Experimental study of the dissociation of natural methane hydrate in the channel in the presence of air flow

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Abstract. Experimental studies have been carried out on the combustion of natural gas hydrate at different rates of oxidant \( U \) (air) in the laminar flow regime and at a fixed channel height. It is established that the dissociation rate \( J \) is related to the velocity \( U \) in a non-linear manner. With an increase in rate from 0 to 0.6 m/s, the dissociation rate increases and reaches a maximum. With a further increase in rate, \( J \) decreases. The dissociation rate does not depend on the initial concentration of methane in the sample. Experimental dependences of the effect of \( U \) on the dissociation rate of a natural hydrate in a channel have been obtained for the first time. The conducted studies are important for further development of natural hydrate combustion technologies.

1. Introduction

The discovered deposits of natural gas hydrates in a hydrated state substantially exceed the reserves extracted by conventional methods. Today, gas hydrate deposits are located mainly in remote deep-water areas, which significantly complicates their production. For the extraction of natural gas hydrate, drilling is used. Stimulation of decomposition is applied due to thermal factors, pressure drop, the use of chemical additives and surface-active substances. Technology of transportation and storage of the gas hydrate granules was presented in Ref. [1]. The kinetics of nonisothermal dissociation of CO\(_2\) gas hydrate is given in [2]. The combustion of a mixture of propane hydrate and quartz sand, unlike pure propane hydrate, is unstable and takes place in a shorter period of time [3]. Dissociation of gas hydrates depends on heat flux [4, 5]. One way to increase the growth rate of hydrates is to increase the surface of the reaction. The formation of a large number of small gas bubbles leads to very high reaction rates of gas hydrate growth [6, 7]. A study of the rate of flame propagation at different surface ignition temperatures with a constant external flow rate and the dissociation rate during combustion were studied in [8-10]. It is necessary to take into account the influence of the porosity of the granules and their size on the kinetics of gas hydrate dissociation [11]. It is necessary to consider the heat transfer for both the granule and the gas medium. Various methods of organizing the combustion of methane hydrate are considered in [12].

When modeling the kinetics of natural gas hydrate dissociation, there are many parameters that are uncertain. The extraction rate can be significantly overestimated due to inaccurate calculations. Therefore, additional experimental data are needed to test the existing models. The purpose of the research is to determine the experimental dependence for the dissociation rate \( J \) of natural methane hydrate on several key factors. The effect of the air flow rate \( U \) and the methane concentration \( C_0 \) in the natural sample on the dissociation rate was studied.
2. Experimental data

A detailed description of the experimental setup is presented in [11]. In the course of the experiment, the temperature of the powder rose from the temperature of liquid nitrogen to 0 °C. The sample was heated due to the heat flux from the ambient medium (a laminar air flow was arranged on the surface of the powder). Hydrate dissociation began when the temperature of the sample exceeded the equilibrium temperature. The dissociation rate of natural gas hydrate \( J \) was measured using the gravimetric method (\( J = \Delta m / \Delta t \) is the change in sample mass \( m \) versus time \( t \)). The temperature of the gas hydrate was measured by the thermal imager (NEC-San Instruments). Thermocouples were placed inside the powder layer to measure the transverse temperature profile.

Fig. 1 (a) shows experimental data on the rate of dissociation of natural gas hydrate during its combustion (at a constant height of the air channel \( H = 30 \) mm), depending on the speed of the incoming air flow \( U \). The beginning of the reading in Fig. 1 (a) corresponds to the start time of combustion for a natural gas hydrate. The dependence for \( J \) is non-linear. Extremum (maximum) corresponds to speed \( U = 0.6 \) m/s.

 ![Figure 1](image)

**Figure 1.** (a) The dissociation rate \( J = \Delta m / \Delta t \) during the combustion of natural gas hydrate: 1 - \( U = 0 \) m/s; 2 - \( U = 0.3 \) m/s; 3 - \( U = 0.6 \) m/s; 4 - \( U = 2.2 \) m/s (channel height for air \( H = 30 \) mm); (b) The dissociation rate \( J_F \) (\( J_F = \Delta m / (F \Delta t) \), where \( F \) is the surface area of the layer) at different mass concentrations of methane (\( C_{CH4} \)) in the gas hydrate: 1 - \( C_{CH4} = 11\% \); 2 - \( C_{CH4} = 5\% \).

When the rate exceeds 0.6 m/s, the dissociation rate decreases. This decrease in \( J \) is unexpected. With an increase in the Reynolds number (\( Re \)) for an external gas, the heat transfer coefficient (\( \alpha \)) should increase (\( \alpha \sim (Re)^{0.5} \)). The growth of heat transfer should lead to an increase in the rate of dissociation. From the photographs of the flame, it can be seen (Fig. 2) that for \( U_a > 1.5-2 \) m/s, the rate profile has a strong inclination to the wall. The stoichiometric ratio (a certain ratio of the concentration of oxygen to the concentration of methane) for the combustion region is strongly disturbed due to a substantial excess of oxidant. As a result, the burning temperature and dissociation rate decrease. Fig. 1 (b) shows the experimental data on the dissociation rate for two different values of the mass concentration of methane \( C_{CH4} \). The change in the concentration of \( C_{CH4} \) almost did not affect the dissociation rate.
Fig. 2 shows photographs of the flame for two different air rates $U$. When the rate exceeds 2 m/s (b), the flame leans towards the wall and part of the combustion region is realized outside the powder surface (the combustion region partially moves in the direction of gas flow).

**Conclusion**

As a result of the experiments performed, the dependences for the dissociation rate of natural methane hydrate during combustion have been established. A laminar air flow was applied over the horizontal surface of the powder in the rate range of 0-2.2 m/s.

With increasing air flow rate, the dissociation rate of gas hydrate increases and reaches a maximum at a rate of 0.6 m/s. With further increase in air rate, the dissociation rate drops by about 30%.

The dissociation rate does not depend on the initial concentration of methane in the sample.

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