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SELECTING THE METHOD OF GAS HYDRATE DEPOSITS DEVELOPMENT IN TERMS OF THE REGULARITIES OF THEIR FORMATION

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ABSTRACT

Purpose. To establish and show regularities of gas hydrates fields distribution in the World Ocean for the development of flow diagrams of methane extraction depending on genetic structures and the composition of the host rocks.

Methods. The analysis of the existing fields of gas hydrates is made and, in view of impossibility to carry out detailed investigation, an opportunity to develop them is proved, a theoretical approach to a preliminary estimation of mining-and-geological conditions of such fields' excavation is developed.

Findings. On the basis of the data obtained in the suggested way, it becomes possible to calculate the necessary technological parameters of processes related to deposits' opening and gas production from the bottom of the World Ocean.

Originality. At the present stage of the research into a new alternative and the most promising source of energy, in the total absence of experience in the gas hydrates fields development, great practical significance is attached to the classification of fields by mining-and-geological conditions of their occurrence, as well as to the methodological approach to their development and calculation of technological parameters of methane extraction process from the bottom of the World Ocean with minimum effect onto the Earth's hydrosphere.

Practical implications. Types of gas hydrates fields are determined for the first time in terms of mining-and-geological conditions of their development on the basis of genetic origin and structure of the host rocks. A theoretical approach to the description of the processes taking place in the seam during gas hydrates fields development is elaborated.

Keywords: *gas hydrate, methane, development, mining-and-geological conditions, classification*

1. INTRODUCTION

Nowadays, in conditions of intensive energy consumption, it is becoming clear that in the future humanity will exhaust all natural gas fields which allow extracting gas by conventional ways. Due to this, the international scientific community is actively conducting the research focused on the transition to alternative fuels and on searching for additional sources of conventional energy resources (Bondarenko, Svietkina, & Sai, 2017). But nobody has invented another type of fuel yet that can be an optimal substitute for conventional fuels, so the development of new ways to extract conventional fuel is becoming the primary task (Bondarenko, Maksymova, & Koval, 2013; Dychkovskyi et al., 2018). The methane-containing gas hydrate is such an additional energy resource that can solve the above mentioned problem (Ovchynnikov, Ganushevych, & Sai, 2013; Zhao, Song, Lim, & Lam, 2017).

According to the most pessimistic estimates of scientists, hydrates of hydrocarbon gases, with reserves of 250 trillion cubic meters, are regarded as the most promising energy resource of the future. To compare, according to the current BP Statistical Review, reserves of conventional gas deep in the Earth are estimated at 188 trillion cubic meters (British Petroleum, 2017).

In the past 50 years, interest in the research of gas hydrates has sharply increased. Scientists from many countries discuss issues of gas hydrates existence and study the conditions of their formation in nature. During this period, Yu. Makogon, K. Kvenvolden, Y. Okuda, V. Kobolev, A. Bondarev, E. Sloan et other discovered the presence of gas hydrates in the mainland and widespread hydrate deposits' occurence in the interior of the shelf and bed of the World Ocean (Lapina, 1964; Bondarev, Babe, Groysman, & Kanibolotskiy, 1976; Kvenvolden, 1988; Sloan, 1990; Okuda, 1998; Makogon, 2010; Kobolev & Verpakhovskaya, 2014). Yu. Dyadin, G. Ginzburg and E. Sloan (USA) claim in their works that gas hydrates reserves (2×10^{16} m^3) are commensurate with the amount of oxygen in the Earth's atmosphere (8×10^{17} m^3). Considering high specific concentration of gas in natural hydrates (up to 160 m^3/m^3), their relatively shallow occurrence (under the seabed from the water depth of 300 – 500 m), bottom gas hydrates are considered a real alternative to the gas currently produced by conventional methods. Nowadays, the United Kingdom, Germany, Canada, China, the US, Japan and Norway are engaged in the development of gas hydrate extraction technology (Chen et al., 2011; Wu et al., 2011; Yamamoto et.al., 2014).

Successful attempts of gas hydrates field development are recorded by Japanese and Canadian researchers. In Canada, for example, gas has been extracted from the gas hydrates deposits in the permafrost zone. Despite the fact that they managed to support a stable gas output only for six days, and the experiment cost being 48 million Canadian dollars, the scientific community hailed that it was a real breakthrough in the field of "blue fuel" production; because in its Arctic part, Canada possesses gas hydrates reserves which are suffice to meet the needs of its domestic market for several centuries. In 2012, Japan saw the beginning of one of the largest national priority programs in the world with budgetary financing aimed at the development of marine gas hydrate deposits of Nankai trough from the depth of 950 m. For the first time in history, Japanese gas companies managed to extract gas from gas hydrates on the ocean floor. This production can be regarded as a trial operation of the well (Nath, 2007; Lee, Ryu, Yun, Lee, & Cho, 2011; Huo & Duan, 2014; Chong, Yang, Babu, Linga, & Li, 2016; Lozynskyi, Saik, Petlovanyi, Sai, & Malanchyk, 2018).

2. RELEVANCE OF THE RESEARCH

The relevance of the research is confirmed by the insufficiency of scientifically grounded methods for the technology of gas hydrates deposits development by mining engineers. Chemists, ecologists and scientists of other disciplines are actively engaged in these problems. Today, it is necessary to elaborate a scientifically reasonable technology based on the realities of mining science to develop these fields. However, it is obvious that in order to efficiently master the additional natural energy resources, it is necessary to work out a comprehensive approach and technological schemes, taking into account a particular geological and morphological structure of each specific deposit, and the technology of gas production from gas-hydrate deposits which will be most friendly to the environment. Given the scale of global research in this field, it becomes apparent that it is necessary to thoroughly investigate the nature of the interaction of all processes in these systems, to study in detail the phase transitions of gas hydrate accumulations of different composition in each specific field and take them into account in the development of resource extraction schemes.

The value of these studies has also been confirmed by the need to achieve thorough understanding of processes controlling methane production from gas hydrates. In our view, any discovery of a new type of the mineral, and even more so the intention of its development, requires comprehensive assessment of the effect of its production on the geosphere subsurface layers, especially in regard to its possible impact on the processes leading to global environmental changes. Various techniques of gas hydrates extraction, developed in the world at present, must take into account the threat of the World Ocean bottom pollution with chemical reagents or by uncontrolled release of gas resulting from violation of the phase equilibrium "temperature – pressure". To obtain methane, it is necessary to transform gas hydrate into gas and separate the gas component with minimal impact onto the underwater ecosystem. We are deeply convinced that Ukrainian scientists should possess an appropriate theoretical and scientific potential in the field of gas hydrate technology. For the development of these fields in the future, it is necessary to work out the most feasible and environmentally-friendly technology of gas production from gas-hydrate deposits. In this case, an integrated approach to the development of this natural resource is necessary. It involves the development of various relevant approaches and technological schemes, taking into account particular geological and morphological structure of each specific deposit.

3. THEORETICAL APPROACH TO THE REGULARITIES OF GAS HYDRATES DEPOSITS FORMATION IN THE WORLD OCEAN

The formulation of a theoretical approach to the determination of gas hydrates deposits formation in the oceans was based, first of all, on the analysis and comparison of several aerial maps of the discovered gas hydrate deposits, maps of tectonic plates and Earth's fractured surface. The imposition of these maps shows and confirms the fact that the major part of these deposits are confined to these zones (Figure 1 – 3).

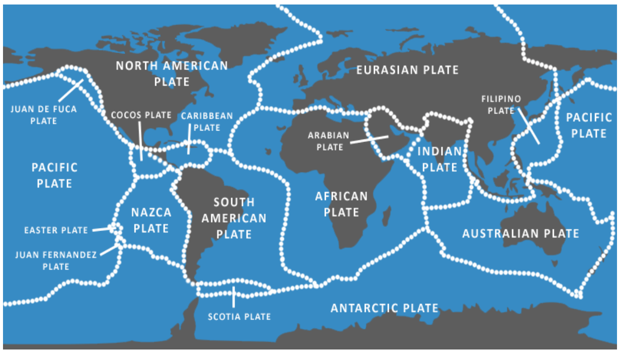

Figure 1. Plate map of the continents and the World Ocean floor (Plate Tectonics, 2016)

Figure 2. The Earth's Fractured Surface (The Earth's Fractured Surface, 1999)

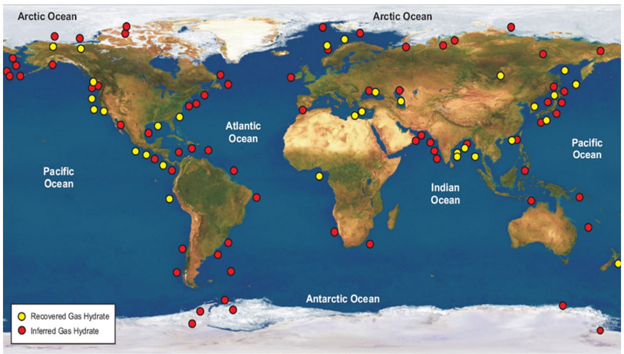

Figure 3. The deposits of gas hydrates confirmed by sampling (Gayle, 2013)

In Figure 1, the red lines indicate the boundaries of crustal plates. In this aspect, it should be noted that the terms "plate" and "mainland" are not identical from the standpoint of the world scientific geological community. For example, the North American tectonic plate extends from the middle of the Atlantic Ocean to the west coast of the North American continent (Fig. 1). The plate is covered both by water and by land. Pacific plate is completely under the Pacific Ocean. South American Plate includes the continent of South America, and half of the Atlantic, which runs along the border of Mid-Atlantic Ocean Ridge. African Plate includes the whole of Africa and the part of the Atlantic Ocean to the west and, accordingly, of the Indian Ocean to the east (Fig. 1, 2). That is, the plate boundaries and coastlines of the continents do not necessarily coincide. Studying the Earth's fractured surface map (Fig. 2), it becomes apparent that their contours and those of the lithospheric plates concur. This alignment is most noticeable where the plates come into contact with each other. The proposed theoretical approach does not consider the hypothesis of lithospheric plate movement, which has neither been confirmed nor refuted in the modern scientific world. One of our tasks is to show the coincidence or overlapping (full or partial) of the contours of explored gas hydrates deposits and the contours of plates and tectonic faults. Comparing the maps in Figures 1 and 2 with the map of gas hydrate deposits, confirmed by sampling (Fig. 3), it is possible to clearly see the replication of configurations both of plates and tectonic faults. Departing from these considerations, the theoretical approach was suggested based on the concept below: depending on the genetic origin and mining confinement to a particular structure, gas hydrate deposits will occur in a variety of host rocks and structures. All lithological variations of enclosing strata, from fine alumino-silicate deposits to fine quartz sands and coarse breccia of different mineralogical composition of rock-forming strata will have unique field-wise parameters of heat conductivity, specific heat capacity, porosity and permeability which must be taken into account when deciding how to develop each specific field. Due to geological and structural features of these deposits, there will be different development schemes.

For example, over the centuries, the basin of the Arctic Ocean with the rivers runoff and beach erosion has been receiving the suspended material of a rather varied composition and grain size, as well as the dissolved material of different chemical composition. Accretion of suspended particles coming into the basin is determined by several factors, primarily by the hydrological regime and topography of the basin. These factors are specific in the Arctic Ocean, as a result of which the overall scheme of mechanical differentiation has a number of deviations. For example, argillaceous sediments are observed on the bottom of the northern seas, at relatively shallow depths; while coarse-grained sediments occur in the central part of the basin at great depths.

In the coastal zone and in shallow water, where tidal and wind-driven currents and churnings play an important role, causing leaching of fine-grained material, coarse and sand sediments are formed. In the deep-sea trenches and cavities, as well as in the areas of large ice fields, i.e. in the zone of water masses reduced activity, argillaceous sediments are deposited. On the most part of the seabed, though, aleurolitic sediments are observed.

4. SELECTING THE SCHEME OF GAS HYDRATE DEPOSITS DEVELOPMENT ON THE BASIS OF THE DEPOSIT HEATING RATE CALCULATION

As an example, we considered the field of gas hydrates, confined to the Arctic Ocean bed, with the depth of aleurolitic strata from 1100 to 1350 m. Heat transfer occurs in a continuous medium at the borderline of wellbore contact with the deposits' body. This process starts at the time when the heat carrier emerges in the seam. For the phase equilibrium shift towards the gas hydrate dissociation into gas and water under constant pressure, it is enough to increase the temperature in the deposit by a few degrees. For this purpose, the sea water from the upper layers with a temperature of, for example, 20°C is fed into well *1*, which has a semi-closed structure (Fig. 1). At the opposite mouth of the well *1*, the cooled water is self-draining.

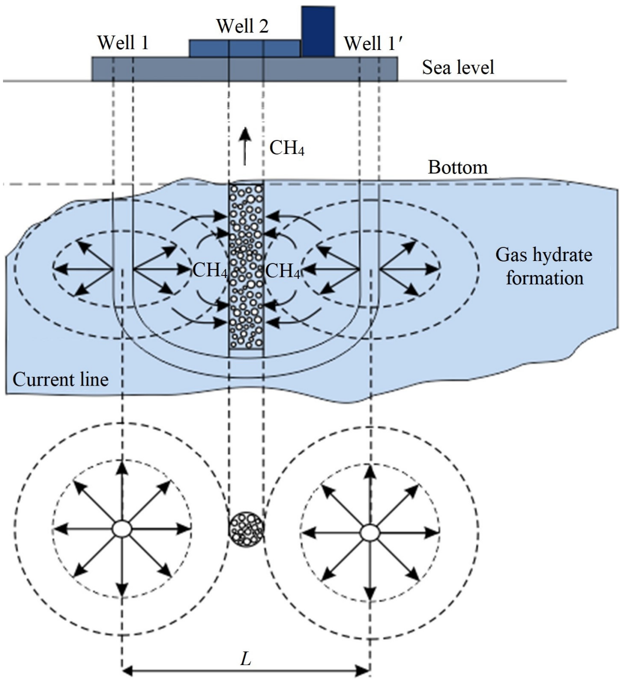

Figure 4. Scheme of developing bottom gas hydrates deposits

The calculations depart from the assumed model of a conditional horizontal seam with the given boundary conditions, of the finite conditional thickness and length in a stable state for thermobaric hydrate formation with a specific type of host rocks, according to the established field type, such as aleurolitic fine sands. Moreover, the process of building such a model should be divided into stages with the corresponding constant porosity, specific weight of the host rocks skeleton, water mineralization and gas components composition. Under the impact of heat, the model will be divided into at least three zones: zone I will be presented by gas, water, and the host rocks skeleton, zone II will comprise gas, the host rocks skeleton and gas hydrates, and zone III is a gas hydrate and the solid part of the host rocks. Obviously, it will be a mobile system with mixed fronts and a certain motion velocity. At minor speeds, that is, in conditions of laminar motion, it is possible to apply Darcy's law to this system for describing a filtration process both of water and gas. To define the process of heat transfer, it is proposed to use Fourier's law:

$$q = \lambda\left(-\frac{\partial t}{\partial n}\right), \quad (1)$$

where:

λ – coefficient of thermal conductivity;

$\frac{\partial t}{\partial n}$ – temperature gradient across the normal to the isothermal surface.

In the paper, we calculated the parameters of the thermal field passage velocity from a well with a heat-carrier by the model for "half-bounded – seam-band", according to the methods widely used in hydrogeological calculations. Depending on the type of deposits and lithological composition of the host rocks, the weighted average characteristics of the host rocks are included in the transformed formula:

$$\Delta T_y = \Delta T^o erfc\frac{y}{2\sqrt{at}}, \quad (2)$$

where:

ΔT_y – temperature increment at the computational point to the coordinate y;

$\Delta T°$ – temperature increment relative to the deposits temperature and the flow temperature;

y – spatial coordinate, m;

t – time, s;

a – thermal diffusivity, m^2/s.

The main parameters before starting the works and for the subsequent monitoring of the system development are the thermal conductivity of the host rocks. Since the thermal conductivity depends on the physical state of the matter, its composition, purity (homogeneity), temperature and pressure, which are determined at the early stages, then, prior to the start of the work, it is necessary to determine the composition of the considered working area, according to the specific laws of each individual field formation by a genetic type. At the very first stages of the heat-carrier passage through a gas-hydrate deposit, shifting its phase equilibrium, it should be taken into account that three-phase medium will appear in the near-wellbore area: gas hydrate in the form of ice, methane and solid fraction of particles (the skeleton) of host rocks. Methane will go toward its discharge zone along the open pores, the zone being the perforated production well. To control production and endothermic processes that will occur in the gas hydrate deposit, it is suggested to use in heat transfer calculation weighted average values of the initial values of thermal conductivity coefficient, specific heat capacity and density of the ice and the host rocks in the ratio equivalent to the coefficient of the deposit porosity respectively. The fact that genetically the gas hydrate is related to the active porosity of the host rocks is a prerequisite to this conclusion. For example, if the host rocks are muddy siltstones, with the active porosity of about 40%, then 40% of these host rocks will contain gas hydrate.

Calculations completed by the Formula (2) have shown that in 30 days, the temperature in the near-wellbore area will gradually increase by 4.08°C at 1 m from hole *1* with the heat carrier, at a distance of 2 m – by 1.21°C, and at a distance of 3 m – by 0.223°C. At greater distances, at the given parameters, the heat carrier action will be virtually invisible (Table 1).

Table 1. Main parameters of the deposit heating rate calculation

y, m	a, m^2/s	t_1, s	t_2, s	ΔTy_1, °C	ΔTy_2, °C	T_1	T_2
1	4.3184E-07	2592000	5184000	4.089558562	2.610566308	13.08955856	15.70012487
2	4.3184E-07	2592000	5184000	1.211379333	0.309128389	10.21137933	10.52050772
3	4.3184E-07	2592000	5184000	0.223305152	0.013534127	9.223305152	9.236839280
4	4.3184E-07	2592000	5184000	0.024908993	0.000208521	9.024908993	9.025117514
5	4.3184E-07	2592000	5184000	0.001652649	1.10134E-06	9.001652649	9.001653750
6	4.3184E-07	2592000	5184000	6.45101E-05	1.96445E-09	9.000064510	9.000064512
7	4.3184E-07	2592000	5184000	1.47085E-06	1.17251E-12	9.000001471	9.000001471
8	4.3184E-07	2592000	5184000	1.9492E-08	2.32786E-16	9.000000019	9.000000019
9	4.3184E-07	2592000	5184000	1.49615E-10	1.53107E-20	9.000000000	9.000000000
10	4.3184E-07	2592000	5184000	6.6346E-13	3.32644E-25	9.000000000	9.000000000

The regularities and the methodological approach selected on their basis as to the choice of opening schemes of different hydrate structures allow to control the gas flow rate of the well *2*, which is essential, since at such supply of the heat carrier, it must be kept in a given mode. At the same time, it is obvious from the proposed model that by placing the next platform at a distance of 6 meters, it is possible to carry out the methane extraction by the so-called "nest" way along the expansion of gas hydrate deposits. Further incremental calculations are necessary to adjust the process parameters in accordance with the process of production, moving platforms to other development areas. In the future, on the basis of similar numerical modeling of gas hydrate decomposition process in the depths of the sea, we can choose the most optimal scheme of drilling and development of any particular field of gas hydrates.

5. CONCLUSIONS

Huge deposits of gas hydrates in the World Ocean are considered as an additional source of hydrocarbons. The paper analyzes the existing deposits of gas hydrates and their confinement to global tectonic faults is proved.

A theoretical approach is suggested to the preliminary assessment of the geological conditions of such deposits development. Based on the data obtained by the proposed method, it becomes possible to perform the necessary calculations of technological parameters of the processes of deposits opening and gas production from the bottom of the oceans. The introduction of the science-based technology of gas hydrates deposits development and their extraction allows the use of this energy resource in a timely and optimal way.

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УРАХУВАННЯ ЗАКОНОМІРНОСТЕЙ УТВОРЕННЯ РОДОВИЩ ГАЗОВИХ ГІДРАТІВ ПРИ ВИБОРІ СПОСОБУ ЇХ РОЗРОБКИ

Е. Максимова

Мета. Виявлення закономірностей поширення родовищ газових гідратів у Світовому океані для розробки технологічних схем вилучення метану залежно від генетичних структур і складу вміщуючих порід.

Методика. Для досягнення поставленої мети в роботі виконано комплексний аналіз, зіставлення й накладення карт аерофотознімків виявлених газогідратних родовищ у Світовому океані, карт тектонічних плит і зон глобальних тектонічних розломів для виявлення відношення більшості даних родовищ до цих зон. Для вибору схеми розробки родовища газових гідратів на основі розрахунку швидкості нагрівання покладу застосовано закон Дарсі для опису процесу фільтрації води і газу, та закон Фур'є – для процесу теплопереносу.

Результати. Розроблено теоретичний підхід до попередньої оцінки гірничо-геологічних умов залягання родовищ газових гідратів до розробки. На підставі запропонованого підходу є можливим виконання необхідних розрахунків технологічних параметрів розкриття газогідратних покладів і видобутку газу з дна Світового океану. Аналітичним способом визначені основні технологічні параметри та швидкість нагрівання покладу газових гідратів в умовах Північного Льодовитого океану.

Наукова новизна. Вперше виділені типи родовищ газових гідратів за гірничо-геологічними умовами розробки на основі їх генетичного походження і складу вміщуючих порід. Розроблено новий теоретичний підхід до опису процесів, що відбуваються у пласті при розробці родовищ газових гідратів.

Практична значимість. Розподіл родовищ газових гідратів за генетичним походженням дозволить більш точно підходити до оцінки раціональних технологічних схем їх розробки. Створено методологічний підхід до розробки газових гідратів і розрахунку технологічних параметрів процесу вилучення метану з дна Світового океану з мінімальним впливом на гідросферу Землі.

Ключові слова: *газовий гідрат, метан, розробка, гірничо-геологічні умови, класифікація*

УЧЕТ ЗАКОНОМЕРНОСТЕЙ ОБРАЗОВАНИЯ МЕСТОРОЖДЕНИЙ ГАЗОВЫХ ГИДРАТОВ ПРИ ВЫБОРЕ СПОСОБА ИХ РАЗРАБОТКИ

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Цель. Выявление закономерностей распространения месторождений газовых гидратов в Мировом океане для разработки технологических схем извлечения метана в зависимости от генетических структур и состава вмещающих пород.

Методика. Для достижения поставленной цели в работе выполнен комплексный анализ, сопоставление и наложение карт аэрофотосъемок обнаруженных газогидратных месторождений в Мировом океане, карт тектонических плит и зон глобальных тектонических разломов для выявления приуроченности большинства данных месторождений к этим зонам. Для выбора схемы разработки месторождения газовых гидратов на основе расчета скорости нагревания залежи применен закон Дарси для описания процесса фильтрации воды и газа, и закон Фурье – для процесса теплопереноса.

Результаты. Разработан теоретический подход к предварительной оценке горно-геологических условий залегания месторождений газовых гидратов к разработке. На основании предложенного подхода представляется возможным выполнять необходимые расчеты технологических параметров вскрытия газогидратных залежей и добычи газа со дна Мирового океана. Аналитическим способом определены основные технологические параметры и скорость нагревания залежи газовых гидратов в условиях Северного Ледовитого океана.

Научная новизна. Впервые выделены типы месторождений газовых гидратов по горно-геологическим условиям разработки на основе их генетического происхождения и состава вмещающих пород. Разработан новый теоретический подход к описанию процессов, происходящих в пласте при разработке месторождений газовых гидратов.

Практическая значимость. Разделение месторождений газовых гидратов по генетическому происхождению позволит более точно подходить к оценке рациональных технологических схем их разработки. Создан методологический подход к разработке газовых гидратов и расчету технологических параметров процесса извлечения метана со дна Мирового океана с минимальным воздействием на гидросферу Земли.

Ключевые слова: *газовый гидрат, метан, разработка, горно-геологические условия, классификация*

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