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Camouflet-hydromonitor airlift method – a theoretical model for deep-sea solid minerals development

Nikita R. Pedan[1], Iurii A. Vasianovich[1], Vasilii A. Startsev[2]
[1] Vladivostok State University, Vladivostok, Russia
[2] Ural State Mining University, Ekaterinburg, Russia
e-mail: myname@nikpedan.ru

Abstract

Introduction. *Deep-sea deposits development is becoming a strategic priority with the depletion of onshore mineral resources. The article presents a theoretical model of a camouflet-hydromonitor airlift technology for efficient and environmentally safe extraction of solid minerals.*

Methods of research. *The development of the camouflet-hydromonitor airlift method is based on a systems approach that includes a critical analysis of existing mining technologies, geological exploration data for seabed structure and rock properties examination, and an integrated environmental assessment. The process flow diagram combines three key stages: the creation of an underground cavity (storage) without disrupting the seabed surface; washing away the resulting blasted mass with a hydromonitor and converting it into pulp; and the following airlift to the surface for further processing.*

Results. *Advantages revealed by the theoretical research are as follows: the localized impact of the underground cavity minimizes shock waves and suspended solids formation, while the combination of a hydromonitor and airlift ensures high productivity and ability to operate at great depths, reducing the impact on benthic ecosystems.*

Application of research results. *The proposed concept is universal and adaptable for deep sea mining of different solid minerals, including metallic ore, as well as for underwater storage facilities construction. The method lays the foundation for future standards in deep-sea mining, combining economic efficiency and strict consideration for environmental parameters.*

Conclusions. *The concept is promises sustainable development of deep-sea mineral resources. Further research is to field test the method, develop a mathematical model and a regulatory framework for its safe implementation.*

Keywords: *camouflet-hydromonitor airlift technology; hydromonitor; airlift; mineral extraction; solid minerals; seabed.*

Introduction. Deep-sea solid minerals development gains more interest with the depletion of onshore mineral resources [1], even with its significant technological complexity and environmental risk that require new, more efficient, and safer methods [2, 3].

The seabed requires a tailored approach and specific technologies for efficient and safe mineral extraction, considering the environmental and economic parameters given, and yet the concept proposed in this research is universal for deep-sea mining.

The research objective is to develop and implement an innovative camouflet-hydromonitor airlift (CHA) method for efficient and safe extraction of solid minerals from the seabed, considering the environmental and economic parameters given.

Methods of research. Traditional mineral extraction methods were critically analyzed in this research, existing practices and their impact on the marine ecosystem were studied, making it possible to identify weaknesses and justify the implementation of innovative technologies. The research centered around a detailed examination of the seabed structure and the physical properties of the extracted minerals. Geological exploration data formed the basis for developing effective methods of extracting minerals and minimizing associated environmental risks. An integrated assessment of potential environmental impacts was carried out, including an analysis of risks associated with environmental disasters and underwater ecosystems destruction, which helped to develop recommendations for minimizing the negative impact on the marine environment. The study considered various factors, such as geographic, hydrological, and environmental aspects, which contributed to the development of an integrated approach to deep-sea mining ensuring more efficient and safer resource extraction and considering all potential risks and consequences.

Key aspects and advantages of the camouflet-hydromonitor airlift method. The method does not disturb the surface layers of the seabed and ocean floor on an ongoing basis, therefore the impact on the surrounding aquatic environment is minimized [4, 5]. The explosive is applied according to geological conditions, which prevents the propagation of shock waves and shock phenomena beyond the explosion zone.

The advantages of the method include:

– reduced environmental impact;

– more precise and controlled rock destruction;

– reduced risk of prolonged shock waves and shock phenomena propagation.

The CHA method enables the efficient extraction of deep-sea solid minerals, minimizing the negative impact on the marine environment and ensuring safer working conditions.

Currently, mineral extraction is limited to the surface layers of the seabed, which considerably reduces the potential for optimal use of available resources [6–8]. However, deep-sea solid minerals located directly in the subsoil of the seabed are considerable and largely untapped. This research therefore examines the development of a new method for extracting deep-sea solid minerals located directly in the subsoil of the seabed rather than on its surface. The new method includes the following stages of deep-sea solid deposit development: camouflet blast, hydraulic monitor, and airlift. Let us consider each stage of the proposed concept.

Camouflet blast is a preliminary explosion of divided charges in through-holes and does not damage the working face. It is performed to create a fracturing zone in the immediate area for partial seam degassing, dynamic relief, and preliminary rock mass loosening (GOST R 58150-2018). A camouflet charge is an explosive charge placed inside the target object, it creates a cavity in the ground without breaking through to the surface compacting and crushing the rock immediate to the charge (GOST R 57704-2017).

Camouflet blast application in deep-sea mining opens up new horizons in mineral extraction.

A camouflet blast creates a spherical or elliptical cavity on the seabed 50 to 1,000 times greater in volume than the blast, making it possible to efficiently extract valuable minerals (metallic ore). Careful planning of blast location is essential to avoid unnecessary seabed disruption and impacts on marine life. It is also important to monitor seabed conditions before and after blasting to assess potential changes and minimize damage.

Camouflet blast can be applied not only for deep sea mining but also for constructing underwater storage facilities for liquid and gaseous products, such as oil and natural gas [9, 10]. This may include waste disposal facilities on the seabed and ocean floor which require strict adherence to environmental standards and waste management regulations. When designing the storage facilities, it is vital to consider the potential impact on the marine ecosystem [11] and monitor the environment.

Managing the stress-strain state of rock mass. Camouflet blasting is used to create fracturing zones around the blast, which enhances coal seams loosening and degassing, increases oil and gas recovery rate, and intensifies rock crushing for further in-situ leaching.

Safety and environmental friendliness. In hard rock, the volume of compaction and fracturing zones is no more than 15 times as big as the blast volume, which minimizes the negative impact on the environment.

Seabed camouflet blasting technique. *The first stage* of the seabed camouflet blasting is drilling a borehole to a starting diameter. A drilling location is selected, taking into account the area's geology and geophysics. At this stage, drilling rigs capable of drilling a borehole to the designed depth and diameter are used. Drilling quality is critical, as it determines the following work stages.

In the second stage (well casing), the casing is made and the annular space is cemented to protect the borehole walls from collapse and prevent the ingress of extraneous liquid and gas. Cementation involves filling the space between the borehole walls and the casing with a special cement mixture that hardens and forms a strong and sealed barrier. The borehole cementation stages include: preparation (inspection and cleaning of the casing, installation of special devices to control the process); supply of the cement mixture (uniform injection of the cement mixture into the annular space); compaction (air removal from the cement mixture; applying vibrators to compact the mixture); hardening (waiting and time control based on conditions and requirements).

Borehole cementation on the seabed at great depths has its own unique characteristics and requires additional precautions. Particular conditions require particular cementation techniques (single-stage, two-stage, reverse, etc.). After cementation is complete, the hole is drilled to its bottom diameter, which ensures the required width and depth for further operations, such as perforating.

The third stage. The first perforation involves a targeted impact on the newly constructed underground deep-sea storage facility. At this stage, with the specialized equipment and technologies the explosive charge is prepared for initiation. Perforating involves penetrating the borehole walls to create pores which will provide access to the resources or storage space. At the third stage, the perforation depth and direction, as well as the choice of explosive type are essential [12–14]. The first perforations can be made in multiple directions for maximum efficiency and best conditions for substance access and storage. The second perforation is performed after analyzing the outcome of the first one. At this stage, the actions are targeted and aimed at optimizing the structure of the underground storage facility and evaluate its performance. This stage is crucial, as it allows to identify weak points and optimize them for further explosive impact. The second perforation can include extra parameters to improve the characteristics of the newly constructed underground storage facility. Depending on the outcome of the previous stage, various methods and technologies can be applied to achieve the best possible result.

The fourth stage is the principal stage which involves detonating the main explosive charge.

The fifth stage is the final one. The underground storage facility is ready for mineral extraction.

A hydromonitor is a device for generating and controlling the motion (the flight motion) of a high-speed water jet [15, 16] (Figure 1). High productivity of hydromonitors under a relatively low operating cost is their main advantage. Hydromonitors play a key role in the method proposed since they can effectively break and move materials freeing from using bulky and expensive equipment. They not only contribute to faster and more efficient extraction of deep-sea minerals but also help to minimize the environmental risks of deep sea mining. Their overwhelming advantage is its ability to operate in conditions where access to resources is limited, significantly reducing the costs and time required for operations. Advanced hydraulic monitors can be equipped with various head-pieces and nozzles for different jet directions and pressure, which makes it possible to adapt to various operating conditions. This is especially important given the diversity of geological formations. Similar designs were proposed in the works of G. E. Kuvshinov (Far Eastern State Technical University, FESTU) devoted to the power supply and depth stabilization of underwater charging stations [17].

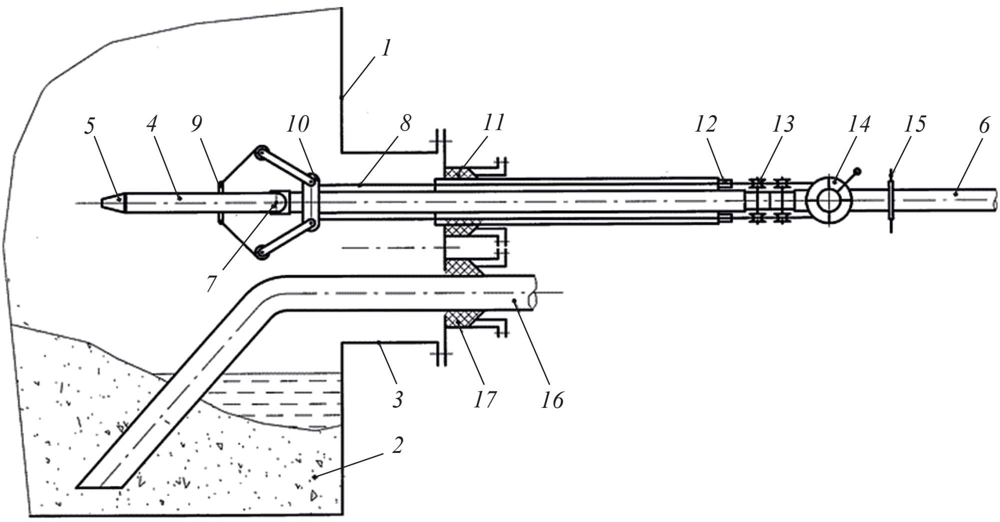

Figure 1. Assembly diagram of a hydromonitor: *1* – camouflet storage facility; *2* – seabed sediments; *3* – side wall; *4* – barrel; *5* – nozzle; *6* – swivel joint; *7* – cable; *8* – cable support; *9* – bracket with guide rollers; *10* – pressure pipeline inlet; *11* – gland sealing; *12* – cable outlet sealing; *13* – support rollers; *14* – drum; *15* – control handle for the pressure pipeline position; *16* – airlift; *17* – airlift gland sealing

Рисунок 1. Схема устройства гидромонитора: *1* – камуфлетное хранилище; *2* – донные отложения; *3* – боковая стенка; *4* – ствол; *5* – сопло; *6* – шарнир; *7* – трос; *8* – опора для троса; *9* – кронштейн с направляющими роликами; *10* – ввод напорного трубопровода; *11* – сальниковое уплотнение; *12* – уплотнение выхода троса; *13* – опорные ролики; *14* – барабан; *15* – ручка управления положением напорного трубопровода; *16* – эрлифт; *17* – сальниковое уплотнение эрлифта

Airlift is a gas-lift system for extracting liquid resources using compressed atmospheric air to raise the liquid (Figure 2). Airlifts are also used for municipal and domestic purposes. An airlift method uses density differences to lift suspended solids and minerals to the surface. It is widely used in mining to lift materials from great depths to the surface. When combined with camouflet blasting, it allows for the efficient extraction of gold, silver, copper, and others minerals contained in sedimentary rocks.

The principle of operation is quite simple. The blast breaks the solid rock, and the resulting sediment, containing minerals, is mixed with water. After that, a water pipe is lowered into the casing (borehole), and a compressor unit reduces the pressure and changes the blasted mass density in the borehole, which allows the suspended solids raise to the surface. According to the law of communicating vessels, the annular space liquid columns between pipes *1* and *2* and the lighter mixture in the water-rising pipe reach equilibrium. The column of water in the casing forces the column of mixture in the riser pipe upward. Upon impact with the gas-liquid separating body frame *3*, the mixture releases air, and the water is collected in reservoir *4*. In practice, airlifts can raise water to a height *H* of up to 200 meters, but theoretical calculations reveal the possibility of lifting suspended solids not only hundreds but also thousands of meters with an airlift [18].

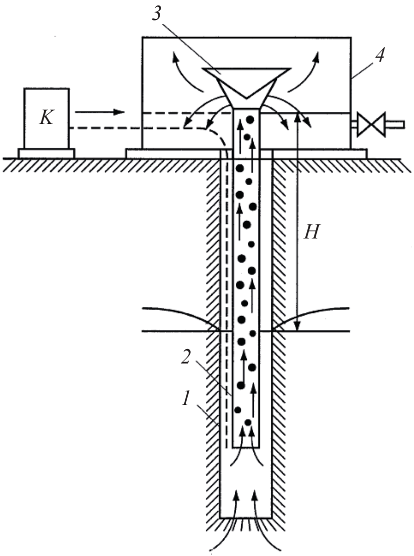

Figure 2. Airlift operation diagram: *1* – casing (borehole); *2* – water pipe; *3* – gas-liquid separating body frame; *4* – reservoir; *K* – compressor; *H* – practical height of airlift operation (200 m)

Рисунок 2. Схема работы эрлифта: *1* – обсадная труба (скважина); *2* – водопроводная труба; *3* – отбойный корпус; *4* – резервуар; *K* – компрессор; *H* – практическая высота применения эрлифта (200 м)

An airlift significantly simplifies and accelerates the production process, which is especially important when working at great depths, where traditional methods may be ineffective.

Camouflet-hydromonitor airlift method. The principle of operation. The development of solid mineral resources on the seabed and ocean floor using the method proposed by the author includes the following stages.

Site selection and equipment arrangement. The first stage involves determining location for the main equipment and supporting structures. Here, geographic, hydrological, and environmental factors are to be taken into account to minimize impact on the marine ecosystem and ensure operational safety. After that, drilling and blasting equipment capable of operating at depths typical for the area is to be installed. It must be equipped with specialized devices for subsea drilling.

Borehole drilling. The second stage involves drilling boreholes which must be located at a sufficient distance from each other to avoid rock fracture between them.

Explosives placement. The third stage involves placing explosives in the boreholes. The amount and type of explosives depend on the type and depth of mineral.

Camouflet blasting. The fourth stage involves performing a camouflage blast that creates a cavity for mineral extraction.

Hydromonitor. The fifth stage involves using a hydromonitor to create an emulsion in the storage facility. The hydromonitor nozzle is inserted into the same borehole mouth the drilling was performed through. After that, the rig begins operation.

Airlift. The sixth stage involves using airlifts to raise the emulsion.

A camouflet storage facility represents a specially designed structure for the temporary storage of blasted rock mass. It ensures an even distribution of load on the equipment involved in the following washaway process, which is one of the key stages of camouflet storage facility operation. Washaway is not only a workflow process but also a crucial stage that determines the purity and quality of the final product. Powerful jets of water wash away the blasted material, converting it into a pulp, i.e. an aqueous suspension of rock particles. Hydromonitors allow for the efficient removal of small rock particles and extraction of essential minerals, which in turn increases overall enterprise productivity, minimizing environmental impact through organized waste accumulation and processing.

After the washaway stage is complete, airlifts are used, i.e. specialized lifting devices that efficiently transport the pulp from lower levels to the surface for further processing. An airlift significantly simplifies and accelerates the extraction process, which is especially important when working at great depths, where traditional methods may prove ineffective. Airlifts are also chosen as a means of lifting pulp due to their high productivity and reliability. They can handle large volumes of pulp, ensuring the smooth operation of the entire production process.

The entire method, based on a combination of camouflet storage, hydromonitor washaway, and airlift transportation of pulp, shows high efficiency not only due to the reduced production costs but also due to the improved finished product quality. This, in turn, positively impacts the enterprise's economic performance and enhances its market competitiveness.

In summary, a new term can be introduced, *the camouflet-hydromonitor airlift method*, which combines all key process elements and emphasizes its innovativeness and efficiency.

Research results. It has been established that hydromonitor technology provides high productivity with minimal mechanical impact on bottom sediments. Combination with camouflet blasting improves the efficiency of compact rock destruction, while airlift transportation reduces energy costs. However, risks of increased water turbidity were identified, which requires additional environmental monitoring measures.

Conclusions and application of the results. The developed method demonstrates significant advantages over traditional extraction methods in both productivity and environmental safety. The results demonstrate reduced anthropogenic impact on marine ecosystems under high economic efficiency. The developed camouflet-hydromonitor airlift method holds promise for the development of deep-sea solid mineral deposits.

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Information about the authors:

Nikita R. Pedan – PhD student, academic assistant of the Department of Mining, Vladivostok State University. E-mail: myname@nikpedan.ru; https://orcid.org/0009-0006-9428-4922
Iurii A. Vasianovich – DSc (Engineering), Professor, professor of the Department of Mining, Vladivostok State University. E-mail: vasyanovich_2011@mail.ru
Vasilii A. Startsev – PhD (Engineering), Department of Mining, Ural State Mining University. E-mail: starcev.1992@list.ru

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Камуфлетно-гидромониторный эрлифтный метод – теоретическая модель для освоения глубоководных твердых полезных ископаемых

Педан Н. Р.[1], Васянович Ю. А.[1], Старцев В. А.[2]
[1] Владивостокский государственный университет, Владивосток, Россия.
[2] Уральский государственный горный университет, Екатеринбург, Россия.

Реферат

Введение. *В условиях истощения минеральных ресурсов суши освоение месторождений морского дна становится стратегическим направлением. В статье представлена теоретическая модель камуфлетно-гидромониторной эрлифтной технологии, призванной обеспечить эффективную и экологически безопасную добычу твердых полезных ископаемых.*

Методология. *Разработка камуфлетно-гидромониторного эрлифтного метода основана на системном подходе, включающем критический анализ существующих технологий добычи, данные геологоразведки для изучения структуры дна и свойств пород, а также комплексную экологическую оценку. Технологическая схема метода* *объединяет три ключевых этапа: создание подземной полости (хранилища) без разрушения поверхности дна; гидромониторный размыв образовавшейся взорванной массы с превращением ее в пульпу; последующий эрлифтный подъем на поверхность для дальнейшей переработки.*

Результаты. *Теоретическое исследование демонстрирует преимущества метода: локализованное воздействие подземной полости минимизирует ударные волны и образование взвесей, а сочетание гидромонитора и эрлифта обеспечивает высокую производительность и возможность работы на больших глубинах, снижая воздействие на донные экосистемы.*

Область применения. *Предложенная концепция является универсальной и может быть адаптирована для разработки различных видов твердых полезных ископаемых на морском дне, включая металлсодержащие руды, а также для создания подводных хранилищ. Метод закладывает основу для будущих стандартов в области глубоководной добычи, сочетая экономическую эффективность со строгим учетом экологических параметров.*

Выводы. *Концепция представляет перспективное решение для устойчивого освоения минеральных ресурсов морей. Дальнейшие исследования должны быть направлены на практическую апробацию метода, математическое моделирование и разработку нормативной базы для его безопасного внедрения.*

Ключевые слова: *камуфлетно-гидромониторная эрлифтная технология; гидромонитор; эрлфит; добыча полезных ископаемых; твердые полезные ископаемые; морское дно.*

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Поступила в редакцию 11 февраля 2025 года

Сведения об авторе:

Педан Никита Русланович – аспирант, специалист кафедры горного дела Владивостокского государственного университета. E-mail: myname@nikpedan.ru; https://orcid.org/0009-0006-9428-4922
Васянович Юрий Анатольевич – доктор технических наук, профессор, профессор кафедры горного дела Владивостокского государственного университета. E-mail: vasyanovich_2011@mail.ru
Старцев Василий Андреевич – кандидат технических наук, доцент кафедры горного дела Уральского государственного горного университета. E-mail: starcev.1992@list.ru; https://orcid.org/0009-0008-7562-5191

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