

## GAS HYDRATES EXTRACTION

*The work is dedicated to alternative energy sources, namely extraction of methane gas from gas hydrate fields. In Ukraine they are represented by gas hydrate fields of the Black Sea. The technology of methane extraction from the sea gas hydrates is suggested. Three basic methods of gas extraction from the gas hydrate-bearing reservoirs are known, namely: pressure reduction lower than the pressure equilibrium of hydrates formation at the designed temperature; heating gas hydrate-containing rock to the temperature exceeding the temperature balance; gas hydrate bearing formations disintegration. All the above methods require high energy consumption. It is suggested to enrich sea gas hydrate-bearing formations directly in the field they underlay in. The purpose of the present study is developing and analyzing the gas hydrates extraction method, which is characterized by the absence of the phase transitions at gas hydrates extraction from the productive stratum and, consequently, by the increased versatility and the economical efficiency of the process. Separate steps of the enrichment process are set for this purpose. The suggested technology requires extracting the main bulk of gas hydrates without energy consumption for the phase transition. Meanwhile, it is suggested to dissociate part of gas hydrate in the rock on account of the sea water's low potential energy.*

**Keywords:** gas hydrates, gas hydrates reservoir, dissociation, enrichment.

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## ВИДОБУВАННЯ ГАЗОВИХ ГІДРАТІВ

*Роботу присвячено пошуку нетрадиційних джерел енергії, а саме видобуванню метанового газу з газогідратних родовищ. Запропоновано технологію вилучення метану з морських газогідратів. Відомо три основні методи вилучення газу з гідратоносних пластів: зниження тиску нижче рівноважного гідратоутворення при заданій температурі, нагрів гідратовмісних порід до температури, вищої за рівноважну, а також їх механічне руйнування. Усі ці методи передбачають великі витрати енергії. Запропоновано здійснювати збагачення морських газогідратовмісних порід безпосередньо на місці їх залягання. Метою роботи є розроблення й аналіз способу видобування газогідратів, який вирізняється відсутністю фазових переходів при вилученні газогідратів із продуктивного пласта і за рахунок цього підвищенням технологічності й економічності процесу. Для цього виділено окремі етапи процесу збагачення. Технологією, що пропонується, передбачено вилучення основної маси газогідрату без витрати енергії на фазовий перехід. При цьому дисоціацію частини газогідрату в породі запропоновано здійснювати за рахунок низькопотенційної енергії морської води.*

**Ключові слова:** газові гідрати, газогідратний пласт, дисоціація, збагачення.

**Introduction.** The energy problem, including diversifying the hydrocarbons sources, is acute for Ukraine nowadays, and is one of the most important for the country. Prognosis evaluations indicate that the amount of methane in gas hydrates is sufficient to meet the needs of mankind for centuries [1]. Prospects of methane gas hydrates raises interest to this subject in a number of scientific schools and companies that are positioned in the sector of energy minerals extraction in France, Germany, USA, Canada, Japan and other countries [2 – 10].

**Review of recent research sources and publications.** Analysis of the data concerning the today's known gas hydrates kicks and their features in the oceans and lakes permits to conclude that the aquagenic gas hydrates can form clusters, which are located at great sub-bottom depths (hundreds of meters) and are controlled by the zones of percolation in the conditions of distributed fluids filtering, or are located in the close proximity to the sea floor, at the bottom or at very shallow sub-bottom depths (first meters).

Results of the experimental studies of gas filtration through the hydrates-saturated rocks, presented in [11, 12, 13], indicate that their gas permeability is by two, three or more orders of magnitude less than the permeability of samples unsaturated with hydrates. Low permeability is associated, in particular, with the initial water saturation, since at some of its meaning hydrate is formed throughout the whole of the porous medium, filling all pores and micro fissures. Most of hydrates are present in coarse-grained sedimentary deposits, but when performing the research, hydrates were also found in fine-grained sediments as small interlayers, lenses and thin, almost vertical loads. For example, the study of well NGHP-01-10 detected a powerful range of fractured clays, the hydrates content of which is among the highest in the world [14].

Thus, the choice of technology for gas hydrate deposits development depends on the specific geological and physical conditions of their bedding (presence or absence of free gas under a deposit) and the level of «supercooling» (the difference between the temperature of the reservoir and the hydrate formation equilibrium). Also, unlike a pure gas deposit development, exploitation of gas hydrate deposits is a non-isothermal process.

There are three basic methods of extracting gas from gas hydrate-bearing layers: lowering the pressure below the hydrate formation equilibrium at a designed temperature; heating hydrate-containing rocks to temperatures higher than the equilibrium and their mechanical disintegration. Also solutions are known, suggesting to use the reagents, which can influence the chemical activity of water and gas, causing a shift in the equilibrium of formation and dissociation reactions of gas hydrates to the lower temperatures zone (the so called inhibitors: methanol, ethylene glycol, electrolyte solutions, etc. ).

Most of the presently known methods for gas hydrate deposits development suggest a combination of the above methods.

Classic examples of thermal methods for gas hydrate deposits development is the US Patent 6192691: it suggests hot water injection under the gas collecting dome, installed over the bottom set gas hydrates accumulation, and application US 20050161217: it suggests electric heating of a productive reservoir and to extract the gas released through the production well. The international application WO 2007/136485 suggests gas hydrate reservoir heating by means of the laser radiation energy.

An example of the combined action on a gas hydrate reservoir (in this case thermal energy and inhibitors are meant) are patents US 4,424,866 and US 6,733,573.

However, the disadvantage of thermal methods for gas hydrate deposits development is significant energy consumption. Thus, besides the relatively small energy consumption for gas hydrates dissociation (about 7% of the extracted gas combustion energy), most of them will be used to heat hydrate saturated stratum's rocks and its subface and roof rocks. Moreover, considering the thermal and physical properties of rocks and gas hydrates, it is obvious that the heat action zone in the reservoir will be limited to a few meters.

The most profit-proved technology of gas hydrate deposits development in terms of energy costs is reducing the reservoir pressure below the equilibrium, followed by free gas extraction. An example the above method is described in international application 2007/072172, which suggests reducing pressure in the gas hydrate reservoir by degassing the lower horizons. However, this method is available for deposits, where hydrates saturation is insufficient and a reservoir has sufficient gas or water permeability. Naturally, hydrate saturation raising (and, hence, permeability reducing), the above method's efficiency plunges. Thus, when the pore space is saturated with hydrates by more than 80%, it is virtually impossible to obtain gas inflow from the hydrate deposit by lowering the bottomhole pressure. Another disadvantage of the said method, based on reducing pressure in the hydrate bearing reservoir, is associated with the secondary anthropogenic formation of hydrates in the bottomhole formation zone due to the Joule – Thomson effect.

As it is known, the phase transition enthalpy «natural gas–hydrates» is about 0,54 MJ/kg. Therefore, at a high initial supercooling and hydrate saturation of the rock, the limiting factor in the hydrate dissociation process can be a drop in the productive reservoir's temperature close to that of the hydrate formation equilibrium, and reducing the temperature in the zone of active phase transition (bottomhole, fissures dissemination at hydro-fracturing, the lower limit of gas hydrate stability between the hydrates reservoir and free gas) is below 273 K.

As a result, hydrate containing rock will be «safely» locked by an impermeable layer of ice and by hydrate of its secondary formation process for a long time (determined by the speed of heat input and, thus, by the thermal properties of its own and those of the subface and roof rocks). For example, at the initial temperature of the reservoir making 283 K and at 5,74 MPa pressure, the Joule – Thomson ratio is 3 – 4 K per 1 MPa depression. Thus, at the depression of 3 – 4 MPa, the bottom-hole temperature may reach the freezing point of water. The process is additionally complicated by the fact that the rocks containing over 60% of hydrate is virtually gas impermeable [5].

In addition, gas hydrates could serve as «cement» for particles of the formation's rock. Dissociation of clathrates in sediments causes abnormally high porosity and releases large masses of water [15]. Thus, the destabilization of gas hydrates will lead to a significant weakening of sedimentary structures in the dissociation zone. Therefore, destruction of a gas hydrate structure by reducing the pressure, raising temperature or introducing inhibitors may lead to decompaction of the hydrate cemented rock and transforming them into an overwetted unstable structure with gas bubbles inclusions. Due to the depression, created for extracting gas, overwetted stratum destruction and suction of an unlimited number of rock species together with water and gas into the reservoir's bottom hole, will inevitably happen, making for further exploitation of the well practically impossible.

Analyzing the information concerning practical implementation of a project to develop gas hydrate deposits off the coast of Japan [16], we can make a conclusion that this process led to the early termination of the experiment on obtaining gas from a gas hydrate reservoir by means of its depressurization (an impressive flow of rocks from the well and sealing the separation equipment with it) was recorded. There are also ways to simultaneously reduce pressure and heat supply to wells. Moreover, hydrate dissociation in the reservoir is mainly due to lower pressure; and heat, supplied to the bottomhole, permits reducing the zone of secondary hydrate formation, thus positively affecting the gas flow rate. However, a combination of these methods does not solve the above disadvantages (problems).

A number of methods suggests open-cut mine development of marine gas hydrate deposits by their mechanical disintegration. Thus, in the application US 2008/0088171 it is suggested to perform bottom gas hydrate containing sediments extraction by means of underwater excavators; to lift them to the surface in containers; to accumulate gas, obtained after their dissociation, under the gas collecting dome, located in the ship's bottom.

The method of extracting bottom and near-bottom gas hydrates, described in the application WO 00/47832, suggests destruction of gas hydrates stratum by means of the compressed air, using a special high-density solution (or pressure actuated water), ducted through a pipe; separation from the bottom and surfacing of hydrate floating pieces; their further collection and dissociation. The possibility of heating the compressed air and fluid is also stipulated.

The method of extracting gas hydrates from the seabed, described in the application RU 2004106857/03, suggests using an extraction device in the form of a self-propelled harvester and a device, delivering them to the surface as barge, surfacing on its own.

**Highlight unsolved parts of the general problem.** However, the surface of gas discharge areas, which are located near the bottom gas hydrates deposits, is mainly covered with a layer of sediments (often submarine hydrates occur, starting from a depth of 0,4 to 2,2 m below the bottom surface [7]). In addition, in an aqueous medium, the fluid stream energy of a hydro-monitor fades quickly with the distance to the object increasing.

One should also keep in mind that in most cases gas hydrate fills the pores or is an unconsolidated rock's cement (i.e. the ratio of the gas hydrate volume to the mineral part is insignificant). So, using a method, suggesting the gas hydrates disintegration by means of air or liquid streams, and also using the open-cut mine rock cutting machinery, located directly on the seabed, will be inefficient.

Displaying unsolved aspects of the problem. Development of industrial gas production by the accepted method of extracting gas from marine gas hydrate deposits requires reducing the energy consumption to the minimum, necessary for its implementation, based on the integrated considering of thermal properties and the interaction parameters of the system's components within the frame of the developed deposit and the present-day engineering level. Today the problem is studied insufficiently.

**Formulation of the problem.** The purpose of the article is development and analyzing the method of gas hydrates extraction, which is marked by the absence of phase transitions while extracting gas hydrate from the production reservoir, and thus increasing processibility and saving efficiency of the process.

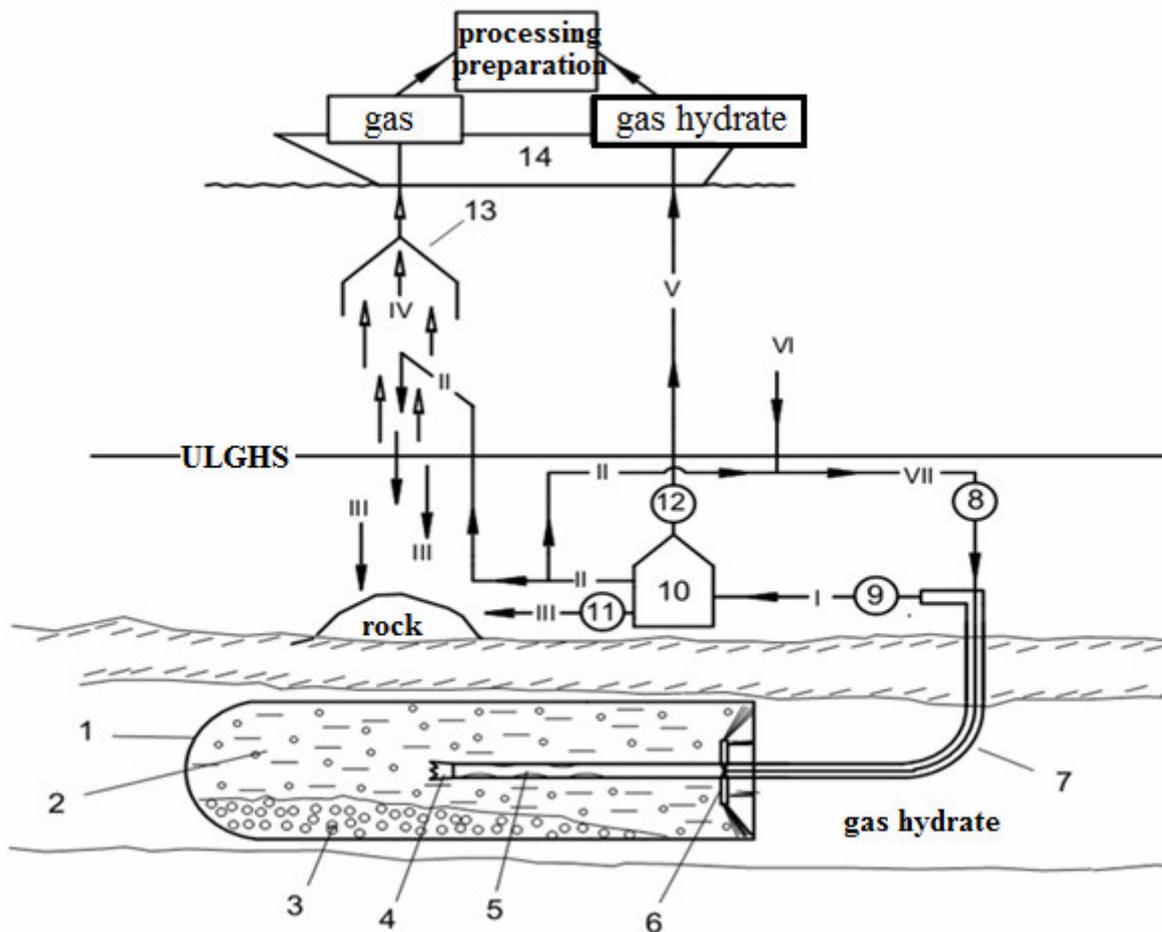
**The main material and results.** Basic material and results. In mining industry, the method of minerals hydromining [17] is well known, it stipulates drilling the well in the deposit field, rock decompaction in the place of its location by means of transferring it into a moving state by means of a hydraulic monitor jet and extracting the hydraulic fluid (pulp) to the surface.

Taking into account the peculiarities of well hydromining, thermodynamic and thermobaric parameters of hydrate accumulation zones and thermal properties of gas hydrates, we suggest a method to develop gas hydrate deposits (Fig. 1) [18], which includes:

1) hydrate containing reservoir's disclosure by well (8) drilling to a maximum length of horizontal layers, and the wells in thick layers should be vertically or obliquely directed to their bottoms;

2) the impact on the productive layer (starting with the well drilling) with the purpose of its disintegration by means of mechanical grinding at the minimum level of dissociation and gas hydrates recrystallization (due to the formation of local zones for a short time under the non-equilibrium conditions) as a result of immersed jets of high-pressure mixture of water and abrasive material (stream VII) using hydro-monitor 6. Notably, to increase the output volume, steel stems with jet gun nozzles are extended in the operating position, occupying the position perpendicular to the well's axis and, turning around it, are moving along to the contact with the front of disintegration.

3) formation, as a result of mixing the grinded hydrate containing rock with water of the water-hydrate mineral pulp (2);



**Figure 1 – Principal diagram of the method for marine gas hydrate deposits development: ULGHS – the upper limit of gas hydrate stability;**

- 1 – excavation in the hydrate-saturated reservoir;
- 2 – space in the excavation site filled water-hydrate mineral pulp;
- 3 – sediment of rock solid inclusions; 4 – drill bit; 5 – pulp intake;
- 6 – jet gun device; 7 – well; 8, 9, 11, 12 – pump; 10 – gravity separator;
- 13 – gas collecting dome; 14 – production platforms; streams;
- I – water-hydrate mineral pulp; II – gas hydrates depleted pulp; III – «waste» rock;
- IV – gas released from the pulp as a result of gas hydrate dissociation;
- V – water gas hydrate mixture; VI – sea water;
- VII – working fluid for rock disintegration (sea water and pulp mixture)

4) gravity separation of part of the relevant density and fractional composition rock mineral inclusions (3) from the water-hydrate mineral pulp (2) at some distance behind the active operating zone;

5) withdrawal of the pre-enriched water-hydrate mineral pulp from the excavation site (1) through the pulp intake (5), located behind the active operating zone, to the separator (10), located at the seabed level;

6) separation from the water-hydrate mineral pulp (stream I) (under the pressure higher than that of the hydrate formation equilibrium) in a gravity separator (10) as a deposit of «waste» rock's part, which is pumped out with the pump (11) to the bottom or through another well - to the discharged rock (stream III) and as a fraction that comes to the surface: a mixture of water and free gas hydrates (stream V) (natural and partly recrystallized);

7) transporting water gas-hydrate mixture with the pump (12) (stream V) (if the target product of the extraction technology is a gas hydrate) or gas and water gas-hydrate mixture using the gas-lifting method (by means of creating thermobaric conditions in the pipeline for the partial hydrate dissociation, if the target product of the technology is gas) to the mining platform;

8) selection of the gas hydrates depleted water-hydrate mineral pulp's part (stream II) after separation, adding thereto sea water (stream VI) and supply (pump 8) resulting mixture (stream VII) under pressure to hydraulic jet gun (6) for rock disintegration (solid fraction of the formed mixture acts as an abrasive);

9) pumping out the rest of the depleted pulp (stream II) under the gas collecting dome (12) into the sea through a pipe, the open end of which is located above the upper limit of the gas hydrate stability (ULGHS). Meanwhile, as a result of being exposed to non-equilibrium conditions and the heat exchange with sea water, dissociation of the remaining gas hydrates into gas and water is taking place in the depleted pulp;

10) sedimentation of the rocks onto the bottom (stream III), accumulation of gas in the gas collecting dome (13) and its supply to the platform (14).

Taking into account the possible approximate ratio of the obtained gas and gas hydrate extracted amounts, the latter, according to the suggested method, after appropriate processing, is taken as the target technology product, and the obtained gas is used mainly for technological needs.

The suggested method for the hydrate deposit development suggests 4 basic stages [11]: 1) hydrate containing rock disintegration in order to transfer it into the movable state; 2) concentrating pulp in the well as result of the rock cuttings sedimentation at a certain distance behind the active layer disintegration area; 3) separation (enrichment) of free gas hydrates in the gravitational separator and reducing the volume of pulp per the volume of water gas hydrate mixture and sedimentary rocks; 4) gas release as a result of the gas hydrate residues dissociation in the process of rock passing through the thickness of sea water at the interval exceeding the upper limit of this composition gas hydrate stability.

**Conclusions.** The suggested method for the gas hydrate deposit development requires extracting the maximum amount of marine gas hydrate in its natural form by means of gravitational separation from the waste rock, i.e. without energy consumption for the phase transition, and performing the forced dissociation of gas hydrates residues in the rock at the expense of the seawater's low potential energy, taking into account the physical properties of gas hydrates and the change of the sea water column and the depth parameters.

In further research, one should focus on the study of quantitative characteristics of marine gas hydrates enrichment process and its modeling.

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