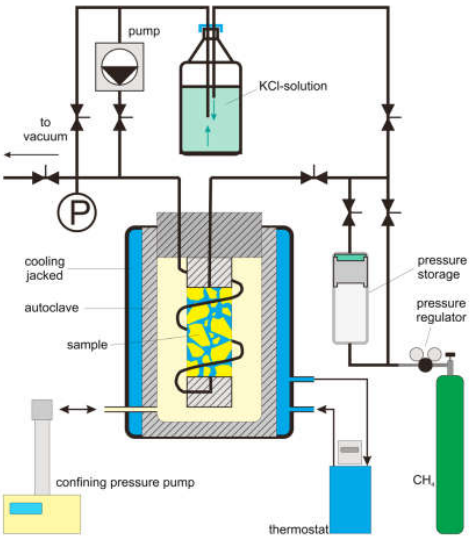

Fig. 1 Schematic of setup

For the permeability measurement of the sample with hydrate, the injected solution was precooled to 274 K and injected into the sample to avoid hydrate decomposition by thermal stimulation. The outlet was connected to the pressure storage which was kept at 5 MPa. The inlet pressure and the injection rate were recorded in real time.

3. RESULTS AND DISCUSSION

Figure 2 shows the change of the inlet pressure during the initial permeability measurement using brine injection with different injection rates of the sample DK-8-I. Because the outlet is open to atmosphere, the inlet pressure measured with a relative pressure sensor, can be considered as the pressure difference of the inlet and outlet pressure. As seen from this figure, the pressure differences proportional to the injection rate. According to Darcy's law, the permeability can be calculated by the following equation:

$$K = \frac{q\eta L}{A(P_1 - P_2)} \qquad (1)$$

in which, K is the effective permeability; q is the injection rate; η is the viscosity of the solution; L is the length of the sample; A is the sectional area of the sample; P1 is the inlet pressure; P2 is the outlet pressure.

The permeability can be calculated using Eq. 1 with the experimental results of the pressure difference

shown in Fig. 2. The results of the calculated permeability are presented in Fig.3. However, it turned out that the permeability estimates at the lower injection rates (0.5 ml/min, 1 ml/min) were unstable. It may be due to the fact that the pump was not accurate at lower injection rates. Therefore, the calculated results with injection rate from 2 ml/min to 4 ml/min are selected for permeability estimation. The average of these permeability values is considered the effective permeability for this sample in this test. The initial permeability of the sample DK-8-I is 26.2 mD.

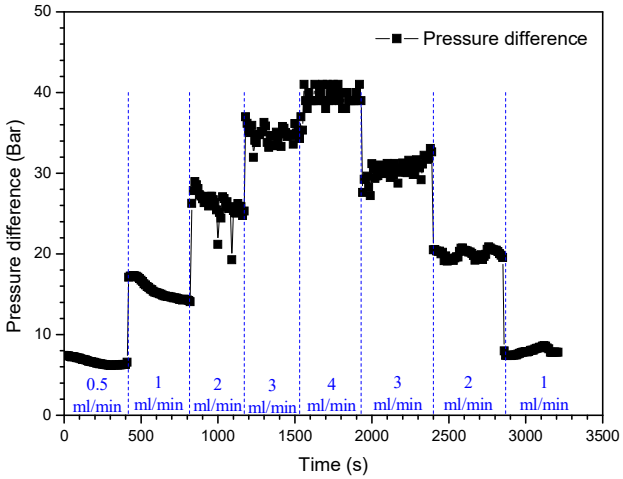

Fig. 2 Changes of pressure difference during brine injection with different injection rate

After methane hydrate was synthesized in the sample DK-8-I with the hydrate saturation of 33% the permeability was determined to be 15.3 mD (Fig. 4). The reduction of permeability is due to the fact that the methane hydrate occupies a part of the pore volume, which originally contributed to the transport network in the sample. However, in these previous studies, the permeability was recovered after hydrate dissociation in the sediment. In contrast, we observed a decrease of the permeability of sample after hydrate decomposition to 2 mD. The phenomenon can be considered as "reservoir formation damage", which is a generic term referring to the impairment of the permeability of petroleum-bearing formations by various adverse processes.

4. CONCLUSIONS

In this study, we investigate the changes of permeability during hydrate formation and dissociation processes in sand-silt core samples. Hydrate dissociation leads to reservoir damage and fine migration in clay-sand sediment. The following conclusions of this study are summarized:

(1) Permeability decrease after hydrate dissociation because that the pure water releasing from hydrate dissociation leads to migration of fine particles.

(2) Migration of fine particles may be due to the synergistic effect of electrical double layer variation and fluid dynamic.

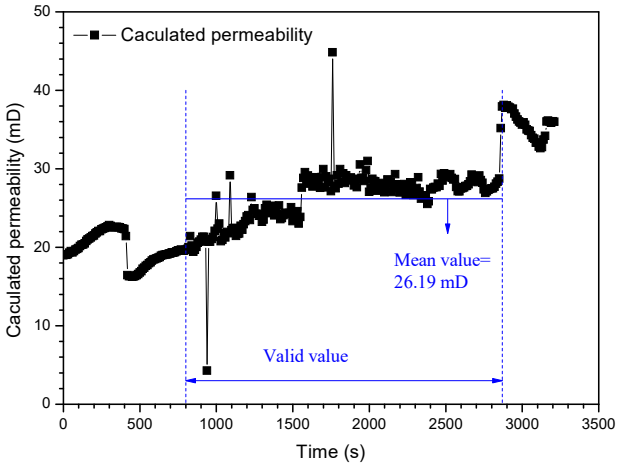

Fig. 3 Permeability calculated by Darcy's law during brine injection with different injection rate.

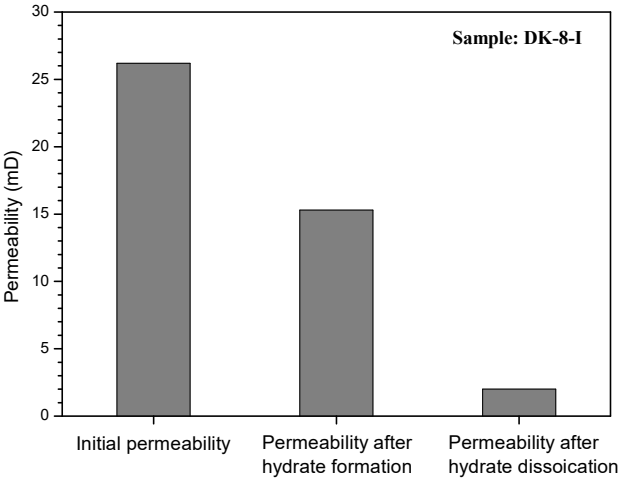

Fig. 4 Initial permeability, permeability after hydrate formation, and permeability after hydrate dissociation

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