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# DETERMINATION OF RATIONAL PARAMETERS FOR JET DEVELOPMENT OF GAS HYDRATE DEPOSITS AT THE BOTTOM OF THE BLACK SEA

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**ABSTRACT**

The paper presents methodology for determining penetration depth of water jet into gas hydrate deposit and investigation results on influence of water pressure on wall thickness of working column pump pressure, rotation and lifting speeds of working column, diameter of hydromonitor nozzles on penetration depth of high pressure seawater jet into gas hydrate deposit on bottom of the Black Sea. It has been determined that for safe water supply regime at a pressure of 50 MPa, the wall thickness of pipe of the boring column should be less than 0.0065 m. The dependencies for water jet penetration into gas hydrate disperse deposits within a working water supply pressure range of 10 MPa to75 MPa to hydromonitor nozzles. for nozzle diameter of 0.05, the rotation speed of 100 rpm and lifting speed of 1 m/min, have been established. The increase of pressure by about 8 times increases penetration depth of water gets into gas hydrate deposits by no less than two times. The established dependency shows that with an increase of hydromonitor nozzle diameter from 0.01 m to 0.2 m, the radius of penetration depths increases from 0.29 m to 23.85 m, i.e. by 82 times. The study on dependency penetration depth on hydromonitor rotation speed from 20 rpm to 100 rpm, at water supply pressure of 50 MPA, and lifting speed of 1 m/min and a nozzle diameter of 0.15 m have revealed, that expected value is constant and is equal to 15.4 m. The study on influence of lifting speed of hydromonitor in range of 0.5 m/min to 3 m/min, at water supply pressure of 50 MPa, rotation speed of 20 rpm and nozzle diameter of 0.15 m, have revealed that depth of water penetration into gas hydrate body, increases from 8.5 m to 21.3 m, with decreasing speed of monitor lifting. Thus the most rational parameters for jet technology for developing gas hydrate deposits on the bottom of the Black Sea are: nozzle diameter 0.15 m, hydromonitor lifting speed 0.5 m/min, water supply pressure 50 MPa, rotation speed 20 rpm, the wall thickness of working column 0.065 m. At these parameters, the diameter of destroyed gas hydrate deposit reaches 42 m.

**Keywords:** jet technology, gas hydrate deposits, technological parameters, penetration depth.

## INTRODUCTION

The population of Earth has been growing rapidly for the past 30 years, and has already reached 7.3 billion people. The demand for hydrocarbon raw material grows proportionally to population number squared i.e. the power consumption exceeds population growth rate by two times. As of present, about 85% of energy is obtained from hydrocarbons. However, natural deposits of hydrocarbons are not infinite. According to studies of American scientists Hubbert, assuming world's oil consumption of 27 billion of barrels per year, the oil supply would last for 30 years [1]. This is also relied on the fact that alongside depletion of world's oil deposits as is the profitability of easily accessible oil drops significantly.

As for natural gas, according to preliminary calculations, it's deposits would be exhausted within the first half of XXI century. The growth rate of gas mining from traditional deposits from 1980 to 2015 has increased by 3 times and continues to grow steadily each year [2]. Thus, world's leading countries have started to work on searching alternative power sources, which in near future could substitute traditional hydrocarbon power.

One of such sources are gas hydrate - crystalline compounds that form under specific thermobaric condition from water and gas and deposit in depths of precipitate rocks of seas and oceans, and also in some rocks located in permafrost. One cubic meter of gas hydrate is equal to 160 - 200 $m^3$ of methane.

Natural gas hydrates - are one of the forms of natural gas deposits in Earth crust. The natural gas in gas hydrate veins is deposited as not free but in bound form. Water molecules form a framework in this deposits that "trap" gas molecules. Changes in hydrogen bond length under Van der Waal's forces leads to the formation of gas hydrate clusters of natural gas. The amount of hydrocarbons in gas hydrates exceed other forms of hydrocarbon deposits by about 2 times (Figure-1), and according to various estimations it is equal to 133 - 8895 trillion $m^3$ [1, 3 - 5]. The distribution of potential hydrocarbon sources in Earth's crust is rather unequal - 98 % of discovered gas hydrates lie at bottom of World Ocean and the rest 2 % - lie within permafrost zones [6].

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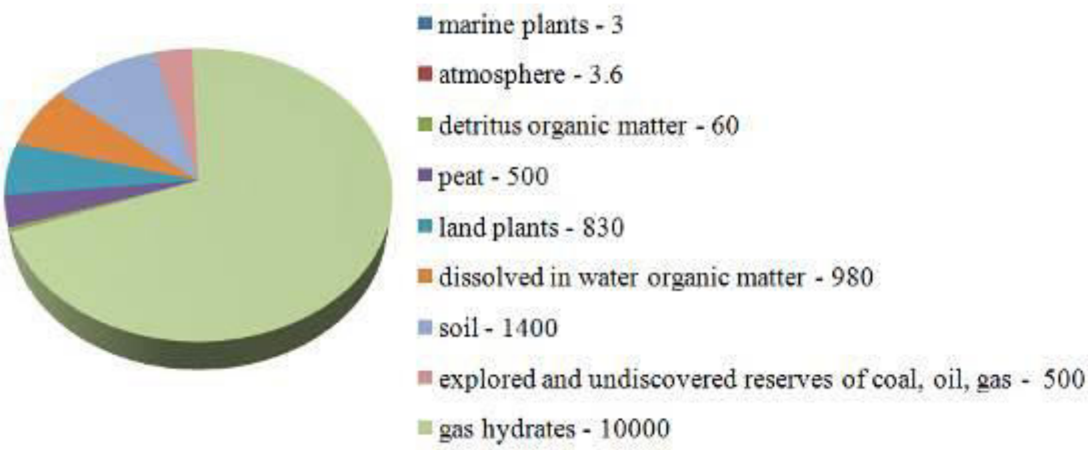


**Figure-1.** Distribution of hydrocarbons on Earth, billion t [1].

The energy dependency of Ukraine is currently one of the main unsolved problems. The gas mining in Ukraine over prior to 2014 - 2016 varied between 19.9 billion $m^3$ to 20.5 billion $m^3$. While its consumption has decreased significantly from 39.7 billion $m^3$ in 2014 to 30.3 billion $m^3$ in 2016. However, the decreased gas consumption by 24% is not compensated by own mining. As such, the relevant problem for the country, as part of the course to reduce gas import, is the development of alternative sources [7 - 8], such as: coalbed gas, shale gas [9] and natural gas in gas hydrate clusters on the bottom of the Black Sea [10 - 12]. It can be seen from Figure-1, that natural gas is the most perspective for development owing to the large volume of deposits [13 - 15]. According to most pessimistic estimations, the amount of natural gas in gas hydrate clusters at the bottom of the Black Sea is 20 trillion $m^3$ [16]. For comparison, totally confirmed deposits in traditional collectors, according to Naftogaz of Ukraine - 1.04 trillion $m^3$. As such, the development of a method for gas mining from gas hydrate deposits of the Black Sea is an important and relevant problem. One of such methods (jet technology) for development of bottom gas hydrate deposits of the Black Sea using high-pressure water jets have been proposed by authors of paper [17], however, the main technological parameters of gas hydrate destruction have not been determined.

## EXPERIMENTAL

The application field of jet technology in world scientific practice is rather wide. The most common is the application of high-pressure jets in the industry are: ore mining [18 - 21], boring [22 - 24], restoration of concrete monolithic constructions [25 - 26], water jet metal cutting [27 - 29] and binding of disperse ore [30].

The known mechanism for destruction process, proposed in the given method, for instance, had been used for binding disperse ore during the mining operation. For this purposes a methodology was developed for determining physical (density of binding solution and treated ore, ore toughness) and technological (pressure of supplied water, nozzle diameter, duration of jet application, consumption of binding solution, speed of rotation and lifting of working instrument) parameters on penetration process of high pressure binding solution jets into disperse ores [31 - 33]. According to this methodology, the penetration depth of high-pressure jet into weak disperse ore have been calculated. During binding of disperse ores, the most ration diameter of created soil-concrete structures is 1.0 - 1.5 m. As for the development of gas hydrate deposits, the destruction radius should be large as possible.

The main aims of using jet technology are: first, is the achievement of the maximum penetration depth of high-pressure water jets into gas hydrate deposit; second, is to provide thermodynamic processes for the transition of gas hydrate into free gas.

As such, in order to achieve the first aim, the main objective is to rationalize the methodology for destruction of gas hydrate deposits on bottom of the Black Sea and to determine rational parameters of gas hydrate development process, namely: pressure of supplies seawater in working column, diameter of hydromonitor nozzles, rotation and lifting speeds of hydromonitor, penetration depth of high pressure jet into gas hydrate body.

The methodology used for jet technology binding was analyzed with the aim to improve and adapt it for development of gas hydrate clusters under the condition of the Black Sea bottom. The main differences of developing a methodology from the already know one, are fundamentally different technological conditions for jet technology and the end result. In this case, the maximum destruction at maximum achieved a penetration depth of high-pressure jets into gas hydrate deposits is limited by technological characteristics of employed equipment.

## RESULTS AND DISCUSSIONS

**Methodology for deterring penetration depth of water jet into gas hydrate deposit.** During mining of natural gas, the Van der Waal's bonds of gas hydrates are broken by application of high-pressure water jet, resolving in the evolution of natural gas.

Initial parameters for determining penetration depth of water jet into gas hydrate deposit:

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- $\rho_2$ –the density of gas hydrate deposit, $\mathrm{kg/m^3}$;
- $\rho_1$ – the density of destructing water jet, $\mathrm{kg/m^3}$;
- $\eta$ – toughness of gas hydrate deposit, $(\mathrm{N \cdot s})/\mathrm{m^2}$;
- $\mathrm{P_0}$ – pump pressure, MPa;
- $d_0$ – nozzle diameter, m;
- $d_1$ – the diameter of working column, m;
- $\omega$ – the rotation speed of hydromonitor, rpm;
- $\Delta\mathrm{P_{total}}$ – losses in the system, MPa
- $v_n$ – lifting speed of working element, $\mathrm{m/min}$.

Calculated parameters:

- Penetration constant

$$C = 0.018\left(\frac{\rho_2}{\rho_1}\right)^2 - 0.005 + \left(\frac{\rho_2}{\rho_1}\right) + 0.209.$$

- Volumetric flow, $\mathrm{m^3/s}$

$$Q = \frac{\pi \cdot \mathrm{d}_0^2}{4} \cdot \mu_p \cdot \sqrt{\frac{2\cdot(P_0 - \Delta P_{\text{общ}})}{\rho_1}},$$

where $\mu_p$ – nozzle's flow coefficient:

$$\mu_{\mathrm{p}} = 0.592 + \frac{5.5}{\sqrt{Re}}.$$

- Jet's speed at the nozzle exit, $\mathrm{m/s}$

$$u_0 = \mu_{\mathrm{p}}\sqrt{\frac{2\cdot P_0}{\rho_1}}.$$

- Penetration speed, $\mathrm{m/s}$

$$u^k = \sqrt{\frac{8}{\pi}\cdot\frac{\eta}{\rho_1 \mathrm{d}_0}}.$$

- Time for one rotation of working column, s

$$T^1 = \frac{1}{\omega}.$$

- Monitor raising time, s

$$T_1 = \frac{1}{\upsilon_{\mathrm{n}}}.$$

- Time ratio

$$K = \frac{T^1}{T_1}.$$

- Possible penetration radius, m

$$h_{\mathrm{m}} = \sqrt{\frac{2.73\cdot d_0^2\cdot u_0}{\pi\cdot d_1\cdot\omega\cdot c\cdot\left(1+\frac{\rho_2}{\rho_1}\right)\cdot K}}.$$

- Maximum penetration depth, m

$$h = \frac{1.365\cdot d_0\cdot u_0}{c\cdot\sqrt{\frac{8}{\pi}\cdot\frac{\eta}{\rho_1\cdot d_{0\pi}}}}.$$

Taking into account depth of conducted operation and boring amounts, it is necessary to determine rational parameters of gas hydrate deposit destruction technology by varying such parameters as the pressure of supplied water, nozzle diameter, hydromonitor rotation and lifting speeds.

***Determination of ration parameters of gas hydrate deposit development technology employing hydromonitor***. In order to determine rational technological parameters of jet technology for destruction of gas hydrate disperse ore during extraction of natural gas from it, it is a necessity to determine the limit value of supply pressure and dependency of the penetration depth of high-pressure water jet on working pump pressure, nozzle diameter, hydromonitor rotation and lifting speeds.

The limit pressure value was determined from allowed stress on pipe wall of working column. The pipe wall thickness (Figure-2) was also determined with consideration for increasing pressure of supplied water [34].

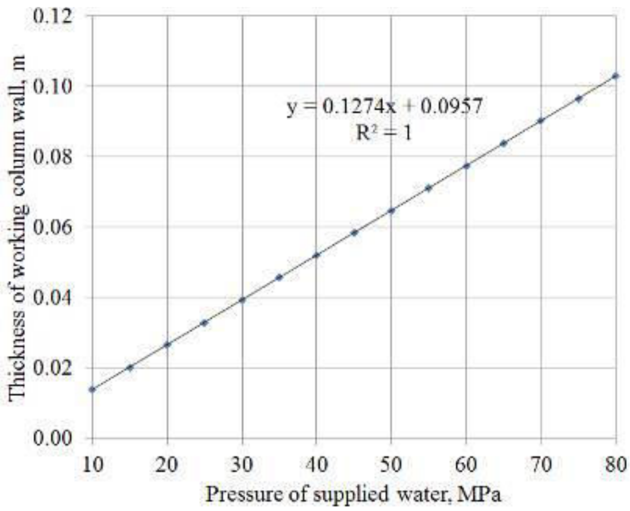


**Figure-2.** Dependency of pressure $P_0$, created by universal pump station SIN31.44 on the necessary minimal wall thickness of the working column

Wall thickness with an account for its strength was calculated from the formula:

$$\delta = \frac{p+d}{2K_z} + a,$$

where

| | |
|---|---|
| $\delta$ | - wall thickness, cm; |
| $d$ | - standpipe diameter of working column, cm; |
| $p$ | - pressure onto pipe wall, $\mathrm{kg/cm^2}$; |
| $K_z$ | - allowed the tensile stress of riveted and welded pipes $K_z$ = 800 $\mathrm{kg/cm^2}$; |
| a | - wall thickness margin, that accounts for corrosion, abrasion wear etc.: for thin metal pipes the value $a$ is assumed up to 4.0 mm of thickness, $a$ = 1.0 mm for other pipes. |

Linear dependency (Figure-2) shows that with an increase of water supply pressure from 10 MPa to 80 MPa, the wall thickness increases from 0.0137 m to 0.1029 m, i.e. almost by 8 times. The dashed line on the graph shows maximum pressure value of supplied water for steel pipes of the working column - 78 - 79 MPa. With accent for this fact, the water supply system would operate in safe regime at a supplied water pressure of about 50 MPa. Choice of this value is also supported by economic point of view, namely the mass of the pipe that is necessary for operation at working pressures in 50 - 78 MPa range.

The next stage of the study was determination of penetration depth of high pressure water jet into gas hydrate ore in range of working pressures of water supply to hydromonitor's nozzles, from 10 MPa to 75 MPa, at nozzle diameter of 0.05 m, rotation speed of 100 rpm and lifting speed of 1 m/min (Figure-3).

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The graph presented in Figure-3 shows power dependency $h_{\text{m}} = 1.2139 \cdot \text{P}_0^{0.2505}$ with determination coefficient of $R^2 = 0.9999$. It can be seen that penetration radius is proportional to the fourth root of supply pressure. This graph supports a theoretic conclusion with a degree of precision ($h_{\text{м}} = \sqrt{\frac{2.73 \cdot d_0^2 \cdot u_0}{\pi \cdot d_1 \cdot \omega \cdot c \cdot \left(1+\frac{\rho_2}{\rho_1}\right) \cdot K}}$ . $u_0 = \mu_{\text{p}} \sqrt{\frac{2 \cdot P_0}{\rho_1}}$ . $\Rightarrow h_{\text{м}} \sim \sqrt[4]{P_0} = P_0^{0.25}$ ).

Graph analysis allows concluding that upon increasing perusing by almost 8 times, the penetration depth of water jet into gas hydrate deposits can be increased by less than 2 times (1.67 $\sqrt[4]{8} = 1.682$). At a pressure of 50 MPa, the penetration depth of water jet into gas hydrate deposit is only3.2 m.

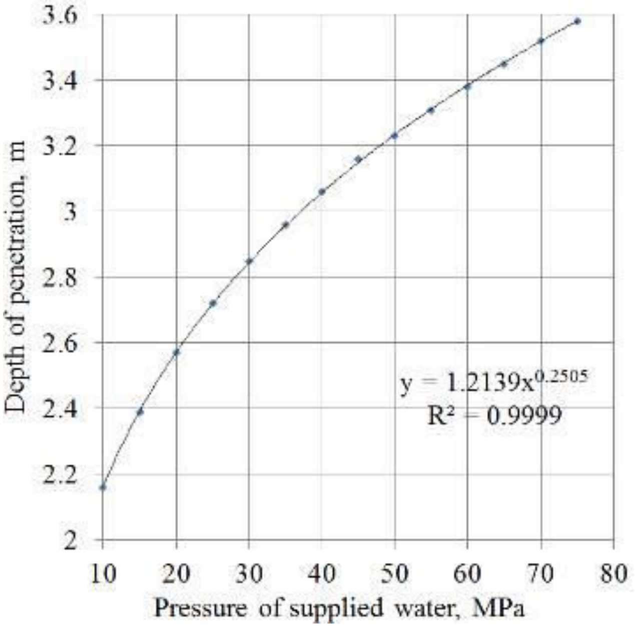


**Figure-3.** The dependency of penetration depth $h_{\text{m}}$ of high-pressure water jet into gas hydrate body on pump pressure $P_0$, at speeds: rotation $\omega$ = 100 rpm, lifting $v_n$ = 1 m/min and hydromonitor nozzle diameter $d_0$ = 0.05 m

On next stage of the study was to determine the influence on the penetration depth of high-pressure jet into gas hydrate deposit at varying diameter of hydromonitor nozzles. The study was conducted at water supply pressure of 50 MPa, speeds of rotation 100 rpm and lifting - 1 m/min (Figure-4). The final studied nozzle diameter was chosen as the diameter of the working column – maximum possible diameter for this monitoring station.

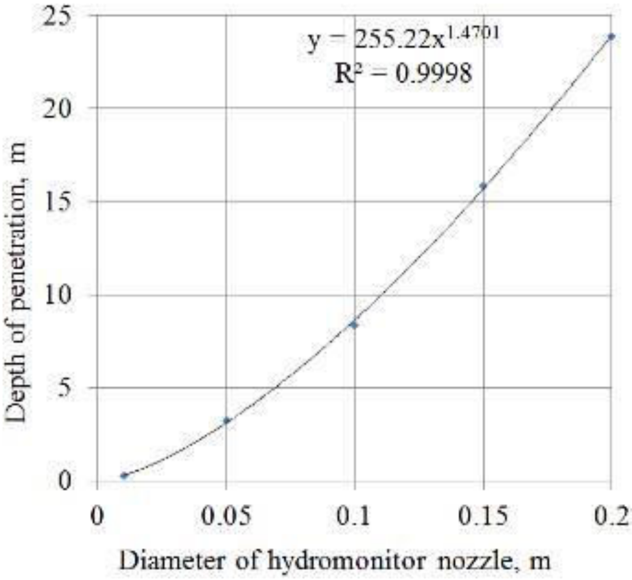


**Figure-4.** Dependency of penetration depth $h_{\text{m}}$ of high pressure water jet into gas hydrate body on hydromonitor nozzle diameter $d_0$, speeds : rotation $\omega$ = 100 rpm, lifting $v_n$ = 1 m/min and pressure $P_0$ = 50 MPa

The power dependency (Figure-4) shows, that change of hydromonitor nozzle diameter is the key parameter for achieving a maximum penetration depth of high-pressure jets into gas hydrate disperse ore. $h = \frac{1.365 \cdot d_0 \cdot u_0}{c \cdot \sqrt{\frac{8}{\pi} \cdot \frac{\eta}{\rho_1 \cdot d_{0\pi}}}}$, i.e. $h \sim d_0^{3/2} = d_0^{1.5}$, which is in good agreement of approximation results of experimental curve $h = 225.22 d_0^{1.4701}$ with determination coefficient of $R^2 = 0.9998$.

With the increase of hydromonitor nozzle diameter from 0.01 m to 0.2 m, the radius of penetration depth increases from 0.29 m to 23.85 m, i.e. by 82 times.

The next stage of the study was a determination of hydromonitor rotation speed on the penetration depth of high-pressure water jet. The study revealed that with a change of rotation speed from 100 rpm to 20 rpm with the step of 20 rpm, working pressure of 50 MPa, and hydromonitor nozzle diameter of 0.15 m and lifting speed 1 m/min, the penetration depth is constant and is equal to 15.4 м.

Taking into account technical capabilities of regulating the speed of boring station, it was decided to further assume the oration speed of hydromonitor to be equal to 20 rpm. When determining the influence of hydromonitor lifting speed on penetration depth, the main parameters were not changed.

The power dependency ($h_{\text{m}} \sim \frac{1}{\sqrt{v_n}} = v_{\text{п}}^{-1/2} = v_{\text{п}}^{-0.5}$) (Figure-5) according to approximation results of the experimental graph ($h_m = 15.12 v_{\text{п}}^{-0.504}$), with a determination coefficient of $R^2 = 0.9994$, reveals, that increasing the lifting speed of hydromonitor significantly decrease penetration depth radius of high pressure water jet. Upon increase of hydromonitor lifting speed from 1 m/min to 3 m/min, the penetration depth has decreased by

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about 50%. For further calculations, it was decided to decrease hydromonitor lifting speed to 0.5 m/min, which in turn allowed to increase penetration depth radius of high pressure water jet into gas hydrate disperse ore to 21.3 m and diameter of destruction zone to 42.6 m.

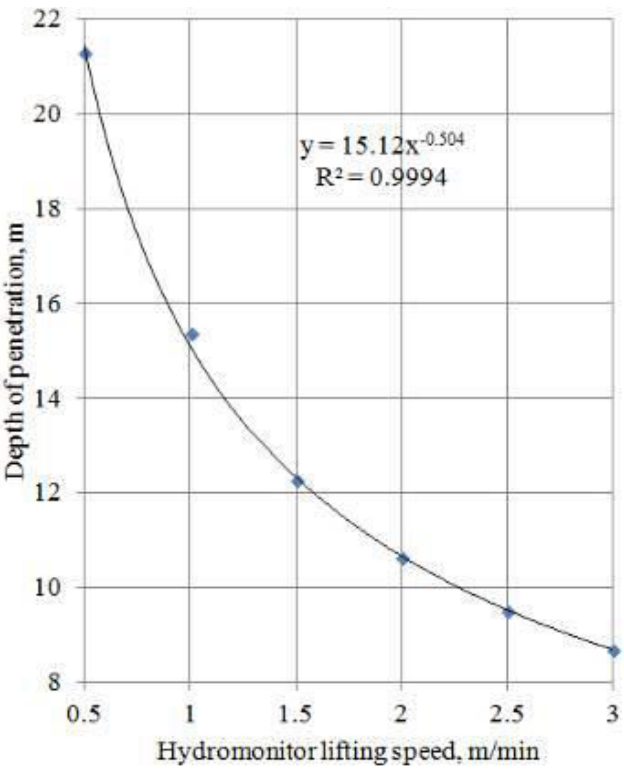


**Figure-5.** Dependency of penetration depth $h_m$ of high-pressure water jet into gas hydrate body on hydromonitor lifting speed $v_n$, at rotation speed $\omega$ = 20 rpm, nozzle diameter $d_0$ = 0.15 m and pressure $P_0$ = 50 MPa.

## CONCLUSIONS

Conducted studies allowed determining ration parameters for jet technology for the development of gas hydrate deposited on the bottom of the Black Sea: nozzle diameter 0.15 m, supplied water pressure 50 MPa, rotation speed 20 rpm, hydromonitor lifting speed 0.5 m/min, the wall thickness of working column no less than 0.065 m. At such parameters, the penetration depth of high-pressure water jet formed in hydromonitor's nozzles, into gas hydrate disperse ores is about 21 м, and diameter of the destroyed region is - 42 м.

For future studied it is necessary to develop a technological diagram of gas hydrate deposit development under the condition of the sea bottom and conduct modeling of the geotechnical process that occurs in well pillars.

## REFERENCES

[1] Kunsler D.G. 2011.Chto nas zhdet, kogda zakonchitsya neft, izmenitsya klimat i razrazyatsya drugie katastrofyi XXI veka. Piter, St. Petersburg.

[2] Arutyunov V.C. 2016. Neft XXI. Mifyi i realnost alternativnoy energetiki. Algoritm, Moscow.

[3] Maria van der Hoeven. 2013. Resources to Reserves. Oil, Gas and Coal Technologies for the Energy Markets of the Future. IEA, Paris.

[4] Byakov Yu. A. 2001. Gazogidratyi osadochnoy tolschi Chernogo morya - uglevodorodnoe syire buduschego. Razvedka i ohrana nedr, 8: 14.

[5] Shnyukov E.F. 2004. Gidratyi prirodnyih gazov. Naukova dumka, Kyiv.

[6] Shnyukov E.F. 2013. Gazovyiy vulkanizm Chernogo morya. Logas, Kyiv.

[7] Bondarenko V.I., Ganushevych K.A. and Sai K.S. 2011. To the question of the underground mining of gas hydrates, Naukovyi visnyk Natsionalnoho hirnychoho universytetu. Scientific Bulletin of National Mining University. 1(121): 60-66.

[8] Maria van der Hoeven. 2013. Resources to Reserves. Oil Gas and Coal Technologies for the Energy Markets of the Future. IEA, Paris.

[9] Reig P. *et al.* 2014. Global shale gas development: Water Availability and Business Risks. World resources institute. 82.

[10] Dudley B. 2015. Statistical Review of World Energy. Centre for Energy Economics Research and Policy, Pureprint Group Limited, London.

[11] Sloan E. D. 2007. Clathrate Hydrates of Natural Gases. CRC Press Taylor & Francis Group, Golden.

[12] Kvenvolden K. A. 1994. Natural Gas Hydrate Occurrence and Issues. Natural Gas H. 715(1): 232-246.

[13] Makogon Yu. F. 2010. Gazogidratyi - dopolnitelnyiy istochnik energii Ukrainyi. Neftegazovaya i gazovaya promyishlennost. 3: 47.

[14] Rogers R. 2015. Offshore Gas Hydrates. Starkville, Elsevier,

[15] Kruglyakova R.P., Kruglyakova M.V., Shevtsova N.T. 2009. Geologo-geohimicheskaya harakteristika estest-vennyih proyavleniy uglevodorodov v Chernom more. Geologiya i poleznyie iskopaemyie Mirovogo okeana. 1: 37.

ARPN Journal of Engineering and Applied Sciences



[16] Korsakov O.D., Byakov Yu. A., Stupak S.N. 1989. Gazovyie gidratyi Chernomorskoy vpadinyi. Sovetskaya geologiya. 12: 3.

[17] Vlasov S.F., Babenko V.E. 2017. Obosnovanie sposoba dobyichi gaza metana iz gazogidratnyih zalezhey dna Chernogo morya. Zbirnik Naukovih prats NGU. 52: 57.

[18] Ciccu R. 2003. Feasibility of water jet slotting in underground granite quarries. Study University of Cagliari, Instabul.

[19] Vijay M. 2007. Water jet cutting techniques for processing of hard rock material. Sendai, Proc. 9th Int. Symp. on Jet Cutting Technology.

[20] Agus M., Bortolussi A., Ciccu R., Kim W., Manca P. P. 1993. The influence of rock properties on waterjet performance. Seatle, Proc. 7th American Waterjet Technology Conference.

[21] Bondarenko V.I., Samusya V.I., Smolanov S.N. 2005. Mobile lifting units for wrecking works in pit shafts. Gornyi Zhurnal. 5: 99-100.

[22] Gauert C.D.K, Westhuizen W.A., Claasen J.O., Viljoen S., Grobler J. 2013. A progress report on ultra-high-pressure waterjet cutting underground: the future of narrow reef gold and PGE mining. The Journal of the Southern African Institute of Mining and Metallurgy. 113: 441-448.

[23] Fraser P. 2010. Hydropower technology can assist in meeting the safety and health ‘2013 milestones’ and save energy: a case for ‘localized’ hydropower systems in general and hydropowered stope drill rigs inparticular. 4th International Platinum Conference, Platinum in transition ‘Boom or Bust’, Sun City, South Africa, 11–14 October 2010. Southern.

[24] Pickering R.G.B. 2007. Presidential address: has the South African narrow reef mining industry learnt how to change? Journal of the Southern African Institute of Mining and Metallurgy. 107: 557-565.

[25] Bodnarova L., Sitek L., Hela R., Foldyna J. 2011. New potential of high-speed water jet technology for renovating concrete structures. Slovak journal of civil engineering. 19(2): 1-7.

[26] Sitek L., Martinec P., Foldyna J., Ščučka J., Bodnárová L, Hela R., Mádr. V. 2008. Flat water jets for disintegration of concrete. Proceedings of the Int. Repair Conf. (Sanace) 2008. Brno.

[27] Borkowski J., Borkowski P. 2008. Wysokociśnieniowe technologie hydrostrumieniowe. Wydawnictwo Uczelniane Politechniki Koszalińskiej, Koszalin.

[28] Akkurt A. 2009. Surface properties of the cut face obtained by different cutting methods from AISI 304 stainless steel materials, Indian Journal of Engineering & Materials Sciences. 16: 373-384.

[29] Krajcarz D. 2014. Comparison Metal Water Jet Cutting with Laser and Plasma Cutting. Procedia Engineering. 69: 838-843.

[30] Vlasov S.F. 1999. Teoreticheskie i prikladnyie osnovyi struynogo zakrepleniya slabyih dispersnyih porod pri vedenii gornyih porod: dis. dok. tehn. nauk NGU, Dnepropetrovsk.

[31] Bondarenko V.I., Vlasov S.F., Tkachuk S.V. 1993. Selection of the governing parameters of jet soil stabilization. Hydrotechnical Construction. 11: 12.

[32] Bondarenko V.I., Vlasov S.F., Tkachuk S.V. 1993. Substantiation of modeling the processes of the jet technology of stabilizing rocks. Hydrotechnical Construction. 9: 34.

[33] Bondarenko V.I., Vlasov S.F., Tkachuk S.V., Pochepov V.N. 1994. Results of modeling jet technology of stabilizing rocks. Gidrotekhnicheskoe Stroitel'stvo.1: 35.

[34] Gorodetskiy L.I. 1960. Spravochnik po gornorudnomu delu. Moscow.