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Technologies for methane production from hydrogen using a heated liquid

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Abstract. The paper presents a mathematical model of dissociation of methane hydrate under thermal influence on a porous layer. The problem of influence of a heat source (hot liquid) on a porous layer of finite length initially saturated with methane hydrate is considered. Temperature distributions in the system at different times are constructed. The influence of the heat source temperature on the character of the phase transition boundary motion is investigated. A technological scheme is proposed, and on its basis a mathematical model is constructed that describes heating and simultaneous gas extraction into a combined well consisting of two coaxial pipes. The efficiency of the proposed method of gas production is analyzed.

1. Introduction

At present, gas hydrates are considered to be a unique natural gas field on our planet, which can compete with classical natural fields. Gas hydrate deposits are one of the most promising energy resources in the world due to the shallow occurrence. According to various studies, the global reserves of gas hydrates are several times higher than the reserves of traditional energy sources (natural gas, oil, coal). About 98% of all deposits are located in the depths of the oceans. The remaining 2% are located in the Arctic [1, 2]. Gas hydrates act as a potential hydrocarbon material here. Their widespread prevalence and ability to concentrate large volumes of natural gas make gas hydrates an inexhaustible source of energy in the long term.

Hydrates are the clathrate compounds of hydrocarbons with water. They have every chance to be present under specific thermobaric conditions. In nature, gas hydrate deposits most often occur at the bottom of the oceans and coastal permafrost. World reserves of natural gas in the form of gas hydrates are estimated up to $2 \cdot 10^{16}$ cubic meters. [3], which significantly exceeds the reserves of gas in classical fields. The production of gas from gas hydrates in this period is associated with large heat consumption and the difficulty of extraction due to the depth from 500-1500 m at the bottom of the oceans. Nevertheless, some states of Southeast Asia, and in addition the United States of America, Canada are rapidly studying technological processes for studying gas hydrate deposits. For the first time in 1967, there was found the Messoyakhskoye gas subsoil in Western Siberia, in which place the gas hydrate field existed in an industrial study.

In addition to their energy potential, gas hydrates are also considered a comfortable and promising storage facility for the purpose of conserving as well the utilization of various greenhouse and industrial gases [1-3]. The result of «self-preservation» of gas hydrates is popular, which makes it possible to preserve gas hydrates in a metastable state for an extended period.



These other qualities of gas hydrates also activate the interest of many experts from the point of view of abstract and also experimental studies. There are a large number of academic works associated with the tasks of the decomposition of gas hydrates and gas production from hydrated formations. The current scores of global gas hydrate reserves as well as a study of the financial performance of gas hydrate deposits call for a subsequent study to also search for the latest current gas hydrate technology.

At present, there are a large number of works dedicated to the creation of the decomposition of gas hydrates in spongy spheres. These activities of such experts, as well as Mokogon Yu.F., Istomin V.S., Yakushev V.S., Nigmatulin R.I., Tsypkin G.G., Bondarev E.A., Shagapov V.Sh. and others [4-7].

The presence of the study of multiphase direction in spongy textures is rapidly using accurate forecasting. The abstract representation of these actions is based on the equations of mechanics of multiphase concepts [8, 9]. The importance of accurate forecasting during this period is undeniable, since the results of forecasting significantly reduce the costs of field studies.

The current technological processes for the production of gas from gas hydrates are based on dissociation, as a result of which gas hydrate decomposes into blue fuel as well. Destruction is permissible in the presence of depression, warming, jumps of inhibitors, electromagnetic and sound effects. The heating technique is implemented by the method of circulating warm water, experimentally studied in the Canadian Mallik field. Another method is heating by injection by a coolant line. The effectiveness of this method increases the presence of summing up heated water in an isolated cycle. In addition, direct heating using galvanic current is permissible. The presence of this electrode will be included in the upper and the underside of the hydrated layer, whereby an electric current is passed. All without exception, the above technological processes of heating are distinguished by their simple implementation and they do not at all call for a difficult technical one. But there are conditions which complicate the gas production: high heating costs and totaling the coolant, slow movements of hydrate dissociation into blue fuel and some water, the need for a continuous increase in the amount of heat delivered, environmental hazards.

The method of gas production from gas hydrate through modifications of thermobaric environments is depicted in [11]. The influence of different thermal influence systems on the dissociation rate and gas output was studied in [12], where a theoretical model of gas production during the injection of hot water was created. In [13], a model of the process of pumping warm gas into a snow mass in the initial state saturated with the same gas is proposed.

Also, the uniqueness of gas hydrates can be explained by their thermophysical properties. That is, gas hydrate is able to remain in a metastable state at any temperature for a long time. Questions of mathematical modeling of hydrate decomposition processes are considered in [9-13]. It is shown that even a slight thermal effect can lead to an increase in pressure during decomposition of gas hydrate. For this reason, the thermophysical properties of gas hydrates are of particular interest.

The purpose of this study is to construct a mathematical model describing the process of hydrate decomposition in an axisymmetric formulation.

In this paper, we study the process of decomposition of gas hydrate in a porous medium of finite length when it is heated. A theoretical model of the decomposition of methane hydrate under thermal influence is constructed. The assumption is that the system of two wells is replaced by a single reduced one, through which the formation is simultaneously heated and gas is extracted. The heat consumption for heating the reservoir, the mass of methane produced over the considered period of time at different values of the heating temperature, pressure differences and duration of heating the reservoir are analyzed. Numerical solutions to the problem are obtained and reservoir temperature distributions are constructed. In Addition, the influence of the coolant temperature on the rate of hydrate decomposition and gas output from the gas hydrate is studied. The obtained solutions make it possible to analyze various modes of thermal impact from the point of view of energy efficiency.

2. Problem statement and basic equations

Let's assume that there is a porous layer of length L that contains only methane hydrate in its initial state. We assume the initial pressure p_0 and temperature T_0 of the system corresponding to the conditions of

stable existence of methane hydrate, i.e. $T_0 < T_s(p_0)$, where $T_s(p)$ is the equilibrium temperature corresponding to pressure p . In this case, we assume the dependence of the equilibrium temperature $T_s(p)$ on the pressure as [6]:

$$T_s(p) = T_{h0} + T_* \ln(p/p_{s0}),$$

where T_{h0} is the equilibrium dissociation temperature of the hydrate corresponding to the pressure p_{s0} . T_* – an empirical parameter that depends on the type of gas hydrate and on the considered temperature and pressure ranges.

Suppose that there is a cellular layer of length L , including in its original initial residence only a methane compound. Let us take the initial influence of p_0 as well as the T_0 heat of the concept under the circumstances of sustainable life of methane hydrate, polyadelphite letter. $T_0 < T_s(p_0)$. Because of thermal influence, 2 spheres arise in the formation: the nearest, brightest hydrate decay product (gas as well as water) is also distant, including a compound in its composition. The presence of this appears mobile facet of the phase transition, moving into the depth of the layer also in which the process of decomposition of gas hydrates.

The heat-mass transfer procedure in the formation will be characterized by a single-temperature modification. We assume that friability is a stable size; spongy framework, compound and moisture are also considered incompressible and immovable:

$$m, \rho_{sk}, \rho_h, \rho_w = \text{const}; v_{sk} = v_h = v_w = 0.$$

Here m is friability, also ($j = g, sk, h$, in accordance with this, the real saturation is also the rate of the j -th phase; p is the effect; Polyadelphite heat; R_g continuous gas. The real indices sk, h, w and g also correspond to the characteristics of the skeleton, hydrate, water and gas. The connection is assumed a binary concept with public concentration of gas G .

The equations of continuity are also heat influx with the goal of a close sphere, including food products of the decay of methane hydrate has the type [9]:

$$\frac{\partial}{\partial t}(S_g m \rho_g) + \frac{1}{r} \frac{\partial}{\partial r}(r S_g m \rho_g v_g) = 0, \quad (1)$$

$$\rho c \frac{\partial T}{\partial t} + \rho_g c_g m S_g v_g \frac{\partial T}{\partial r} = \lambda \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right). \quad (2)$$

Here r is the radial coordinate; t is the time; T is the temperature; ρ_g, c_g, v_g, S_g are the density, heat capacity, velocity, and saturation for the gas phase, respectively. The values of the specific volume heat capacity ρc and the coefficient of thermal conductivity λ will be considered constant, since they are determined by the parameters of the skeleton of a porous medium. In this case, according to the problem statement, the temperature in the area saturated with hydrate will be considered constant and equal to the initial temperature T_0 , and the pressure – equal to p_0 over the entire length of the formation.

The calorically perfect gas equation is used as the equation of state:

$$\rho_g = \frac{p}{R_g T}, \quad (3)$$

where R_g is the reduced gas constant.

Gas mass balance conditions and at the phase transition boundary:

$$m \rho_h (1 - G) \dot{r}_{(s)} = m S_w \rho_w \dot{r}_{(s)}, \quad m S_g \rho_g^0 \left(v_{g(s)} - \dot{r}_{(s)} \right) = -m \rho_h G \dot{r}_{(s)}. \quad (4)$$

Here $r_{(s)}$ is the coordinate of the phase transition boundary, and $r_{(s)}$ – the speed of its movement. From the first equation of the system (4) for the values of gas and water saturation, we can write:

$$S_w = \frac{\rho_h(1-G)}{\rho_w}, \quad S_g = 1 - \frac{\rho_h(1-G)}{\rho_w}.$$

The value of the gas velocity at the phase transition boundary is determined from the second equation of the system (4)

$$v_{g(s)} = \left(1 - \frac{\rho_h G}{S_g \rho_g^0}\right) \dot{r}_{(s)} \quad (5)$$

The heat balance condition at this phase transition boundary will take the form:

$$\left(\lambda \frac{\partial T}{\partial r}\right)^- = m \rho_h L_h \dot{r}_{(s)}, \quad (6)$$

where L_h is the specific heat of hydrate dissociation.

We will consider the solution of the problem in the homobaric approximation, i.e. we assume that the pressure along the entire length of the reservoir does not change over time and is equal to the initial p_0 . Then from the continuity equation (1), taking into account the assumption of water immobility, the expression for the gas filtration rate through any cross section defined by the coordinate r can be represented as:

$$v_g(r) = \frac{r_{(s)}}{r} v_{g(s)}. \quad (7)$$

Taking into account (5), we get that the rate of gas filtration through each section is determined by its coordinate, the rate of movement, the limits of the phase transition. The presence of this one, since the temperature differences ΔT in the field of gas filtration are insignificant according to comparison with the initial temperature of the concept T_0 ($\Delta T \ll T_0$), it is possible to record:

$$\rho_g = \frac{p_0}{R_g(T_0 + \Delta T)} \approx \frac{p_0}{R_g T_0} \left(1 - \frac{\Delta T}{T_0}\right) \approx \frac{p_0}{R_g T_0} = \rho_g^0,$$

where ρ_g^0 is the initial density of the gas.

The initial and boundary conditions for the problem under consideration have the form:

$$t = 0: T = T_0 \quad (r_c \leq r \leq R_k), \quad (8)$$

$$r = r_c: T = T_e \quad (t > 0), \quad (9)$$

$$r = R_k: T = T_0 \quad (t > 0). \quad (10)$$

The requirement (10) is necessary from this, that the heat in the sphere of bright gas hydrate is unchanged is also the same as the initial fever T_0 .

The concept of equations (2), (7) with initially boundary-value criteria (5), (6), (8) - (Ten) is considered closed. For the purpose of her decision, a frontal catching method in a plastic mesh module [20] is used, which consists in the fact that due to the unfamiliar transient phase that was also established in the process of solving the problem, the phase transition region moves exactly according to the coordinate grid in a single stage.

3. Calculations results

For parameters that characterize the state of the system, the following values are taken: $r_w = 0.10$ m, $R_k = 50$ m at a coolant temperature of $T_e = 294$ K. The initial pressure was assumed to be $p_0 = 3.69$ MPa, the initial temperature, in accordance with (1), $T_0 = 276$ K. The following values are accepted for the remaining parameters characterizing the system: $G = 0.12$, $\rho_h = 900$ kg/m³, $\rho_w = 1000$ kg/m³, $R_g = 520$ J/(K·kg), $\lambda = 2$ W/(m·K), $c_g = 2600$ J/(K·kg), $L_h = 5 \cdot 10^5$ J/kg.

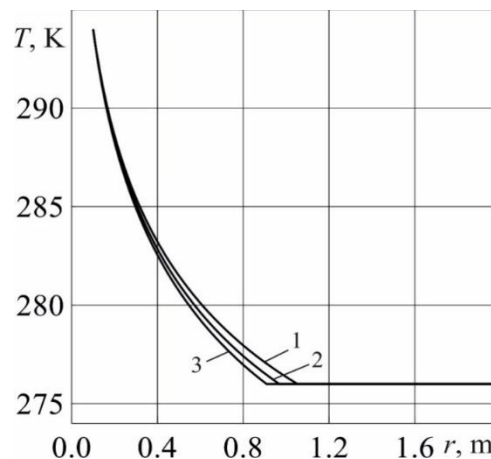


Figure 1. Formation temperature distribution for: 1 – $m = 0.12$; 2 – $m = 0.15$; 3 – $m = 0.18$.

Figure 1 shows the distribution of the temperature of the layer during various factors of the period $t = 20$ days. Equally as is evident from figure 1, the layer heat in a sphere saturated with gas as well as water decreases nonmonotonously. With the movement of time, the heat acquired from the well mainly passes into the heating of the frontline sphere.

Figure 2 shows the degree of moving the location of the front of the phase transition. Obviously, with the passage of the period, the rate of movement of the decay front decreases. This is associated with this, that the destruction of the hydrate is due to the result of conductive heat, the presence of a continuous change in the painting of a trip. With a period, a sphere among the outer wall also breaks out, which leads to an increase in its thermal reaction. From figure 2, it is also obvious that with an increase in the porosity of the layer, a reduction in the movement of the decay region is made.

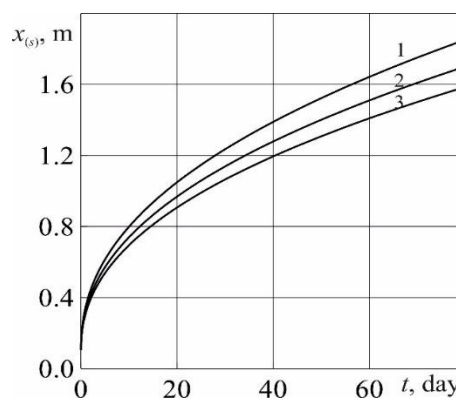


Figure 2. The dependence of the coordinate of the phase transition front on time for: 1 – $m = 0.12$; 2 – $m = 0.15$; 3 – $m = 0.18$.

This is due to the fact that the decomposition of the hydrate occurs due to conductive heat with a constant change in temperature $\Delta T = T_w - T_0$. Over time, the region between the outer wall and the decomposition front expands, which leads to an increase in its thermal resistance. Figure 2 also shows that with an increase in the porosity of the formation, a decrease in the movement of the decomposition zone occurs.

Figure 3 presents the relationship between public gas consumption (part but) and energy efficiency (part letter) from the period the presence of different porosity of the layer. Equally As is evident from figure 3a, with the course of the period, global gas consumption decreases. This is associated with this, that the gas flow is reduced by the saturation of the decomposition of the hydrate, then that decreases with the period. The amount of heat spent in the destruction of methane, we find starting from the correspondence. At that time, the energy efficiency of hydrate production is oriented according to temperature.

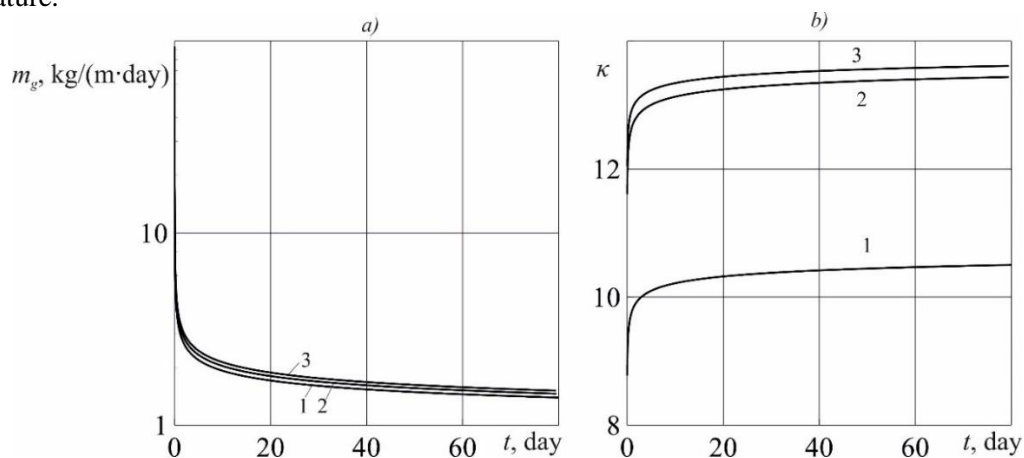


Figure 3. Mass flow and energy efficiency versus time for : 1 – $m = 0.12$; 2 – $m = 0.15$; 3 – $m = 0.18$.

Grain 4 shows the interdependence of the energy efficiency of methane production in connection with the period (part but) also of the temperature difference (figure 3 b).

4. Conclusion and perspectives

The question of the ability of the decomposition of gas hydrate to the presence of heat is resolved. With the aim of the radial problem with the front line of the phase transitions, regulations have been created that represent the temperature steppe, but in addition the dynamics of the hydrate decomposition limits are also global gas consumption. The effect of the difference in temperature of the layer of injected water on the energy efficiency of the decomposition of methane hydrate and the presence of different porosities of the layer are investigated.

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