In Arctic - new technical means and technologies for the development of oil and gas fields in long-term freezing deepwater areas

Ch S Guseynov
Department of «Automation of Design of Oil and Gas Industries», Gubkin Russian State University of Oil and Gas (National Research University), 65, Leninsky prospect, Moscow, 119991, Russia

Email: guseinov2@yandex.ru

Abstract. The article presents the rationale for the need to create submarine oil and gas vessels / structures in the Arctic for the development of oil and gas fields in deep-sea long-freezing seas due to ice impacts that destroy offshore platforms. The need to solve the problems of developing oil and gas resources of the Russian sector of the Arctic seas of the Arctic Ocean is undeniable. However, the cost-effectiveness of implementing measures requires not only a careful selection of modern technologies and technical means, but also the development of new technical solutions with increasing consideration of the environmental safety problems of the entire oceans. Especially important is the fact that for the development of deeper long-term freezing Arctic seas, it is necessary to create subsea oil and gas production platforms, including, of course, drilling platforms that should be combined with production vessels. It is equally important for the Arctic deep-sea gas and gas condensate fields to use the new technology for liquefying natural gas, specially created for underwater conditions, since modern liquefaction technologies can only be used for surface conditions.

1. Introduction
A lot of works have been published about perspective hydrocarbon resources of the Arctic. And the urgency of solving the problems of development of oil and gas resources of the Russian sector of the Arctic seas of the Arctic Ocean is undoubted, but the profitability of the implementation of the relevant measures requires not only a careful choice of modern technologies and technical means, but also the development of new technical solutions with increasing consideration of environmental safety issues throughout the entire World Ocean. If the development of shallow waters of the Arctic seas is quite possible with the use of traditional ice-resistant structures/platforms, then for the development of deeper long-term freezing Arctic seas it is necessary to create subsea oil and gas production platforms, including, obviously, drilling platforms also, which, in our opinion, should be combined with the extractive vessels (perhaps, this issue requires separate consideration, in terms of choosing a more economical option). In this regard, in our opinion, two varieties of underwater oil and gas facilities should be created: underwater submersible for depths of about 150-180 m (i.e. installed directly on the seabed through the template supports) and underwater floating ones for depths over 200 m; at the same time, they should be fixed at a given point using ropes / anchor chains (to depths of 300-350 m), and at
depths greater than 350 m, fixed at a point using a dynamic positioning system (controlled by the Glonass system). Each of these varieties its advantages and disadvantages; these structures can have a different shape and shape so that existing underwater currents flow around them in the best way (this is especially important for underwater floating structures, in which it is necessary to minimize energy consumption for fixation). But the main advantage of both varieties is that they will not be exposed to powerful and dangerous ice impacts; moreover, they will stably stay in constant comfortable temperature conditions in comparison with surface structures, which are affected by low temperatures and wind loads. It is also impossible not to notice that the costs associated with ensuring their tightness (i.e., metal investments to create a strong shell) are significantly lower than the same costs of creating ice resistance of these structures. Previously, these conditions were considered in more detail and substantiation [1-20].

2. Methods and materials
Forecasts of climate change trends up to 2080-2100 for the Arctic, where, despite the steady warming, wind loads will increase significantly, passing into storms and ice rains, also testify in favor of the proposals made above; at the same time, the frequency of these weather disturbances will also noticeably increase [9, 10]. And, if in the past years, these phenomena posed a serious threat in the period of navigation even to the drilling of exploration wells from traditional ships [11], it is unnecessary to consider it possible to drill production wells in the period of navigation (with the subsequent operation from subsea mining complexes), because the period of development of the oil and gas field, stretched for decades, in principle, should be excluded.

In this regard, we believe that in the future it is necessary to start creating both submarine floating drilling vessels (for prospecting and exploratory drilling), and submarine floating drilling vessels (which will be designed to drill production wells with simultaneous hydrocarbons from previously drilled wells). As a possible and promising, in our opinion, option of an underwater drilling facility, we offer such an underwater floating structure where it will be possible to accomplish tasks: drill production wells, extract hydrocarbon raw materials, prepare submarine tankers for long-distance transportation, including liquefying natural gas in underwater conditions and transport it by underwater gas tankers also. As such, we in Fig. 1 proposed a conceptual design of a structure / vessel, the configuration of which was carefully and comprehensively justified by us in previously published works [2-4].

![Figure 1. Underwater floating oil and gas structure for drilling and production (in accordance with the accepted terminology of "subsea oil and gas platform")](image-url)
Figure 1 shows: 1-wellhead module for placement of drilling complex and fountain armature at wellheads; 2-main (toroidal) hull of the vessel, where all technological and auxiliary modules (including power) are located; 3 - corridor along the outer circle of the toroid equipped with a lock device used for personnel transfer from the moored submarine vessel, transfer of necessary spare equipment and materials; 4a and 4b - sectioned compartments of the hull (4a for ballast and preparation/storage of drilling fluid; 4b - for keeping the vessel in a horizontal position, t. f. its differentiation with the use of sea water); 5-ballast section with steel shot to compensate for positive buoyancy with the blowing system; 6-internal transition gallery between the wellhead module and other functional modules; power, technological (for the preparation of produced formation products), engineering, auxiliary, storage, residential and central control point; 7- propulsion devices for dynamic.

Dimensions of the presented (conceptual) platform are calculated based on the size of modern technological and injection equipment, placed in the toroid of about 100 m (the outer diameter of the toroidal horizontal section), and its diameter (in the perpendicular section) will be about 20 m (more accurate dimensions, of course, will be determined by a specific design). Perhaps in the long term, these dimensions may decrease due to the improvement of the equipment for our needs; the height of the drilling/wellhead module may also be changed, if drilling will be carried out using smaller number of drilling pipes sparks plugs; and so far, this height may be about 40 m (taking into account the fact that the drilling module will be located flush with the “bottom” of the toroid, the conical elevation over the toroid may not exceed 20 m. At the same time, all the above mentioned in figure 1 ballast containers will be in the toroid, which will significantly simplify the overall configuration and improve the flowability of our structure. And the only thing that will be under the toroid (underwater-floating version) is 4 propulsion devices (shown in figure 1), which are designed to keep the platform at a given point instead of anchor systems, if the depth of the sea under the toroid will exceed 300-350 m (ie, dynamic positioning system).

In our opinion, the presented technical solution is optimal of all kinds of geometric shapes in terms of effective streamline, along with the maximum saturation of the necessary underwater floating oil and gas extraction facilities. And since submarine drilling and operational vessels should have autonomous power (mainly with the use of nuclear power plants), engineering and technical services (including water supply, heating and air regeneration) and specialized technological services, which operate in separate compartments, of course, their circular sequential placement by sector follows; in the center of our facility wells can be placed in the so-called wellhead module, designed for 10-12 wells and representing a geometrically truncated cone with a rounded apex, in which a drilling rig is installed [3]. The circular shape of the whole structure is almost traditional and most adequate to our needs on existing "surface" oil and gas field platforms; it is well streamlined in the underwater space in any direction of sufficiently constant and calm currents, and the strength of the hull should be designed for a given depth of immersion; the platform should be in operation for at least 25-30 years, because it is designed for cost-effective development of large oil and gas fields. In our opinion, the underwater floating structure should be located at a depth of 100 m, which is guaranteed to exclude ice impacts, at this depth (if necessary) can freely work divers. Further immersion of the structure, regardless of the depth of the sea, we believe it is inexpedient not to make the thickness of the hull heavier.

Obviously, for such a long period of permanent stay in the marine environment it is necessary to use durable materials, which include composite materials designed primarily for durability (unlike military vessels, which are designed primarily for the strength of the hull, able to withstand shock loads). Thus, it is already necessary to take seriously the search for and creation of such a modern composite material capable of safely serving a given period of time.

3. Discussion
Undoubtedly, the solution of such a strategic problem should take many years, given the vastness of our seas and the importance of the extracted products for the economy of the country, but the
conceptual solutions should be started immediately, as these resources are already claimed by many countries of our planet. And therefore, our defense measures in our Arctic zone are very timely.

But the strategy of successful development of the Arctic oil and gas resources (as well as other natural products) should include the creation of a number of subsea support vessels, without which it will be impossible to proceed with the implementation of the above problem, combining, where possible, the functions of the majority of subsea support operations in order to increase their profitability, but with strict compliance with certain ranges of depths to be developed (a list of required oil and gas vessels should be given attention in a separate article, which will set out the initial requirements for them).

In the above conditions one should look for other fundamentally different design and technological solutions that allow implementation of the ideas of oil and gas field (OGF) development on the long term freezing Arctic seas. Such solutions, undoubtedly, should be subsea scenarios of OGF development, among which there can be creation of subsea fields directly located on the seabed, regardless of depth. The precedents of this approach have already been implemented in the ice-free waters of the USA, Brazil, Norway, Guinea and our Sea of Okhotsk. However, large depths are mastered there by drilling wells with the help of traditional floating/semi-submersible drilling means (semi-submersible drilling rigs and drilling vessels), i.e. all drilling operations are carried out traditionally afloat in the atmospheric conditions, i.e. on the water surface, which is practically impossible in the conditions of the Arctic Ocean and, therefore, all of the above technical solutions are quite correct and relevant. It should be noted that the presented dimensions of the new vessels allow providing for the reception device for the transport vessels intended for changing the crew, receiving the necessary products, materials and equipment.

The conditions for the development of Arctic oil and gas fields are very specific due to the practical lack of industrial infrastructure almost throughout the entire length of the Arctic coast. And this determines the absolute necessity to use only tanker export of the extracted formation products, because the construction of offshore pipelines in this region is completely meaningless (there only field pipelines can be laid within the field). However, this fact allows diversifying oil and gas supply (the latter only in liquefied state) to different consumers, which may vary depending on the situation. But now liquefaction of gas is carried out at the above-water liquefaction plants; these plants occupy large areas, using rather expensive in obtaining multi-component refrigerants and consuming significant energy: for example, the Sakhalin LNG plant occupies an area of 1000x1000 m and consumes about 8-10% of gas for its own needs in liquefaction; moreover, according to not very reliable information from the Internet: in order to get 3 tons of LNG, it is necessary to burn 1 ton of LNG! In any case, the energy intensity of the modern process of liquefaction of natural gas is very high. Nevertheless, the global demand for LNG is very high, especially due to the increased environmental requirements for air protection. The success of NOVATEK, which is already active on the Yamal coast, testifies to this: NOVATEK's subsidiaries Arktik-1 and Arktik-2 are already constructing new LNG plants on the Gydan Peninsula, where new gas and gas condensate fields have been discovered. Modern gas liquefaction technology, improved with the use of the cold arctic air, is fully designed for its implementation in onshore conditions, and floating LNG plants have already begun to become widely used in the world.

However, these technologies are not designed for implementation in underwater conditions. In this regard, we proposed other more widespread and cheaper refrigerants (liquid nitrogen and liquid air [12-14]); moreover, these refrigerants can be obtained from the air rather than supplied from the gas-processing plants); it is appropriate to note that the cost of production of these refrigerants, including import, affects the cost of LNG). The use of liquid air (LA) as the main refrigerant for liquefying gas is justified by the fact that the temperature of its liquid state reaches minus 196 C, while natural gas (mainly consisting of methane) is liquefied at the temperature of minus 163 C (LPG), and this temperature excess of cold, undoubtedly, leads to the desired result. And the efficiency of using liquid air for methane liquefaction is also conditioned by the fact that it can be obtained by the cheapest way possible in the process of regasification of LNG at the point of sale, i.e. at the onshore terminal, where
LNG is delivered. Thus, in essence, we use the cooling capacities of both refrigerants twice only with the difference that for the liquefaction of methane, the cooling ability of liquid air is more than enough; at the same time, for the liquefaction of air, the cooling capacity of methane is already becoming insufficient, and after cooling the air to a temperature of minus 140-150 ° C, in order to bring it to a liquid state, it is necessary to expend the additional energy used in the traditional way to obtain the desired state. To achieve this temperature difference, it is necessary to expend energy, the main cost of which determines the cost of obtaining liquid air. Based on the current cost of liquid air (in the distribution network) of 10 rubles / l, the ton of liquid air should, in our opinion, be within no more than 2 thousand rubles (and perhaps even less).

This is not the only advantage of the proposed technology. In our opinion, more significant for underwater technology in conditions of limited space / volume is the possibility of its implementation practically without the involvement of personnel, since the most important thing in our technology is the natural process of counter-current heat exchange, which does not require human intervention and is carried out under various kinds of continuous monitoring sensors and other automatic devices. Indeed, the process of counter-current liquefaction of natural gas by liquid air is so technologically advanced that it practically does not require the use of automatic control means. It is this factor that makes it much easier to equip the liquefaction process with automation means and moreover does not require additional personnel on the underwater platform. Besides, the effective heat exchange will be implemented: for natural gas - under the influence of formation pressure, and only for pumping liquid water in a counterflow will require the energy produced by autonomous energy sources, for example, underwater version of nuclear power plants (NPPs). It should be noted that the entire liquefaction process does not require a large amount of space (and area, of course), and within the proposed toroid can be accommodated quite compactly.

In the end, these advantages ultimately may determine the proposed method of liquefaction of natural gas in underwater conditions, as well as coastal complex terminals with additional functions in the form of producing liquid air, which will be transported for subsequent liquefaction of gas directly to deep-water gas condensate fields located in large areas of long-term freezing water areas of the Arctic Ocean.

But even the "double" use of LNG and LA cooling capabilities (directly at the field and on the terminal) does not exhaust the advantages of the new technical solution: LA cooling capacity should also be used in the conditions of subsea facilities:

- For liquefaction of the degassing gas formed in the ascending drilling mud in the system of its continuous circulation while drilling wells;
- For liquefaction of the so-called "flare" gas (for offshore drillers the flare installation is well known on traditional platforms!).

In addition, after the use of liquid air as a refrigerant, it should be directed to all the rooms of the underwater facility to create the necessary comfort environment for all the personnel of the platform, and then the exhaust air should be forced to drain into the water column, enriching it with a residual amount of oxygen (which will certainly have a positive impact on the life of all marine flora and fauna).

The design of subsea oil and gas production facilities should take into account the possibility of such changes, without which it would be unthinkable to continue normal operations within them; and this would require additional (calculated) quantities of LA consumed, as well as LA and individual allocated containers on the shuttle tanker-gas carrier, regularly bringing in LA and transporting LNG and other liquefaction products. But for the existing offshore oil and gas production platforms, significant transformations will be required: installation of additional compact counter-current heat exchangers, special isothermal tanks, small-size pumping devices, reconstruction of piping. For such transformations it is necessary to organize regular delivery of liquid air, or it will be necessary to adjust on site production of this refrigerant. It will be easy to calculate both options which only require
taking into account that at own production of liquid air it will be necessary to organize regular export of newly received hydrocarbon products in liquid form.

Many aspects of this article require separate consideration, especially since the volume of the accumulated liquefied natural gas (LNG) product significantly exceeds the total capacity of the toroid, it is necessary to provide for its storage (in the process of accumulation prior to the arrival of the tanker) another underwater floating structure - 2 tanks with a capacity of at least 100 thousand tons: one - for LNG, the other - for LA, as well as an additional tank for liquid nitrogen (capacity not less than 5 thousand tons) required for flushing the tanks at each arrival of the tanker, as LA will be delivered and LNG will be taken away to avoid the formation of a dangerous gas-air mixture. Naturally, this floating storage facility should be located next to the subsea toroid gas production facility proposed by us.

4. Conclusion

In conclusion, we believe it is necessary to address another important issue - the security of our future and already constructed offshore oil and gas facilities, given their clear vulnerability to any external deliberate threat. Now their safety is especially topical and vital in relation to the appearance and rapid development of unmanned flying striking devices - the so-called drones. But it is almost useless to constantly guard these objects, barraging around and near them, because there can always be some omissions, which can be used by an unfriendly observer / pest (it can be an unfriendly country or some terrorist organization, or even just some "amateur" - pests, who constantly experience a mental aversion to our country.

Regarding such obvious threats, it is already necessary at the stage of designing our facilities to provide such anti-terrorist technical means and devices that can independently and, what is the most important, prevent such acts in due time (at least for the time till the approach of specialized protective units), because human, material and environmental consequences in case of realization of such threats are incomensurable with further financial costs that will arise later. Not predetermining the design specifics of future protective (air, surface and, in our case, underwater) technical means of protection and prevention, it is already necessary to recommend their creation both in stationary version for their use on platforms and on traditional auxiliary vessels (including underwater ones) designed to protect these expensive Arctic drilling and oil and gas extracting facilities.

In future Arctic doctrines, it is all the more necessary to lay down these very important provisions, as the number of pirate attacks on peaceful objects in the world has increased quite sharply. At the same time, it is necessary to give preference to our own shipbuilding and other specialized industrial enterprises in the creation of our specialized oil and gas fleet. And if even if our state for financial reasons will order traditional oil and gas production vessels, then at our shipyards it is necessary to place the additional equipment for retrofitting of newly purchased vessels with the devices that will provide clear and timely performance of the above mentioned protective functions in interaction with similar equipment installed on drilling oil and gas extraction platforms.

References

[1] Guseynov C S et al. 2010 Methodological recommendations for developing a strategy for the development of offshore oil and gas fields (Moscow: Rospatent)
[2] Guseynov C S et al. 2012 The development of hydrocarbon resources of the Arctic Ocean is the immediate and urgent prospect Drilling and Oil magazine 1
[3] Bär F and Teodoriu C 2013 Approaches for determination and reduction of non-productive times of drilling rigs for deep wells Logistics Journal
[4] Schubert Y Z et al. 2013 Casing failure mechanism and characterization under HPHT conditions in south texas 2013 Society of Petroleum Engineers - International Petroleum Technology Conference 2013, IPTC 2013: Challenging Technology and Economic Limits to Meet the Global Energy Demand 3 2207-17
[5] Teodoriu C 2012 Selection criteria for tubular connection used for shale and tight gas
applications Society of Petroleum Engineers - SPE/EAGE European Unconventional Resources Conference and Exhibition pp 865-70

[6] Starokon I V, Ovsannikov Y M, Golovachev A O and Glebova E V 2019 Method of calculating the parameters of vibrational oscillations of the supports of offshore stationary platforms in the presence of variable eddy formation Akustika 32 264-68

[7] Starokon I V, Ovsannikov Y M and Golovachev A O 2019 Investigation of vibro-oscillatory processes of the supports of offshore stationary platforms under conditions of alternating vortex formation caused by the influence of sea currents Akustika 32 pp 262-6

[8] Starokon I V, Golovachev AO and Nadyrov R I 2019 IOP Conf. Ser.: Earth Environ. Sci. 27 03209

[9] Starokon I V and Golovachev A O 2019 IOP Conf. Ser.: Earth Environ. Sci. 272 032089

[10] Starokon I V 2015 Inzhenernyi zhurnal 10 21-31

[11] Starokon I V 2015 Inzhenernyi zhurnal 11 50-9

[12] Starokon I V 2015 Inzhenernyi zhurnal 10 51-6

[13] Boersheim E C et al 2019 Proceedings of the SPE Europec featured at 81st EAGE Annual Conference & Exhibition

[14] Pudlo D, Flesch S, Albrecht D and Reitenbach V 2018 Geophysical Research Abstracts 20 8606

[15] Hagemann B et al 2016 Environmental Earth Sciences 20 595-606

[16] Reitenbach V, Ganzer L., Albrecht D and Hagemann B 2015 Environmental Earth Sciences 73 6927–37

[17] Boersheim E C et al 2019 Summary of an experimental investigation to evaluate potential technical integrity issues in porous UGS containing hydrogen EAGE/DGMK Joint Workshop on Underground Storage of Hydroge

[18] Panfilov M et al 2016 Environmental Earth Sciences 75(4) 313

[19] Reitenbach V et al 2014 Influence of Hydrogen on Underground Gas Storage (Research Report DGMK-752, Hamburg)

[20] Ganzer L et al 2014 Acta Geotechnica 9/1 39-47